BARR

Lacombe Flood Study

Main Report

Prepared for
Alberta Environment and Protected Areas
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Barr Project: 61011343.00

March 31, 2025

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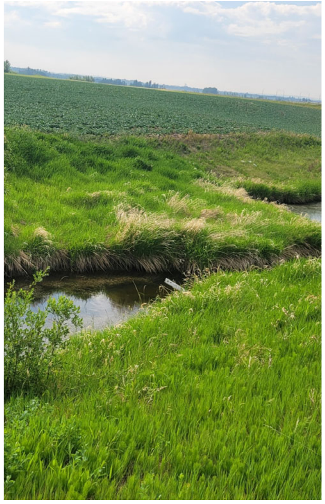

Executive Summary

Alberta Environment and Protected Areas (EPA) retained Barr Engineering and Environmental Science Canada Ltd. (Barr) in March 2023 to conduct the Lacombe Flood Study (the study). The primary purpose of the study is to assess and identify river and flood hazards in the vicinity of the City of Lacombe and Lacombe County. The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancing public safety and reducing future flood damages by identifying river and flood hazards. Project stakeholders include the Government of Alberta, the City of Lacombe, Lacombe County, and the public.

The previous provincial flood hazard study for Lacombe was completed by Alberta Environmental Protection (AEP) in 1996. This study will supersede the previous study, expanding the modelling and flood mapping coverage for the open water flood scenarios. 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
- Open water flood inundation mapping
- Design flood hazard mapping

The total length of the Wolf Creek study reach is approximately 16.5 km, the total length of the Unnamed Tributaries study reaches is approximately 13.7 km. There are a total of six unnamed tributaries within the study area. The survey was completed in the summer of 2023. The hydraulic features in this study are summarized in Table ES–1. The downstream model boundary in HEC-RAS was extended for approximately 400 m beyond the study area to enable specification of reliable downstream boundary conditions.

Table ES–1 Summary of Survey Features

Features	Wolf Creek	Unnamed Tributaries	Total
Cross-sections	174	149	323
Bridges	7	1	8
Culverts	9	10	19
Flood Control Structure	None	None	None

A site visit of the study reach was completed on June 16, 2023. Survey of cross-sections and other base data was completed between June 22 and June 25, 2023. It is noted that there was no flowing water in the study reach during the site visit, however, there was a storm during the week of survey that resulted in low water flowing in a few reaches of Wolf Creek.

A hydrology assessment was completed to provide the flood peak discharge estimates for the study area as inputs to the HEC-RAS model.

A combination of coupled 1D/2D (one-dimensional/two-dimensional) and fully 2D HEC-RAS hydraulic model was developed for the study area. The HEC-RAS model setup for the study area was initially informed by approximate two-dimensional modelling, excluding channel bathymetry, bridges and culverts in the geometry. The HEC-RAS model includes a coupled 1D/2D model of the lower portion of Wolf Creek and a fully 2D model of upper Wolf Creek and all tributaries to Wolf Creek.

There is no highwater mark (HWM) available within the study area and the model was calibrated for low flow conditions, with limited water levels and discharges collected during the survey in June 2023.

The calibrated Wolf Creek channel Manning's n value was 0.035. In the absence of flood data or HWMs for model calibration for Unnamed Tributaries, a channel Manning's n value of 0.04 was estimated for flood flow conditions. The Manning's n values for the floodplain areas were estimated and selected based on the land use types.

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 for the 100-year flood event. The results of the sensitivity analysis show that variations of the channel and floodplain roughness values have small impacts on the simulated water levels along the Wolf Creek and Unnamed Tributaries within the study area. Changes of the energy slope at the downstream boundary have also small impacts on the simulated flood levels for approximately 0.3 km upstream of the downstream boundary.

The fully 2D and coupled 1D/2D HEC-RAS model produces a continuous water surface of directly inundated areas for each simulated flood event. Directly inundated areas were mapped where there is a direct connection between the main river channel and inundated areas on the floodplains. This includes areas where inundation is caused by topographic or structural overtopping points as well as backwater flooding. Flood inundation and hazard maps were prepared for the study reaches of the Wolf Creek and Unnamed Tributaries using ArcGIS.

Based on the simulation results, residential areas west of 45th Street, in the Mckenzie Ranch area, are impacted by flooding. This flooding would be mainly caused by backwater from the 45th Street culvert crossing. Direct inundation begins from the right bank of Unnamed Tributary 3 during the 100-year event along 45th Avenue.

The floodway was defined based on the 1 m depth, 1 m/s velocity, inundation extent, and main channel criteria with some professional judgment. The results of the design flood hazard mapping are the delineation of floodway and flood fringe zones including high hazard flood fringe areas. Based on the flood hazard maps, no residential or commercial properties are situated within the floodway zone within the study area.

Credits and Acknowledgements

The study was completed by the Government of Alberta under the provincial Flood Hazard Identification Program, which aims to enhance public safety and reduce 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.

Barr Engineering and Environmental Science Canada Ltd. (Barr) acknowledges the contributions of the following staff of Alberta Environment and Protected Areas (EPA):

- Mr. Muhammad Durrani, EPA's project manager for the study, coordinated the participation from EPA, provided technical advice and guidance for the overall project and review of this report.
- Mr. Peter Onyshko, EPA's technical advisor for the study, provided technical review and guidance, in particular for the hydrology assessment and hydraulic modelling methodology.

Barr also acknowledges the following staff from the City of Lacombe and Lacombe County for providing information for this study:

- Mrs. Amber Mitchelle (City of Lacombe)
- Mr. Jordan Thompson (City of Lacombe)
- Mr. Dion Burlock (Lacombe County)
- Mr. Tim Timmons (Lacombe County)
- Mr. Jordan Nakonechny (Lacombe County)

The contributions of the following staff from Barr are acknowledged:

- Dr. Hossein Kheirkhah Gildeh, Barr's project manager, was responsible for overseeing the entire project and providing senior inputs and review, quality control, and assurance for the study.
- Mr. Tom MacDonald was senior advisor and reviewer for this study.
- Dr. Omid Mohseni, senior hydrologist, was responsible for open water hydrology assessment.
- Dr. Moges Wagena, hydrologist, was responsible for open water hydrology assessment.
- Dr. Christian Frias, senior hydraulic modeler, was responsible for review of hydraulic model and providing guidance to Mr. Paul Orban.
- Mr. Paul Orban, the main hydraulic modeler for the study, was involved in site visit and construction and simulation of the HEC-RAS model.
- Mr. Eddie Anderson, Senior GIS specialist, was responsible for preparing the flood inundation maps and flood hazard maps for this report.
- Mrs. Emily Cristobal, GIS specialist, prepared the flood inundation maps and flood hazard maps for this report.

- Mr. Doug West (of Trout Hydrography Inc.), field survey lead for this study, was responsible for field survey and hydraulic structure data collection.

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Lacombe Flood Study

March 2025

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Abbreviations

1D	One-dimensional
2D	Two-dimensional
3TM	three-degree Transverse Mercator
AEP	Alberta Environmental Protection & Annual Exceedance Probability
ASCM	Alberta Survey Control Monuments
Barr	Barr Engineering and Environmental Science Canada Ltd.
CGVD28	Canadian Geodetic Vertical Datum of 1928
CSRS	Canadian Spatial Reference System
DTM	Digital Terrain Model
EPA	(Alberta) Environment and Protected Areas
FHIP	Flood Hazard Identification Program
GNSS	Global Navigation Satellite System
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HWM	Highwater Mark
HWY	Highway
LiDAR	Light Detection and Ranging
LOB	Left Overbank
NAD83	North American Datum of 1983
ROB	Right Overbank
RS	River Station
RR	Range Road
RTK	Real-Time Kinematic
SWE-ELM	Shallow Water Equations – Eulerian Langrangian Momentum
TIN	Triangulated Irregular Network
TWP Rd	Township Road
USACE	The U.S. Army Corps of Engineers
WSC	Water Survey Canada

1 Introduction

1.1 Study Background

Alberta Environment and Protected Areas (EPA) retained Barr Engineering and Environmental Science Canada Ltd. (Barr) in March 2023 to conduct the Lacombe Flood Study (the study). The primary purpose of the study is to assess and identify river and flood hazards in the vicinity of the City of Lacombe and Lacombe County. The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancing public safety and reducing future flood damages by identifying river and flood hazards. Project stakeholders include the Government of Alberta, the City of Lacombe, Lacombe County, and the public.

The previous provincial flood hazard study for Lacombe was completed by Alberta Environmental Protection (AEP) in 1996. This study will supersede the previous study, expanding the modelling and flood mapping coverage for the open water flood scenarios. 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
- Open water flood inundation mapping
- Design flood hazard mapping

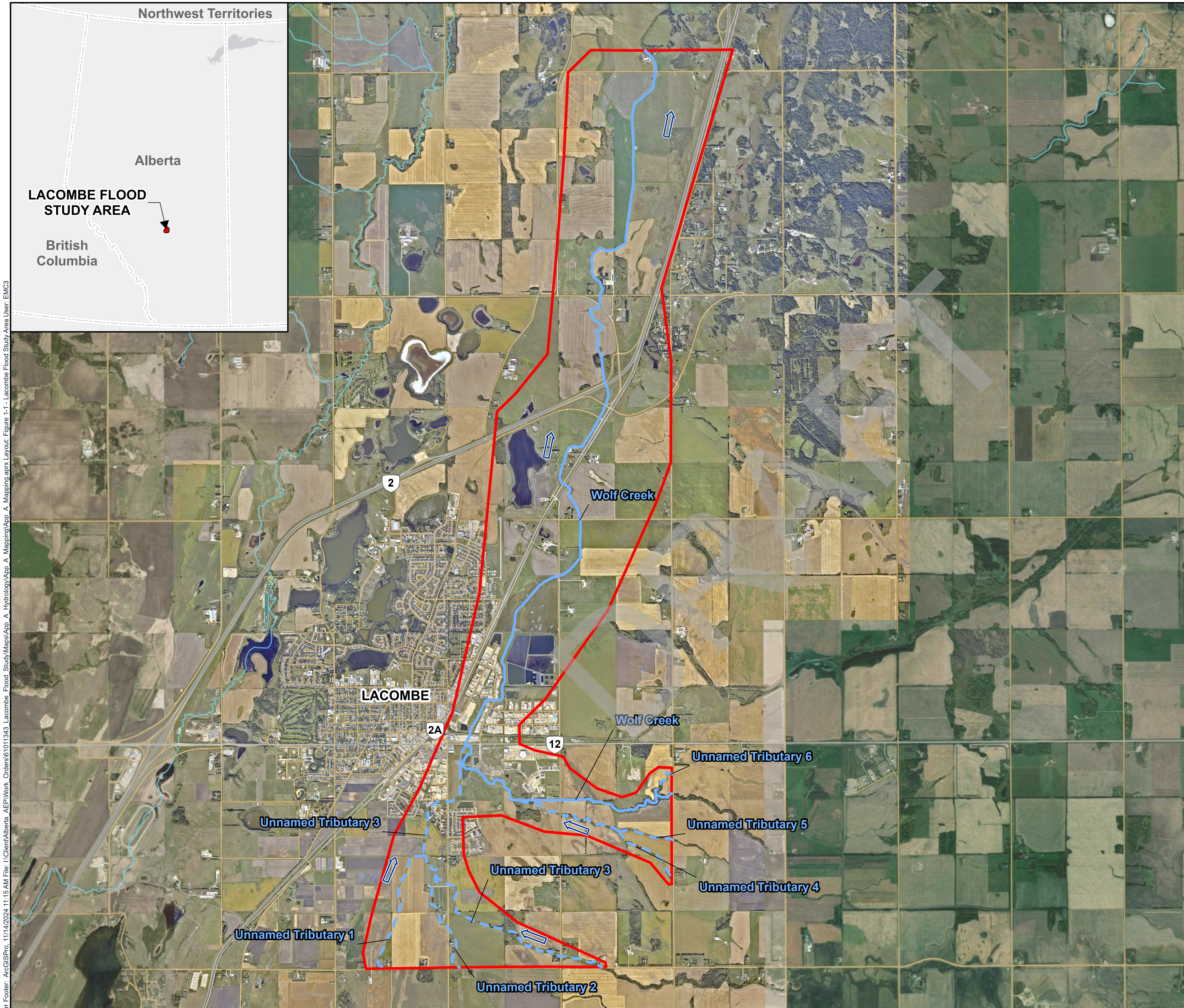
1.2 Study Objectives

The overall goal of the Lacombe Flood Study is to enhance public safety and support the assessment and identification of flood hazards in the study area. The study results are intended to reduce potential future flood damages and associated disaster assistance costs, mitigate flood impacts by informing land use planning decisions, and inform emergency preparation.

1.3 Study Area and Reach

The headwaters of Wolf Creek drain from east to west towards the City of Lacombe, which is in south-central Alberta, approximately 125 km south of the City of Edmonton. The creek then flows northerly along the city's east side towards Highway 2A and Highway 2. Figure 1-1 shows the study extent and the overall watershed area. Within the study area, there are a total of six unnamed tributaries.

The total length of the Wolf Creek study reach is approximately 16.5 km, and the total length of the Unnamed Tributaries study reach is approximately 13.7 km. River reaches in the study area, description of each reach, and each reach length are summarized in Table 1-1.



LEGEND

- STUDY AREA
- FLOW DIRECTION
- WOLF CREEK
- TRIBUTARIES
- WATERCOURSE
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD

0 1 2
KILOMETRES
SCALE: 1:55,000

REFERENCES

ORTHOPHOTO IMAGERY ACQUIRED BY OGL ENGINEERING FOR ALBERTA ENVIRONMENT AND PROTECTED AREAS: OGL ENGINEERING (2023). ESRI IMAGERY SOURCED BY MAXAR (2021).

BASE DATA FROM ALBERTA ENVIRONMENT AND PROTECTED AREAS.

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

LACOMBE FLOOD STUDY AREA
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 1-1

Table 1-1 River Reaches in the Study Area

River	Reach Descriptions	Length (km)
Wolf Creek	Originates at Range Road (RR) 263, flows approximately 3.7 km, entering Lacombe from the east, travels through Lacombe and along HWY 2A north, ending approximately 7 km northeast of Lacombe.	16.5
Unnamed Tributary 1	Originates at Township Road (TWP Rd) 402, flows approximately 2 km until the confluence with Unnamed Tributary 3.	2.0
Unnamed Tributary 2	Originates at TWP Rd 402, flows approximately 1.7 km until the confluence with Unnamed Tributary 3.	1.6
Unnamed Tributary 3	Originates at TWP Rd 402, flows approximately 5.9 km until the confluence with Wolf Creek.	5.9
Unnamed Tributary 4	Originates at RR 263, flows approximately 2.8 km until the confluence with Wolf Creek.	2.8
Unnamed Tributary 5	Originates at RR 263, flows approximately 0.8 km until the confluence with Unnamed Tributary 4.	0.8
Unnamed Tributary 6	Originates at RR 263, flows approximately 0.6 km until the confluence with Wolf Creek.	0.6
Total		30.2

2 Survey and Base Data Collection

A site reconnaissance was conducted by representatives from EPA, Lacombe County, Barr, and Trout Hydrography Inc. (TROUT) on June 16, 2023. The site visit involved the following:

- Reviewed and confirmed the preliminary survey plan
- Confirmed the locations and numbers of channel cross-sections and hydraulic structures to be surveyed
- Familiarized with the study area

Barr retained TROUT for completing the survey of Wolf Creek and Unnamed Tributaries flowing into Wolf Creek on the upper portion of the study area. A survey of cross-sections and other base data was completed between June 22 and June 25, 2023. It is noted that there was no flowing water in the study reach during the site visit. However, there was a storm during the survey week that resulted in low water flowing in a few reaches of Wolf Creek. The objective of the survey program was to survey channel cross-sections and hydraulic structures along the study reach to support the development of a HEC-RAS hydraulic model.

Survey data was collected at 323 cross-sections and for 27 hydraulic structures.

The survey scope included the following:

- survey of channel cross-sections and hydraulic structures
- measurement of discharge and water surface profile

2.1 Survey Procedures and Methodology

The survey equipment and procedures used to collect the topographic, bathymetric, and structure data for this study included Real-time Kinematic (RTK) Global Navigation Satellite Systems (GNSS) and Trimble R10 GNSS receivers.

The proposed locations of all cross-sections were identified in a digital georeferenced vector format. The survey crew utilized them on the data collectors to guide the survey. A georeferenced survey plan was uploaded into the data collector to aid the surveyor in maintaining precise spacing and alignment of cross-sections along each study reach.

A SonTek FlowTracker2® Acoustic Doppler Velocimeter (ADV), in combination with a top-set wading rod, was used to conduct discharge measurements on Wolf Creek.

2.1.1 Coordinate System and Datum

Horizontal positions were referenced to the local three-degree Transverse Mercator (3TM) projection of the Canadian Spatial Reference System (CSRS) North American Datum of 1983 (NAD83), which has a central meridian of 114°W. Orthometric heights are based on the Canadian Geodetic Vertical Datum of 1928 (CGVD28) and the HTv2.0 geoid model.

2.1.2 Control Network

A control network was established from local Alberta Survey Control Monuments (ASCMs) and GNSS surveying to provide a spatial reference for the survey program. Three ASCMs were used in the network along with four project control points established by TROUT for the survey program. Table 2-1 lists the surveyed control points in the network.

Table 2-1 Control Points Used in the Survey

Name	Type	Northing (m)	Easting (m)	Elevation (m)
ASCM 378372	ASCM	5813524.149	5813524.149	854.609
ASCM 755967	ASCM	5824564.569	5824564.569	842.602
ASCM 401091	ASCM	5812726.534	5812726.534	846.229
Survey Control	TROUT Control Point	5814034.160	5814034.160	849.241
Survey Control	TROUT Control Point	5814033.012	5814033.012	846.335
Survey Control	TROUT Control Point	5820653.128	5820653.128	846.929
Survey Control	TROUT Control Point	5820623.720	5820623.720	844.056

Note: ASCM 325720 and ASCM 344184 were identified as potential ASCMs before the survey, but they were not found during the survey.

Table 2-2 summarizes the comparison between the survey and published ASCM coordinates and elevations. As shown in Table 2-2, the surveyed ASCM elevations are within 4 cm of the published elevations.

Table 2-2 Comparison Between Surveyed and Published ASCMs

ASCM No.	Published Values			Surveyed Values			Difference (Surveyed Minus Published)		
	N (m)	E (m)	H (m)	N (m)	E (m)	H (m)	N (m)	E (m)	H (m)
325720	5814338.805	18811.661	846.855	NOT FOUND / DESTROYED			N/A		
378372	5813525.257	20452.206	854.587	5813524.149	20450.418	854.609	1.108	1.788	-0.022
755967	5824565.677	22812.687	842.58	5824564.569	22810.899	842.602	1.108	1.788	-0.022
401091	5812727.681	18803.139	846.195	5812726.534	18801.346	846.229	1.147	1.793	-0.034
344184	5814478.680	19292.218	848.164	NOT FOUND / DESTROYED			N/A		

Note: N=Northing; E=Easting; H=Elevation.

2.2 River Cross-Section Survey

Cross-section locations were selected to ensure adequate representation of the channel geometry in the hydraulic model, with consideration given to the location of cross-sections from the most recent flood study (NHC, 1996). During the planning process for the survey, each cross-section was assigned a number in an effort to organize the cross-sections sequentially on each reach. However, cross-section lines and associated survey points shown in Appendix A are labelled according to their river stationing (RS).

The Trimble RTK GNSS receivers used for the survey of cross-sections are accurate to ±0.02 m (when the GNSS receiver is mounted to a tripod with a clear view of the sky, with sufficient satellites to accurately establish the receiver position). The overall expected accuracy of ground-based survey points is ±0.05 m, except in areas with dense vegetation or steep banks where the satellite coverage is poor.

A summary of the cross-sections surveyed in each reach is provided in Table 2-3. A total of 323 cross-sections were surveyed; 174 cross-sections on Wolf Creek and 149 cross-sections on Unnamed Tributaries. Survey point data has been assembled and provided as part of the digital file submission.

Table 2-3 Summary of Surveyed Cross-Section

<table>
<tr><th>River</th><th>Length (km)</th><th>Number of Cross-Sections</th><th>Average Spacing (m)</th></tr>
<tr><td>Wolf Creek</td><td>16.5</td><td>174</td><td rowspan="2">90</td></tr>
<tr><td>Unnamed Tributaries</td><td>13.7</td><td>149</td></tr>
</table>

All cross-sections along Wolf Creek and Unnamed Tributaries were surveyed by wading the channel and walking the banks. TROUT ensured that they surveyed enough details at each cross-section to properly define the channel's geometry during the hydraulic modelling. Figure 2-1 shows a schematic view of the cross-section survey completed.

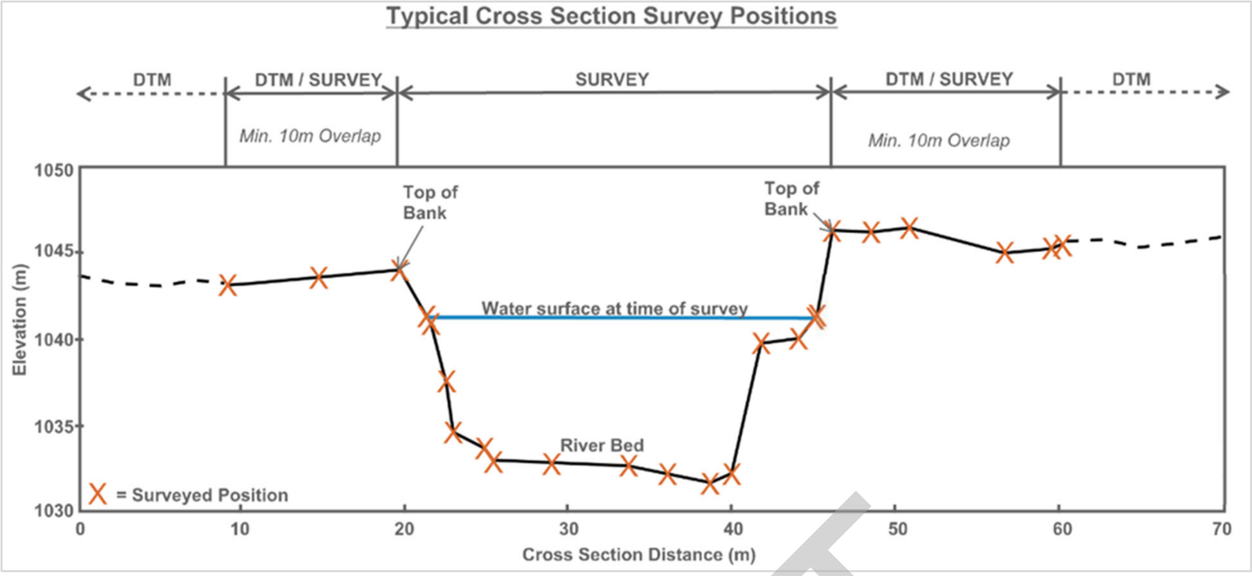


Figure 2-1 Schematic View of Cross-Section Survey

2.3 Discharge and Water Level Profile

As previously mentioned, Wolf Creek and all tributaries were either dry or had stagnant water during the site visit on June 16, 2024. Fortunately, during the cross-section survey the following week, Lacombe experienced a storm that resulted in flowing water in parts of Wolf Creek. The survey crew collected discharge and water surface elevations at three locations on Wolf Creek for the purpose of low-flow model calibration. Table 2-4 provides a summary of the discharge measurement data. TROUT collected several water surface elevations in the vicinity of the discharge measurement locations, within half an hour of discharge measurement, to be used for low flow model calibration.

Table 2-4 Discharge Measurement Summary

River	Date	Discharge Measurement Location	Measured Discharge
Wolf Creek	06/23/2023	Wolf Creek at approximately, RS 15,500 m.	0.011
		20 m upstream of TWP Rd. 41-2A culvert crossing (RS 4,216 m)	0.134
		30 m upstream of TWP Rd. 41-4 culvert crossing (RS 365 m)	0.291

2.4 Hydraulic Structures

Table 2-5 summarizes the hydraulic structures in the study reach. A total of 8 bridges and 19 culvert crossings were identified and surveyed within the study area. Hydraulic structure locations are shown in Appendix A. Survey data for these structures has been assembled and provided as part of the digital study file; bridge and culvert details are provided in Appendix B.

Table 2-5 Summary of Hydraulic Structures

River	Structure Type	Description	Corresponding Figure Number in Appendix B
Wolf Creek	Bridge	CP Trestle B	B-1
Wolf Creek	Bridge	50 Ave. B	B-2
Wolf Creek	Culvert	34 St. C N	B-3
Wolf Creek	Culvert	Wolf Crk Dr C	B-4
Wolf Creek	Bridge	34 St. B	B-5
Wolf Creek	Bridge	PVT 12-33 B	B-6
Wolf Creek	Bridge	TWP Rd. 41-0 B	B-7
Wolf Creek	Culvert	CN RL C	B-8
Wolf Creek	Culvert	HWY 2A C	B-9
Wolf Creek	Bridge	CE Tr. B	B-10
Wolf Creek	Bridge	TWP Rd. 412 B	B-11
Wolf Creek	Culvert	HWY 2 C	B-12
Wolf Creek	Culvert	TWP Rd. 41-2 C	B-13
Wolf Creek	Culvert	TWP Rd. 41-2A C	B-14
Wolf Creek	Culvert	Field Tr. 1 C	B-15
Wolf Creek	Culvert	TWP Rd. 41-4 C	B-16
Unnamed Tributary 2	Culvert	RR 265 C S	B-17
Unnamed Tributary 2	Culvert	PVT Dr. C	B-18
Unnamed Tributary 3	Culvert	34 St. C S	B-19
Unnamed Tributary 3	Bridge	PVT 17-40 B	B-20
Unnamed Tributary 3	Culvert	RR 265 C N	B-21
Unnamed Tributary 3	Culvert	Field Tr. 4 C	B-22
Unnamed Tributary 3	Culvert	Unnamed Rd. C	B-23
Unnamed Tributary 3	Culvert	45 St. C	B-24
Unnamed Tributary 4	Culvert	Field Tr. 2 C	B-25
Unnamed Tributary 4	Culvert	Field Tr. 3 C	B-26
Unnamed Tributary 4	Culvert	34 St. C M	B-27

PVT: Private
Tr.: Trail

Data collected at each bridge includes:

- 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
- 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
- Photographs of the bridge

Data collected at each culvert includes:

- Number of culverts
- Barrel length
- Culvert opening dimensions
- Upstream and downstream invert elevations
- Culvert type (e.g., corrugated steel pipe, concrete box, timber-framed)
- Culvert shape (e.g., circular, arch, elliptical, square, rectangular)
- Entrance condition (e.g., projecting from fill, mitered to conform to slope)
- Top of roadway profile
- Photographs of the culvert

2.5 Flood Control Structures

In collaboration with EPA and local authorities, Barr has confirmed that there are no official flood control structures within the study area (see Appendix C).

2.6 Other Features

2.6.1 Site Photographs

Appendix D provides reach representative photographs obtained during the June 2023 survey program. The location, time, and other metadata information are embedded in the electronic images and included as part of the digital file submission.

2.6.2 Aerial Imagery

Aerial imagery was acquired for EPA by OGL Engineering Ltd. on September 10 and September 14, 2023. Fully processed, orthophoto mosaics were provided to Barr by EPA on August 13, 2024.

2.6.3 LiDAR Data

LiDAR topographic data was collected by LSI in October 2023 and provided by EPA to Barr on June 21, 2024. This dataset was verified by EPA to meet or exceed a vertical accuracy of ± 15 cm at 95% on hard, flat, open (non-vegetated) surfaces, using independently collected survey data. The horizontal spatial reference system was 3TM 114, NAD83 (CSRS), epoch 2002 and the vertical datum was CGVD28.

2.6.4 Other Base Mapping Data

In addition to the datasets mentioned above, other base mapping data were obtained to support modelling and mapping for the study, including road network, hydrography, administrative boundaries, topographic maps, interim 1 m LiDAR (bare-earth digital elevation model (DEM) and bare-earth hillshade) and 2021 SPOT6 1.5 m RBG imagery (provided to Barr by EPA on March 24, 2023), interim 2023 SPOT6 1.5 m RBG imagery (provided to Barr by EPA on July 2, 2024), Altalis LiDAR 25 m, and Alberta Township System (ATS) grids within the study area.

3 Open Water Hydrology Assessment

This section provides a summary of the open water hydrology assessment for the study. A more detailed assessment of open water hydrology is provided in Appendix E.

3.1 Flooding History

3.1.1 General Information

Wolf Creek is a small prairie stream with a relatively flat watershed. The average slope of the watershed is approximately 2.3%. Most of the creek is perennial; however, the tributaries intermittently drain into the creek. The creek has been channelized within the City of Lacombe. The watershed area of Wolf Creek was delineated using the 25 m DEM of Altalis sourced by the EPA in March 2023. The gross watershed area of Wolf Creek at Highway 2 is approximately 100 square kilometers (km^2), and its watershed area within the flood study area is 125 km^2.

3.1.2 Open Water Floods

Wolf Creek and Unnamed Tributaries within the study area are ungauged; therefore, there are no modern recorded open water floods. Historic floods generally refer to major floods that occurred prior to the period of hydrometric data collection and systematic recording of water level and discharge. The magnitude of historic floods can be estimated based on observations or anecdotal information. However, no record of flooding was available in talking to local authorities or researching online for past floods within the study area. Most of the past floods reported in the City of Lacombe were localized urban flooding and not from Wolf Creek or Unnamed Tributaries.

3.1.3 Ice Jam Floods

No ice jam flood information was found for Unnamed Tributaries or Wolf Creek within the study area.

3.2 Open Water Flood Frequency Analysis

A flood frequency analysis was carried out to determine estimates of flood frequencies for a range of return periods up to 0.1% annual exceedance probability (AEP). Details on the flood frequency analysis are provided in the Technical Memorandum on Open Water Hydrology Assessment in Appendix E.

3.2.1 Flood Frequency Flow Estimates

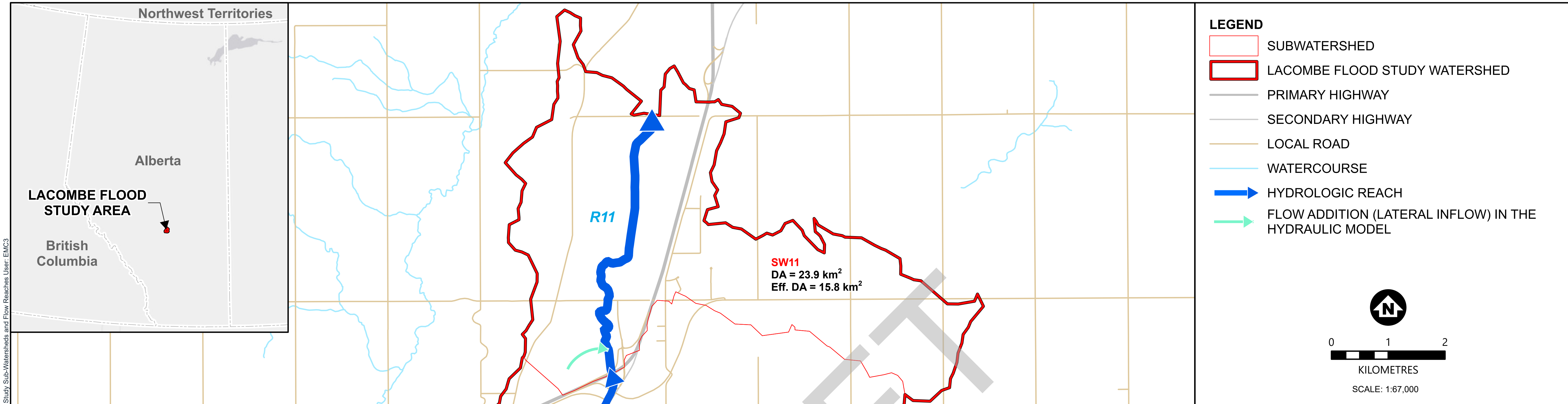
Since there is no WSC streamflow gauge on Wolf Creek or its tributaries within the study area, the flood flow time series of eight WSC gauge stations were downloaded from the Environment and Climate Change Canada (ECCC) website for completing a regional flood frequency analysis (ECCC, 2023). The streamflow gauges were selected based on 1) their proximity to the study area, 2) the size and slope of the basin, and 3) land cover and topography. Four gauges are in the South Saskatchewan River Basin and four in the North Saskatchewan River Basin. Table 3-1 lists the WSC gauges, the available period of records, and the gross and effective watershed areas. The WSC gauge 05EA011 on Carrot Creek was initially selected because of its size and proximity to Lacombe; however, after further review of the flow data recorded at the gauge, it was eliminated from the list because of the short record length and the number of missing data. Because some of the instantaneous peak flows were missing from the records, the missing instantaneous peak flows were approximated using the daily peak flows. After completing flood frequency analyses on the records of the streamflow gauges listed in Table 3-1, multilinear regression analyses were completed for each AEP event. In the final assessment, the magnitude of each AEP event was determined to be a function of the effective drainage area and the average basin slope (see Appendix E). Subsequently, peak flows of the selected AEP events were estimated for different reaches of Wolf Creek and the Unnamed Tributaries.

Table 3-1 WSC Streamflow Gauges Used for Regional Flood Frequency Analysis

WSC Gauge Station Name (1)	Station ID	Range of Record	Years of Record (2)	Alberta's Major Watersheds or River Basins	Gross Watershed Area (km^2)	Effective Watershed Area (km^2)
West Whitemud Creek near Ireton	05DF007	1976–2021	41	North Saskatchewan River Basin	65.4	53.2
Block Creek near Leedale	05CC010	1976–2020	35	South Saskatchewan River Basin	56.8	56.6
Maskwa Creek No. 1 above Bearhills Lake	05FA014	1972–2021	33	North Saskatchewan River Basin	79.1	61.2
Haynes Creek near Haynes	05CD006	1978–2021	36	South Saskatchewan River Basin	165.0	165.0
Bigknife Creek near Gadsby	05FC002	1967–2021	42	North Saskatchewan River Basin	281.0	194.0
Lloyd Creek near Bluffton	05CC009	1965–2020	35	South Saskatchewan River Basin	239.0	239.0
Waskasoo Creek at Red Deer	05CC011	1984–2020	32	South Saskatchewan River Basin	487.0	250.0
Whitemud Creek near Ellerslie	05DF006	1969–2020	42	North Saskatchewan River Basin	330.0	301.0

(1) All gauges are non-regulated (i.e., natural).
(2) Excluding the missing years of record.

Since a combination of fully 2D and coupled 1D/2D model was selected for hydraulic modelling, it was verified in the hydrology assessment that flow accumulations along the tributaries and different Wolf Creek reaches met the overall flow mass balance in the study area as expected in a quasi-steady state model. Moreover, since the estimated flood peaks appeared to be too small for Unnamed tributaries and upstream reaches of Wolf Creek for hydraulic modelling, estimated peak flows were further adjusted in the final hydrology assessment, for the purpose of this study, in consultation with EPA. In this exercise, flood frequency estimates along reaches R3 through R8 were revised and are based on the ratio of the reach effective drainage area to the total effective drainage area of reach R9. The flood frequency estimates along reaches R9, R10, and R11 are based on the derived regional regression equations. Figure 3-1 shows the sub-watersheds used for the hydrology assessment and the reaches used for reporting the flood peaks. Table 3-2 summarizes the final peak discharges recommended to be used for the hydraulic modelling. Note that in Figure 3-1 and Table 3-2, reaches R1 and R2 are not shown. These two reaches were eliminated from the final assessment because of very small flows through these two reaches. In addition, during the site visit on June 13, 2023, no creek could be identified for sub-watersheds 1 and 2 (labeled as SW1 and SW2 on Figure 3-1).



REFERENCES
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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

Alberta
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STUDY SUB-WATERSHEDS AND FLOW REACHES
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS
FIGURE 3-1

BARR

Table 3-2 Final Flood Frequency Estimates Recommended to be Used in the Hydraulic Model

AEP	Reaches along Wolf Creek and its Tributaries								
	R3	R4	R5	R6	R7	R8	R9	R10	R11
1:2	0.36	0.13	0.59	0.61	0.30	0.22	1.41	2.19	2.74
1:5	0.70	0.26	1.16	1.21	0.59	0.44	2.78	4.46	5.68
1:10	1.03	0.38	1.69	1.76	0.86	0.64	4.06	6.61	8.50
1:20	1.43	0.53	2.34	2.44	1.19	0.89	5.64	9.28	12.01
1:35	1.80	0.68	2.96	3.09	1.50	1.12	7.12	11.83	15.39
1:50	2.06	0.77	3.39	3.53	1.72	1.28	8.15	13.63	17.78
1:75	2.43	0.91	3.99	4.16	2.03	1.51	9.59	16.12	21.10
1:100	2.69	1.01	4.41	4.61	2.24	1.67	10.62	17.91	23.48
1:200	3.40	1.28	5.59	5.83	2.84	2.12	13.45	22.89	30.16
1:350	4.04	1.51	6.64	6.93	3.37	2.52	15.97	27.38	36.21
1:500	4.55	1.71	7.48	7.81	3.80	2.84	18.00	31.01	41.12
1:750	5.19	1.95	8.52	8.89	4.33	3.23	20.51	35.53	47.26
1:1,000	5.59	2.10	9.18	9.58	4.67	3.48	22.09	38.40	51.15

3.2.2 Comparison with Previous Studies

Three flood frequency analyses were completed in 1992 (De Boer for AEP), 1996 (AEP), and 2014 (MPE Engineering) for Wolf Creek. The results of the current study are significantly smaller than the 1992 study for Wolf Creek at Highway 2 and about 50% of those obtained in the 1996 study. However, the results are in good agreement with the 2014 study and slightly larger. To better understand the difference between the current study and the 1996 study, Barr estimated the flows of reach R10 with all AEPs using the 1996 method. Table 3-3 lists the results of the three methods for reach R10. Note that in the 2014 method, which was completed by MPE, flows were estimated at Highway 2A and Township Road 41-2, which are upstream and downstream of the outlet of reach R10. The difference between 1996 and 1992, as stated in the 1996 report, was in accounting for the effects of storage.

Table 3-3 Estimated Flood Flows at Location 10 in m3/s for Selected AEPs Using the Current Method, Using the 1992/1996 Method, and the 1996 Estimates

AEP	Current Study	1992 Estimates	1996 Estimates1	2014 Estimates2
1:2	2.19	-	7.6	0.75
1:5	4.46	-	-	2.26
1:10	6.61	-	18.9	4.01
1:20	9.28	-	-	6.40
1:35	11.83	-	-	-
1:50	13.63	-	30.6	10.89
1:75	16.12	-	-	-
1:100	17.91	75.4	36.4	15.46

(1) In the 1996 Flood Risk Mapping Study, flows were estimated only for the 1:2, 1:10, 1:50, and 1:100 AEP events (4^{th} column)
(2) The 2014 study provided estimates at Highway 2A and the Township Road 41-2. The values reported in the last column are at Highway 2A. If the 2014 study had been used to estimate the flows at Highway 2, the flows would have been slightly larger than those listed in the last column of the table.

4 Open Water Hydraulic Modelling

The following sections describe the methodology and results of the open water hydraulic modelling component. The scope of this component includes a summary of available data and stream/valley features in the study area, hydraulic model setup, hydraulic model calibration and validation, selection of Manning's n roughness values, 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.

4.1 Available Data

The data available to develop and calibrate the hydraulic model are described below. Additional information, such as past studies and existing hydraulic models, also informed model development.

4.1.1 Digital Terrain Model

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

4.1.2 Existing Models

A previous hydraulic model was developed as part of the 1996 Lacombe Flood Risk Mapping Study. This model included Wolf Creek from 34th Street to the intersection of Highway 2 and Highway 2A and Unnamed Tributary 3 from Township Road 402 to its confluence with Wolf Creek. It is noted that a different naming convention was used in the 1996 study. The Upper Wolf Creek (i.e., the reach flowing westward) was named East Reach, and Unnamed Tributary 3 from Township Road 402 to its confluence with Wolf Creek was considered part of Wolf Creek. Barr adopted the naming convention shown on Figure 1-1 in consultation with EPA for the current study. A HEC-2 model was created for 9 km of Wolf Creek and 2 km of East Reach. Flood frequency maps for 10-, 50-, and 100-year flood events were prepared.

4.1.3 Highwater Marks

There is no highwater mark (HWM) data available along the study reach of Wolf Creek and Unnamed Tributaries.

4.1.4 Gauge Data and Rating Curve

There is no active Water Survey of Canada (WSC) hydrometric gauging station located on Wolf Creek or Unnamed Tributaries within the study area. However, a discontinued WSC hydrometric gauging station is located on Wolf Creek within the study area (i.e., WSC Station 05FA026 – Wolf Creek at Township Road 410). This station only operated for 3 years (2007 to 2009) with no water level report or vertical datum information. Therefore, this gauge data could not be used for the hydraulic model calibration.

4.1.5 Flood Photography

No flood photography is available along the study reach of Wolf Creek and Unnamed Tributaries.

4.2 River and Valley Features

4.2.1 General Description

The Wolf Creek watershed lies within the Central Parkland natural subregion, on the boundary of the Western Alberta Plains and the Eastern Alberta Plains physiographic regions. The watershed contains well-drained topography as well as shallow topographical relief containing numerous potholes, sloughs, and shallow lakes characterized by poor drainage. Land use is predominantly agriculture with some natural areas and growing clusters of urbanization (MPE, 2014). The watershed lies in the Black Soil Zone, with soils generally medium textured, including loams and silty loams. Contained within the Central Parkland sub-region, the watershed also has hummocky and ground moraines, and deposits of fine textured glaciolacustrine and coarse outwash.

4.2.2 Channel Characteristics

About 13 km of the main stem of Wolf Creek, from within the City of Lacombe to the boundary of Lacombe County and Ponoka County, was channelized in the early 1980s and is maintained by the City of Lacombe under a Water Act approval (MPE, 2014). Wolf Creek and associated tributaries have been identified as fish bearing from their mouths upstream to about 3 km north of the City of Lacombe (west and downstream of Highway 2). Wolf Creek's average channel width is approximately 2 to 4 m upstream of its confluence with the Unnamed Tributary 3 (i.e., Upper Wolf Creek) and approximately 6 to 8 m downstream of the confluence (i.e., Lower Wolf Creek). The overall reach-average channel slopes are 0.0007 m/m and 0.005 m/m for Lower and Upper Wolf Creek, respectively.

The Unnamed Tributaries generally flow north-westerly, as shown on Figure 1-1. These tributaries are generally poorly defined and only flow during a storm event, mainly in spring or summer. The overall reach-average channel slopes for Unnamed Tributaries, as well as Wolf Creek, are summarized in Table 4-1. For the naming convention of Unnamed Tributaries, refer to Figure 1-1.

Table 4-1 Reach-Average Channel Slope Summary

Reach	Reach-Average Channel Slope (m/m)
Upper Wolf Creek	0.005
Lower Wolf Creek	0.0007
Unnamed Tributary 1	0.001
Unnamed Tributary 2	0.005
Unnamed Tributary 3	0.004
Unnamed Tributary 4	0.010
Unnamed Tributary 5	0.014
Unnamed Tributary 6	0.013

4.2.3 Floodplain Characteristics

The floodplain on both sides of Wolf Creek and Unnamed Tributaries is generally flat. The vegetation consists mainly of cultivated crop lands upstream and downstream of the City of Lacombe, where the predominant land use is agricultural. There is an area east of Wolf Creek near the downstream end of the study area (east of Highway 2 and railway), between Milton Road and Township Road 414, where the land cover consists of bush and dense trees.

4.2.4 Anthropogenic Features

The City of Lacombe is located approximately 125 km south of the City of Edmonton and has a population of 14,344, as of 2023, according to the Office of Statistics and Information, Alberta Treasury Board and Finance. A total of 27 hydraulic structures (e.g. bridges, culverts) have been documented along the study reaches. Details on these hydraulic structures are provided in Appendix B.

4.3 Model Construction

4.3.1 Methodology

The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center-River Analysis System (HEC-RAS) computer program (Version 6.5, February 2024) was used to calculate the flood levels along the study reaches. HEC-RAS can perform one-dimensional (1D), two-dimensional (2D), or combined 1D and 2D hydraulic calculations for a network of channels and hydraulic structures. There were several meetings between EPA and Barr to agree on the modelling approach for this unique flood study due to poorly defined channels of Unnamed Tributaries (intermittent prairie origins of the watershed), and small flood frequency peaks resulting from hydrology assessment.

Initially the plan was to build a coupled 1D/2D model of the study area. However, upon completion of the site visit and survey in June 2023, it was evident that most of the tributaries are comprised of poorly defined reaches.

After receiving the high-resolution DTM for the Lacombe Flood Study area (the high-resolution DTM delivery for the study was delayed), Barr further reviewed the streams and identified some poorly defined sections along the Upper Wolf Creek and Unnamed Tributary 3 (see Figure 4-1 to Figure 4-3). Based on the site survey and review of DTM and ground conditions, the modelling approach was altered to have a coupled 1D/2D model for the well-defined reach of Lower Wolf Creek, and the rest of the study reaches (including the Upper Wolf Creek) to be modelled as full 2D domains.

It is noted that the transition from a full 2D domain to a coupled 1D/2D domain just upstream of Highway 12 (50 Avenue) (i.e., confluence of Wolf Creek and Unnamed Tributary 3) could be challenging due to the back-to back hydraulic structures (50 Avenue Bridge and CP Rail Bridge) as well as complex flow areas due to the borrow pits and stormwater pond in that area. Therefore, the transition was moved to approximately 100 m downstream of CP Rail Bridge.

A preliminary 1D model was constructed for the entire study area in the early stages of model development to inform the final methodology. This model utilized clipped cross-sections in Wolf Creek where there was a high degree of confidence in the coupled 1D/2D methodology. In the upper reach of Wolf Creek and associated tributaries, full cross-sections were created spanning the floodplain. This was done to investigate whether a one-dimensional model would be appropriate for the poorly defined channels in the upper reaches. A1D model for the upper reaches was found unsuitable as the detailed

DTM not only fell above the survey elevations for the main flowpath/channel (as expected) but was also higher than water levels for low flood events (e.g., 2-, 5-, 10-year flood events).

Finally, the model approach discussions and preliminary model evaluations considered potential complications in the mapping stage due to the unique channel and floodplain characteristics of the area and assigned flows from the hydrology assessment.

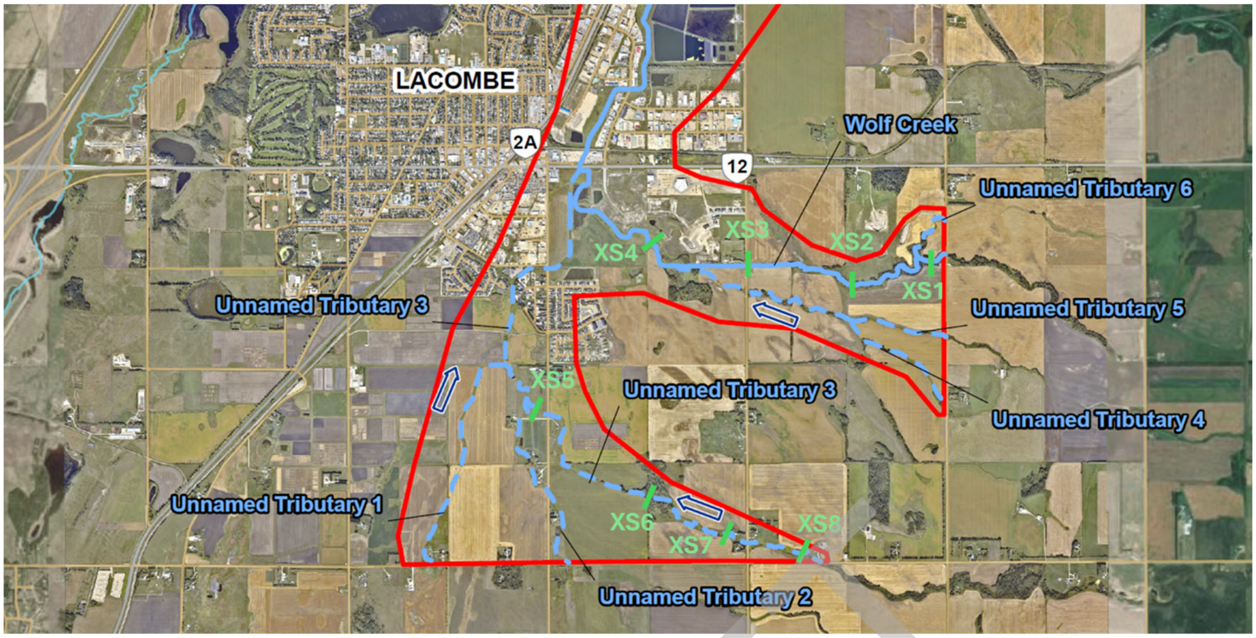


Figure 4-1 **Example of Cross-Sections on Upper Wolf Creek and Unnamed Tributary 3 (Green Cross-Sections Are Shown in Figure 4-2 and Figure 4-3)**

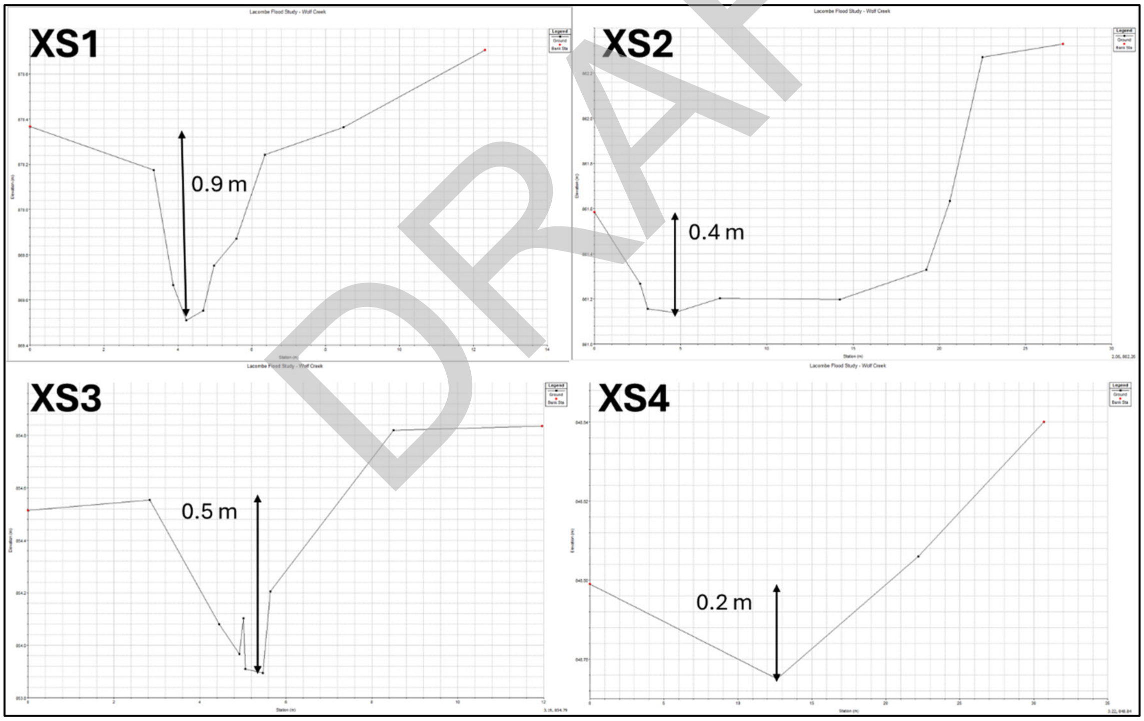


Figure 4-2 **Example Cross-Sections along the Upper Wolf Creek**

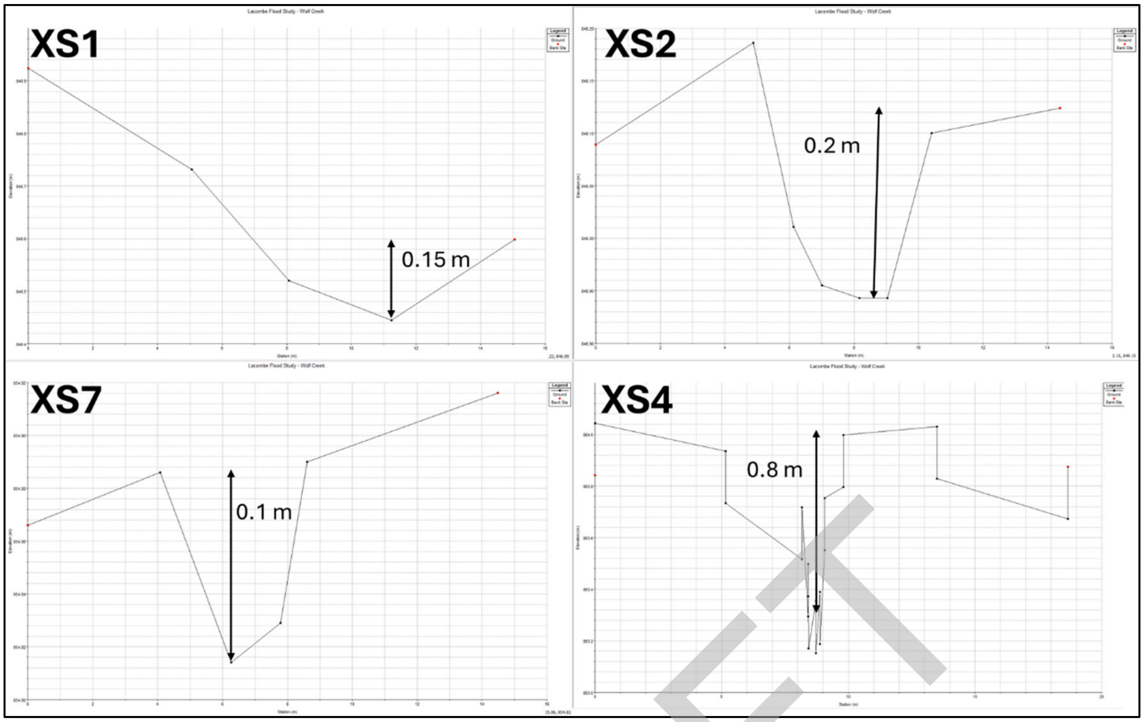


Figure 4-3 Example Cross-Sections along the Unnamed Tributary 3

Compared to the 1D HEC-RAS modelling approach that is based on cross-sections and would require simplifications, approximations, and professional judgement to adequately simulate the complex flow conditions, the coupled 1D/2D and fully 2D HEC-RAS models offer the following benefits:

- A 1D component maintains benefits of the 1D HEC-RAS model (e.g., accurate simulation of the main channel hydraulics for well-defined channel of Lower Wolf creek).
- 2D modelling for large and flat floodplain areas will reduce the uncertainty in defining the alignment of cross-section and the selection of appropriate ineffective flow areas for large floodplains in the model domain.
- The complicated flow paths in the wider floodplain of Lower Wolf Creek are better represented with 2D modelling.
- 2D modelling will lower the risk of profiles crossing at the locations where ineffective flow area would be activated when flood control structures, levees, or roads would be overtopped.

4.3.2 Model Setup

4.3.2.1 Model Domain

Using a single geometry file to simulate floods of various return periods is generally desirable. Therefore, the model domain should be defined to cover inundation extents of the largest flood event to be simulated. The model domain extent was defined in consideration of the simulation results of a supplemental approximate HEC-RAS 2D model, which was set up based on the LiDAR DEM without the inclusion of the channel bathymetry to provide conservative water level estimates. The upper portion of the model was created as a fully 2D model to approximately 300 m downstream of the 50 Avenue Bridge. Downstream of this location to the most downstream extent of the study area, a coupled 1D/2D model was created. Figure 4-4 shows the model domain and transition between the full 2D model and coupled 1D/2D model.

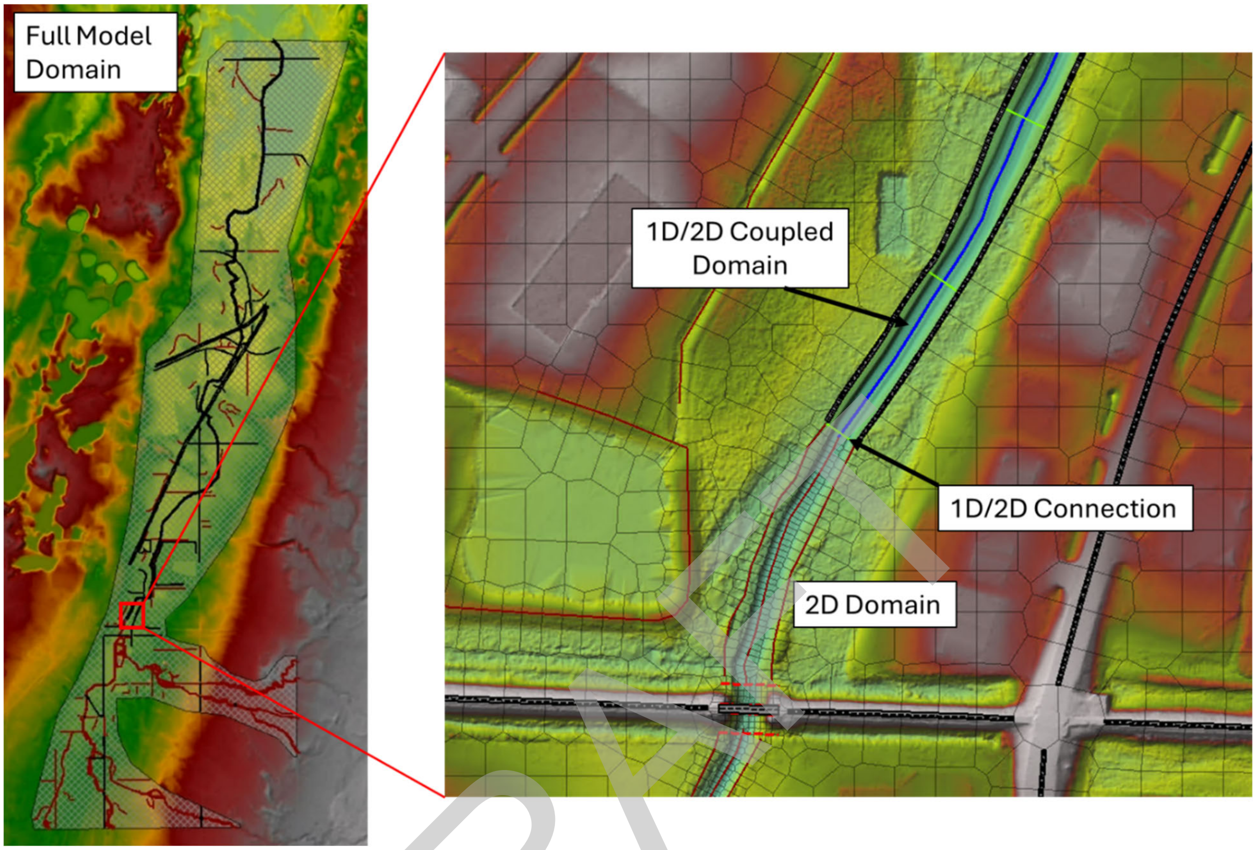


Figure 4-4 Lacombe Flood Study Model Domain and Transition between Coupled and 2D Domains

4.3.2.2 2D Model

For the fully 2D model, a refined mesh system was utilized. The main channel mesh size is 2 m × 2 m for the smallest Unnamed Tributaries and increases to 3 m × 3 m for larger streams. Three breaklines were used in the channel centerline and two banklines were used to ensure computation accuracy for the main channel and properly capture the banks in the model. Moreover, extra attention was paid to transition the mesh smoothly to coarser mesh sizes on the floodplain. The largest cell size on the outer floodplain in the 2D model is 20 m × 20 m. Local refinement along key structures, side channels, ponds, and high grounds was implemented in the model. Some of key linear structures in the 2D domain were set up as weirs to more accurately simulate the flow pattern near those structures. These structures include Highway 2, Highway 12 (50 Avenue), railway, and several local roads. A total of 19 km of reaches were modelled as fully 2D domain in this study. Figure 4-5 provides a detailed view for a section of the 2D model.

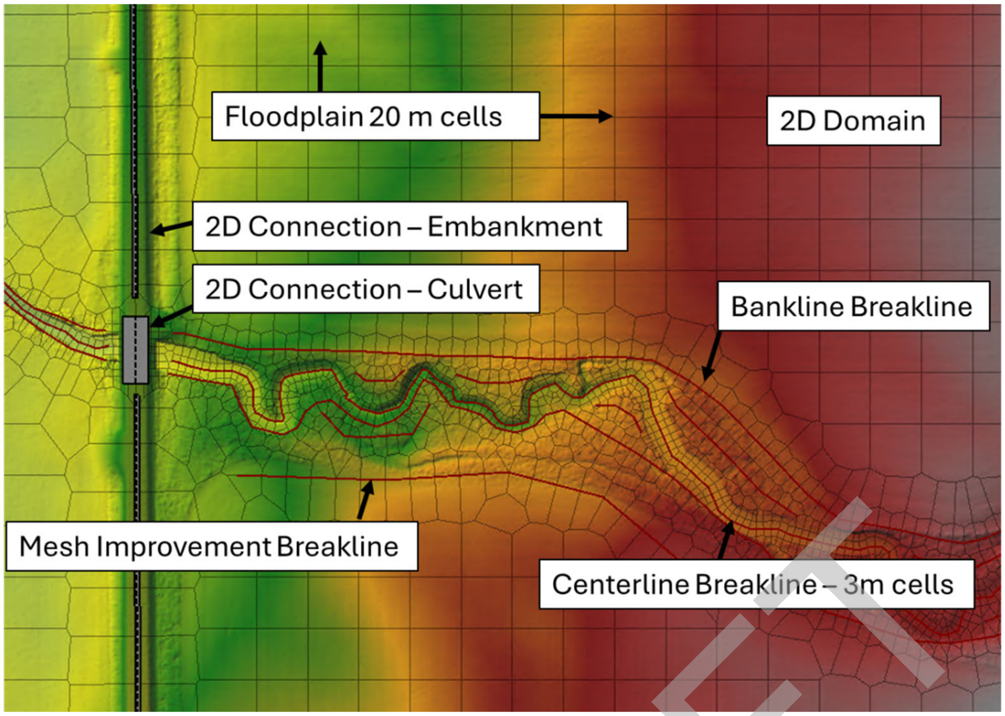


Figure 4-5 An Example of 2D Model

4.3.2.3 Coupled 1D/2D Model

The coupled 1D/2D model in the current study includes the following.

- 1D cross-sections were defined along the main channel of Lower Wolf Creek based on surveyed river cross-sections. This was completed in RAS-Mapper.
- 2D model areas were defined for the left and right floodplains of Lower Wolf Creek with the average mesh size of 20 m x 20 m with local refinement along key structures, side channels, ponds, and high grounds.
- Some of the key linear structures in the 2D domain were set up as weirs to more accurately simulate the flow pattern near those structures. These structures include Highway 2 and several local roads.
- The upstream full 2D domain was connected to the downstream coupled 1D/2D domain at the most upstream cross-section.
- The left and right overbank 2D model domains were connected to the 1D model domain by lateral structures located at the top of bank, in the Lower Wolf Creek reach.

A total of 12 km of reaches were modelled as coupled 1D/2D domain in this study. Figure 4-6 provides a detailed view of a section of the coupled 1D/2D model.

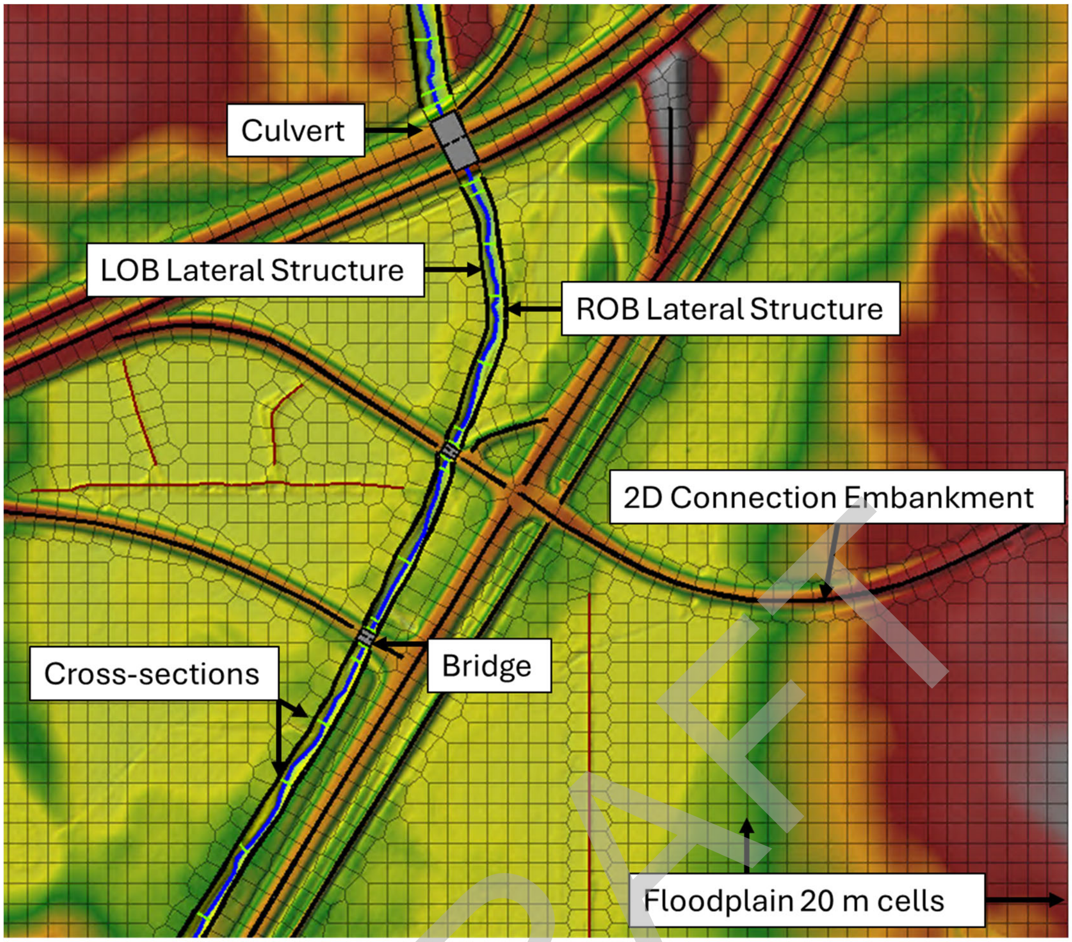


Figure 4-6 An Example of Coupled 1D/2D Model

4.3.2.4 Boundary Conditions and Other Inflows

The fully 2D and coupled 1D/2D HEC-RAS models require specification of boundary conditions at all open and internal boundaries. The open boundaries of the hydraulic model are listed below.

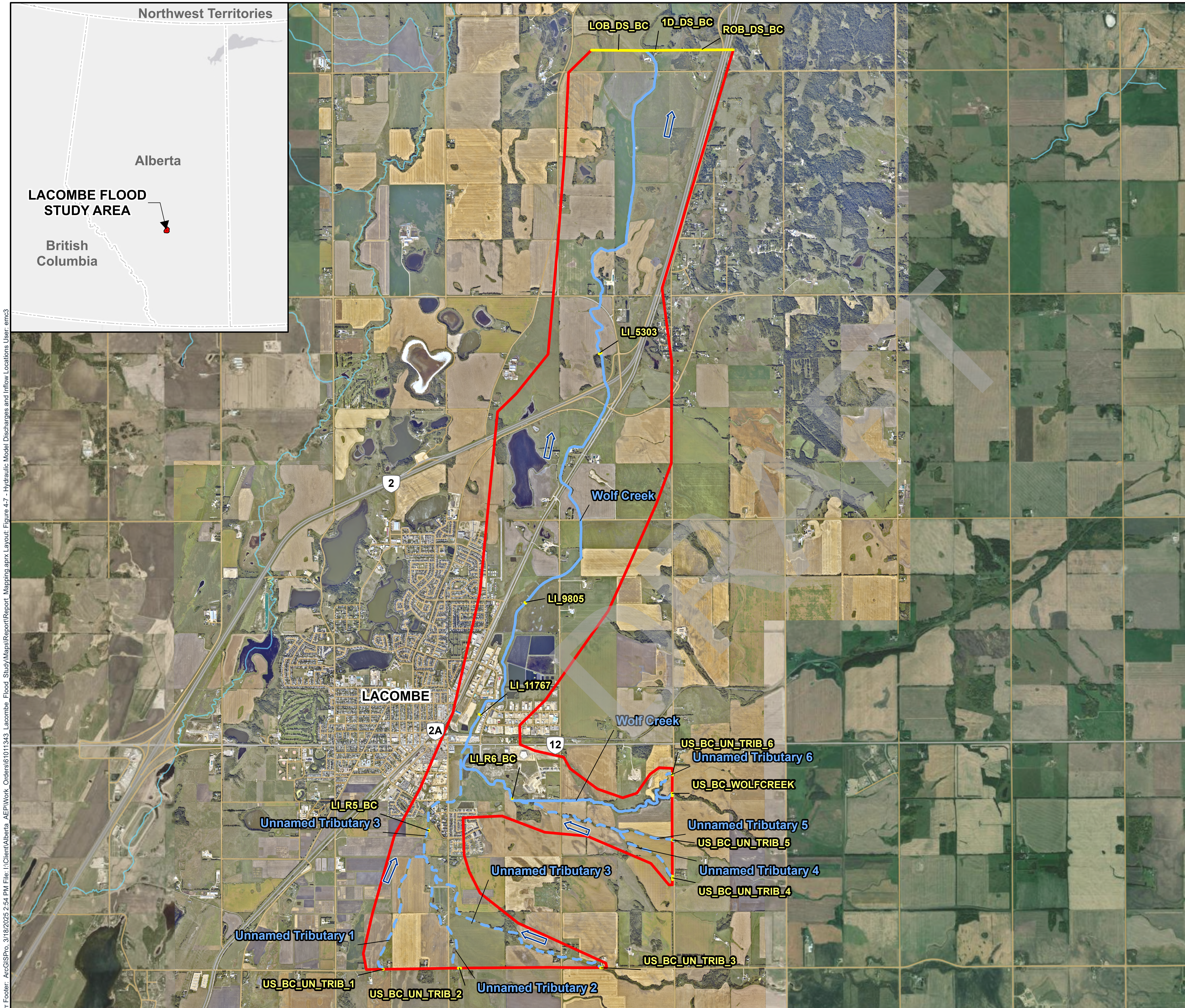
- Discharges at the upstream model boundaries of the Upper Wolf Creek and all Unnamed Tributaries in the 2D domain
- Normal flow condition (with an estimated energy slope of 0.03%) at three downstream model boundaries of the Lower Wolf Creek (one for the left floodplain, one for the main channel, one for the right floodplain)
- Inflows along some reaches to satisfy the flow accumulation in the model due to the unsteady-state nature of the model

Flow peaks used in the model and their locations are summarized in Table 4-2 and shown on Figure 4-7. For hydrology reach naming convention, refer to Figure 3-1.

Table 4-2 Hydraulic Model Discharges and Inflow Locations

Hydrology Reach [1]	Reach	RS (m)	Inflow Locations [3]	Return Period and Discharge[4] (m^3/s) 2-yr	5-yr	10-yr	20-yr	35-yr	50-yr	75-yr	100-yr	200-yr	350-yr	500-yr	750-yr	1,000-yr
R4	Unnamed Tributary 1	2,000	US_BC_UN_TRIB_1	0.13	0.26	0.38	0.53	0.68	0.77	0.91	1.01	1.28	1.51	1.71	1.95	2.10
R3 [2]	Unnamed Tributary 2	1,650	US_BC_UN_TRIB_2	0.18	0.35	0.51	0.71	0.90	1.03	1.21	1.34	1.70	2.02	2.28	2.59	2.79
R3 [2]	Unnamed Tributary 3	5,880	US_BC_UN_TRIB_3	0.18	0.35	0.51	0.71	0.90	1.03	1.21	1.34	1.70	2.02	2.28	2.59	2.79
R7 [2]	Unnamed Tributary 4	2,840	US_BC_UN_TRIB_4	0.15	0.29	0.43	0.60	0.75	0.86	1.01	1.12	1.42	1.69	1.90	2.17	2.33
R7 [2]	Unnamed Tributary 5	780	US_BC_UN_TRIB_5	0.15	0.29	0.43	0.60	0.75	0.86	1.01	1.12	1.42	1.69	1.90	2.17	2.33
R8 [2]	Wolf Creek	16,500	US_BC_WOLFCREEK	0.11	0.22	0.32	0.44	0.56	0.64	0.76	0.84	1.06	1.26	1.42	1.62	1.74
R8 [2]	Unnamed Tributary 6	560	US_BC_UN_TRIB_6	0.11	0.22	0.32	0.44	0.56	0.64	0.76	0.84	1.06	1.26	1.42	1.62	1.74
R5	Unnamed Tributary 3	1,570	LI_R5_BC	0.10	0.19	0.27	0.38	0.48	0.55	0.65	0.72	0.91	1.08	1.22	1.39	1.50
R6	Wolf Creek	13,730	LI_R6_BC	0.09	0.18	0.26	0.37	0.46	0.53	0.62	0.69	0.87	1.04	1.17	1.33	1.43
R9	Wolf Creek	11,767	LI_11767	0.21	0.42	0.61	0.85	1.07	1.23	1.45	1.60	2.03	2.41	2.71	3.09	3.33
R10	Lower Wolf Creek	9,805	LI_9805	0.78	1.68	2.55	3.65	4.72	5.48	6.53	7.29	9.45	11.41	13.02	15.03	16.31
R11	Lower Wolf Creek	5,303	LI_5303	0.55	1.23	1.89	2.73	3.56	4.15	4.97	5.57	7.27	8.83	10.11	11.72	12.76

(1) Refer to Figure 3-1 for naming of hydrology reaches.
(2) Discharge is divided evenly between branches of a hydrologic reach.
(3) Refer to Figure 4-7 to see the location of inflows used in the hydraulic model.
(4) Discharges above are incremental values used in the unsteady-state hydraulic model. Cumulative discharges from hydrology assessment are shown in Table 3-2.



LEGEND

- STUDY AREA
- FLOW DIRECTION
- MODEL BOUNDARY AND INFLOW
- WOLF CREEK
- TRIBUTARIES
- WATERCOURSE
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD

0 1 2
KILOMETRES
SCALE: 1:55,000

REFERENCES
ORTHOPHOTO IMAGERY ACQUIRED BY OGL ENGINEERING FOR ALBERTA ENVIRONMENT AND PROTECTED AREAS: OGL ENGINEERING (2023). ESRI IMAGERY SOURCED BY MAXAR (2021).

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

NOTES

BC = BOUNDARY CONDITION	ROB = RIGHT OVERBANK
DS = DOWNSTREAM	TRIB = TRIBUTARY
LI = LATERAL INFLOW	UN = UNNAMED
LOB = LEFT OVERBANK	US = UPSTREAM

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HYDRAULIC MODEL DISCHARGES AND INFLOW LOCATIONS
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS
FIGURE 4-7

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4.3.2.5 Numerical Details

Based on the modelling approach selected (as explained above), the HEC-RAS model required an unsteady-state numerical solver. Note that inflows in the model were treated as a quasi-steady state, where the flow increases until it reaches the peak flow estimated in the hydrology assessment and then kept constant for the duration of simulation. The most robust solver available in HEC-RAS was selected for computation: SWE-ELM, which stands for Shallow Water Equations with a Eulerian-Langrangian Method. This approach uses a Eulerian solver for advection. The new SWE equation solution method is more momentum conservative but may require smaller time steps and longer run times (compared to the default diffusion wave solver). In general, this solver captures changes in water surfaces and velocities at and around hydraulic structures, piers/abutments, and tight contractions and expansions, better than the diffusion wave solver in HEC-RAS.

A refined mesh system was used to balance accuracy and computational cost. A total of approximately 106,648 cells were used in the model. Modelling started with a uniform coarse mesh of 3 m × 3 m for the Unnamed Tributaries and was reduced to 2 m × 2 m for smaller channels to ensure mesh dependency in water level results and accuracy of the model. It is noted that the 2D mesh initially covered a larger area; however, to reduce run time, the model domain was cut (in an iterative process) to reduce the total number of cells. The final model domain was selected to encompass the 1,000-year flood inundation extent with a general buffer of approximately 100 m.

The lateral structures were used in the model to connect the 1D cross-sections of Lower Wolf Creek to the left and right floodplains. Breaklines and weirs were used in the 2D model, where needed. Table 4-3 summarizes the numerical details of the HEC-RAS model.

Table 4-3 Model Numerical Details

Parameter	Value
Fully 2D Reach Length (km)	18.2
Coupled 1D/2D Reach Length (km)	12.0
Computational Solver	SWE-ELM
Timestep (s)	1
Approx. Simulation Time (hr.)	10
Number of Cells in 2D Domain	94,342
Smallest Cell Size (m)	2
Largest Cell Size (m)	20
Number of Actual Cross-sections (i.e., surveyed cross-sections)	129
Number of Interpolated Cross-sections	65
Cross-Section Interpolation Distance (m)	100
Number of Lateral Structures in Coupled 1D/2D Domain	31
Number of Breaklines	269
Number of 2D Connections (2D hydraulic structures and as Weirs on Major Roads)	91

4.3.3 Geometric Data Base

The geometric database provides all of the components of the HEC-RAS model geometry, including cross-sections, 2D model domain and mesh, roughness, and hydraulic structures. Each component is described below.

4.3.3.1 Cross-Section Data for Lower Wolf Creek

The Lower Wolf Creek Reach was modelled as a coupled 1D/2D domain, where the main channel was modelled as 1D and connected to the 2D floodplains along the top of the bank using lateral structures. The locations of the cross-sections in the model were selected based on the locations of the surveyed cross-sections and modelling requirements, such as appropriate spacing and structure definition as defined in the HEC-RAS user manual (USACE, 2024). The cross-section data was obtained from the river survey data collected for this study in June 2023.

Cross-sections were created in RAS-Mapper with bank points and roughness values assigned to each cross-section. The total length of the Lower Wolf Creek main channel is approximately 12 km and was modelled using 128 surveyed cross-sections.

4.3.3.2 2D Model Terrain

For the fully 2D domain (i.e., for Unnamed Tributaries and Upper Wolf Creek), a composite surface of surveyed cross-sections (for the main channel) and high resolution DTM (for the floodplain) was needed to be used as terrain in the model. During the initial model simulations, it was found that there are sections in the coupled 1D/2D model where the water levels for low flood events (mainly 2- and 5-year) are above the channel terrain of Lower Wolf Creek. Therefore, a composite surface was created for the entire study area. Note that the cross-sections in the Lower Wolf Creek use the survey points and are not extracted from this composite surface. However, the composite surface will be used for mapping and will eliminate the issue of dry regions due to water levels in the main channel being lower than the DTM. A Barr-developed GIS tool, which uses the surveyed cross-sections to create interpolated intermediate cross-sections, was used to create the composite surface. The tool helped to define the distance between the interpolated cross-sections, allowing for accurate capture of the channel geometry. The cross-sections were then used to create a Triangulated Irregular Network (TIN) surface within the banklines, which was then converted to a channel bathymetric DTM. This raster was then mosaicked into the floodplain DTM to create a final model surface. Special attention was paid to inspecting the composite surface for accuracy and anomalies, as it was the basis for modelling and mapping. Figure 4-8 shows an example composite surface created to be used in the HEC-RAS model.

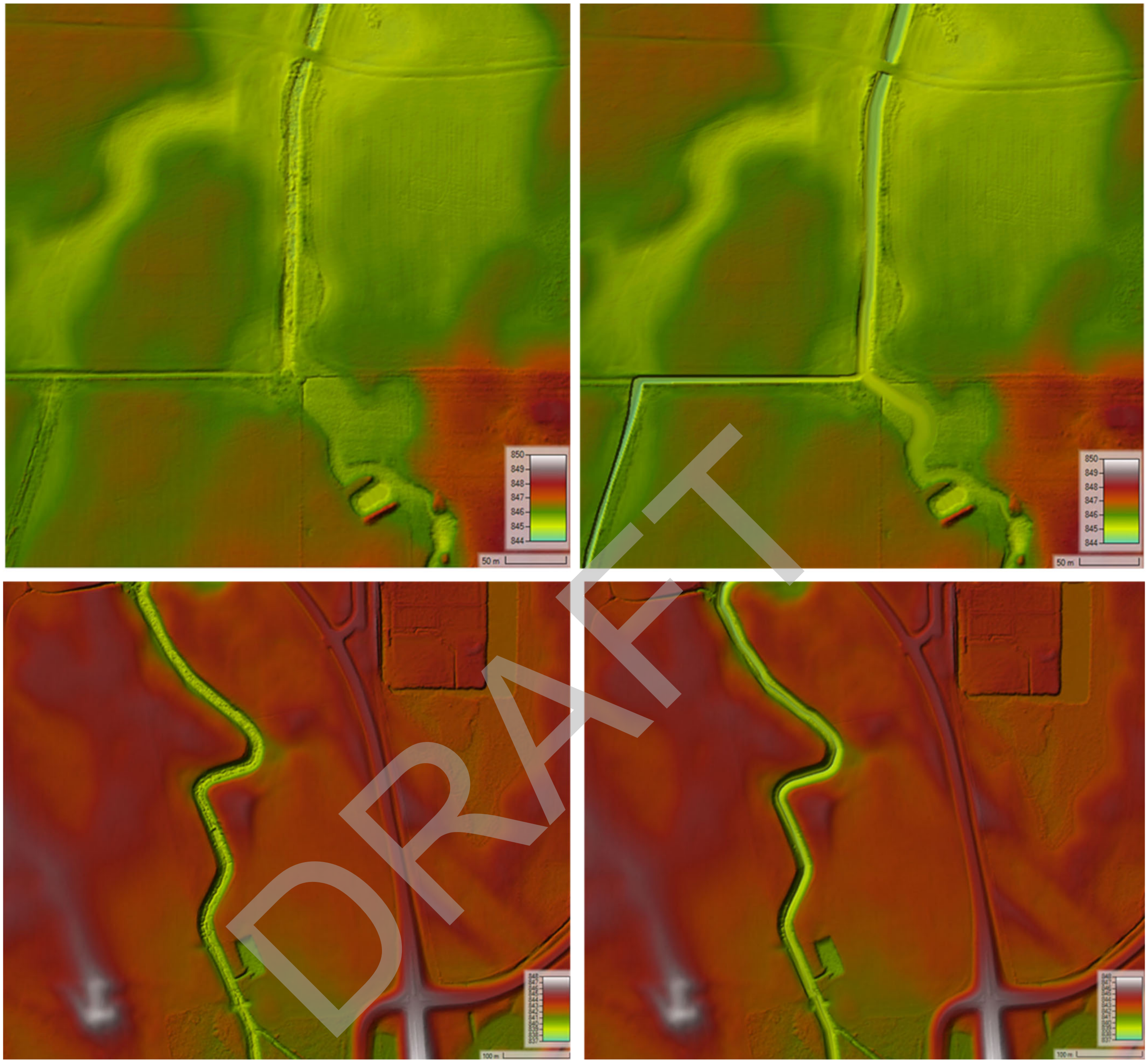


Figure 4-8 Comparison of the LiDAR DTM (left) Covering Unnamed Tributaries 1 and 3 (Top) and Wolf Creek (Bottom) and the Same Area with the Channel Bathymetry Tied into the DTM (right)

4.3.3.3 Roughness Coefficients

Manning's n values were specified using the distributed roughness approach, which allows for multiple, varying roughness values within the study area. The initial roughness distribution was specified based on the following data.

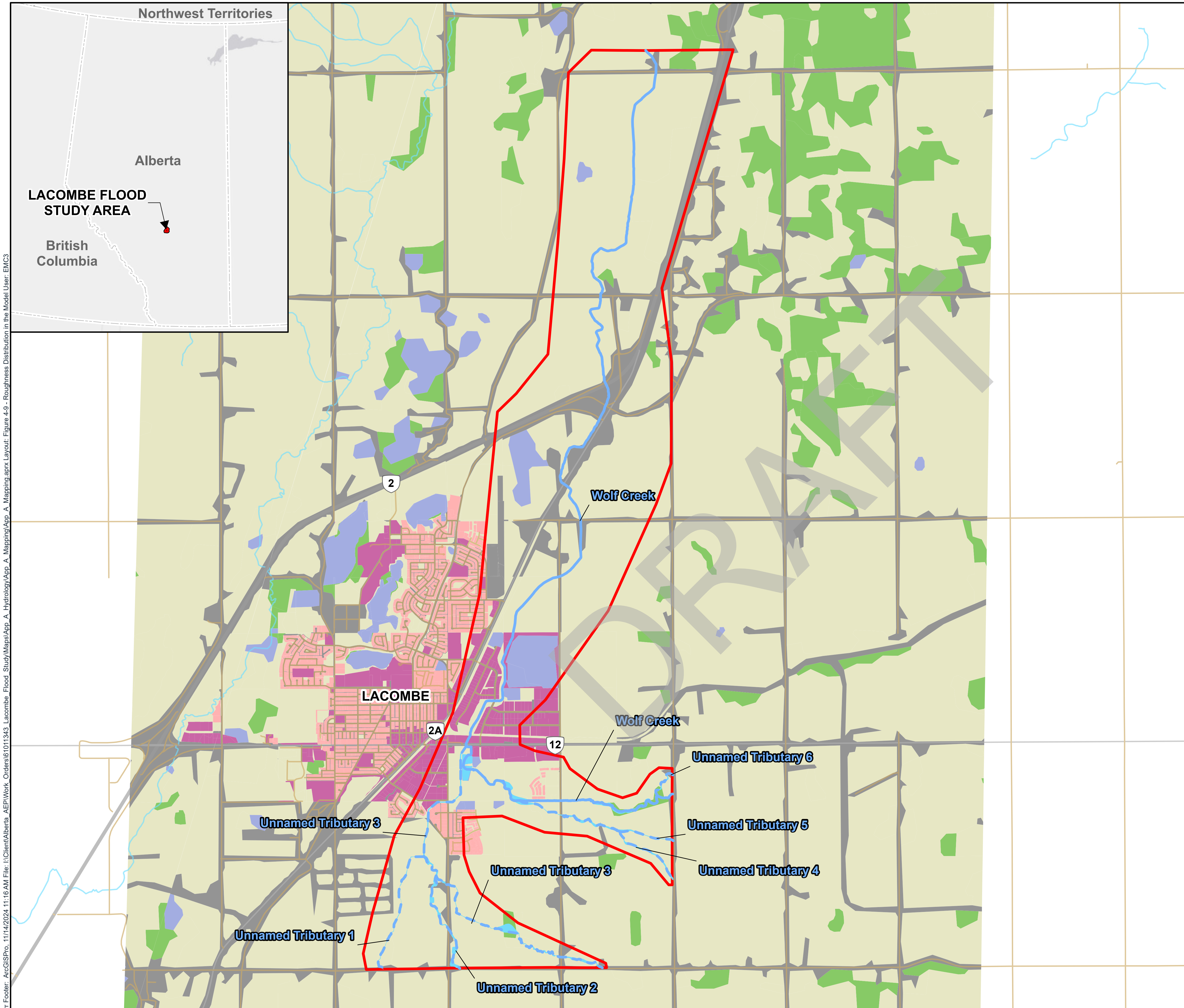
- Banklines established from the LiDAR data, aerial imagery and surveys to identify the main channels (for coupled 1D/2D model area)

- Land use layer provided by the City of Lacombe for the City boundary
- Land use information from the Government of Alberta

Seven roughness classes were used for the model setup. The initial Manning's n values assigned to the classes are listed in Table 4-4. These initial values were selected based on channel bed materials and vegetation types (Chow 1959; USACE 2024). These roughness values were modified at some locations during the model calibration. The distribution of land uses with defined roughness classes is shown in Figure 4-9.

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

Roughness Class	Initial Manning's n Values
Stream Channel	0.035-0.04
Grassland and Farmland	0.05
Developed – Commercial and Industrial	0.06
Developed – Residential	0.08
Roads and Paved Surfaces	0.025
Brush and Forest	0.15
Ponds and Lakes	0.03



LEGEND

- STUDY AREA
- WOLF CREEK
- TRIBUTARIES
- WATERCOURSE
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- STREAM MAIN CHANNEL
- BRUSH AND FOREST
- DEVELOPED - COMMERCIAL AND INDUSTRIAL
- DEVELOPED - RESIDENTIAL
- GRASSLAND AND FARMLAND
- PONDS AND LAKES
- ROADS AND PAVED SURFACES

0 1 2
KILOMETRES
SCALE: 1:55,000

REFERENCES
BASE DATA FROM ALBERTA ENVIRONMENT AND PROTECTED AREAS.

ADDITIONAL BASE DATA FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

LANDCOVER DATA FROM CITY OF LACOMBE AND ALBERTA BIODIVERSITY MONITORING INSTITUTE.

DATUM: NAD 83 CSRS PROJECTION: 3TM 114

LAND USE DISTRIBUTION IN THE MODEL
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 4-9

Classification: Public

4.3.3.4 Hydraulic Structures

4.3.3.4.1 Bridges

The bridge geometries used in the HEC-RAS model were defined based on river and bridge surveys conducted in June 2023 (see Section 2). 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.

Since fully 2D and coupled 1D/2D approaches were used in the model, there was no need to identify ineffective areas for bridge constrictions.

The initial values of the contraction and expansion coefficients at the bridge were selected to be 0.3 and 0.5, respectively. These are typical values listed in the HEC-RAS User Manual.

A total of 5 bridges were implemented in the 1D portion of the model (in the Lower Wolf Creek reach), and a total of 3 bridges were implemented in the 2D portion of the model.

The three bridges in the 2D portion of the model were modelled as 2D connections, under the bridge classification.

4.3.3.4.2 Culverts

Culverts were represented in the HEC-RAS model based on the survey data. Pertinent culvert information, including size, length, and upstream and downstream invert elevations, was specified in the model. Culvert entrance loss coefficients of 0.5, 0.7, and 0.9 were used depending on the culvert inlet configuration. An exit loss coefficient of 1 was used for all culvert structures.

A total of 8 culverts were incorporated into the 1D portion of the model (in the Lower Wolf Creek reach), and a total of 11 culverts were incorporated into the 2D portion of the model.

4.3.3.4.3 Weirs and Dams

There are no weirs or dams in the study area.

4.3.3.4.4 Flood Control Structures

There are no flood control structures in the study area.

4.3.4 Model Calibration

4.3.4.1 Methodology

Generally, in flood models, Manning's n and contraction/expansion coefficients are the two primary model calibration parameters. Selection of initial Manning's n values included consideration of river bed/bank materials, vegetation cover, site information collected during the field inspection, and experience from previous hydraulic modelling studies. Manning's n values may reduce with increased stage; therefore, flood-appropriate values were considered for the study.

There is no HWM or flood imagery available for Wolf Creek or Unnamed Tributaries within the study area, and therefore, no high flow calibration could be completed.

The limited surveyed water levels and measured discharges on Wolf Creek during the river surveys were used for the low flow calibration. There is no flow and water level information available for low flow calibration of Unnamed Tributaries.

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

4.3.4.2 Low Flow Calibration

Initial channel roughness used for Wolf Creek during the model construction was based on observed channel conditions from the site visit, past project experience, and the 1996 HEC-2 model. The channel roughness values were then calibrated based on the water level and discharge data measured on June 23, 2023. Three discharges were measured on Wolf Creek at river stations 15,500 m, 4,236 m, and 395 m with values of 0.011 m^3/s, 0.134 m^3/s, and 0.291 m^3/s, respectively. The maximum discharge measured (at the most downstream location of the three locations) had a discharge of approximately 10% of the 2-year flood peak discharge for that reach (2.74 m^3/s).

Figure 4-10 compares the simulated water surface profile to the surveyed water levels for the surveyed low flow conditions. The average difference between the simulated and surveyed water levels was -0.01 m, and the range of differences was between -0.011 m and +0.09 m. The calibrated channel Manning's n value was 0.035 for the June 2023 flow conditions on Wolf Creek.

There is no measured discharge and water level for the Unnamed Tributaries because no flow was observed during the field survey. Accordingly, low flow calibration was not performed for the Unnamed Tributaries. The channel Manning's n value was selected to be 0.04, in consideration of the stream bed/bank material types, vegetation cover on the banks, site information observed during the site inspection and surveys, and Barr's experience with similar modelling studies.

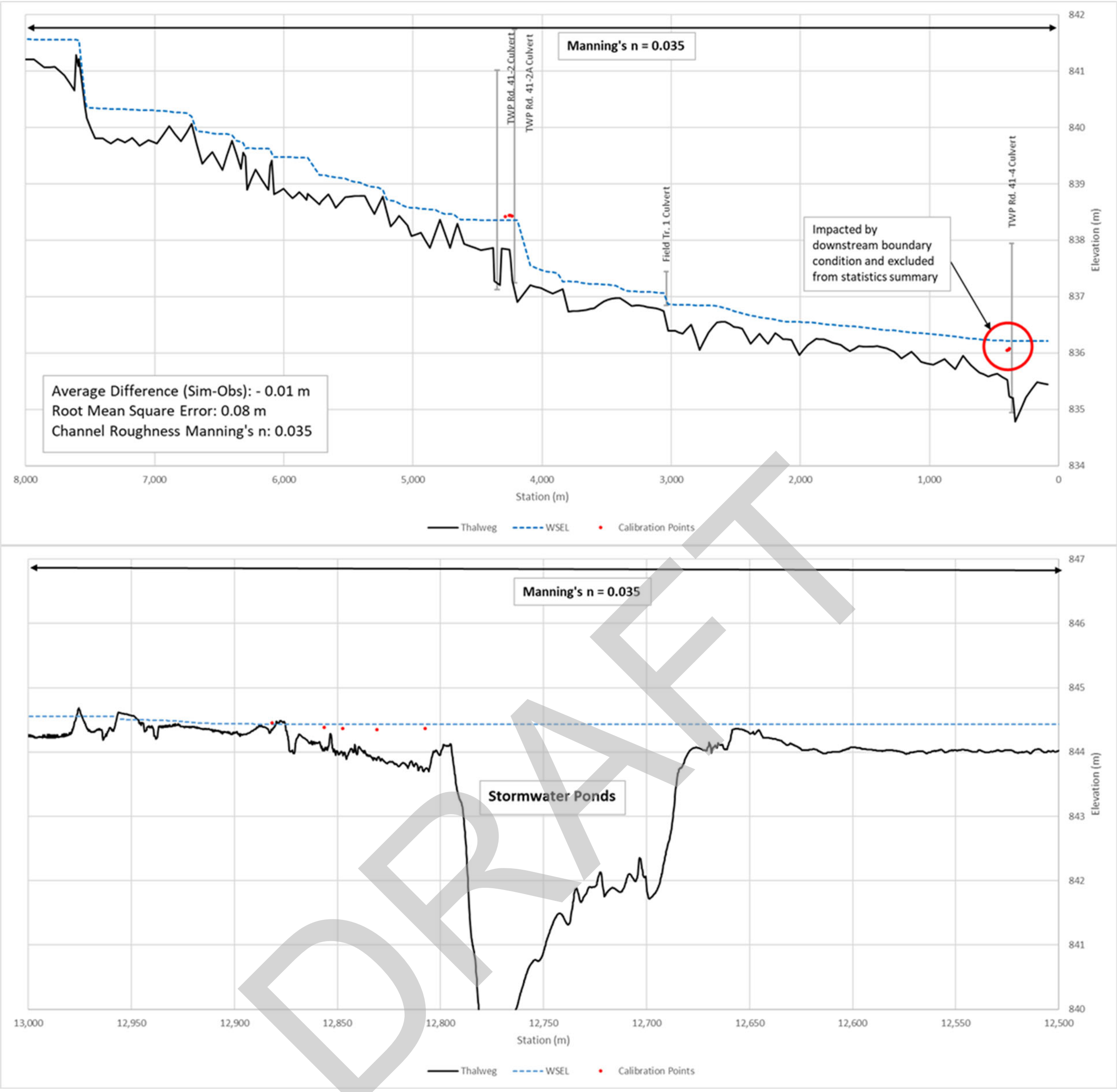


Figure 4-10 Low Flow Calibration Results on Wolf Creek

4.3.4.3 High Flow Calibration

As previously mentioned, there are no HWMs, flood photos, or anecdotal indications available for the reaches within the study area. Therefore, a high flow calibration of the hydraulic model is not possible.

The existing published flood maps for the Lacombe area on the floods.alberta.ca website include 10-, 5-, and 100-year events. Barr has extracted the 100-year inundation boundary for a high-level comparison with the current study results. It is our understanding that the published flood maps are based on the 1996 study completed by NHC. A 1D HEC-RAS model was used in that study. More importantly, and as indicated in Section 3, the current hydrology assessment resulted in lower flood peaks compared to past studies, including the NHC study from 1996. Figure 4-11 illustrates a comparison of inundation boundaries between the current study and NHC's (1996).

The 1,000-year inundation extent was selected for comparison to the 100-year flood inundation extent from the past study as the discharges in the study reaches are closer to those in the NHC's study (see white labels on the figure). As shown, the current study has a generally smaller inundation extent when compared to the NHC's inundation extent. This could be attributed to multiple factors such as modelling methodologies (i.e., 1D steady-state model vs 2D/coupled 1D/2D unsteady-state model), differences in peak flows in the models, changes in main channel alignment and geometry over time, and changes in floodplain over time.

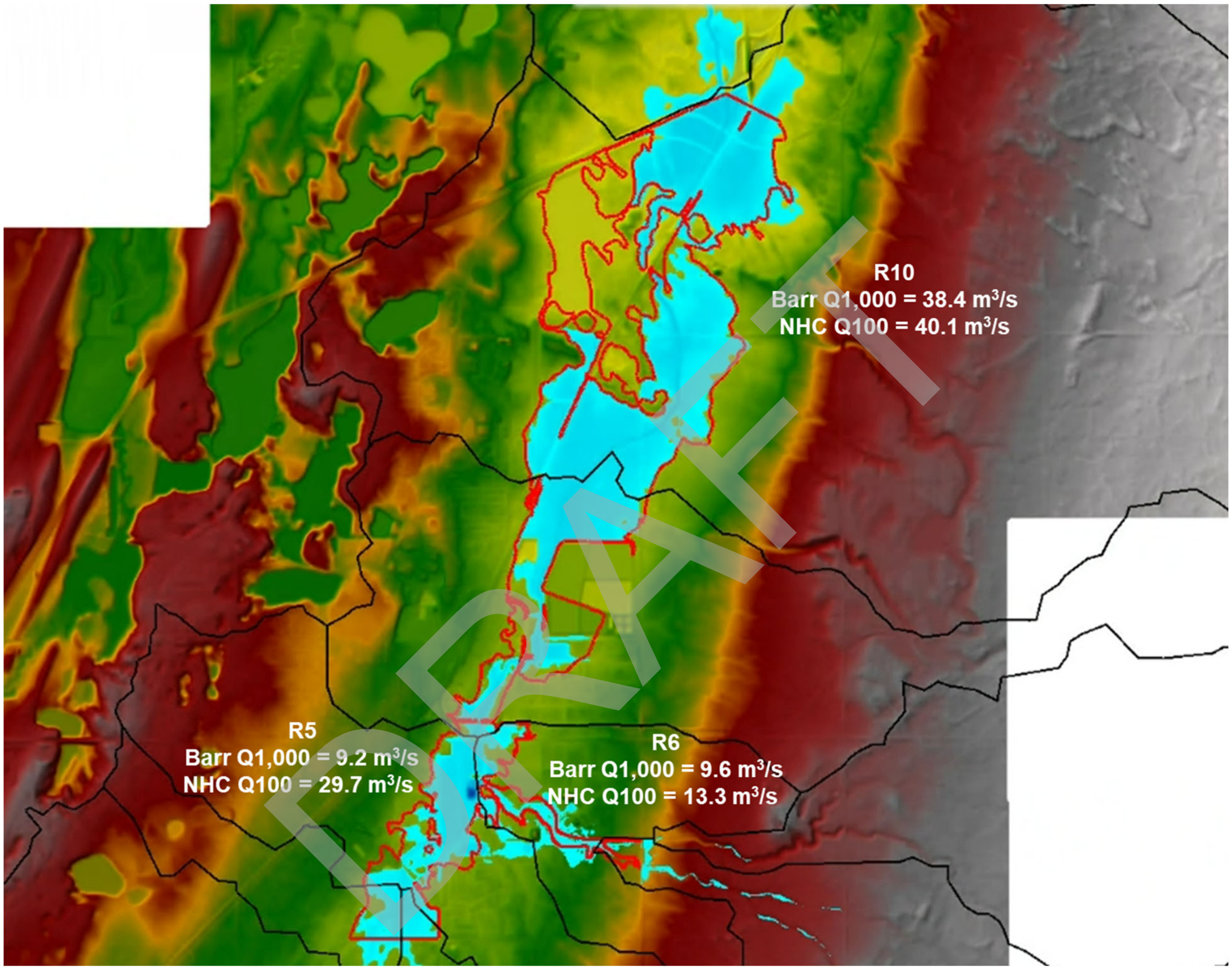


Figure 4-11 Barr's 1,000-Year Inundation (Current Study) in Filled Blue vs NHC's 100-Year Inundation (1996 Study) in Red Boundary. White Labels Describe Flows Used in Two Studies.

4.3.5 Model Parameters and Options

The following sections describe the key model parameters and options adopted in the HEC-RAS model. These include Manning's roughness coefficients for the channel and overbank areas, contraction and expansion loss coefficients, and roadway weir coefficients.

4.3.5.1 Manning's Roughness Values

Manning's roughness is used to account for an array of energy losses that may vary with respect to discharge.

4.3.5.1.1 Channel Roughness

A constant Manning's n value of 0.04 was used for the majority of Unnamed Tributaries. In the lower portion of Unnamed Tributary 3 (from river station 5,880 m to 3,920 m), a Manning's roughness of 0.035 was used. For Wolf Creek, a Manning's n value of 0.04 was used for the upper section (from river station 16,500 m to 15,930 m), where the channel is less defined. For the rest of Wolf Creek, a Manning's n value of 0.035 was used. The selected Manning's n values were found to be reasonable in comparison to typical values of comparable streams (Chow, 1959).

4.3.5.1.2 Overbank Roughness

No change was made for the overbank roughness values, and the values shown in Table 4-4 were adopted in the model.

4.3.5.2 Expansion and Contraction Coefficient

HEC-RAS multiplies the absolute difference in velocity head by a coefficient to account for the effect of flow contraction or expansion on the energy balance between successive cross-sections. The coefficients range from 0.10 for gradual transitions to 0.80 for abrupt transitions (Brunner, 2010). These coefficients are applied in a steady state simulation at all cross-sections. In an unsteady model, the momentum equation accounts for these characteristics and, therefore, coefficients are not necessary. In addition to the 1D domain, expansion and contraction coefficients are used at 2D bridge internal cross-sections. The default coefficients of 0.3 and 0.5 were used in 2D domain bridges (i.e., default values). Finally, culverts in 2D domain do not require any contraction and expansion coefficients.

4.3.5.3 Weir Coefficient

As mentioned previously, weirs were implemented in the fully 2D domain on large roads, highways, railways, etc. HEC-RAS uses a broad-crested weir formulation to represent flow overtopping road, rail, or similar embankments crossing the flowpath. Typical discharge coefficients range between 1.4 to 1.7, with larger values generating less backwater. For this study, a weir coefficient of 1.45 was assigned for all hydraulic structure embankments. A weir coefficient of 0.2 (ranges from 0.11 to 0.28 based on HEC-RAS manual, 2024) was used for the lateral structures, which resemble overland flow rather than a typical broad crested weir.

4.3.6 Flood Frequency Profiles

The calibrated hydraulic model was used to generate flood frequency profiles for the 13 open water floods of varying magnitude ranging from 50% to 0.1% AEPs. The simulated open water flood profiles and tables along the reaches within the study are plotted in Appendix F. Note that for the coupled 1D/2D domain, the water levels were extracted at the actual cross-sections (i.e., not including the interpolated cross-sections). In the fully 2D domain, water levels were extracted every 100 m along the channel centerlines of the modelled reaches to plot.

4.3.7 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 100-year flood event was used for the model sensitivity analysis. The sensitivity analysis results were used to quantify the level of uncertainty associated with the simulated flood levels along the study reach of the Wolf Creek and Unnamed Tributaries.

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

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

The differences between the simulated water levels for the 100-year flood along the study reach of Wolf Creek are graphically presented in Appendix G. The results of the sensitivity analysis indicate the following:

- The uncertainty in the simulated flood levels, on average, is within a range of -0.03 to +0.04 m for Lower Wolf Creek and ±0.02 m for Upper Wolf Creek, based on the differences in the simulated flood levels for a ±10% change to the base channel Manning's n value only.
- The uncertainty in the simulated flood levels, on average, is within a range of ±0.00 m for Lower and Upper Wolf Creek, based on the differences in the simulated flood levels for a ±10% change to the base floodplain Manning's n values only.
- A ±20% change to the energy slope at the downstream boundary influences the simulated flood levels by ±0.06 m for approximately 0.3 km upstream of the downstream boundary.

The differences between the simulated water levels for the 100-year flood along the study reach of Unnamed Tributaries are graphically presented in Appendix G and are summarized in Table 4-5. It is noted that the change in the downstream boundary condition does not impact the water levels in the Upper Wolf Creek and Unnamed Tributaries. Therefore, these profiles are not shown in Appendix G.

Table 4-5 Summary of Uncertainties in Simulated Water Levels of Unnamed Tributaries

Reach Name	Average Water Level Change (m) for Main Channel Manning's n ±10%	Average Water Level Change (m) for Floodplain Manning's n ±10%
Unnamed Tributary 1	-0.02 to +0.03	±0.00
Unnamed Tributary 2	±0.01	±0.00
Unnamed Tributary 3	±0.02	±0.00
Unnamed Tributary 4	±0.01	±0.00
Unnamed Tributary 5	±0.01	±0.00
Unnamed Tributary 6	±0.01	±0.00

5 Open Water Flood Inundation Maps

Flood inundation mapping shows areas of ground that could be inundated by water under one or more flood scenarios for existing conditions. For this study, one flood inundation map series was created for each of the 13 flood frequency return periods from the 2-year through 1000-year scenarios. The study area is covered by a total of seven sheets in tabloid format (11 x 17 in). 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 flood inundation maps were prepared in a geographical information system (Esri ArcGIS Pro 3.3). The maps, including all layers, were provided to EPA as digital files in the Esri ArcGIS Pro project package file format.

The open water flood inundation maps are provided in Appendix H.

5.1 Methodology

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

- Simulated water levels for the 13 flood frequency return periods from the 2-year through 1000-year scenarios
- DTM from the 2023 LiDAR survey
- Aerial imagery of the study area obtained in September 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 HEC-RAS model. The time step results that were one hour prior to the final time step were exported from HEC-RAS to ensure that the model reached a steady state condition.
- Areas that are not directly connected to the main channels are manually removed. Areas where there is no direct overland connection, but a hydraulic connection exists through culverts or other features such as railroad berms, may be included in the inundation extent.

5.2 Manual Flood Extent Modifications

Flood inundation mapping at some locations required manual edits to produce reasonable inundation extents. Necessary modifications were made to the water surface elevation TIN for areas that required manual edits.

There is no flood control structure within the study reach, and thus, no water surface elevation TIN modifications were required for the potential flood control structure failure.

These manual edits are summarized in Table 5-1.

Table 5-1 Summary of Manual Edits for Flood Inundation Polygons

River	Floodplain	Approximate River Station (m)	Description	Flood Events
Wolf Creek	Right & Left	12,250	50th Avenue would be overtopped. Inundated area along the road was manually connected.	750- and 1,000-year flood events
Wolf Creek	Left	9,830	Highway 2A north of 63rd Avenue would be overtopped. Inundated section of the road was manually connected.	350-year flood event
Wolf Creek	Right	6,500	An approximately 90-metre section of Highway 2A would be overtopped. Inundated section of the road was manually connected.	200-year flood event
Wolf Creek	Right	6,120	Milton Road west of Highway 2A and east of Wolf Creek would be overtopped. Inundated section of the road was manually connected.	200-year flood event
Wolf Creek	Left	5,800	Highway 2 would be overtopped. Inundated area was manually connected.	350- and 500-year flood events
Wolf Creek	In-stream	3,040	Farm field culverts (Field Tr. 1 culverts) would be overtopped. Inundated area was manually connected.	2-year flood event
Unnamed Tributary 3	Right	1,500	43rd Avenue would be overtopped. Inundated area along the road was manually connected.	500-year flood event
Unnamed Tributary 4	In-stream	1,550	Farm field culverts (Field Tr. 3 Culverts) would be overtopped. Inundated area was manually connected.	200- to 1,000-year flood events

5.3 Flood Inundation Areas

The residential and commercial areas affected by direct inundation are described below. Detailed inundation maps are provided in Appendix H.

5.3.1 Residential Areas

5.3.1.1 City of Lacombe

- Flooding would occur at residential areas west of 45th Street in the Mckenzie Ranch area. This flooding would be mainly caused by backwater from the 45th Street culvert crossing. Direct inundation begins from the right bank of unnamed tributary 3 during the 100-year event along 45th Avenue. Residences begin to be impacted by this flooding on the east side of 45th Street during the 1,000-year event.

5.3.1.2 Lacombe County

- Flooding would occur at a residence northeast of the Township Road 410 and 34th Street intersection during the 500-year event and greater. This flooding would mainly be caused by the backwater of the Railway and Highway 2 culvert crossings. Flooding would also occur at a residence on the east side of Range Road 264 during the 350-year event and greater. The flooding at this residence would primarily be caused by the backwater of the Township Road 410 bridge.

5.3.2 Commercial and Industrial Areas

5.3.2.1 City of Lacombe

- Flooding would occur in the commercial and industrial areas of Lacombe during the 75-year event where a portion of the eastern lot north of 50th Avenue will be inundated. During the 100-year event, inundation would reach many of the commercial and industrial lots on the left bank of Unnamed Tributary 3 and Wolf Creek. In the 200-year event, one building west of the sewage lagoons would start to be inundated. Additional buildings would be inundated during the 350-year and above on the south side of Lacombe, west of 45th Street.

5.3.2.2 Lacombe County

- There are no impacted commercial or industrial areas outside of the City of Lacombe boundary.

5.3.3 Hydraulic and Flood Control Structures

The Lacombe study area is dominated by numerous hydraulic structures ranging from small culvert crossings to medium trestle bridges. In many cases these structures have capacity for the 1,000-year event, while others are exceeded in the 2-year event. Table 5-2 summarizes any hydraulic structure that would overtop and the smallest event that causes an overtopping.

Table 5-2 Hydraulic Structure Overtopping Summary

River	Structure Type	Description	Approximate River Station (m)	Lowest Event Overtopped
Wolf Creek	Bridge	PVT 12-33 B	8,600	35-Year
Wolf Creek	Bridge	TWP Rd. 41-0 B	8,200	100-Year
Wolf Creek	Bridge	CE Tr. B	6,300	200-Year
Wolf Creek	Bridge	TWP Rd. 412 B	6,100	350-Year
Wolf Creek	Culvert	HWY 2 C	5,800	350-Year
Wolf Creek	Culvert	Field Tr. 1 C	3,050	2-Year
Unnamed Tributary 2	Culvert	PVT Dr. C	200	2-Year
Unnamed Tributary 3	Culvert	Field Tr. 4 C	1,700	100-Year
Unnamed Tributary 3	Culvert	Unnamed Rd. C	1,350	1000-Year
Unnamed Tributary 3	Culvert	45 St. C	950	750-Year
Unnamed Tributary 4	Culvert	Field Tr. 2 C	1,700	20-Year
Unnamed Tributary 4	Culvert	Field Tr. 3 C	1,450	200-Year

There are no flood control structures within the study reach; therefore, there would be no potential flooding due to flood control structure failure.

5.3.4 Water Surface Elevation and Flood Depth Grids

The following GIS data were provided to EPA for each of the 13 open water flood events:

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

All GIS data were created in ArcGIS Pro 3.3 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 114). All raster files have a spatial resolution of 0.5 m. The inundation polygons and raster files were stored in ArcGIS file geodatabases.

6 Floodway Determination

Flood hazard identification involves the delineation of floodway and flood fringe zones for a specified design flood using the FHIP Guidelines (Alberta Environment, June 2022).

6.1 Design Flood Selection

The minimum design flood standard in Alberta is the 1:100 flood, which is defined as a flood whose flow has a 1% chance of being equaled or exceeded in any year. The design flood can also reflect 1:100 ice jam flood levels if they are more severe than 1:100 open water flood levels or be based on a historical flood. The 100-year open water flood was selected as the design flood for Wolf Creek and Unnamed Tributaries in this study.

6.2 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 and may include additional flood fringe sub-zones. Flood hazard maps also show incremental areas at risk for more severe floods such as the 200-year and 500-year floods. Flood hazard mapping is typically used by communities for planning or to help make local land use and development decisions.

6.2.1 Floodway Definition

Floodway 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 portion 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 gets larger or design flood levels get higher. New development is discouraged in the floodway and may not be permitted in some communities.

6.2.2 Flood Fringe Definition

The flood fringe is the portion 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.

6.3 Open Water Flood Hazard Identification

6.3.1 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 (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 get larger if a main channel shifts outside of a previously defined floodway or 2) a floodway could get smaller if an area of previously defined floodway is no longer flooded by the design flood.

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 open water design flood water surface elevations and flow velocities were generated from the HEC-RAS model. The model was run until it reached steady state conditions. The time step that was one hour away from last 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.

For the Unnamed Tributaries (i.e., upper portion of model in the fully 2D domain), most of the floodplain areas inundated by the 100-year flood were included in the floodway as those tributaries are poorly defined and the floodplain is currently used primarily as undeveloped farmland and pasture. Most of the areas inundated during the 100-year flood for these tributaries are shallower than 1 m and velocity is lower than 1 m/s. The inundation areas fall within the general banklines of those poorly defined channels and therefore the edge of inundation was selected as floodway. For inundated areas beyond the general banklines of Unnamed Tributaries, the banklines were selected as limit of floodway. It is noted that the banklines were digitized based on prior modelling and based on survey, LiDAR, and imagery.

For the Upper Wolf Creek, the floodway delineation followed closely the methodology described for the Unnamed Tributaries above. Inundation within the banklines was selected as the floodway and when outside the inundation, the bankline was selected as the limit of floodway. In the Lower Wolf Creek, an existing floodway warranted additional considerations. Where there was existing floodway, the existing floodway was used when within the inundation. When the inundation extent was within the existing floodway, the inundation extent was used to most closely match the existing floodway extent. Exceptions in the old floodway area were made for a few small areas consisting of backwater. When the 1 m contour did not exceed the bankline, the bankline was selected as floodway. In some circumstances, the inundation was smaller than the bankline and therefore, defined as the floodway. The existing floodway does not extend to the current study area. Therefore, downstream of HWY2, the floodway was defined without an existing floodway. In much of this area, the 1 m depth extent exceeded the bankline and was used to delineate the limit of floodway. When the 1 m depth contour did not exceed the bankline, the bankline was used. Furthermore, if the inundation did not exceed the bankline, the edge of inundation was used to delineate the limit of floodway.

6.3.2 Design Flood Levels and Profile

The design flood profile levels were those calculated for the 100-year open water flood condition. The resulting design flood level values and profiles are shown in Appendix F.

6.3.3 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
- previous floodway boundary from the 1996 Lacombe Flood Study
- locations of the main channel top of bank at each cross-section (only applicable for Lower Wolf Creek, where a coupled 1D/2D modelling approach was used)
- location and extent of all cross-sections used in the HEC-RAS model with appropriate labels (only applicable for Lower Wolf Creek, where a coupled 1D/2D modelling approach was used)
- background aerial imagery collected in 2023
- roads, bridges, culverts, and flood control structures, as applicable

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

6.3.4 Design Flood Hazard Maps

The flood hazard maps divide the design flood extents into floodway and flood fringe zones, including boundaries of high hazard flood fringe. The information used to create the flood hazard maps was based on the open water floodway criteria mapping information.

The limits of the floodway were delineated by the floodway boundary developed for the open water floodway criteria map. Areas of high ground or areas of depth less than 1 m inside the floodway boundaries were included as part of the floodway. The resulting floodway was represented as a single contiguous polygon.

The design flood extent developed for the floodway criteria maps was adjusted to create the flood fringe. The limits of the flood fringe followed the extent of direct inundation of the design flood. Areas of high ground within the extent of direct inundation (and outside of the floodway) were preserved and were not indicated as flood fringe in the flood hazard map.

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

6.3.4.1 Areas in Floodway

No notable residential or commercial infrastructure are located in the floodway.

6.3.4.2 Areas in High Hazard Flood Fringe

The high hazard flood fringe includes all inundated areas outside the floodway but within the deeper or faster moving water. No notable residential or commercial infrastructure is located in the high hazard flood fringe.

6.3.4.3 Areas in Flood Fringe

The flood fringe includes all inundated areas outside the limits of the floodway and high hazard flood fringe. Notable inundated areas within the flood fringe include:

- Residential areas west of 45th Street in the Mckenzie Ranch area.

7 Potential Climate Change Impacts

To address the potential impacts of climate change on flood levels, more severe open water flood scenarios were compared to the current design flood estimates in order to obtain a measure of "*freeboard*" that may be generally appropriate for long-term planning purposes. It is noted that the analysis relies on simplified assumptions rather than a comprehensive regional climate change impact assessment. To obtain information appropriate for other applications, the simplified approach taken herein could be supplemented in the future by a more rigorous regional climate analysis and site-specific impact assessment.

For the open water flood hazard, the current 100-year design flood water levels were compared to those associated with discharges that are 10% and 20% greater than the current 100-year flood estimates. This approach is consistent with guidelines prepared by Engineers and Geoscientists British Columbia (EGBC, 2018). EGBC recommends that for basins where no historical trend is detectable in local or regional streamflow magnitude frequency relations, a 10% upward adjustment in design discharge be applied to account for likely future changes in water input from precipitation. On the other hand, if a statistically significant trend is detected, a 20% adjustment may be appropriate, particularly for smaller basins.

No hydraulic modelling parameters were varied other than discharges under the open water conditions. Water level profiles were produced along the study reach for the two additional flow scenarios. The water level differences compared to the baseline 100-year open water discharge were calculated and summarized in Table 7-1.

Table 7-1 Potential Climate Change Impacts on Simulated Design Flood Water Levels

Reach	Average Increase in Design Flood Level (m)	
	Q100+10%	Q100+20%
Upper Wolf Creek	0.04	0.09
Lower Wolf Creek	0.14	0.29
Unnamed Tributary 1	0.06	0.13
Unnamed Tributary 2	0.02	0.03
Unnamed Tributary 3	0.06	0.12
Unnamed Tributary 4	0.02	0.04
Unnamed Tributary 5	0.01	0.03
Unnamed Tributary 6	0.02	0.03

The difference between the simulated water levels for the 100-year climate-impacted flood along Wolf Creek and Unnamed Tributaries study reaches are presented in Appendix J. The simulated climate-impacted open water flood levels are compared to the baseline 100-year open water discharge and summarized in Appendix J.

8 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 late June 2023 meet 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 late June 2023 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 Wolf Creek at Lacombe and Unnamed Tributaries. 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, which generally showed a lower trend when compared to past available studies.
- A regional hydrological analysis was used to develop flood peak discharge estimates by a multilinear regression analysis using the logarithm of the flood frequency estimates, effective watershed areas, and average basin slope.
- Eight WSC gauges were used in the regional hydrology assessment, with data ranging from 1970 to 2022.

8.3 Open Water Hydraulic Modelling

8.3.1 Selection of Manning's n Values

The HEC-RAS hydraulic model built for this study could not be calibrated for high flow events as no WHM was available within the study reach. The model was only calibrated using limited low flow and water level data collected during the survey.

A constant Manning's n value of 0.04 was used for the majority of Unnamed Tributaries. In the lower portion of Unnamed Tributary 3 (from river station 5,880 m to 3,920 m), a Manning's roughness of 0.035 was used. For Wolf Creek, a Manning's n value of 0.04 was used for the upper section (from river station 16,500 m to 15,930 m), where the channel is less defined. For the rest of Wolf Creek, a Manning's n value of 0.035 was used. The selected Manning's n values were found to be reasonable in comparison to typical values of comparable streams (Chow, 1959).

The Manning's n values for the floodplain areas were estimated 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 for Wolf Creek indicate the following:

- The uncertainty in the simulated flood levels, on average, is within a range of -0.03 to +0.04 m for Lower Wolf Creek and ±0.02 m for Upper Wolf Creek, based on the differences in the simulated flood levels for a ±10% change to the base channel Manning's n value only.
- The uncertainty in the simulated flood levels, on average, is within a range of ±0.00 m for Lower and Upper Wolf Creek, based on the differences in the simulated flood levels for a ±10% change to the base floodplain Manning's n values only.
- A ±20% change to the energy slope at the downstream boundary influences the simulated flood levels by ±0.06 m for approximately 0.3 km upstream of the downstream boundary.

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 Open Water 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 residential areas to be affected by open water flooding have been identified as follows:

- Flooding would occur at residential areas west of 45th Street in the Mckenzie Ranch area. This flooding would be mainly caused by backwater from the 45th Street culvert crossing. Direct inundation begins from the right bank of unnamed tributary 3 during the 100-year event along 45th Avenue. Residences begin to be impacted by this flooding on the east side of 45th Street during the 1,000-year event.
- Flooding would occur at a residence northeast of the Township Road 410 and 34th Street intersection during the 500-year event and greater. This flooding would mainly be caused by the backwater of the Railway and Highway 2 culvert crossings. Flooding would also occur at a residence on the east side of Range Road 264 during the 350-year event and greater. The flooding at this residence would primarily be caused by the backwater of the Township Road 410 bridge.

8.5 Design Flood Hazard Mapping

The 100-year open water flood is selected as the design flood on Wolf Creek and Unnamed Tributaries in accordance with the Flood Hazard Identification Program (FHIP) Guidelines (2022). The floodway was determined as part of the floodway criteria mapping. No residential or commercial buildings are located within the *floodway* or *high hazard flood fringe* along Wolf Creek. The residential areas west of 45th Street in the Mckenzie Ranch area are located within the *flood fringe*.

8.6 Potential Climate Change Impacts

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 discharge. 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 effect assessment shows an average increase of 0.04 m to 0.29 m in water levels for Wolf Creek (upper and lower combined) and an average increase of 0.01 m to 0.13 m in water levels for Unnamed Tributaries (all combined).

The analysis in this study was not based on a regional climate change impact assessment but on a simplified assumption that climate changes would result in increased flood peak discharges.

References

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MPE. 2014. Master Drainage Plan for the Wolf Creek and Whelp Brook Watersheds. Report for Lacombe County, Ponoka County, City of Lacombe, and Town of Blackfalds.

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USACE. 2024. HEC-RAS River Analysis System - User's Manual, Version 6.5, February 2024.

Certification

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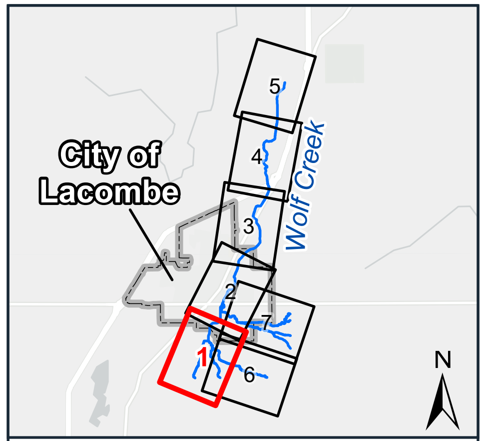
Appendices

Appendix A

Location of Surveyed Cross-Sections and Hydraulic Structures



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
CITY OF LACOMBE BOUNDARY
RAILWAY
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta

Canada

0 100 200 300
Metres
Scale: 1:10,000

Locations of Cross Sections and Hydraulic Structures

Lacombe Flood Study

SHEET A-1

BARR

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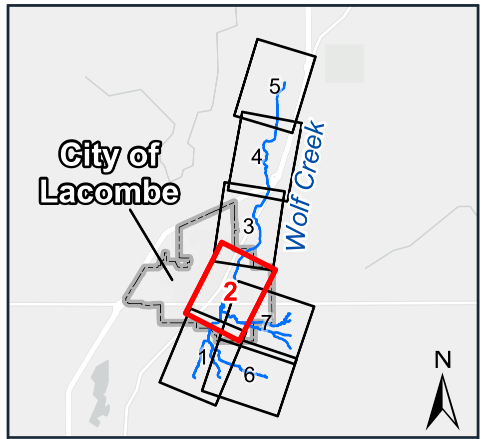
Classification: Public



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
CITY OF LACOMBE BOUNDARY
RAILWAY
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD

0 100 200 300
Metres
Scale: 1:10,000

Locations of Cross Sections and Hydraulic Structures

Lacombe Flood Study

SHEET A-2

Classification: Public

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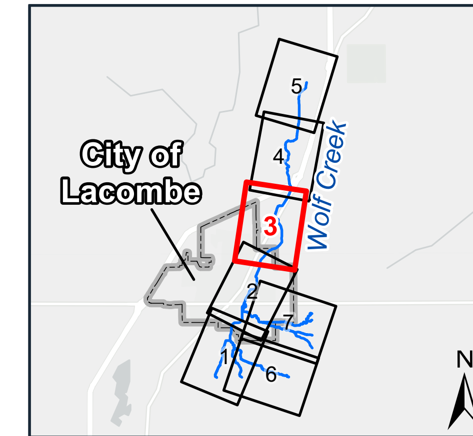


- FLOW DIRECTION
- BRIDGE
- CULVERT
- SURVEYED CROSS SECTION
- SURVEY POINT
- STREAM CENTERLINE
- CITY OF LACOMBE BOUNDARY
- RAILWAY
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD

Alberta

Canada

0 100 200 300
Metres

Scale: 1:10,000

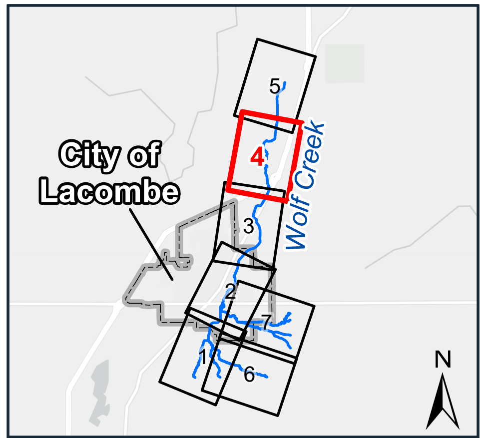
Locations of Cross Sections and Hydraulic Structures

Lacombe Flood Study

SHEET A-3

BARR

Classification: Public



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
CITY OF LACOMBE BOUNDARY
RAILWAY
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta
Canada

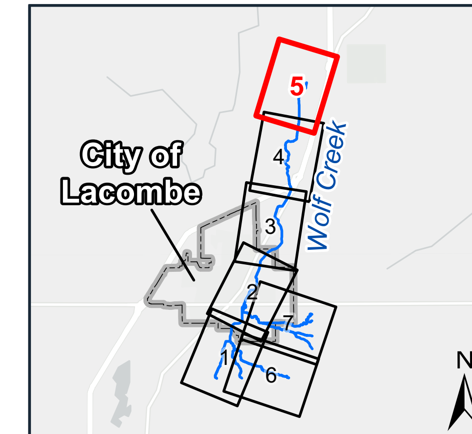
0 100 200 300
Metres
Scale: 1:10,000

Locations of Cross Sections and Hydraulic Structures

Lacombe Flood Study

SHEET A-4

BARR



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
CITY OF LACOMBE BOUNDARY
RAILWAY
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta
Canada

0 100 200 300
Metres
Scale: 1:10,000

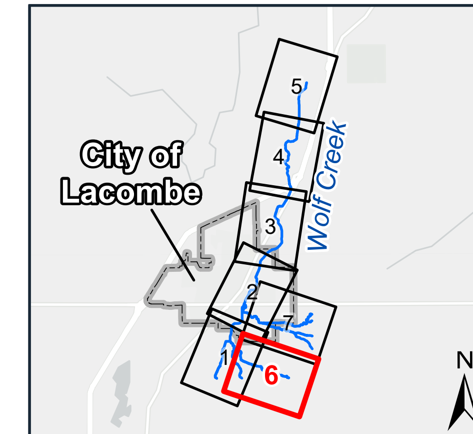
Locations of Cross Sections and Hydraulic Structures

Lacombe Flood Study

SHEET A-5

BARR

Classification: Public



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
CITY OF LACOMBE BOUNDARY
RAILWAY
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta

Canada

0 100 200 300
Metres

Scale: 1:10,000

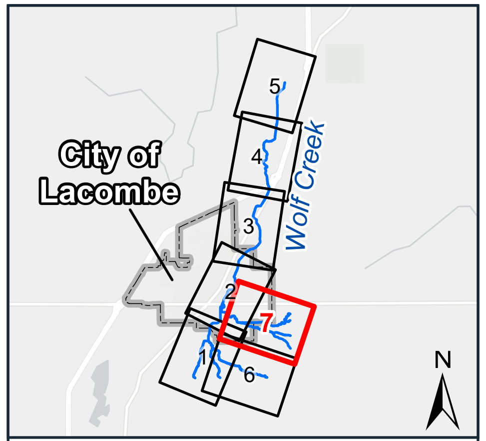
Locations of Cross Sections and Hydraulic Structures

Lacombe Flood Study

SHEET A-6

BARR

Classification: Public



- FLOW DIRECTION
- BRIDGE
- CULVERT
- SURVEYED CROSS SECTION
- SURVEY POINT
- STREAM CENTERLINE
- CITY OF LACOMBE BOUNDARY
- RAILWAY
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD

Alberta

Canada

0 100 200 300
Metres
Scale: 1:10,000

Locations of Cross Sections and Hydraulic Structures

Lacombe Flood Study

SHEET A-7

BARR

Classification: Public

Appendix B

Hydraulic Structure Datasheets

B1

Structure Name: CP TRESTLE Bridge

Bridge File No.: N/A

Water Course: Wolf Creek

Location: CP Rail Line

Description and Type:

☐ Single Span Bridge

☒ Multiple Span Bridge (6)

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☐ Other: PVC Pipes

Notes: 14″ timber piles for piers (6 inline piles per pier), strapped with 4″x7.5″ timbers, concrete pier caps, I-beam girders (4 per span), cross braced with (4″x7.5″ timbers).

Information:

Span: 24.12m

Width: 4.00m

High Chord: 849.03m

(+1m to top of guardrail- US side only)

Low Chord: 848.35m

Pier Type: Timber strapped piles (14″ wood)

Pier Shape: in-line, non-contiguous

Pier Width: 0.36m

Pier Count: 5

Photos:

Looking upstream from midstream:

Looking downstream from midstream:

Pier Detail:

Trailing Face from right bank:

Abutments:

Piers 1 & 5:

B2

Structure Name: 50 Ave. B

Bridge File No.: 78183

Water Course: Wolf Creek

Location: HWY 12 / 50th Ave

Description and Type:

☒ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☐ Other: PVC Pipes

Notes: Modern standard bridge. Random pile line on right abutment – 11" average diameter, 7 piles total.

Information:

Span: 6.03m

Width: 13.94m

High Chord: 846.15m

(+0.57m to top of guardrail)

Low Chord: 845.34m

Pier Type: N/A

Pier Shape: N/A

Pier Width: N/A

Pier Count: N/A

Photos:

Looking upstream from right bank:

Looking downstream from left bank:

Random pile line, looking upstream:

Left abutment looking upstream:

Piles average 11" in diameter:

B3

Structure Name: 34 St. Culvert North

Bridge File No.: BF 82175

Water Course: Wolf Creek

Location: 34th Street (north crossing)

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (triple, N / M / S)

☐ Other:

Notes:

Information:

Total Span: N/A

Diameter: N= 1.04m, M= 1.07m, S= 1.21m

Length: N= 19.57m, M= 19.58m, S= 19.58m

Upstream Invert Elev.: N= 853.56m, M= 853.56m, S= 853.59m

Downstream Invert Elev.: N= 853.45m, M= 853.40m, S= 853.24m

Upstream Crown Elev.: N= 854.79m, M= 854.70m, S= 854.78m

Downstream Crown Elev.: N= 854.49m, M= 854.47m, S= 854.45m

Minimum Road Elev.: 855.55m

Photos:

Looking downstream right bank:

Looking upstream from left bank:

B4

Structure Name: Wolf Crk Dr. Culverts

Bridge File No.: BF 82175

Water Course: Wolf Creek

Location: Wolf Creek under Wolf Creek Dr.

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (Triple, 1-3 RHS-LHS)

☐ Other:

Notes:

Information:

Total Span: 2.5m

Diameter: 2.5m (wide) x 2.5m (tall)

Length: 1,2,3, all 35.5m

Upstream Invert Elev.: 1-843.20m, 2-843.10m, 3-843.07m

Downstream Invert Elev.: 1-843.02m, 2-843.05m, 3-842.98m

Upstream Crown Elev.: 1-844.99, 2-844.98, 3-844.98m

Downstream Crown Elev.: 1-844.99m, 2-844.95m, 3-844.89m

Minimum Road Elev.: 845.98m

Photos:

Looking downstream from mid-channel:

Looking upstream from mid-channel:

B5

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: 34 St. Bridge

Bridge File No.: 13958

Water Course: Wolf Creek

Location: 34th Street

Description and Type:

☒ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☐ Other: PVC Pipes

Notes: Modern standard bridge.

Information:

Span: 11.39m

Width: 7.90m

High Chord: 845.12m

(+0.48m to top of guardrail)

Low Chord: 844.28m

Pier Type: N/A

Pier Shape: N/A

Pier Width: N/A

Pier Count: N/A

Photos:

Looking upstream from right bank:

Looking downstream from left bank:

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: PVT 12-33 Bridge

Bridge File No.: N/A

Water Course: Wolf Creek

Location: 12-33-40-26 W4

Description and Type:

☒ Single Span Bridge

☐ Box Culvert (double)

☐ Multiple Span Bridge ( )

☐ CSP Culvert

☐ Box Culvert (single)

☐ Other: PVC Pipes

Notes: Pile bridge for farm use. Dilapidated and not in use – wooden poles ~14" dia. With trailway tie constructed abutments, no piles, or foundations.

Information:

Span: 9.64m

Pier Type: N/A

Width: 3.45m

Pier Shape: N/A

High Chord: 843.95m

Pier Width: N/A

Low Chord: 843.72m

Pier Count: N/A

Photos:

Looking downstream from left bank:

Looking upstream from right bank:

Left abutment:

-Fallen pole on the DS side.

Bridge deck and abutment from right bank:

B7

Structure Name: TWP Rd. 41-0 Bridge

Bridge File No.: BF 1134

Water Course: Wolf Creek

Location: TWP Rd 41-0

Description and Type:

☒ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☐ Other: PVC Pipes

Notes: Random piling out of line with abutment piles. 14" diameter, approximately 0.35m off the face of the abutment piles on the right.

Information:

Span: 6.08m

Width: 8.43m

High Chord: 844.35m

(+0.55m to top of guard rail)

Low Chord: 843.52m

Pier Type: N/A

Pier Shape: N/A

Pier Width: N/A

Pier Count: N/A

Photos:

Looking downstream from left bank:

Looking upstream from right bank:

Random pile from downstream right bank:

B8

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: CN RL Culvert

Bridge File No.: BF 1134

Water Course: Wolf Creek

Location: Wolf Creek under CN @ HWY 2A

Description and Type:

☐ Single Span Bridge

☐ Box Culvert (double)

☐ Multiple Span Bridge ( )

☐ CSP Culvert

☒ Box Culvert (single)

☐ Other:

Notes: Concrete face on both upstream and downstream ends is degrading.

Crown is approximately 0.65m thick and it formed directly with the wingwalls.

Information:

Total Span: 2.7m

Downstream Invert Elev.: 841.33m

Diameter: 2.7m (wide) x 2.7m (tall)

Upstream Crown Elev.: 845.00m

Length: 43.35m

Downstream Crown Elev.: 844.10m

Upstream Invert Elev.: 841.38m

Minimum Road Elev.: 847.29m

Photos:

Looking downstream from mid-channel:

Looking upstream from mid-channel:

B9

Structure Name: HWY 2A Culvert

Bridge File No.: BF 74076

Water Course: Wolf Creek

Location: Wolf Creek under HWY 2A

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert

☐ Other:

Notes: Slope change from upstream invert, approximately 8.6m, then flattens for duration to outfall.

Information:

Total Span: N/A

Diameter: 3.7m

Length: 43.35m

Upstream Invert Elev.: 841.30m

Downstream Invert Elev.: 840.34m

Upstream Crown Elev.: 845.00m

Downstream Crown Elev.: 844.10m

Minimum Road Elev.: 847.29m

Photos:

Looking downstream from right bank:

Looking upstream from right bank:

B10

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: CE Tr. Bridge Bridge

Bridge File No.: BF 82127

Location: Calgary Edmonton Trail

Water Course: Wolf Creek

Description and Type:

☒ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☐ Other: PVC Pipes

Notes: concrete wing walls tie flush to abutments. Concrete girders.

Information:

Span: 13.17m

Width: 12.61m

High Chord: 842.96m

(+0.87m to top of guard rail)

Low Chord: 841.97m

Pier Type: N/A

Pier Shape: N/A

Pier Width: N/A

Pier Count: N/A

Photos:

Looking downstream from right bank:

Looking upstream from deck:

B11

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: TWP Rd. 412 Bridge

Bridge File No.: BF 82128

Water Course: Wolf Creek

Location: NB Hwy 2-EB Milton Rd/TWP Rd 41-2

Description and Type:

☒ Single Span Bridge

☐ Box Culvert (double)

☐ Multiple Span Bridge ( )

☐ CSP Culvert

☐ Box Culvert (single)

☐ Other: PVC Pipes

Notes: concrete wing walls tie flush to abutments. Concrete girders.

Information:

Span: 13.2m

Pier Type: N/A

Width: 9.95m

Pier Shape: N/A

High Chord: 843.18m (+0.87m to top of guard rail)

Pier Width: N/A

Pier Count: N/A

Low Chord: 842.09m

Photos:

Looking downstream from right bank:

Looking upstream from right bank:

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: HWY 2 Culvert

Bridge File No.: BF 75428

Water Course: Wolf Creek

Location: Wolf Creek under HWY 2

Description and Type:

☐ Single Span Bridge

☒ Box Culvert (double)

☐ Multiple Span Bridge ( )

☐ CSP Culvert

☐ Box Culvert (single)

☐ Other:

Notes: Concrete walls approximately 0.35m thick.

Information:

Total Span (m): 3.5m

Pier Shape: rectangular

Open Width (m): 1.6m x 2

Pier Width: 0.16m

Length (m): 75.0m

Pier Count: 1

Upstream Invert Elev.: 839.38m

Upstream Crown Elev.: 841.35m

Downstream invert Elev.: 838.67m

Downstream Crown Elev.: 840.55m

Pier Type: single concrete wall

Minimum Road Elev.: 842.35m

Photos:

Looking downstream from right bank:

Looking upstream from right bank:

B13

Structure Name: TWP Rd. 41-2 Culvert

Bridge File No.: BF 1133

Water Course: Wolf Creek

Location: Wolf Creek under TWP Rd 41-2

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert

☐ Other:

Notes: Concrete end treatment on both ends, 0.72m on 'wing walls', 0.47m on crown.

Information:

Total Span: N/A

Diameter: 3.9m

Length: 37.6m

Upstream Invert Elev.: 837.12m

Downstream Invert Elev.: 837.17m

Upstream Crown Elev.: 841.01m

Downstream Crown Elev.: 840.98m

Minimum Road Elev.: 843.46m

Photos:

Looking downstream from right bank:

US End Concrete End Treatment:

B14

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: TWP Rd. 41-2A Culvert

Bridge File No.: BF 83160

Water Course: Wolf Creek

Location: Wolf Creek under TWP Rd 41-2A (Old TWP Rd 41-2)

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert

☐ Other:

Notes: Concrete end treatment on upstream end only, 0.76m on 'wing walls', 0.38m on crown.

Information:

Total Span: N/A

Diameter: 4.5m

Length: 30.6m

Upstream Invert Elev.: 837.24m

Downstream Invert Elev.: 836.89m

Upstream Crown Elev.: 841.55m

Downstream Crown Elev.: 841.36m

Minimum Road Elev.: 843.20m

Photos:

Looking downstream from right bank:

US End Concrete End Treatment:

B15

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: Field Trail 1. Culvert

Bridge File No.: N/A

Water Course: Wolf Creek

Location: N=5821557.49m E=21351.12m

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☒ Other: PVC Pipes (x3)

Notes: Landowner installed triple PVC pipes as a field road crossing, beavers dammed the upstream ends – unable to get US culvert data without major excavation.

Information:

Total Span: N/A

Diameter: 0.6 m

Length: approx. 10m

Upstream Invert Elev.: unknown

Downstream Invert Elev.: 836.84m

Upstream Crown Elev.: unknown

Downstream Crown Elev.: 837.46m

Minimum Road Elev.: 837.62m

Photos:

Looking downstream from right bank:

Unavailable

Looking upstream from right bank:

Unavailable

B16

Structure Name: TWP Rd. 41-4 C

Bridge File No.: BF 81967

Water Course: Wolf Creek

Location: Wolf Creek under TWP Rd 41-4

Description and Type:

☐ Single Span Bridge

☐ Box Culvert (double)

☐ Multiple Span Bridge ( )

☒ CSP Culvert

☐ Box Culvert (single)

☐ Other:

Notes: Concrete end treatment on upstream end only, 0.68m on 'wing walls', 0.4m on crown.

Information:

Total Span: N/A

Downstream invert Elev.: 834.96m

Diameter: 3.0m

Upstream Crown Elev.: 837.96m

Length: 16.9m

Downstream Crown Elev.: 837.96m

Upstream Invert Elev.: 834.94m

Minimum Road Elev.: 838.96m

Photos:

Looking downstream from right bank:

Looking upstream from right bank:

B17

Structure Name: RR 265 Culvert South

Bridge File No.: BF 82175

Water Course: Primary Tributary

Location: Range Road 265 (south crossing)

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (double, N / S)

☐ Other:

Notes:

Information:

Total Span: N/A

Diameter: 1.31m

Length: 29.81m

Upstream Invert Elev.: 847.49m

Downstream Invert Elev.: 847.47m

Upstream Crown Elev.: 849.07m

Downstream Crown Elev.: 848.78m

Minimum Road Elev.: 850.00m

Photos:

Looking downstream left bank:

Looking upstream from left bank:

B18

Structure Detail Sheet | *Lacombe AB, June 2023*

TROUT HYDROGRAPHY

Structure Name: PVT Dr. Culvert

Water Course: Wolf Creek

Bridge File No.: N/A

Location: N= 5812270.50m

E= 18584.74m

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☒ Other: LH= 6″ Cast Iron , RH= 8″ HDPE

Notes: Pipes are nearly non-functional due to vegetation growth. Landowner regularly pumps over driveway with a 4″ trash pump.

Information:

Total Span: N/A

Diameter: LH=0.69m, RH=1.30m

Length: LH=10.23m, RH=9.96m

Upstream Invert Elev.: LH=846.66m, RH=846.56m

Downstream Invert Elev.: LH=846.58m, RH=846.47m

Upstream Crown Elev.: LH=846.87m, RH=846.73m

Downstream Crown Elev.: LH=846.79m, RH=846.73m

Minimum Ground Cover Elev.: 846.93m

Photos:

Looking downstream from mid-channel:

Looking upstream from mid-channel:

B19

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: 34 St. Culvert South

Bridge File No.: N/A

Water Course: Secondary Tributary

Location: 34th Street, south crossing

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert

☐ Other:

Notes:

Information:

Total Span: N/A

Diameter: 1.53m

Length: 34.14m

Upstream Invert Elev.: 862.10m

Downstream Invert Elev.: 862.20m

Upstream Crown Elev.: 863.63m

Downstream Crown Elev.: 863.70m

Minimum Road Elev.: 865.70m

Photos:

Looking downstream from mid channel:

Looking upstream from mid channel:

B20

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: PVT 17-40 Bridge

Bridge File No.: N/A

Water Course: Secondary Tributary

Location: SE 17-40-26 W4
N= 5811280.58m ,E= 20375.66m

Description and Type:

☒ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☐ CSP Culvert

☐ Other: PVC Pipes

Notes: Wooden lumber bridge, 4"x4" posts as piers, two sets.

Information:

Span: 11.48m

Width: 3.45m

High Chord: 862.88m (+ 0.98m to top of handrail)

Low Chord: 862.74m

Pier Type: wooden post

Pier Shape: square

Pier Width: 0.10m

Pier Count: 2

Photos:

Looking downstream from left bank:

Looking downstream from left bank:

B21

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: RR 265 Culvert North

Bridge File No.: BF 82175

Water Course: Primary Tributary

Location: Range Road 265 (mid/north crossing)

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (double, N / S)

☐ Other:

Notes:

Information:

Total Span: N/A

Diameter: (N) 1.48m, (S) 1.48m

Length: (N) 17.40m, (S) 17.38m

Upstream Invert Elev.: (N) 846.52m, (S) 846.47m

Downstream Invert Elev.: (N) 846.29m (S) 846.27m

Upstream Crown Elev.: (N) 848.00m, (S) 848.00m

Downstream Crown Elev.: (N) 847.85m, (S) 847.87m

Minimum Road Elev.: 848.75m

Photos:

Looking upstream from right shoulder:

Looking upstream from midstream:

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: Field Tr. 4 Culvert

Water Course: Main Tributary

Bridge File No.: N/A

Location: N= 5812967.29m

E= 18479.63m

Description and Type:

- ☐ Single Span Bridge
- ☐ Multiple Span Bridge ( )
- ☐ Box Culvert (single)
- ☐ Box Culvert (double)
- ☒ CSP Culvert (Triple, RH, C, LH)
- ☐ Other:

Notes:

Information:

Total Span: N/A

Diameter: LH=0.69m, C=0.70m, RH=0.71m

Length: LH=10.23m, C=9.90m, RH=9.96m

Upstream Invert Elev.: LH=844.40m, C=844.41m, RH=844.43m

Downstream Invert Elev.: LH=844.30m, C=844.36m, RH=844.42m

Upstream Crown Elev.: LH=845.09m, C=845.11m, RH=845.14m

Downstream Crown Elev.: LH=845.02m, C=845.04m, RH=845.08m

Minimum Ground Cover Elev.: 845.42m

Photos:

Looking downstream from mid-channel:

Looking upstream from mid-channel:

Structure Detail Sheet | *Lacombe AB, June 2023*

TROUT HYDROGRAPHY

Structure Name: Unnamed Rd. Culvert

Bridge File No.: N/A

Water Course: Main Tributary

Location: N= 5813304.25m
E= 18526.68

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (Triple, RH, C, LH)

☐ Other:

Notes:

Information:

Total Span: N/A

Diameter: LH=1.20m, C=1.85m, RH=1.30m

Length: LH=34.67m, C=29.89m, RH=34.95m

Upstream Invert Elev.: LH=844.28m, C=844.34m, RH= 844.32m

Downstream Invert Elev.: LH=844.11m, C=844.18m, RH=844.16m

Upstream Crown Elev.: LH=845.44m, C=846.19m, RH=845.61m

Downstream Crown Elev.: LH=845.30m, C=846.05m, RH=845.38m

Minimum Ground Cover Elev.: 846.65m

Photos:

Looking upstream from left bank:

Looking downstream from left bank:

B24

Structure Name: 45 St. Culvert

Bridge File No.: BF 82136

Water Course: Main Tributary

Location: 45th Street

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (Double, RH, C, LH)

☐ Other:

Notes:

Information:

Total Span: N/A

Diameter: LH=1.10m, C=1.42m, RH=1.25m

Length: LH=19.57m, C=15.76m, RH=19.13m

Upstream Invert Elev.: LH=843.88m, C=843.98m, RH=843.85m

Downstream Invert Elev.: LH=843.60m, C=843.83m, RH=843.68m

Upstream Crown Elev.: LH=844.98m, C=845.40m, RH=845.10m

Downstream Crown Elev.: LH=844.88m, C=845.21m, RH=844.87

Minimum Road Elev.: 846.06m

Photos:

Looking downstream from right bank:

Looking upstream from right bank:

B25

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: Field Tr. 2 Culvert

Bridge File No.: N/A

Water Course: Tertiary Tributary

Location: N=5813175.07m E=21018.06m

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (double, N / S)

☐ Other:

Notes: Landowner installed double CSP's as a field road crossing.

Information:

Total Span: N/A

Diameter: N= 0.90m, S= 0.90m

Length: approx. N= 18.0m, S= 18.0m

Upstream Invert Elev.: N= 861.27m, S= 861.45m

Downstream Invert Elev.: N= 861.21m, S= 861.20m

Upstream Crown Elev.: N= 862.16m, S= 862.37m

Downstream Crown Elev.: N= 862.11m, S= 862.11m

Minimum Road Elev.: 862.55m

Photos:

Looking downstream from trail:

Looking upstream from trail:

B26

Structure Name: Field Tr. 3 Culvert

Bridge File No.: N/A

Water Course: Tertiary Tributary

Location: N=5813095.52m E=21243.22m

Description and Type:

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (double, N / S)

☐ Other:

Notes: Landowner installed double CSP's as a field road crossing. West / upstream ends buried in heavy sediment/dirt. Possibly placed by landowner for unknown reasons.

Information:

Total Span: N/A

Diameter: N= 0.64m, S= 0.64m

Length: approx. N≈ 7.0m, S≈ 7.0m

Upstream Invert Elev.: N= unknown, S= unknown

Downstream Invert Elev.: N= 863.02m, S= 863.11m

Upstream Crown Elev.: N= unknown, S= unknown

Downstream Crown Elev.: N= 863.63m, S= 863.77m

Minimum Road Elev.: 864.02m

Photos:

Looking downstream from right bank:

Unavailable

Looking upstream from right bank:

Unavailable

B27

Structure Detail Sheet | *Lacombe AB, June 2023*

Structure Name: 34 St. Culvert Mid

Bridge File No.: N/A

Water Course: Wolf Creek

Location: 34th Street (middle crossing)

<u>Description and Type:</u>

☐ Single Span Bridge

☐ Multiple Span Bridge ( )

☐ Box Culvert (single)

☐ Box Culvert (double)

☒ CSP Culvert (triple, N / S)

☐ Other:

Notes:

<u>Information:</u>

Total Span: N/A

Diameter: N= 0.98m, S= 0.94m

Length: N= 15.96m, S= 16.02m

Upstream Invert Elev.: N= 854.38m, S= 854.44m

Downstream Invert Elev.: N= 854.25m, S= 854.23m

Upstream Crown Elev.: N= 855.33m, S= 855.38m

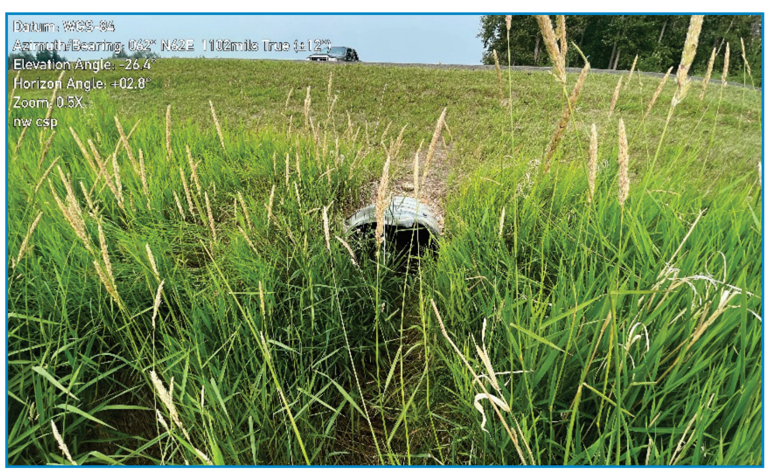
Downstream Crown Elev.: N= 855.18m, S= 855.13m

Minimum Road Elev.: 856.31m

<u>Photos:</u>

Looking upstream at south CSP from left bank:

Looking upstream at north CSP form mid-channel:



Appendix C

Flood Control Structure Memorandum

resourceful. naturally.
engineering and environmental consultants

BARR

Technical Memorandum

To: Mr. Muhammad Durrani, M.Eng., P.Eng. (AEPA)
From: Hossein Kheirkhah Gildeh, Ph.D., P.Eng.
Subject: Flood Control Structures
Date: June 28, 2023
Project: Lacombe Flood Study - 61011343
c: Tom MacDonald (Barr)

1 INTRODUCTION

In 2023, Alberta Environment and Protected Areas (AEPA) retained Barr Engineering and Environmental Science Canada Limited (Barr) to conduct the Lacombe Flood Study. The study is conducted 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. Project stakeholders include the Government of Alberta, the City of Lacombe, the Lacombe County, and the public.

The Lacombe Flood Study includes multiple components and deliverables. This memorandum documents existing flood control structures in the study area.

2 SURVEY PROGRAM

2.1 General

A site visit of the study area was completed by Barr, AEPA and Trout Hydrography (Trout) on June 13, 2023. The survey of the Wolf Creek stream cross sections and hydraulic structures within the study area was conducted between June 20 and 25, 2023. In addition, ASCM benchmarks were surveyed as part of this study. At the time of the site visit there was no flow in the channels, including Wolf Creek, within the study area. However, due to a rain event prior to the survey, the Wolf Creek experienced in-channel flows and thus water levels and discharges were collected. The details of the stream survey are described in the hydraulic model creation and calibration report.

2.2 Flood Control Structures

No flood control structures were found during the site visit and survey. The City of Lacombe and Lacombe County representatives also confirmed there are no flood control structures within the study area.

Certification

Prepared by:

Hossein Kheirkhah Gildeh, Ph.D., P.Eng.
Senior Water Resources Engineer

Reviewed by:

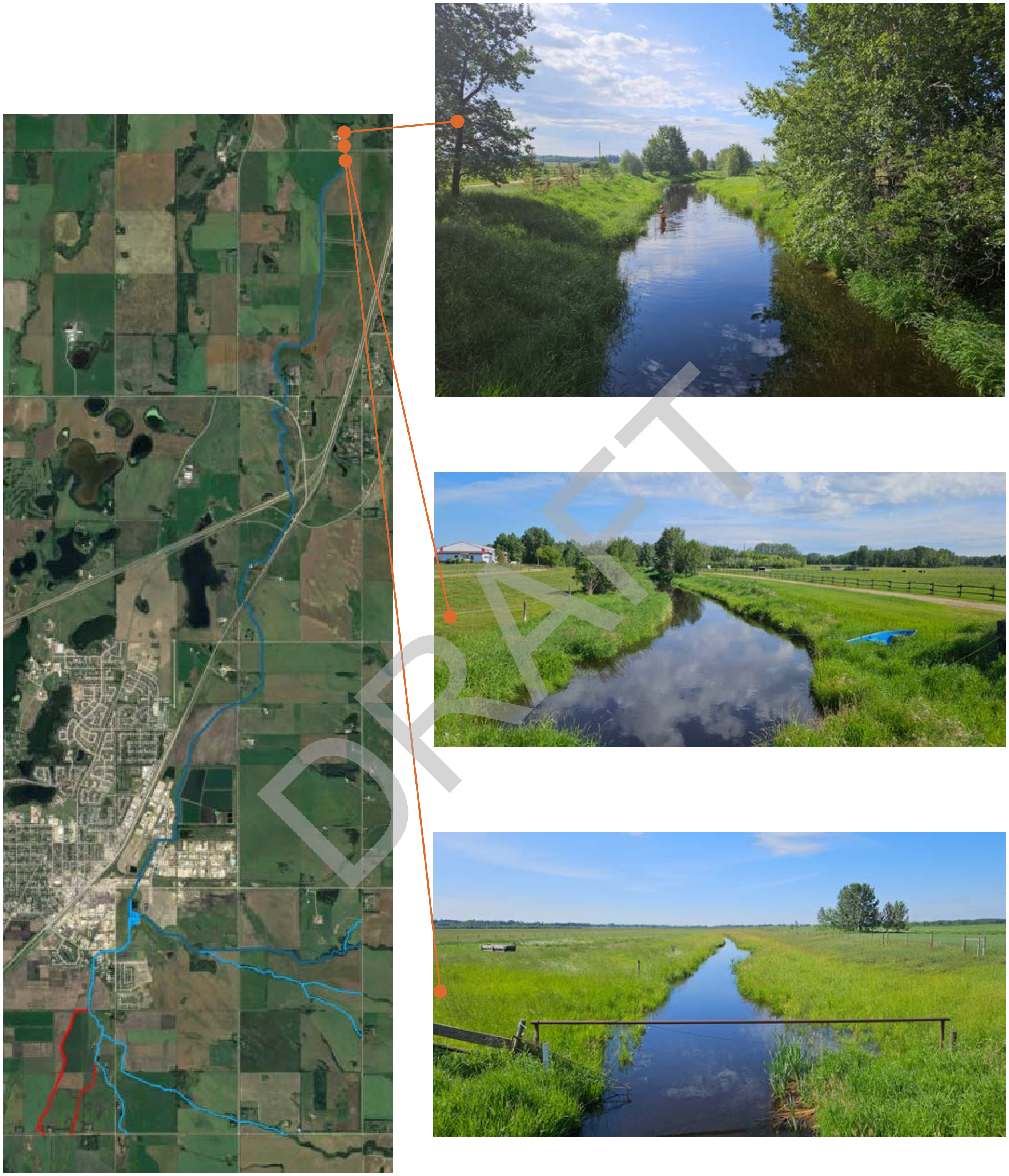
Thomas MacDonald, M.Sc., P.Eng.
Senior Water Resources Engineer

Disclaimer

This report has been prepared by Barr Engineering and Environmental Science Canada Limited (Barr) for the benefit of the client to whom it is addressed. The work described herein was performed in a manner consistent with the level of care and skill ordinarily exercised by other members of the profession practicing in the same locality under similar circumstances. Interpretations, conclusions, and recommendations in this document are based on information available to Barr at the time of preparation. If this information is found to be inaccurate, Barr must be notified promptly. Barr 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 Barr and the client.

Appendix D

Reach Representative Photos



Classification: Public

Appendix E

Open Water Hydrology Assessment Technical Memorandum

Technical Memorandum

To: Mr. Muhammad Durrani, M.Eng., P.Eng. (EPA)
From: Omid Mohseni, Ph.D. and Moges Wagena, Ph.D.
Subject: Lacombe Open Water Hydrology Assessment
Date: January 29, 2025
Project: Lacombe Flood Study - 61011343
c: Hossein Kheirkhah Gildeh (Barr), Tom MacDonald (Barr)

1 INTRODUCTION

In 2023, Alberta Environment and Protected Areas (EPA) retained Barr Engineering and Environmental Science Canada Limited (Barr) to complete a flood study along approximately 16 km of Wolf Creek and its tributaries through the City of Lacombe and Lacombe County. The study is conducted under the provincial Flood Hazard Identification Program, the goals of which include enhancing public safety and reducing future flood damages by identifying river and flood hazards. Project stakeholders include the Government of Alberta, the City of Lacombe, Lacombe County, and the public.

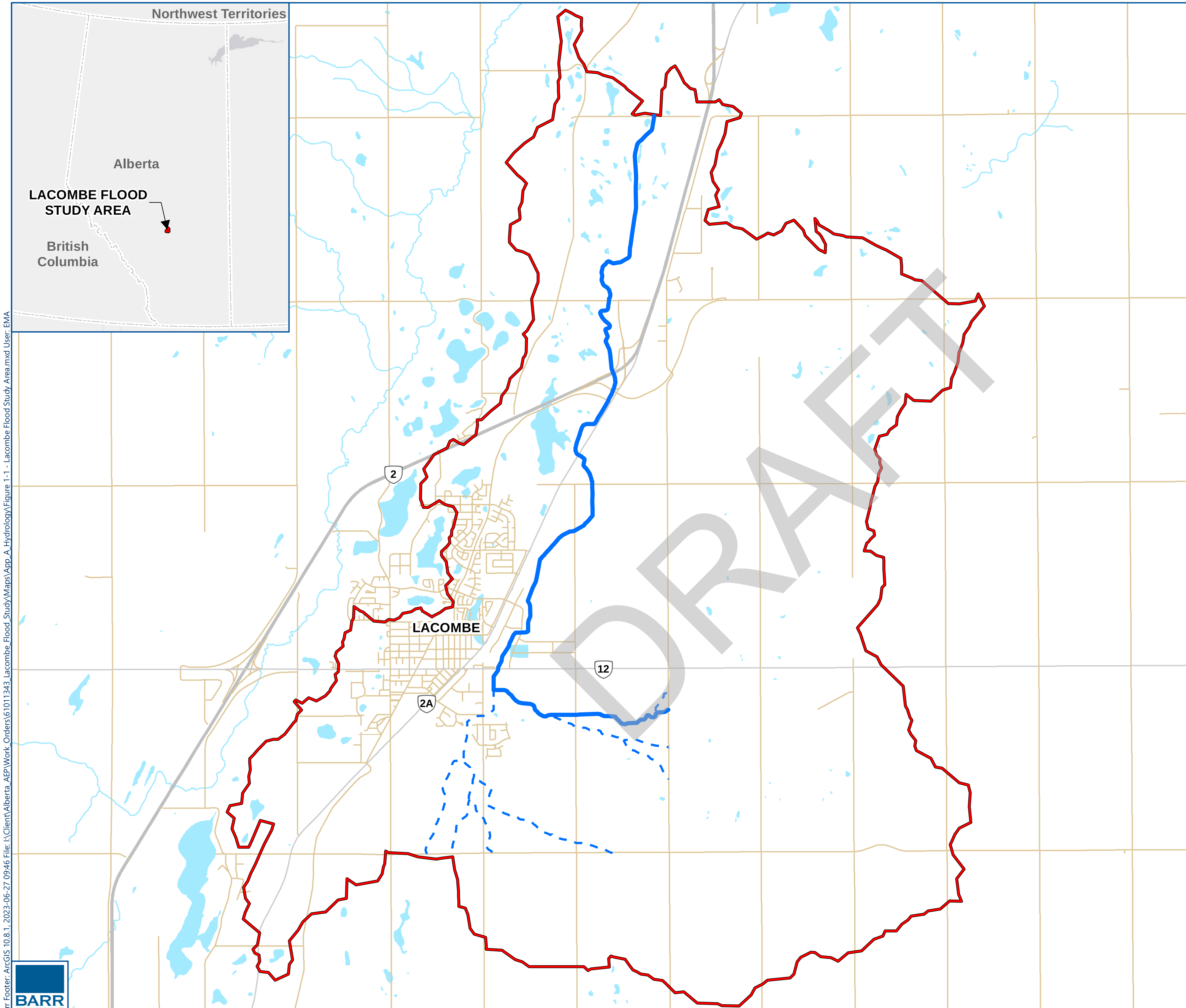
The Lacombe Flood Study includes multiple components and deliverables. This memorandum summarizes the open water hydrology assessment of Wolf Creek and its tributaries, including the flood frequency estimates.

1.1 Study Area

The headwaters of Wolf Creek drain from east to west towards the City of Lacombe, which is in south-central Alberta, approximately 125 km south of the City of Edmonton. The creek then flows northerly along the city's east side towards Highway 2 and Highway 2A. Figure 1-1 shows the study extent and the overall watershed area where flood frequency estimates are required for the open water hydrology assessment.

1.2 Study Objectives

The main objective of the flood frequency analysis was to estimate the flood flows with annual exceedance probabilities (AEPs) of 1:2, 1:5, 1:10, 1:20, 1:35, 1:50, 1:75, 1:100, 1:200, 1:350, 1:500, 1:750, and 1:1,000 at different locations along Wolf Creek and its tributaries that flow through the City of Lacombe and Lacombe County.



LEGEND

- LACOMBE FLOOD STUDY WATERSHED
- WOLF CREEK
- TRIBUTARIES
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERBODY
- WATERCOURSE

N

0 1 2
KILOMETRES

REFERENCES
ROADS AND HYDROGRAPHY OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 114

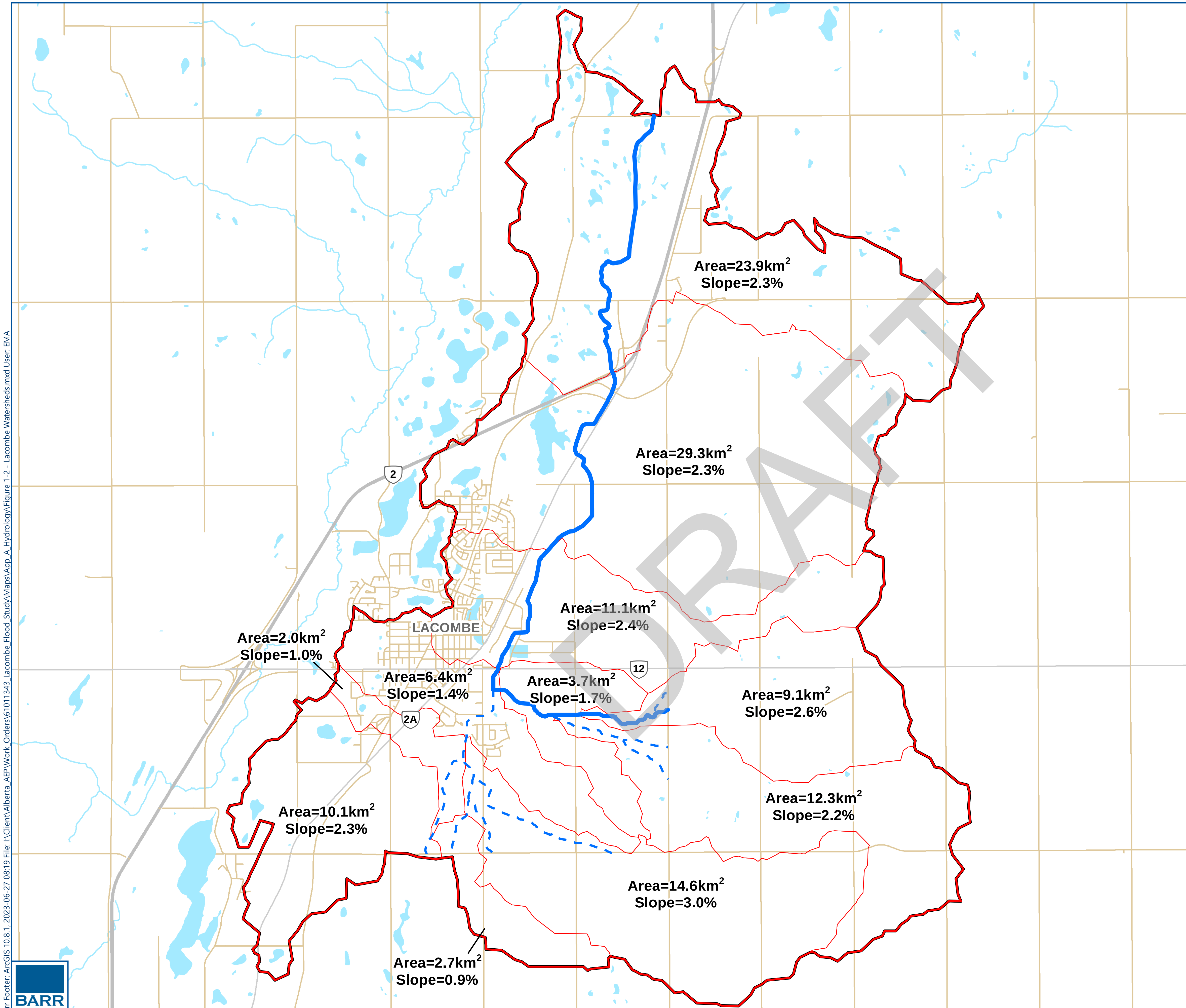
LACOMBE FLOOD STUDY AREA
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 1-1

1.3 Watershed Setting and Flood History

Wolf Creek is a small prairie stream with a relatively flat watershed. The average slope of the watershed is about 2.3 percent. Most of the creek is perennial; however, the tributaries intermittently drain into the creek. The creek has been channelized within the City of Lacombe. The watershed area of Wolf Creek was delineated using the 25-m digital elevation model (DEM) of Altalis sourced by the EPA in March 2023. The gross watershed area of Wolf Creek at Highway 2 is approximately 100 square kilometers (km^2), and its watershed area within the flood study area is 125 km^2. Figure 1-2 shows the Wolf Creek watershed area, tributaries, and the sub-watersheds used in the open water hydrology assessment. The selected sub-watersheds shown in Figure 1-2 are discussed in Section 3.4.

Wolf Creek near Lacombe is known for frequent flooding during spring snowmelt; however, there is no streamflow gauge along the creek. Therefore, there is no record of flooding.



LEGEND

- LACOMBE FLOOD STUDY WATERSHED
- SUBWATERSHED
- WOLF CREEK
- TRIBUTARIES
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERBODY
- WATERCOURSE

N

0 1 2

KILOMETRES

REFERENCES

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

NOTE

1. SUBWATERSHEDS WERE DELINEATED BASED ON A 25-METRE ALTALIS DEM SOURCED BY THE AEPA.

Alberta

Canada

LACOMBE WATERSHEDS
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 1-2

2 AVAILABLE FLOW DATA

As stated in Section 1.3, the only gauge station within the study area is WSC gauge station 05FA026 (Wolf Creek at Township Road No. 410), which is inactive and has very limited data from 2007 to 2009. As a result, a regional flood frequency analysis was conducted on the WSC gauge stations near the project area with similar watershed characteristics and sizes, as explained in Section 0.

2.1 Previous Studies

The Lacombe flood frequency analysis was done by the Hydrology Branch of Alberta Environment (Water Resources Management Services, Technical Services Division) in 1992 (De Boer, 1992). The regional flood frequency analysis used nine WSC gauges with watershed areas varying from 54 to 584 km^2. The watershed area of Wolf Creek at the downstream end of the 1992 Lacombe floodplain study area was estimated to be 103 km^2, i.e., most of the selected WSC gauges had contributing watershed areas two-to-five times the Wolf Creek watershed area.

The WSC gauges had record lengths from 13 to 27 years. However, four of the gauges yielded flood flows per unit watershed area smaller than the other five gauges; therefore, the Hydrology Branch of Alberta Environment used only five WSC gauges to estimate flood flows with AEPs of 1:2, 1:5, 1:10, 1:20, 1:50 and 1:100. The five gauges used in the study were as follows.

- 05CC010 (Block Creek near Leedale) with a watershed area of 54 km^2
- 05CC009 (Lloyd Creek near Bluffton) with a watershed area of 241 km^2
- 05CC008 (Blindman River near Bluffton) with a watershed area of 352 km^2
- 05DE007 (Rose Creek near Alder Flats) with a watershed area of 551 km^2
- 05DF004 (Strawberry Creek near the mouth) with a watershed area of 584 km^2

The 1992 Lacombe floodplain study used the average mean annual yield of the five streams in m^3/s/km^2 and the average ratio of flood flows to mean annual flows to estimate the flood flows at different locations of Wolf Creek, i.e., the study did not use any regional regression equations. As seen above, the watershed areas except for Block Creek were significantly larger than the Wolf Creek watershed area in the 1992 Lacombe floodplain study. The flood flow with the 1:100 AEP of Wolf Creek at Highway 2 was estimated to be 75.4 m^3/s.

In 1996, the River Engineering Branch of Alberta Environmental Protection determined that the flood flows estimated in 1992 were too large because of significant ponding in the floodplain (Alberta Environmental Protection, 1996). The 1996 study accounted for the storage effects on the peak flows by routing flood flows through the system. Therefore, the flood flows were revised, and the 1:100 AEP flood flow of Wolf Creek at Highway 2 was estimated to be 36.4 m^3/s. Note that the 1:100 AEP flood flow of the upstream reach, i.e., from Highway 12 to Highway 2A, was estimated to be about 40.1 m^3/s.

In the current study, with a coupled 1D/2D HEC-RAS modelling approach and constant flows, a reduction of flow from an upstream to a downstream reach of Wolf Creek, as was used in the 1996 study, is not possible because continuity must be satisfied in the coupled 1D/2D HEC-RAS model. However, the effects of storage areas will be explored in estimating flows along the reaches of Wolf Creek.

In 2014, MPE Engineering LTD (MPE) completed a stormwater management study as part of the Master Drainage Plan for the Wolf Creek and Whelp Brook Watersheds (MPE, 2014). In that study, MPE conducted a regional flood frequency analysis to estimate flood flows in Wolf Creek for flood events with AEPs of 1:2, 1:5, 1:10, 1:20, 1:50, and 1:100. MPE used six WSC gauges for the regional flood frequency analysis as listed below.

- 05CC011 (Waskasoo Creek at Red Deer)
- 05CD006 (Haynes Creek near Haynes)
- 05CD007 (Parlby Creek at Alix)
- 05FA012 (Pipestone Creek near Wetaskiwan)
- 05FA014 (Maskwa Creek No. 1 above Bearhills Lake)
- 05FA024 (Weiller Creek near Wetaskiwin)

The watershed areas of the six WSC gauges varied from 79.1 km^2 to 1,030 km^2. MPE used the 3-parameter lognormal probability distributions for flood frequency analysis at all gauges. Finally, they used power functions with the watershed area as the independent variable to develop regional equations for flood flows of the selected AEPs. The 2014 study estimated the peak flow for the 1:100 AEP flood event at Highway 2 to be 17.97 m^3/s, i.e., slightly smaller than 50% of the one estimated in the 1996 study.

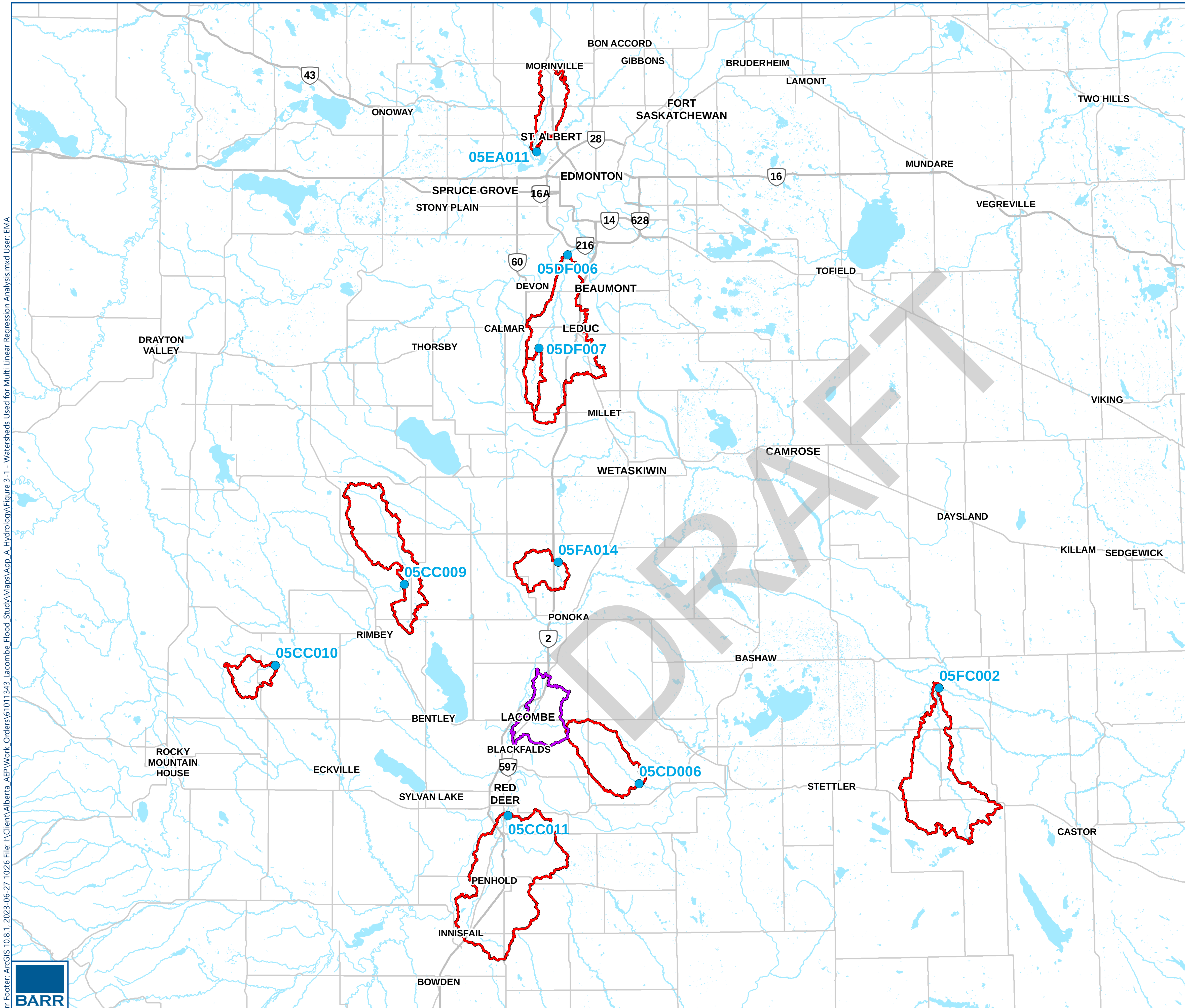
3 REGIONAL FLOOD FREQUENCY ANALYSIS

3.1 Streamflow Gauges

Since there is no WSC streamflow gauge on Wolf Creek and its tributaries within the study area, the flood flow time series of eight WSC gauge stations were downloaded from the Environment and Climate Change Canada (ECCC) website for completing a regional flood frequency analysis (ECCC, 2023). The streamflow gauges were selected based on 1) their proximity to the study area, 2) the size and slope of the basin, and 3) land cover and topography. Four gauges are in the South Saskatchewan River Basin and four in the North Saskatchewan River Basin. Figure 3-1 shows the locations of the WSC gauges and their watershed areas as delineated using the available DEM. Table 3-1 lists the WSC gauges, the available period of records, and the gross and effective watershed areas. The WSC gauge 05EA011 on Carrot Creek was initially selected because of its size and proximity to Lacombe; however, after further review of the flow data recorded at the gauge, it was eliminated from the list because of the record length and the number of missing data.

Note that the gross and effective watershed areas listed in Table 3-1 were downloaded from the ECCC, and they are slightly different from those delineated using the Altalis DEM (as shown in Figure 3-1). The largest difference between the estimated watershed areas by the ECCC and those delineated using the Altalis DEM is for West Whitemud Creek near Ireton and Whitemud Creek. For this study, we decided to use the data downloaded from the ECCC website because, in our watershed delineation, we could not estimate the effective watershed areas of some watersheds close to those estimated by the ECCC.

The gross watershed areas in Table 3-1 vary from about 56 km^2 to 487 km^2, and the effective watershed areas vary from about 53 km^2 to 301 km^2. Table 3-1 is sorted based on the effective watershed area of the selected WSC gauges. The available records for most WSC gauges in Table 3-1 were through 2020 or 2021. EPA and WSC provided 2021 and 2022 provisional flow data for those WSC gauges that did not have the record through 2022 on the ECCC website. After reviewing the provisional data, it was determined that there were no major flood events at the selected WSC gauges in those two years, and the provisional records of 2020 and 2021 would not have any material effects on the probability distribution functions and the estimates of the extreme flood events. Therefore, only the available data on the ECCC website were used for flood frequency analyses.



LEGEND

- WSC GAUGE STATIONS
- LACOMBE FLOOD STUDY WATERSHED
- WSC WATERSHEDS
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- WATERBODY
- WATERCOURSE

N

0 10 20
KILOMETRES

REFERENCES
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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

NOTE
1. THE WATERSHED AREAS FOR REGIONAL WSC GAUGES ARE DELINEATED BY BARR.
2. WSC = WATER SURVEY CANADA.

Alberta
Canada

WATERSHEDS USED FOR MULTI LINEAR REGRESSION ANALYSIS
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 3-1

BARR

Table 3-1 WSC Streamflow Gauges Used for Regional Flood Frequency Analysis

WSC Gauge Station Name[1]	Station ID	Range of Record	Years of Record[2]	Alberta's Major Watersheds or River Basins	Gross Watershed Area (Km^2)	Effective Watershed Area (Km^2)
West Whitemud Creek near Ireton	05DF007	1976–2021	41	North Saskatchewan River Basin	65.4	53.2
Block Creek near Leedale	05CC010	1976–2020	35	South Saskatchewan River Basin	56.8	56.6
Maskwa Creek No. 1 above Bearhills Lake	05FA014	1972–2021	33	North Saskatchewan River Basin	79.1	61.2
Haynes Creek near Haynes	05CD006	1978–2021	36	South Saskatchewan River Basin	165.0	165.0
Bigknife Creek near Gadsby	05FC002	1967–2021	42	North Saskatchewan River Basin	281.0	194.0
Lloyd Creek near Bluffton	05CC009	1965–2020	35	South Saskatchewan River Basin	239.0	239.0
Waskasoo Creek at Red Deer	05CC011	1984–2020	32	South Saskatchewan River Basin	487.0	250.0
Whitemud Creek near Ellerslie	05DF006	1969–2020	42	North Saskatchewan River Basin	330.0	301.0

Notes:

1. All gauges are non-regulated (i.e., natural).
2. Excluding the missing years of record.

The annual instantaneous peak flows and daily flows of the selected WSC gauges were downloaded for their period of record. The selected WSC streamflow gauges operate from March through October (i.e., open water period), with the peak flow often occurring during spring runoff. For instance, the daily flows recorded at the WSC gauge 05CD006 on Haynes Creek near Haynes are plotted in Figure 3-2 and show that flood flows start in March and end mostly by late June.

Some of the data recorded at the streamflow gauges were labeled in the record as ice effected. Because those records were primarily associated with smaller flows in the record, i.e., associated with large AEPs, and the record lengths of stream gauges were relatively short, i.e., in the order of 30 to 40 years, they were not eliminated from the records for flood frequency analysis. Nevertheless, additional tests were completed without the records impacted by ice and the results are discussed at the end of Section 3.2.

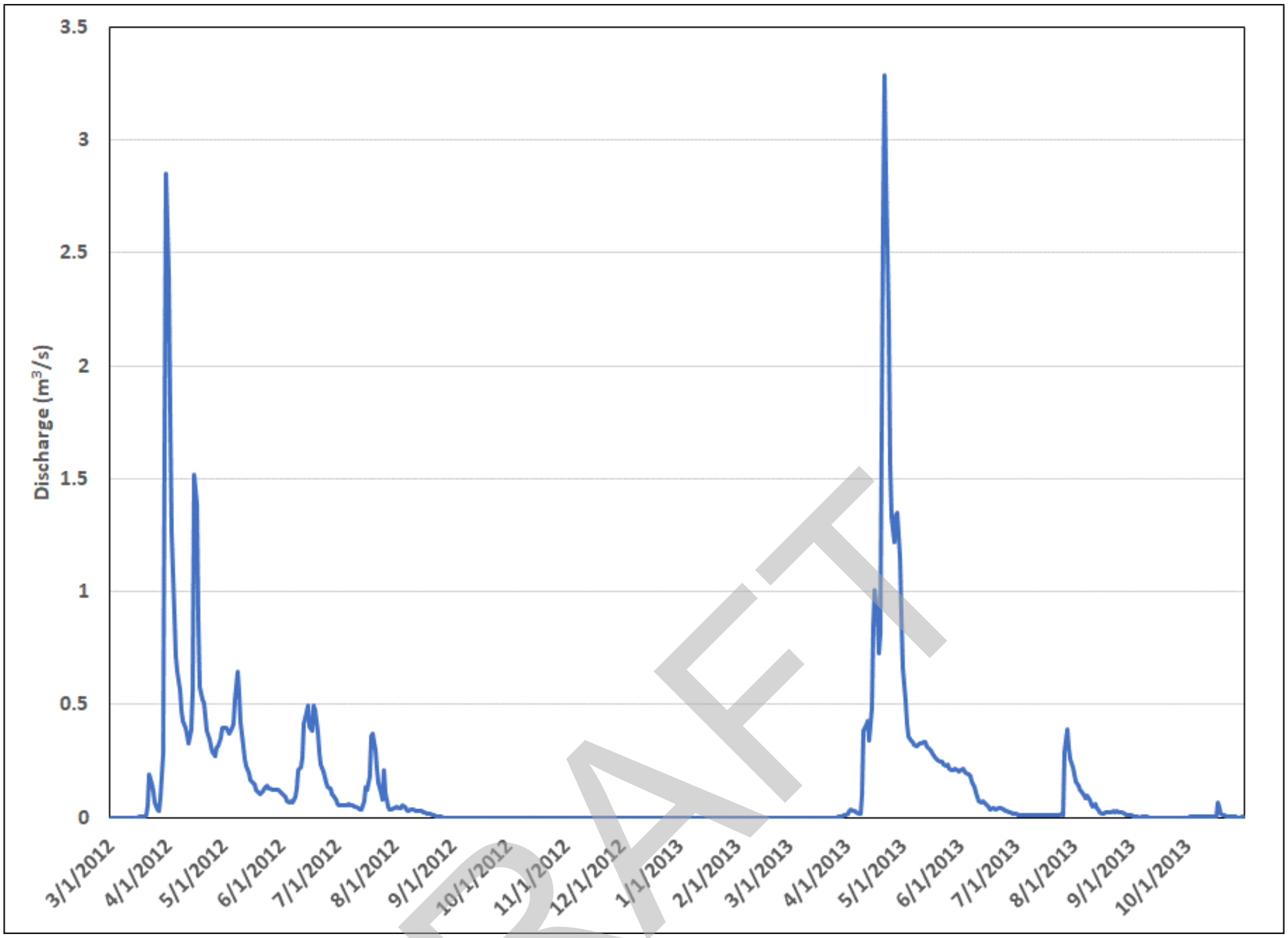


Figure 3-2 Daily Discharge for Haynes Creek near Haynes (05CD006)

Some of the instantaneous peak flows were missing from the records. As a result, the available annual instantaneous peak flows were plotted versus the associated annual maximum daily flows at each streamflow gauge (see Figure 3-3 through Figure 3-10). All records showed that linear relationships could adequately explain the relationship between annual instantaneous peak flows and annual maximum daily flows, with the exception of Waskaso Creek, for which the linear linearship may be underestimating the instantaneous flow smaller than 10 m^3/s (a power function could have been more representative). The linear relationships were used to estimate the missing annual instantaneous peak flows at all gauges.

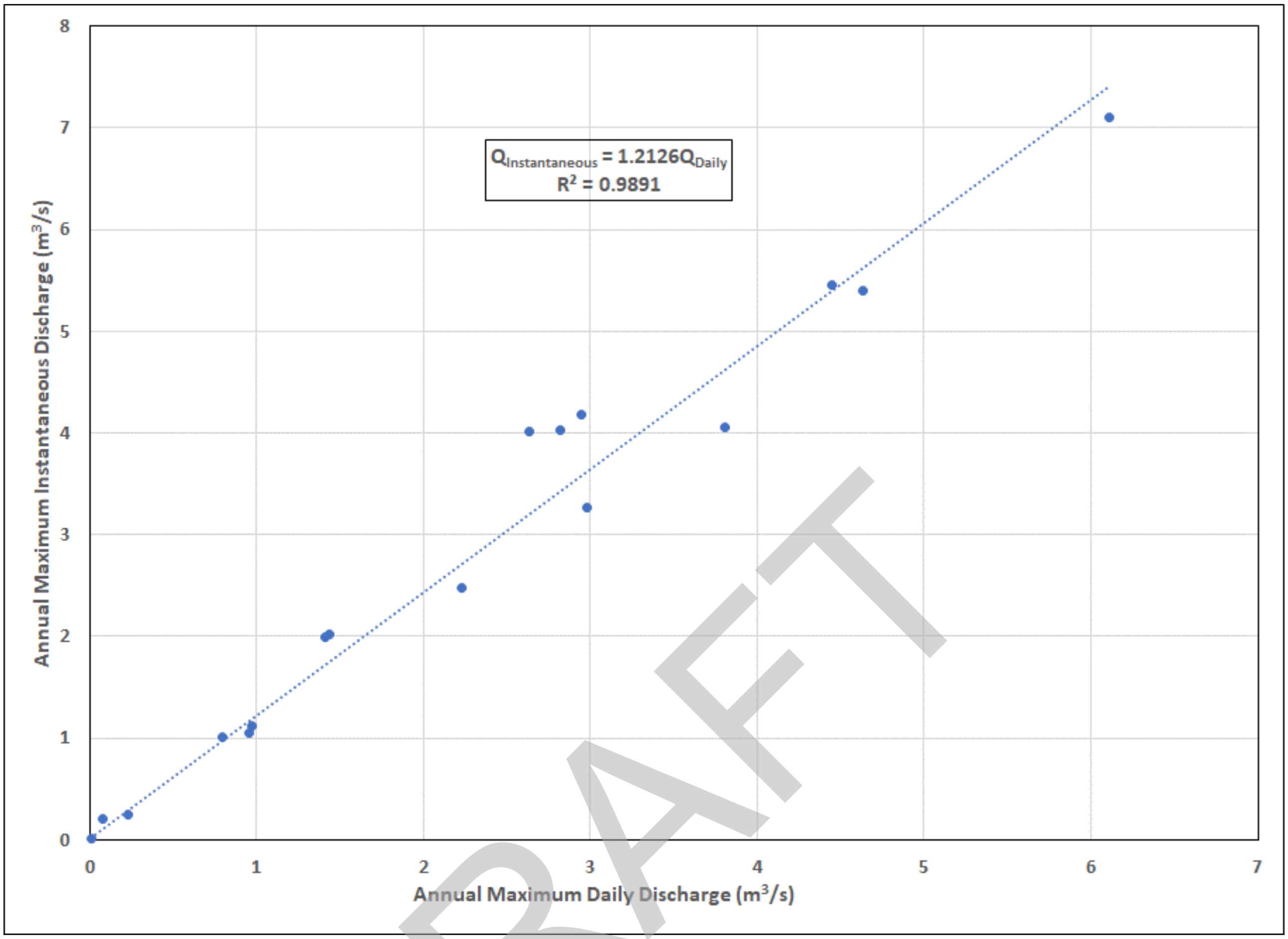


Figure 3-3 **West Whitemud Creek near Ireton (05DF007) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows**

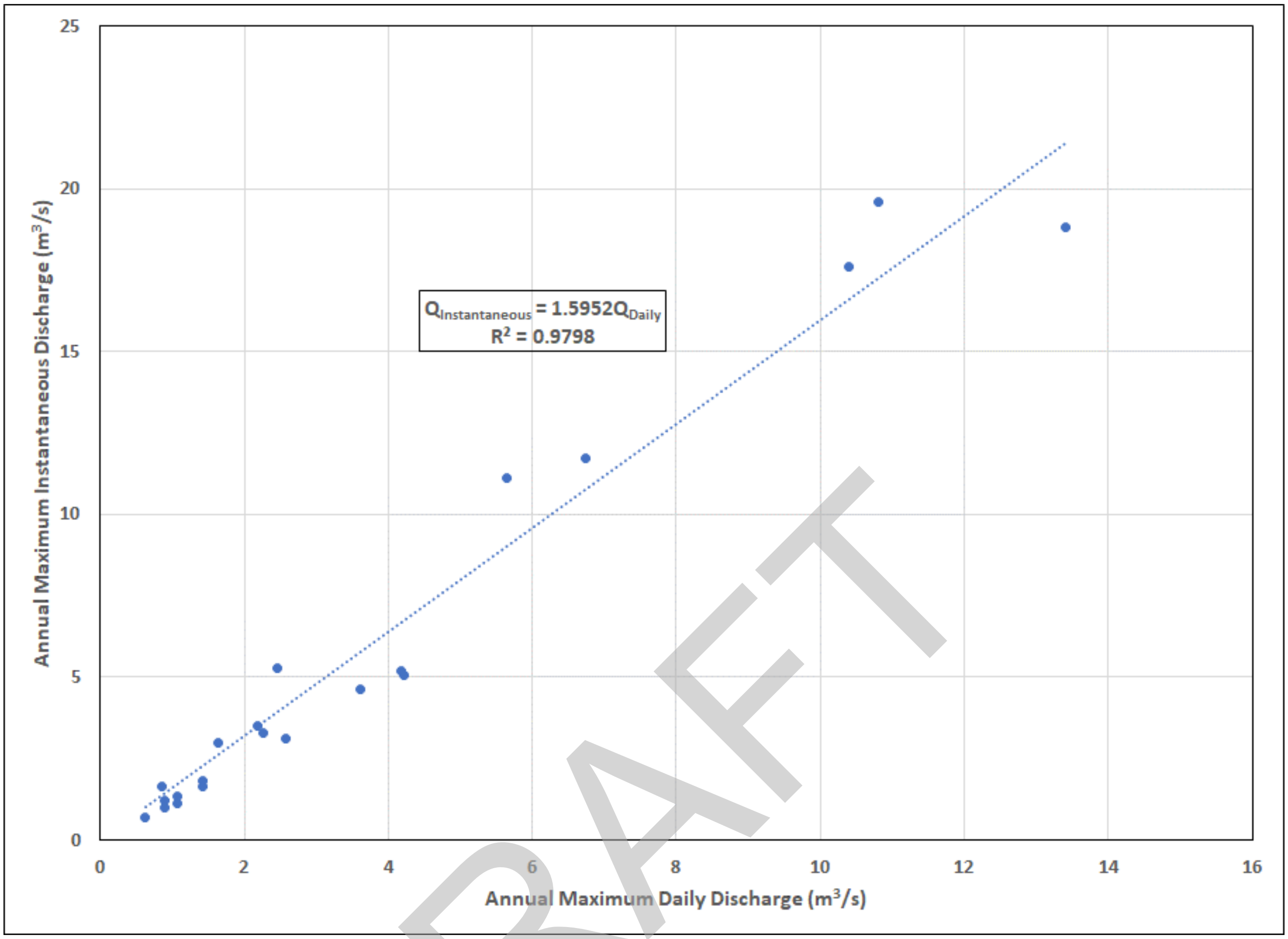


Figure 3-4 Block Creek near Leedale (05CC010) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows

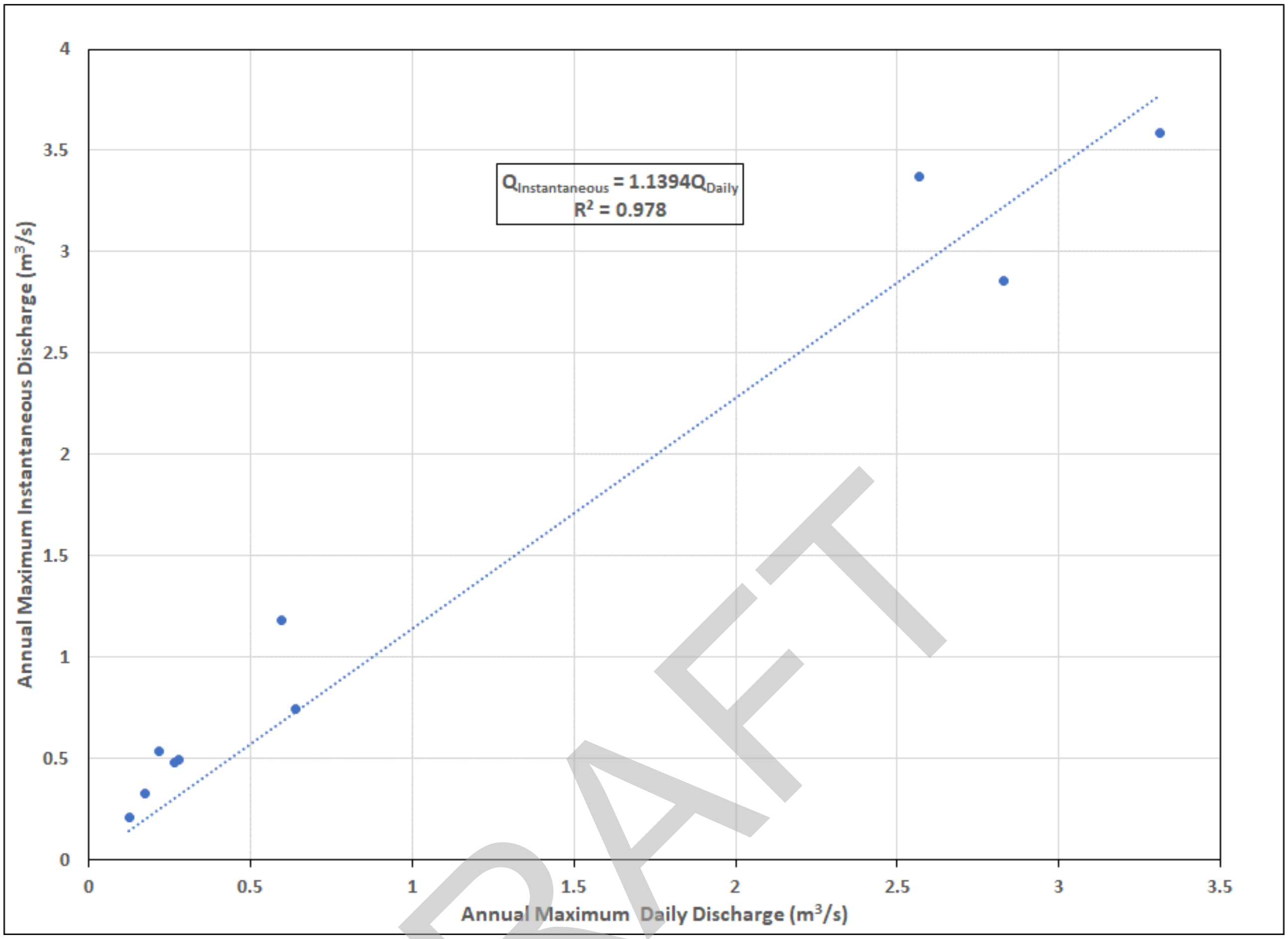


Figure 3-5 **Maskwa Creek No. 1 above Bearhills Lake (05FA014) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows**

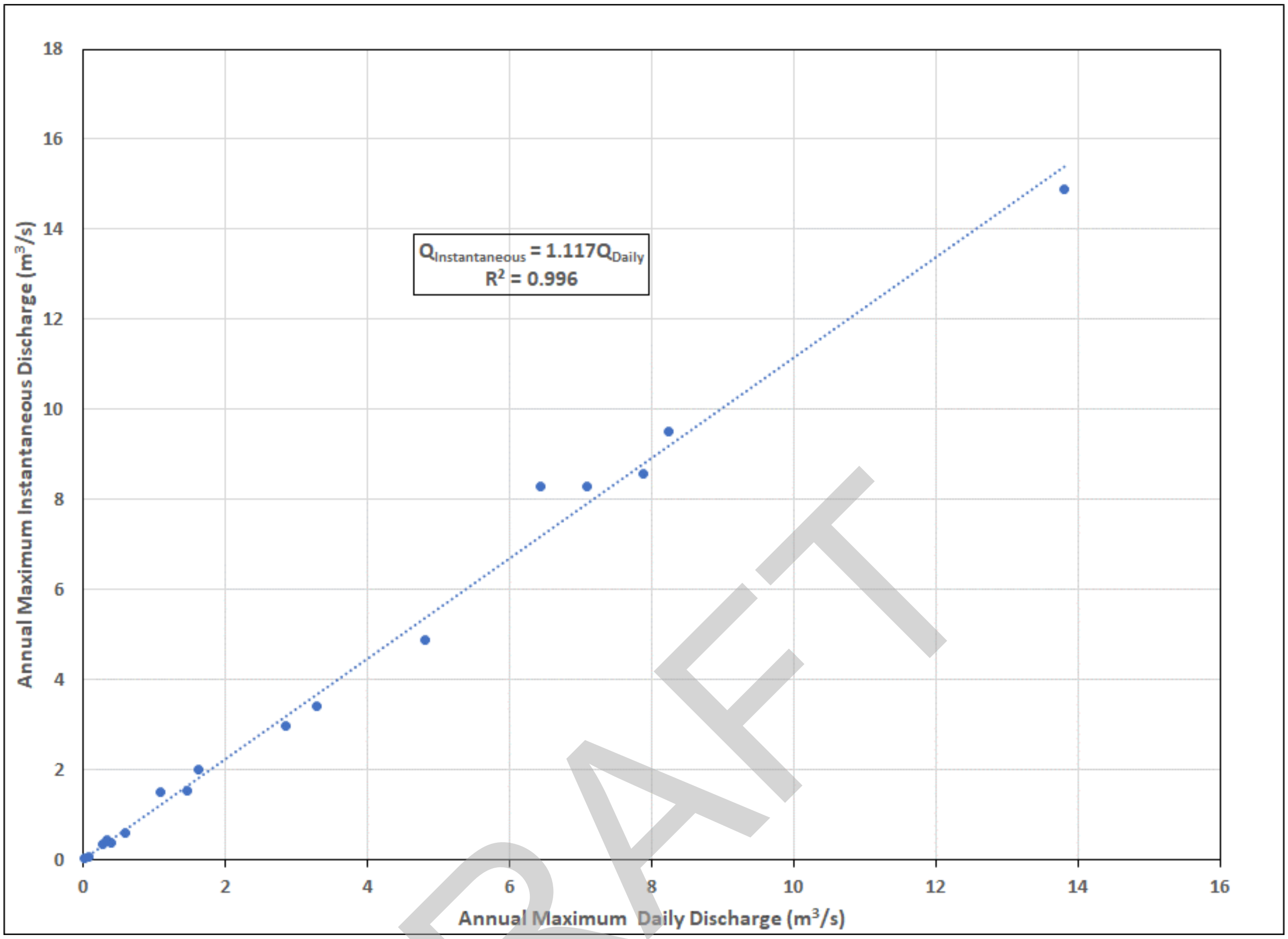


Figure 3-6 Haynes Creek near Haynes (05CD006) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows

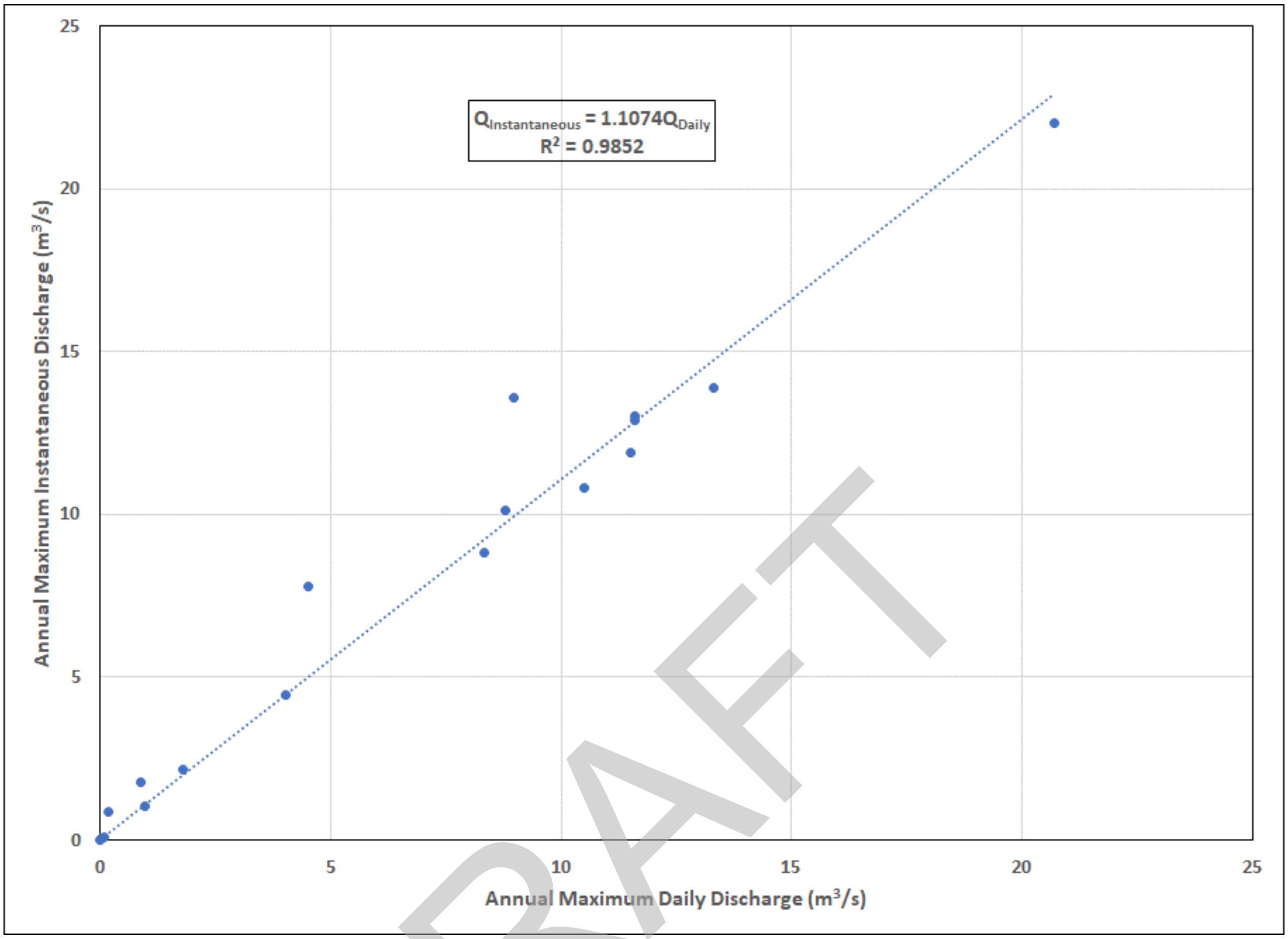


Figure 3-7 Bigknife Creek near Gadsby (05FC002) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows

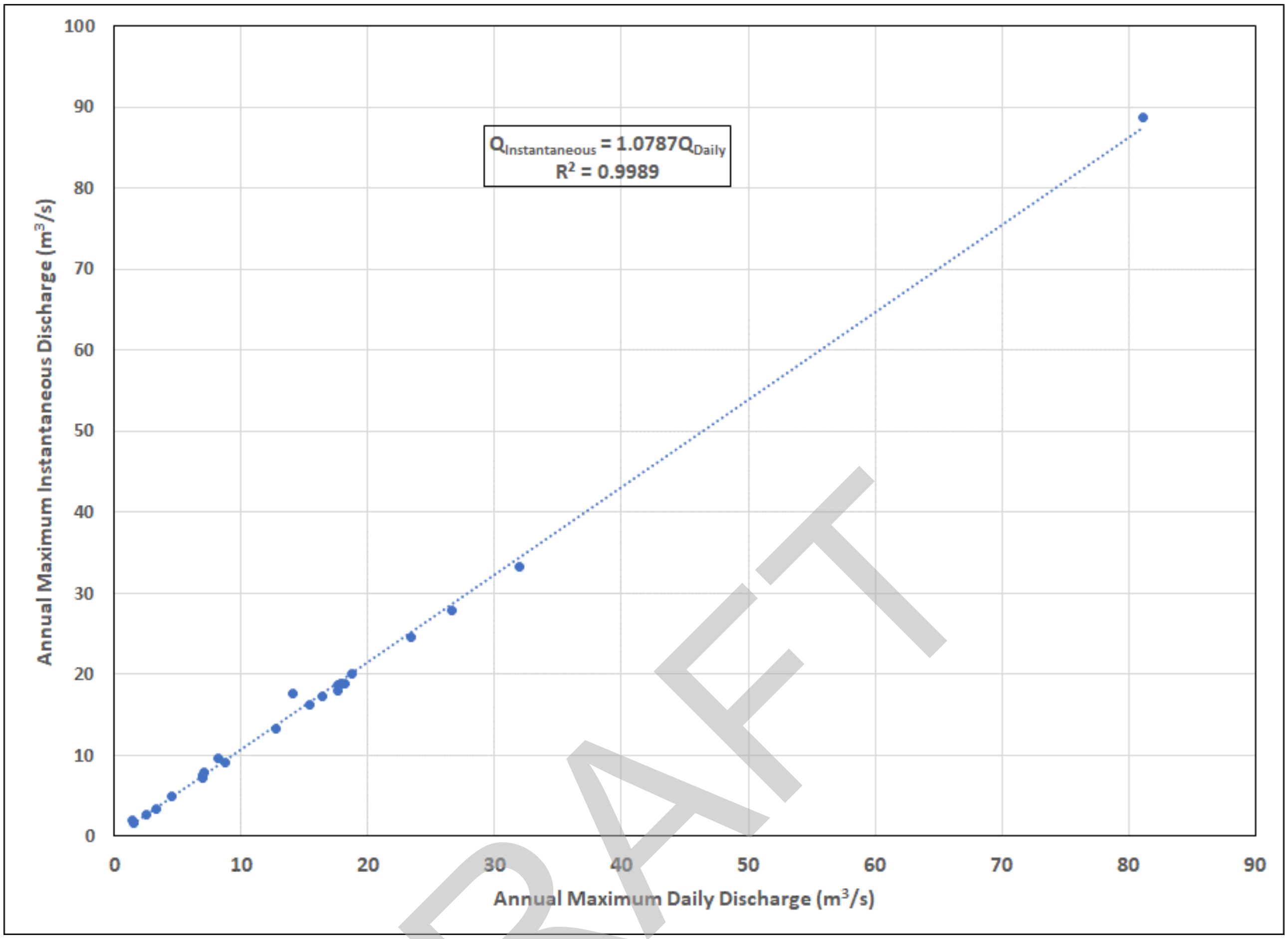


Figure 3-8 Lloyd Creek near Bluffton (05CC009) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows

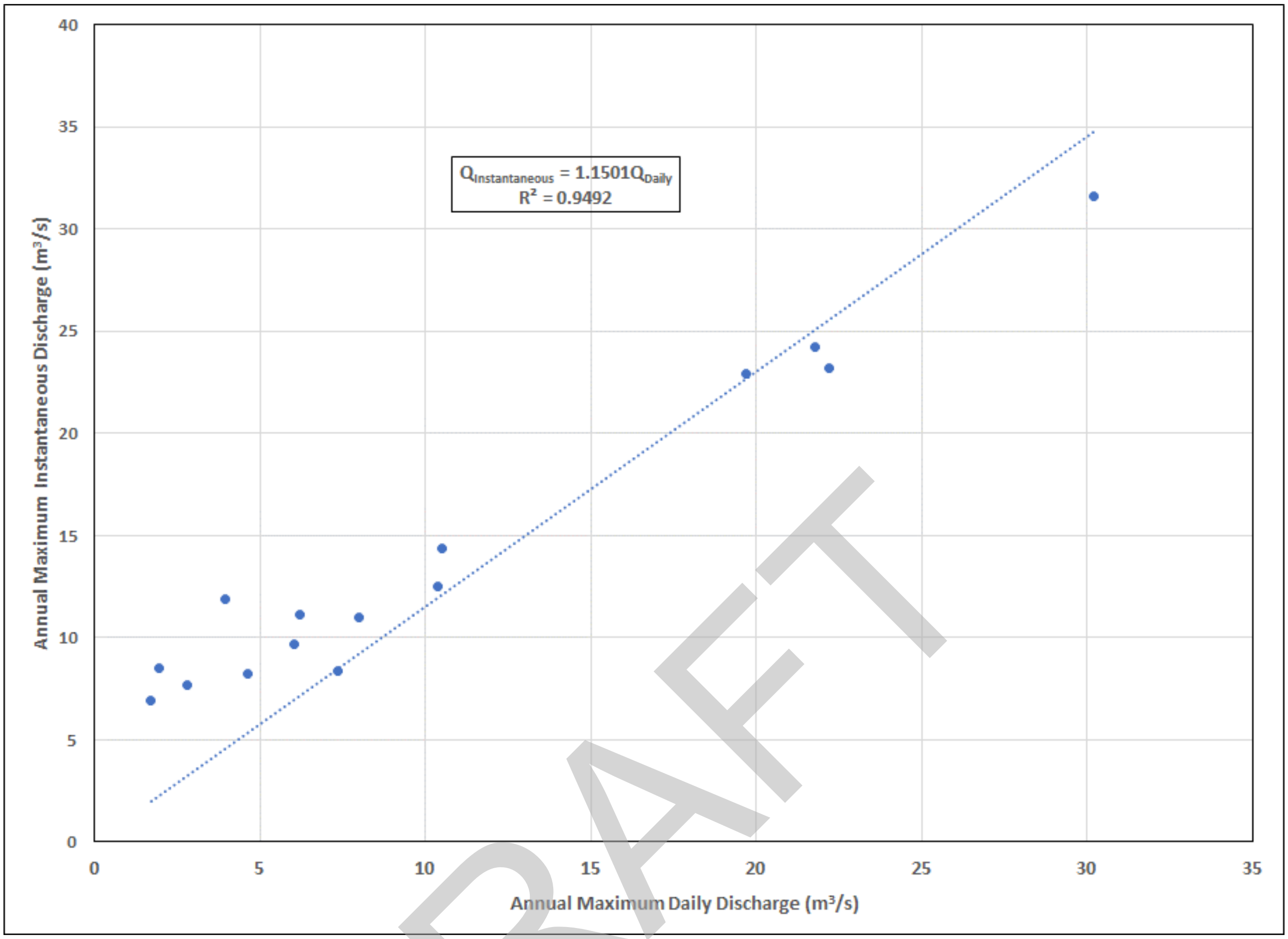


Figure 3-9 Waskasoo Creek at Red Deer (05CC011) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows

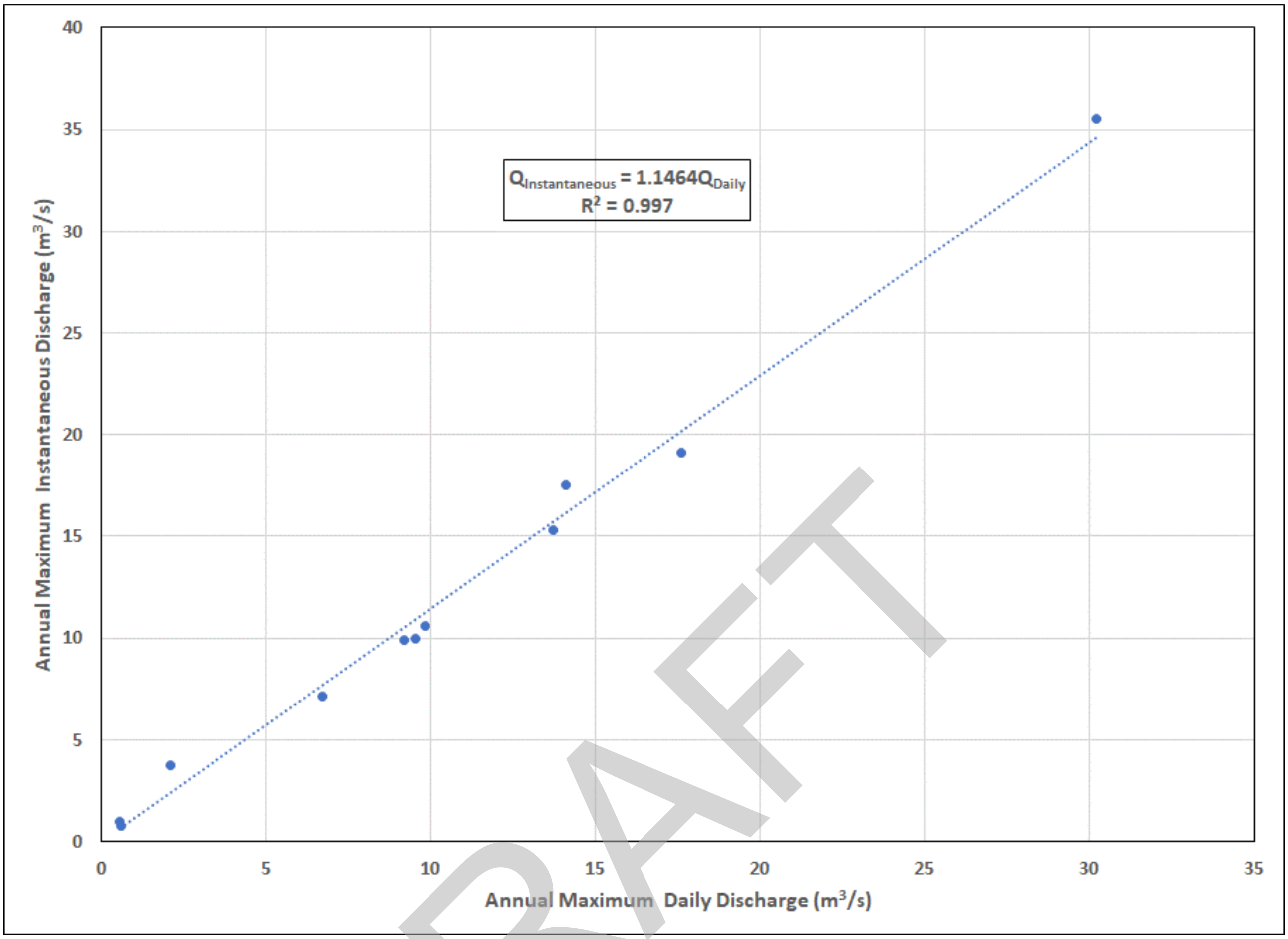


Figure 3-10 Whitemud Creek near Ellerslie (05DF006) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows

3.2 Methodology

Flood frequency analyses were performed for the selected WSC gauge stations using annual instantaneous peak flows (i.e., annual maximum series). The HEC-SSP version 2.2 software program was used for flood frequency analyses. The frequency analyses started with Bulletin 17C EMA (Expected Moments Algorithm), which uses log-Pearson Type III probability distribution; however, other probability distribution functions were also investigated. The annual maximum series of instantaneous peak flows of all eight gauges used in frequency analyses are tabulated in Attachment A.

Bulletin 17C EMA distribution parameters are estimated from the moments of sample data such as mean, standard deviation, and skew. The method also includes adjustment for missing years, estimated flow, low outliers, and historical events by using conditional probability and historical (weighted moments) adjustment, and it characterizes the peak flows as systematic (observed record), historical event, and censured where the peak flow values are missing. The annual peak flow values are presented by flow range with a specified perception threshold each year. For this project, the maximum peak flow value of the station was used as a perception threshold for years with missing peak flow values. Bulletin 17C EMA also provides a computed probability distribution with confidence intervals.

As shown in Figure 3-3 through Figure 3-10 above, there are a significant number of low peak flows. These low values greatly affect the extreme quantiles in the upper tail of the frequency curve. The Grubbs-Beck low outlier test within HEC-SSP was used for all selected WSC gauge stations to overcome distortions of low-value data points on the computed flow frequency curve. The low outlier method will modify perception thresholds and flow ranges when calculating the low outliers of the data.

The flood frequency analysis results using Bulletin 17C EMA are presented in Figure 3-11 through Figure 3-18. The results show the fitted frequency curves and most of the observed peak flow data points are within 90% confidence interval for all WSC gauge stations, although low peak flow data points were out of 95% confidence limits for some WSC gauge stations. The fitted frequency curve for most WSC gauge stations captured higher peak values, and most of the lower peak values are outliers, as shown in Figure 3-11 through Figure 3-18.

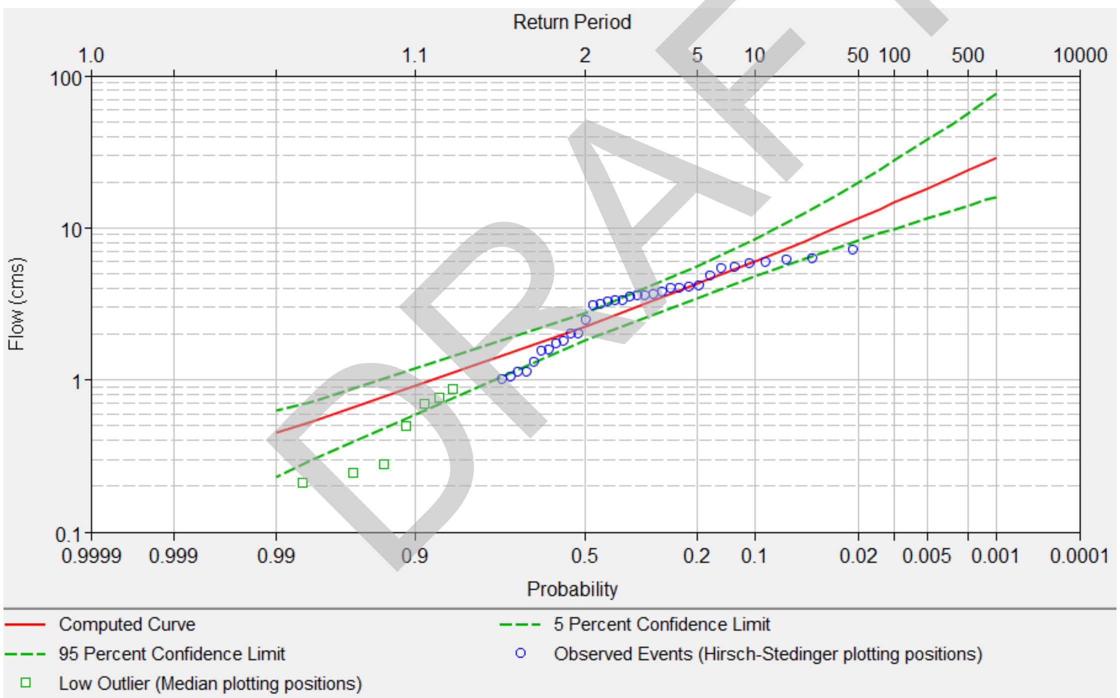


Figure 3-11 Bulletin 17C Flood Frequency Analysis Result for West Whitemud near Ireton (05DF007)

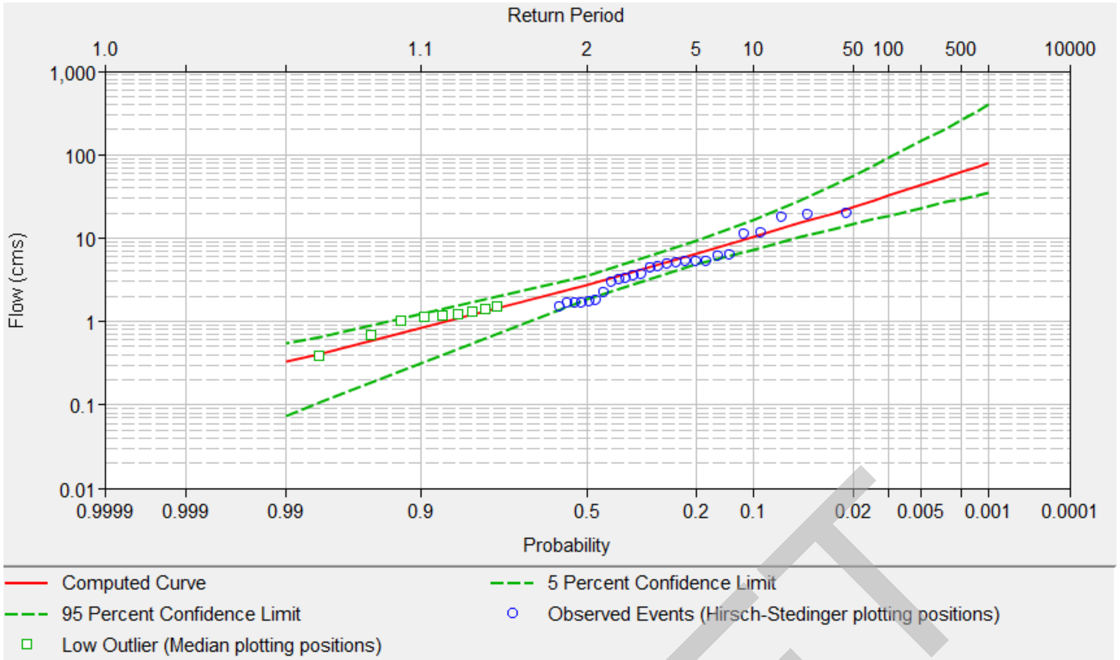


Figure 3-12 Bulletin 17C Flood Frequency Analysis Result for Block Creek near Leedale (05CC010)

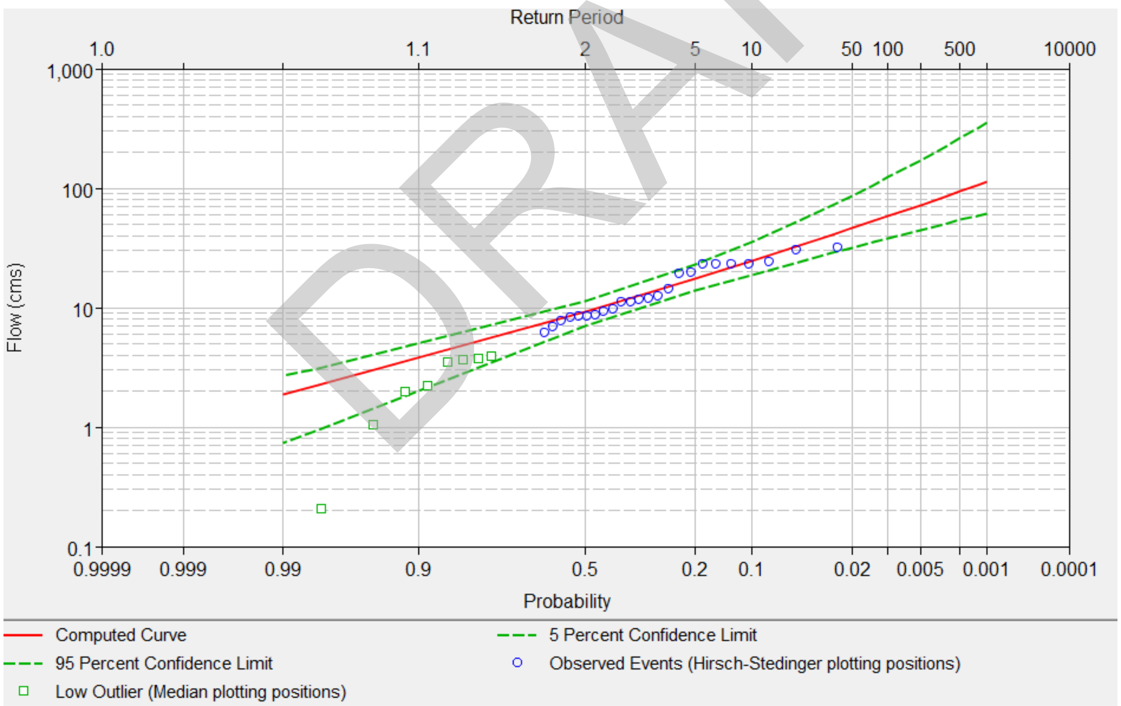


Figure 3-13 Bulletin 17C Flood Frequency Analysis Result for Maskwa Creek No. 1 above Bearhills Lake (05FA014)

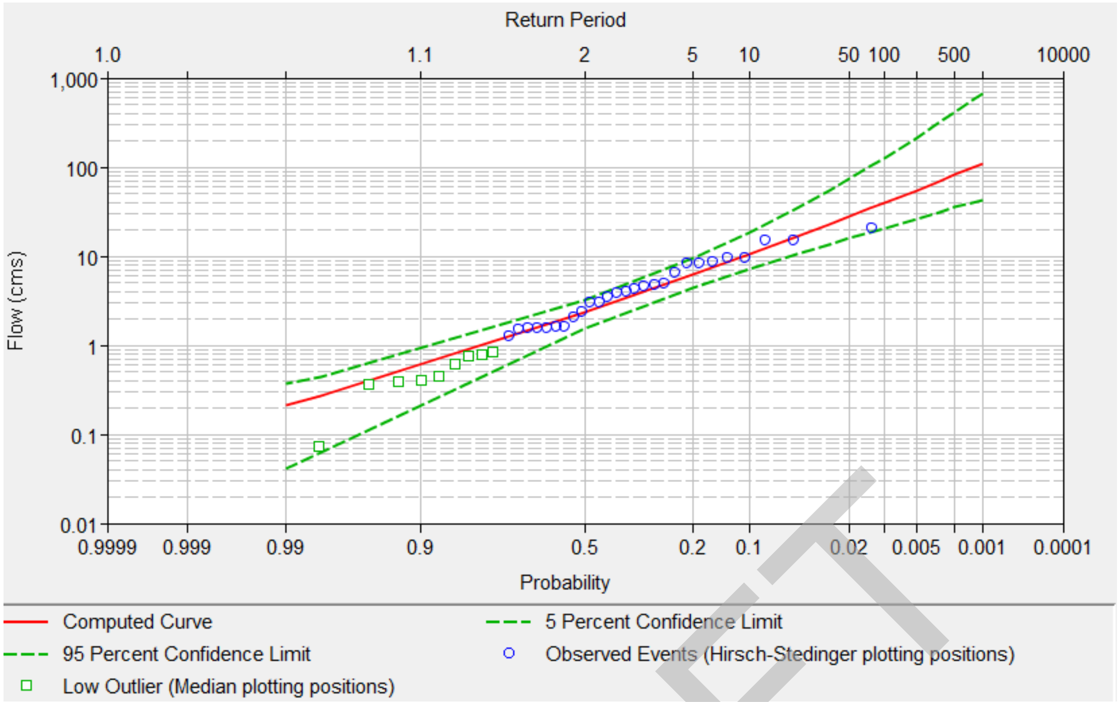


Figure 3-14 Bulletin 17C Flood Frequency Analysis Result for Haynes Creek near Haynes (05CD006)

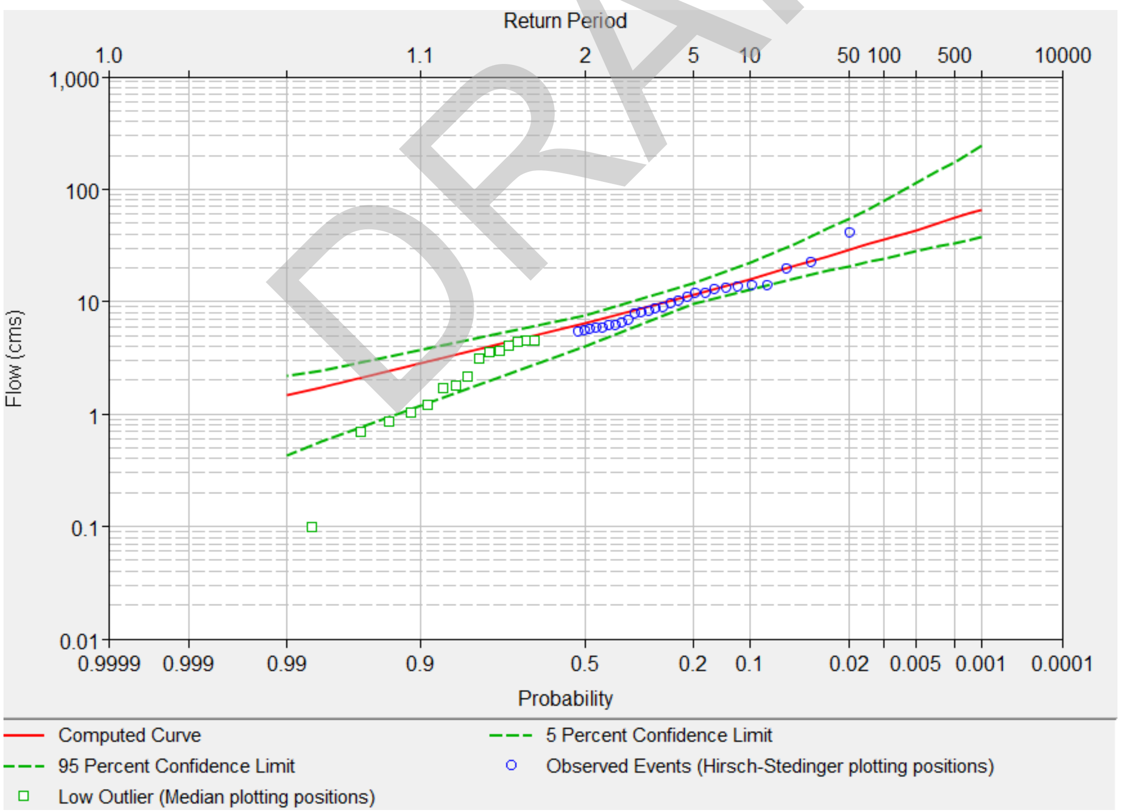


Figure 3-15 Bulletin 17C Flood Frequency Analysis Result for Bigknife Creek near Gadsby (05FC002)

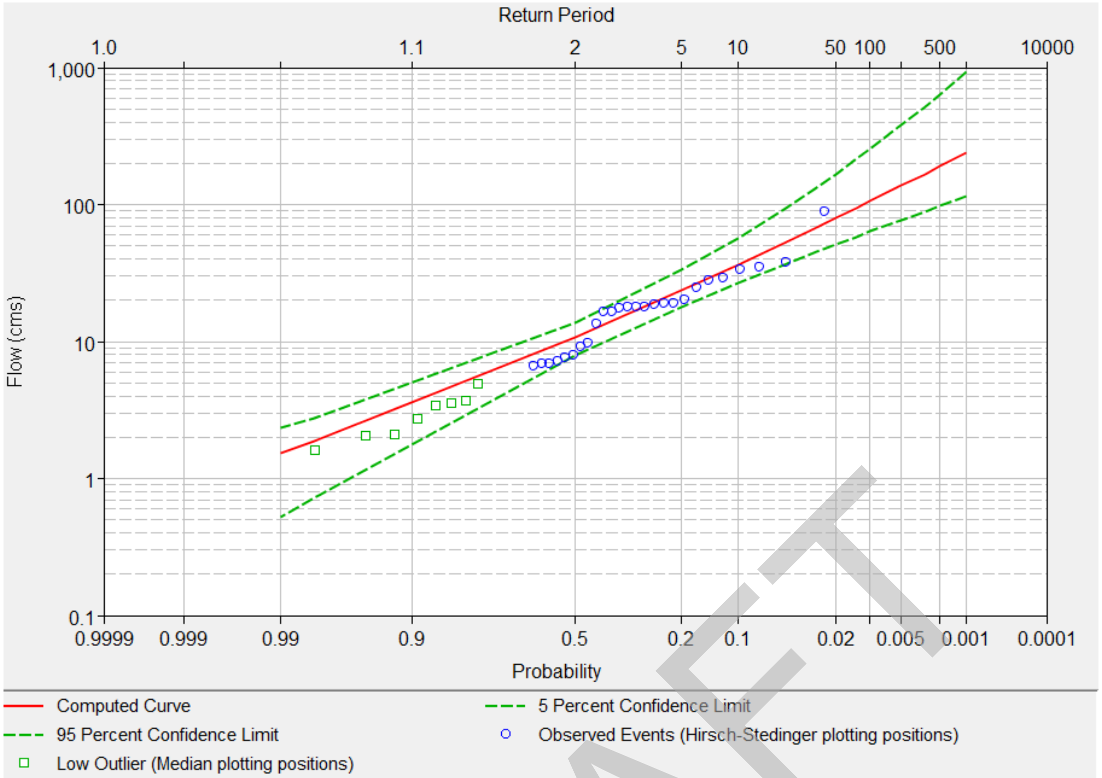


Figure 3-16 Bulletin 17C Flood Frequency Analysis Result for Lloyd Creek near Bluffton (05CC009)

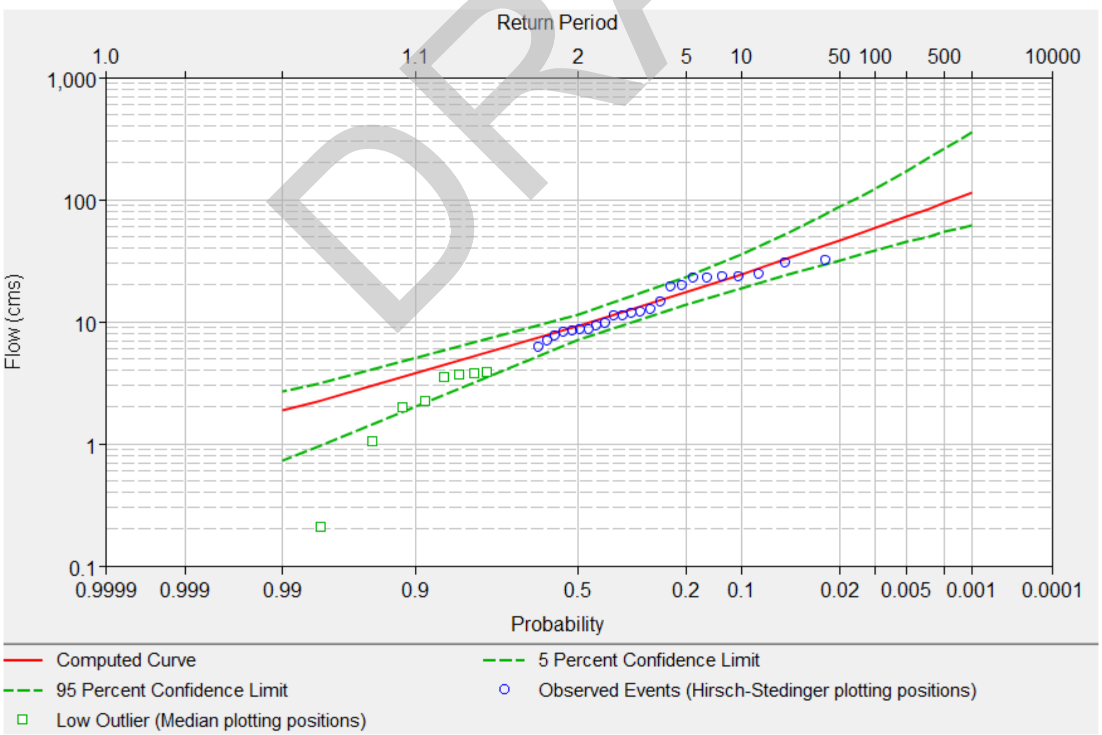


Figure 3-17 Bulletin 17C Flood Frequency Analysis Result for Waskasoo Creek at Red Deer (05CC011)

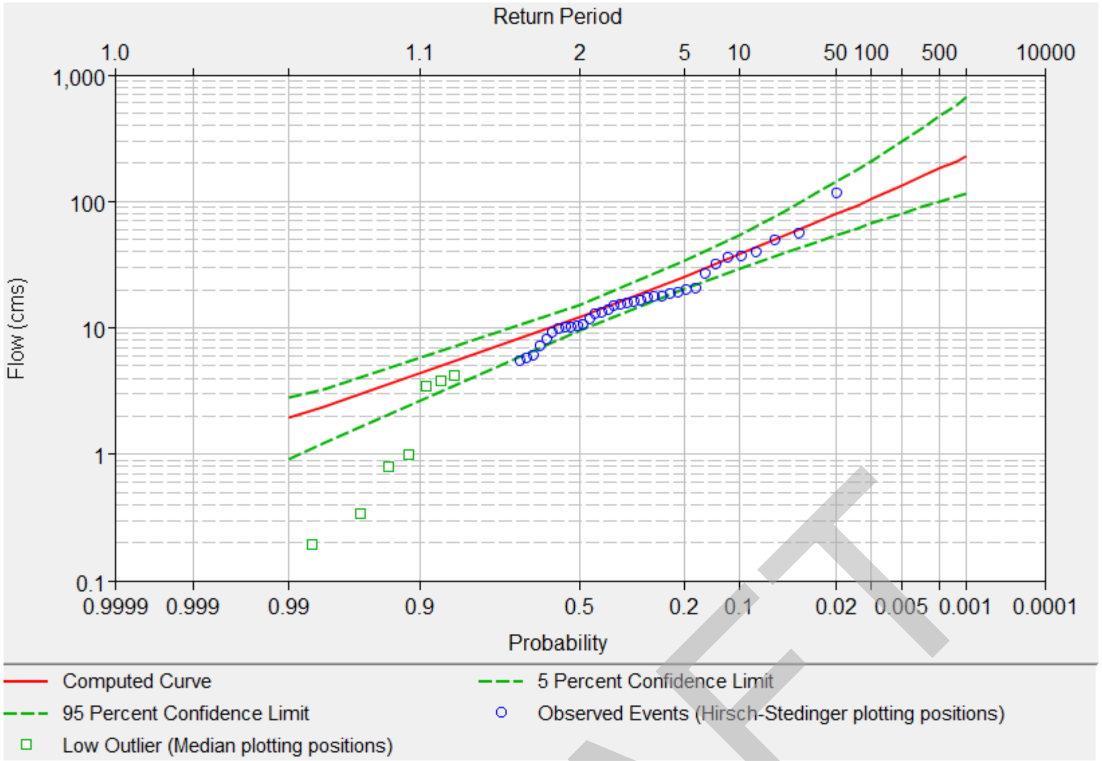


Figure 3-18 Bulletin 17C Flood Frequency Analysis Result for Whitemud Creek near Ellerslie (05DF006)

The general frequency analysis tool in HEC-SSP was also used to compare different distributions with the Bulletin 17C EMA method. This tool allows to analyze flood flow frequency using various distribution methods. The tested distributions were Generalized Extreme Value, Generalized Pareto, Gamma, Normal, Lognormal, Pearson Type III, Log-Pearson Type III, Generalized Logistic, and Empirical. For most gauges tested, Lognormal, Log-Pearson Type III and Empirical were not suitable distributions, i.e., they did not pass the statistical tests. Table 3-2 lists the calculated Kolmogorov-Smirnov (K-S) and Chi-Square test results for the best-fitted probability distributions. The Chi-Square and K-S test values show that all the listed distributions pass both tests at 5-percent and 1-percent significant levels, respectively.

Table 3-2 Statistical Tests Results for Generalized Frequency Analysis Methods

WSC Gauge Station Name	Station ID	Fitted Distribution	K-S	Chi-Square
West Whitemud Creek near Ireton	05DF007	Generalized Pareto	0.094	6.4
Block Creek near Leedale	05CC010	Gamma	0.186	11.9
Maskwa Creek No. 1 above Bearhills Lake	05FA014	Generalized Extreme Value	0.168	25.6
Haynes Creek near Haynes	05CD006	Gamma	0.124	4.4
Bigknife Creek near Gadsby	05FC002	Generalized Extreme Value	0.107	23.2
Lloyd Creek near Bluffton	05CC009	Generalized Extreme Value	0.127	20.0
Waskasoo Creek at Red Deer	05CC011	Generalized Pareto	0.096	4.8
Whitemud Creek near Ellerslie	05DF006	Generalized Pareto	0.107	9.6

Figure B-1 through Figure B-8 in Attachment B show the result of generalized frequency analysis for flood flows of selected WSC gauge stations with the best-fitted distributions as listed in Table 3-2. The fitted frequency curve of all WSC stations mainly followed low values. This shows that the extreme quantiles in the upper tail of the frequency curve are greatly affected since the methods do not incorporate a low outlier test method, as was incorporated in the Bulletin 17C EMA method.

By visualizing fitted functions in Attachment B and listed in Table 3-2 and comparing them to the Bulletin 17C EMA results (Figure 3-11 through Figure 3-18), it appears that the log-Pearson Type III with EMA is more appropriate for the selected gauges. In addition, the Bulletin 17C estimated flood flows with the 1:100 AEP were larger than those simulated by the probability distributions listed in Table 3-2. Therefore, the results of Bulletin 17C were used for regional flood frequency analysis.

To complete the flood frequency analyses, the records labeled as ice-effected were eliminated from the datasets and the flood frequency analysis was repeated using the Bulletin 17C EMA method. The results showed a decrease or increase of 0 to 5 percent for all AEPs at 7 of 8 streamflow gauges. The only gauge with a change of more than 5 percent was Bigknife Creek near Gadsby. In fact, a 6 to 9 percent reduction was estimated for flows with AEPs smaller than 1:75. By adding the ice-effected records back to the dataset and applying the perception thresholds to those records, the change dropped to about 2 percent. Therefore, the original analysis was assumed to be suitable for regional flood frequency analysis.

3.3 Regression Analysis

After flood frequency analyses of eight selected WSC gauge stations were completed, regression analyses were performed to estimate the flood flows with the selected AEPs mentioned in Section 1.2. The magnitude of flood flows with the 13 AEPs at the eight WSC gauges are listed in Table 3-3. R statistical programming software was used to perform multilinear regression analysis. Watershed characteristics, which were the gross watershed area, effective watershed area, average basin slope, average slope and length of the main stem of the creek, and storage areas (i.e., ponds and lakes), were used as predictors and tested for whether they were statistically significant in regression analyses. For instance, if the p-value of the predictor was higher than 0.05 (α, significant level), it meant the predictor was not significant and, in turn, not related to the flood flows (dependent variable). It was determined that the average slope and length of the creek's main stem were insignificant in any of the regression analyses. Storage areas (surface areas of ponds and lakes) were significant in some, but not all, regression analyses. The average basin slope and storage area were not significant for lower return periods (up to 1:20 AEPs), but gross and effective watershed areas were significant in regression analyses of all AEPs.

Table 3-3 Magnitude of 13 Flood Frequency Floods at the Eight WSC Gauges

Parameters	West Whitemud Creek	Block Creek	Maskwa Creek	Haynes Creek	Bigknife Creek	Lloyd Creek	Waskasoo Creek	Whitemud Creek
Effective Watershed Area (km^2)	53.2	56.6	61.2	165.0	194.0	239.0	250.0	301.0
Average Basin Slope (%)	0.99	6.32	1.52	2.59	1.25	3.02	2.34	1.18
AEP	Peak Flows (m^3/s)							
1:2	2.2	2.7	1.2	2.3	6.4	10.8	9.2	12.1
1:5	4.3	6.4	2.2	6.2	11.5	23.6	17.3	25.4
1:10	6.1	10.2	3.1	10.6	15.9	36.2	24.5	38.0
1:20	8.2	15.1	4.2	16.6	20.9	52.1	32.9	53.6
1:35	10.2	20.0	5.2	23	25.5	67.7	40.6	68.5
1:50	11.6	23.7	5.9	27.9	28.6	79.2	46.1	79.5
1:75	13.3	28.5	6.8	34.5	32.6	94	53.0	93.3
1:100	14.6	32.3	7.5	39.7	35.5	105.4	58.1	104
1:200	18.2	43.0	9.3	55.2	43.4	137.4	72.1	133.5
1:350	21.4	53.3	10.9	70.5	50.3	167.4	84.6	160.8
1:500	23.8	61.3	12.1	82.8	55.5	190.6	94.0	181.7
1:750	26.9	71.8	13.6	99.3	61.9	220.6	105.8	208.5
1:1,000	28.9	78.9	14.6	110.6	66.1	240.6	113.5	226.3

The multilinear regression analyses were completed using the logarithm base 10 of the data. Therefore, Equation 3-1 presents the final form of regional flood frequency flow equations.

$$Q_T = a.\, X_1^{b}\, X_2^{c}\, X_3^{d} \qquad \text{Equation 3-1}$$

In Equation 3-1, Q_T was flow in cubic meters per second (m^3/s) with the subscript T being the return period of the flood. X_1, X_2, and X_3 were the watershed parameters (e.g., gross watershed area, effective watershed area, and average basin slope), and *a*, *b*, *c*, and *d* were the regression parameters. After numerous iterations, it was determined that using both the gross and the effective watershed area has the danger of deriving a regression equation with a high goodness of fit but physically meaningless. The effective watershed area was the main predictor, with a p-value of less than 0.05. In some cases, the p-value for the average basin slope was larger than 0.05, but it was evident that the average basin slope would improve the regression model's goodness of fit. As a result, the regional equations for different AEPs included effective watershed area and average basin slope. In the final analysis, the data from Waskasoo Creek at Red Deer (05CC011) and West Whitemud near Ireton (05DF007) were eliminated, which significantly improved the results. It is likely that the soil types in the Waskasoo Creek watershed were different with significantly higher infiltration rates than the other watersheds listed in Table 3-3, and/or a significantly longer time of concentration due to a larger watershed size, and therefore, the calculated peak flows were not in agreement with the other watersheds in Table 3-3. West Whitemud Creek near Ireton peak flow data was not in agreement with the other watersheds listed in Table 3-3 and this could be due to error in the watershed area and/or the estimated average basin slope due to the resolution of the DEM. Block Creek near Leedale appeared to be different from the other watersheds listed in Table 3-3, because most of the annual peak flows in its record occurred during warm seasons unlike the other streams. However, the characteristics of peak flows with different AEPs were in agreement with the other creeks and by eliminating Block Creek from the dataset, the adjusted R^2 of Equation 3-1 improved very slightly. Therefore, Block Creek was used in the regression analyses, and as discussed in Section 3.4, it was re-evaluated to determine the impacts of Block Creek on the estimated flows in Wolf Creek.

Table 3-4 lists the parameters and the adjusted R^2 of Equation 3-1 for each flood frequency. Note that the adjusted R^2 is between 0.8 and 0.9 for AEPs smaller than 1:20.

Table 3-4 Parameters of the Final Multilinear Regression Analysis

AEP	Multilinear Regression Parameters			Adjusted R-Square
	a	*b* X_1 = Effective Area	*c* X_2 = Basin Slope	
1:2	0.0064	1.262	0.339	0.602
1:5	0.0072	1.358	0.544	0.727
1:10	0.0080	1.404	0.647	0.783
1:20	0.0091	1.437	0.727	0.819
1:35	0.0098	1.464	0.787	0.843
1:50	0.0102	1.480	0.824	0.854
1:75	0.0109	1.496	0.862	0.866
1:100	0.0114	1.505	0.887	0.871
1:200	0.0123	1.532	0.948	0.885
1:350	0.0129	1.553	0.995	0.891
1:500	0.0134	1.567	1.025	0.895
1:750	0.0139	1.583	1.060	0.898
1:1,000	0.0142	1.592	1.080	0.899

3.4 Flood Frequency Estimates for Wolf Creek and Tributaries

The results of the multilinear regression analyses were used to estimate flood flows with 13 AEPs at 11 flow change locations along Wolf Creek and its tributaries. These flow change locations were selected to provide inflows to the coupled 1D/2D HEC-RAS model for flood mapping of the study area. With a gross watershed area of about 125 km^2, the number of sub-watersheds selected for Wolf Creek is high. Note that in a coupled 1D/2D model, the continuity requirements should be satisfied by adding additional inflows to the downstream subwatersheds. These inflows will be applied to certain locations in the floodplain area using the topography and drainage patterns. If the magnitude of an inflow is too large in a location, the area around the inflow point in the floodplain will be inundated because of an unrealistic volume rate of inflow and not necessarily due to the backwater effects of flooding in the main stem of a stream. Therefore, the number of subwatersheds was increased to minimize unrealistic localized flooding. An alternative would be adding the inflows at cross sections in the 1D areas.

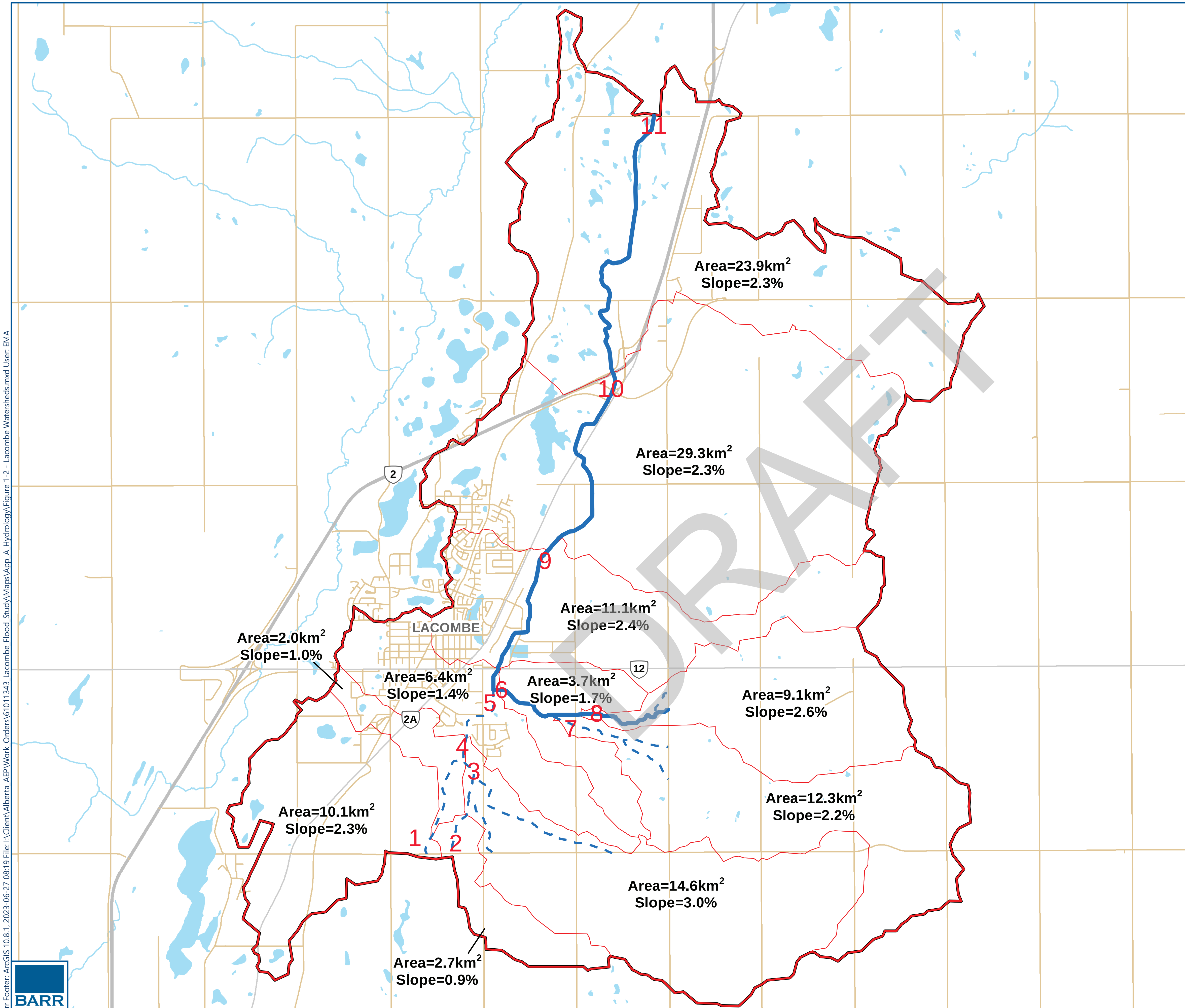
Table 3-5 lists the watershed parameters for the 11 flow change locations (or reaches) in the study area. Note that the numbers shown in Table 3-5 include the characteristics of the entire watershed area upstream of the flow change location. For example, Location 4 includes subwatershed areas 1, 2, and 4; Location 6 includes subwatershed areas of 7, 8, and 6; and Location 11 includes the entire watershed area of the Lacombe flood study.

Table 3-5 Watershed Characteristics for Multilinear Regression

Watershed Outlet	Subwatershed	Subwatershed Effective Area (Km^2)	Reach No.	Effective Watershed Area (Km^2)	Average Basin Slope (%)
1	SW1	2.67	R1	2.67	0.88
2	SW2	1.53	R2	1.53	2.30
3	SW3	14.58	R3	14.58	3.00
4	SW4	1.27	R4	5.47	1.87
5	SW5	3.91	R5	23.96	2.25
6	SW6	3.74	R6	25.01	2.30
7	SW7	12.18	R7	12.18	2.23
8	SW8	9.08	R8	9.08	2.65
9	SW9	8.7	R9	57.66	2.29
10	SW10	23.94	R10	81.60	2.29
11	SW11	15.82	R11	97.42	2.30

Figure 3-19 shows where these flows will be applied on Wolf Creek. The red numbers in Figure 3-19 show the outlets where the calculations have been completed. Figure 3-20 shows the reaches where the estimated flows will be applied on Wolf Creek and its tributaries. The reaches are labeled with the letter R and the flow change location number, e.g., R5, R9, etc. In Figure 3-20, the gross and effective drainage areas of the subwatersheds are also displayed. Figure 3-20 shows the relative magnitudes of flows to be used in the coupled 1D/2D model of Lacombe flood study. In Figure 3-20, reaches R1 and R2 are eliminated and only reaches R4 and R3 are shown (see Figure 3-19). In addition, the light blue/green arrows show the possible locations of inflows to be added to the hydraulic model to satisfy continuity. The locations of arrows will be investigated during hydraulic modelling to determine if they should be applied at the edge of the 2D areas or at certain cross sections in 1D areas.

The results of the flood frequency equations applied to the Wolf Creek reaches are listed in Table 3-6. The 1:100 AEP flood flow at R10, i.e., on Wolf Creek at Highway 2, is estimated to be 17.9 m^3/s. Overall, the flood flows at R1 and R2 for all AEPs are very small and could be eliminated for hydraulic modelling. During the site visit on June 13, 2023, no creek could be identified for the outflows from subwatersheds 1 and 2 (labeled as SW1 and SW2 in Figure 3-20). It is very likely that the estimated flows at R1, R2 and even R4 are not accurate because the drainage areas are significantly smaller than the data used for the development of Equation 3-1 parameters. However, the flows from subwatershed SW3 is significantly large enough that flooding along the creek in subwatershed SW4 will be the result of backwater when subwatershed SW3 discharges into the creek of subwatershed SW4.



LEGEND

- LACOMBE FLOOD STUDY WATERSHED
- SUBWATERSHED
- WOLF CREEK
- TRIBUTARIES
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERBODY
- WATERCOURSE

N

0 1 2
KILOMETRES

REFERENCES
ROADS AND HYDROGRAPHY OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
DATUM: NAD 83 CSRS PROJECTION: 3TM 114

NOTE
1. SUBWATERSHEDS WERE DELINEATED BASED ON A 25-METRE ALTALIS DEM SOURCED BY THE AEPA.

Alberta
Canada

FLOW LOCATIONS
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 3-19

Barr Footer: ArcGIS 10.8.1, 2023-06-27 08:19 File: I:\Client\Alberta_AEP\Work Orders\61011343_Lacombe_Flood_Study\Maps\App_A_Hydrology\Figure 1-2 - Lacombe Watersheds.mxd User: EMA

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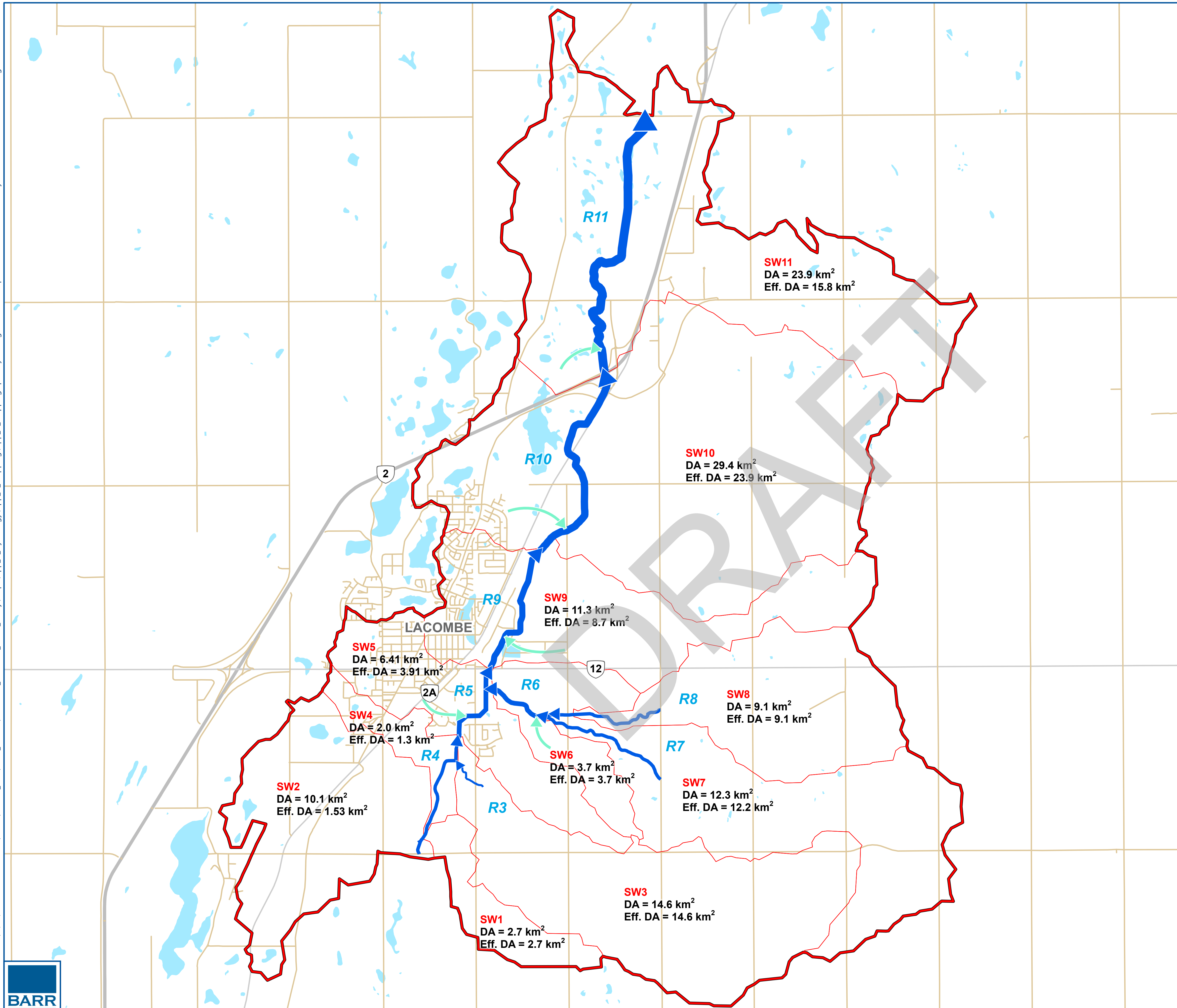
Classification: Public



LEGEND

- LACOMBE FLOOD STUDY WATERSHED
- SUBWATERSHED
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERBODY

N

0 1 2

KILOMETRES

REFERENCES

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Alberta

Canada

PROPOSED LACOMBE FLOOD STUDY
FLOW LOCATIONS AND FLOW CHANGES
LACOMBE FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 3-20

BARR

Table 3-6 Flood Frequency Estimates in m³/s along Different Reaches of Wolf Creek and Its Tributaries

AEP	Reaches Along Wolf Creek and Its Tributaries										
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
1:2	0.02	0.01	0.27	0.07	0.46	0.49	0.20	0.14	1.41	2.19	2.74
1:5	0.03	0.02	0.50	0.10	0.84	0.90	0.33	0.24	2.78	4.46	5.68
1:10	0.03	0.02	0.70	0.13	1.17	1.26	0.45	0.33	4.06	6.61	8.50
1:20	0.03	0.03	0.95	0.16	1.58	1.70	0.59	0.44	5.64	9.28	12.01
1:35	0.04	0.04	1.18	0.19	1.94	2.10	0.72	0.53	7.12	11.83	15.39
1:50	0.04	0.04	1.33	0.21	2.19	2.38	0.80	0.60	8.15	13.63	17.78
1:75	0.04	0.04	1.55	0.24	2.54	2.76	0.92	0.68	9.59	16.12	21.10
1:100	0.04	0.05	1.70	0.26	2.79	3.03	1.00	0.75	10.62	17.91	23.48
1:200	0.05	0.05	2.11	0.30	3.44	3.76	1.21	0.91	13.45	22.89	30.16
1:350	0.05	0.06	2.47	0.34	4.01	4.38	1.39	1.05	15.97	27.38	36.21
1:500	0.05	0.06	2.75	0.36	4.46	4.88	1.53	1.15	18.00	31.01	41.12
1:750	0.06	0.07	3.10	0.40	5.01	5.49	1.70	1.28	20.51	35.53	47.26
1:1,000	0.06	0.07	3.31	0.42	5.36	5.87	1.81	1.36	22.09	38.40	51.15

As stated in Section 3.3, the Block Creek data seemed to be different from the other gauges used for the regional frequency analysis. Therefore, the regression analysis was recomputed by eliminating the Block Creek data and the flows were recalculated along different reaches in the study area. The results showed more than 20-percent reduction in the estimated peak flows and as high as 50-percent reduction during large AEP events. It is important to note that the study area is climatologically in a semi-arid region, and therefore, the winter precipitation events and resulting snowpack do not result in significantly larger cool-season events than warm-season events; or the records are too short to separate warm-season records from the cool-season record for flood frequency analysis. Therefore, the Block Creek data was included in the regression analysis and the values listed in Table 3-6 currently appear to be the best estimates for the Wolf Creek reaches and the tributaries in the study area.

3.5 Comparison to Previous Studies

The results of this study are significantly smaller than the 1992 study for Wolf Creek at Highway 2 and about 50% of those obtained in the 1996 study. However, the results are in good agreement with the 2014 study.

To better understand the difference between the current study and the 1996 study, we estimated the flows of reach R10 with all AEPs using the 1996 method. Table 3-7 lists the results of the two methods for reach R10. Note that the 1992/1996 method uses the mean annual flows with a simple linear scaling. The difference between 1996 and 1992, as stated in the 1996 report, was in accounting for the effects of storage. Equation 3-2 provides the method used in the 1992/1996 method.

$$Q_T = A_{10}\left[\frac{1}{n}\sum\frac{Q_{T_i}}{Q_{m_i}}\right]\left[\frac{1}{n}\sum\frac{Q_{m_i}}{A_i}\right] \quad \text{Equation 3-2}$$

In Equation 3-2, A_{10} is the watershed area of Location 10 (red label in Figure 3-19), n is the number of the WSC gauges used for the regional frequency flood analysis, Q_m is the mean annual flow, and i is the subscript defining the WSC gauges and changes from 1 to n. The two brackets in Equation 3-2 are average values of the ratio of flood frequency estimates to mean annual flows and the ratio of mean annual flows to the effective watershed areas. In Equation 3-2, it appears that mean annual flow could be eliminated, but because it has been used for averaging the data obtained from the WSC gauges, it influences the results. In addition, Equation 3-2 uses a simple scaling of flood flows to estimate the flood flows at Wolf Creek. In general, there are two problems with Equation 3-2. First, it incorporates the mean annual flow, i.e., average flow conditions. Therefore, if a stream exhibits a significant base flow or nearly no base flow, it will affect transferring the flood frequency estimate to the ungauged streams. Second, it assumes that a linear extrapolation is appropriate, while no statistics were provided to show that a linear relationship with the gross watershed area or the effective watershed area could be justified. As a result, we recommend using the flood flows obtained from the regression analysis among the selected gauges. It is important to note that this study's results agree with the 2014 study, even though the regression analyses completed in 2014 used the watershed areas as the sole predictor, with a nonlinear relationship between flood frequency estimates and watershed areas.

Table 3-7 Estimated Flood flows at Location 10 in m³/s for Selected AEPs Using the Current Method, Using the 1992/1996 Method, and the 1996 Estimates

AEP	Regression Method	1992/1996 Method	1996 Estimates
1:2	2.19	4.38	7.6
1:5	4.46	8.73	-
1:10	6.61	12.74	18.9
1:20	9.28	17.60	-
1:35	11.83	22.24	-
1:50	13.63	25.59	30.6
1:75	16.12	29.83	-
1:100	17.91	33.08	36.4
1:200	22.89	42.05	-
1:350	27.38	50.29	-
1:500	31.01	56.57	-
1:750	35.53	64.64	-
1:1,000	38.40	69.99	-

Note: In the 1996 Flood Risk Mapping Study, flows were estimated only for the 1:2, 1:10, 1:50 and 1:100 AEP events (last column)

3.6 Recommended Flows to Be Used in Hydraulic Model

While the computed peak flows of different flood frequencies listed in Table 3-6 appear to be reasonable estimates of different reaches of Wolf Creek and its tributaries in the study area, the estimated values appear to be too small for more frequent flood events, e.g., 1:2 and 1:5 AEP events, for hydraulic modelling of some of the tributaries and reaches of Wolf Creek. The Wolf Creek hydraulic model is a coupled 1D/2D model which is run as a quasi-steady state model. Very small flows in some of the upstream reaches and tributaries may result in numerical instability of the model solution or no solution. To overcome this potential problem in hydraulic modelling and flood mapping of Lacombe, it is recommended to revise the values of reaches R1 through R8, based on the ratio of effective drainage area of each reach to the effective drainage area of reach R9. The results are tabulated in Table 3-8. The values of reaches R9 through R11 are the same as those in Table 3-6. However, there are significant changes in estimated values of reaches R1 through R8 as compared to those in Table 3-6, e.g., the estimated peak flow for reach R4 during the 1:2 AEP event is almost doubled, and for the 1:50 AEP event is quadrupled. The level of increase in the estimated flows is not the same for all reaches, e.g., the estimated flow for reach R5 for the 1:2 AEP event is about 30% higher than the value in Table 3-6. Given the very small flows for reaches R1 and R2 and lack of presence of a defined channel, it is recommended not to model reaches R1 and R2 and start the hydraulic modelling and flood mapping from reach R4.

Table 3-8 Recommended Flood Frequency Estimates in m³/s along Different Reaches of Wolf Creek and Its Tributaries

AEP	Reaches Along Wolf Creek and Its Tributaries										
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
1:2	0.07	0.04	0.36	0.13	0.59	0.61	0.30	0.22	1.41	2.19	2.74
1:5	0.13	0.07	0.70	0.26	1.16	1.21	0.59	0.44	2.78	4.46	5.68
1:10	0.19	0.11	1.03	0.38	1.69	1.76	0.86	0.64	4.06	6.61	8.50
1:20	0.26	0.15	1.43	0.53	2.34	2.44	1.19	0.89	5.64	9.28	12.01
1:35	0.33	0.19	1.80	0.68	2.96	3.09	1.50	1.12	7.12	11.83	15.39
1:50	0.38	0.22	2.06	0.77	3.39	3.53	1.72	1.28	8.15	13.63	17.78
1:75	0.44	0.25	2.43	0.91	3.99	4.16	2.03	1.51	9.59	16.12	21.10
1:100	0.49	0.28	2.69	1.01	4.41	4.61	2.24	1.67	10.62	17.91	23.48
1:200	0.62	0.36	3.40	1.28	5.59	5.83	2.84	2.12	13.45	22.89	30.16
1:350	0.74	0.42	4.04	1.51	6.64	6.93	3.37	2.52	15.97	27.38	36.21
1:500	0.83	0.48	4.55	1.71	7.48	7.81	3.80	2.84	18.00	31.01	41.12
1:750	0.95	0.54	5.19	1.95	8.52	8.89	4.33	3.23	20.51	35.53	47.26
1:1,000	1.02	0.59	5.59	2.10	9.18	9.58	4.67	3.48	22.09	38.40	51.15

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

It is anticipated that in the next 76 years, i.e., to the end of the 21st century, the emission of greenhouse gases could impact the climate of Earth and increase warming across our planet. The projected climate change due to greenhouse gas emissions under the different scenarios studied by climate scientists and presented in the Intergovernmental Panel on Climate Change (IPCC) assessment reports appears to increase the annual precipitation globally. It is also anticipated that the increase in warming and, therefore, evaporation from the oceans and transpiration from the canopy over land surfaces would impact the weather patterns and increase the likelihood of extreme precipitation events.

The results of general circulation models (GCMs), e.g., the GCMs used in CMIP5 we reviewed in the past couple of years, and the downscaling methods applied to the GCM's output show about 5 to 30 percent increase in the magnitude of daily storm events with an AEP of 1:100 in the northern US and southern parts of Canada by the end of 21st century. However, the increases in precipitations also depend on the policies to be adopted by the governments across the globe (e.g., the representative concentration pathway [RCP] of 4.5 W/m^2 indicates that emissions would peak around 2040 and then decline; in RCP 8.5, emissions continue to rise throughout the 21st century).

In 2022, the National Oceanic and Atmospheric Administration (NOAA) completed a study on storm frequencies in the northeastern portion of the United States (NOAA 2022). Depending on the downscaling method, it showed a potential increase of 7 to 15 percent under RCP 4.5 and 10 to 25 percent under RCP 8.5. Given the location of Lacombe in Alberta, it is anticipated that climate change could increase the magnitude of the 1:100 AEP storms with a duration of 24 hours by 10 to 20 percent, based on our review of the BCCAQv2 downscaling method applied to the output of eight GCMs. This increase in storm events could increase runoff and flood flows of different AEPs by approximately 10 to 20 percent to the end of the 21st century.

5 Conclusion

A regional flood frequency analysis was completed on eight WSC gauges to estimate the flood flows with AEPs of 1:2, 1:5, 1:10, 1:20, 1:35, 1:50, 1:75, 1:100, 1:200, 1:350, 1:500, 1:750, and 1:1000 along different reaches of Wolf Creek and its tributaries. The regional flood frequency analysis results were used in multilinear regression analyses using the logarithm of the flood frequency estimates, effective watershed areas, and average basin slope. The model results were used to estimate flood flows with AEPs of 1:2 to 1:1000, as listed in Table 3-6. The results were compared to the previous Lacombe flood risk mapping studies in 1992 and 1996 and the Wolf Creek Watershed Plan in 2014, which was commissioned by Lacombe County, City of Lacombe, Ponoka County and Town of Blackfalds. The flood frequency estimates were about 50 percent of those estimated in 1996 but were in general agreement with those estimated in 2014. Given the methodology used in the 1996 study, we propose to use the results of the current study for the hydraulic modelling of the Lacombe Flood Study. Because of the very small flows during more frequent flood events in the upper reaches of Wolf Creek and its tributaries, the flows in reaches R1 through R8 were revised by using the ratio of effective drainage area of the reach to the effective drainage area of reach R9. This approach increased the flood flows with AEPs of 1:2, 1:5, 1:10, 1:20, 1:35, 1:50, 1:75, 1:100, 1:200, 1:350, 1:500, 1:750, and 1:1000 at different reaches of Wolf Creek and its tributaries.

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Attachment A

Table A-1 Annual Maximum Series of the Eight WSC Gauges Used in Flood Frequency Analyses

Year	Peak Flows (m^3/s)							
	West Whitemud Creek	Block Creek	Maskwa Creek	Haynes Creek	Bigknife Creek	Lloyd Creek	Waskasoo Creek	Whitemud Creek
1970					19.3			36.5
1971					14.0			54.9
1972					5.4			17.4
1973					7.9			17.3
1974					41.1			114.0
1975					11.8			10.3
1976					8.5			0.0
1977	3.14	1.68			0.0			0.0
1978	3.77	1.14			5.6			8.1
1979	3.60	1.37	1.28	1.51	4.0			13.8
1980	3.30	6.32	1.06	0.00	3.6			15.8
1981	1.72	3.70	0.00	0.75	0.7	29.2		12.9
1982	6.21	5.15	5.45	6.56	0.0	37.4		48.6
1983	3.64	1.48	1.99	1.27	3.5	0.0		18.2
1984	0.87	0.38	0.00	0.76	0.0	3.5	0.20	0.0
1985	5.75	0.00	2.73	2.99	0.0	0.0	0.00	39.7
1986	1.13	0.00	0.51	0.00	5.8	34.9	0.00	9.8
1987	3.48	0.00	0.00	0.00	9.6	0.0	0.00	0.0
1988	0.49	0.00	0.00	0.00	4.5	6.8	8.57	4.2
1989	6.16	0.00	0.00	3.80	4.3	16.6	0.00	0.0
1990	4.05	17.60	2.20	1.53	13.6	88.8	22.90	10.6
1991	4.02	3.12	1.28	0.60	4.5	27.8	3.47	13.0
1992	0.75	1.19	0.83	2.33	1.7	4.8	3.63	5.7
1993	1.54	4.29	0.64	1.61	6.5	3.7	9.20	6.0
1994	1.58	1.50	0.00	1.56	8.2	6.8	11.62	14.8
1995	0.69	2.98	0.00	0.44	5.3	2.1	6.10	5.4
1996	3.33	5.05	2.23	20.66	8.8	17.7	30.36	16.4
1997	4.85	6.01	1.36	4.61	13.0	17.3	23.12	15.6
1998	4.18	3.26	0.00	0.07	0.0	7.1	2.22	7.1
1999	4.01	19.60	2.73	4.87	10.8	18.9	19.55	19.1
2000	0.28	11.70	0.48	1.57	1.8	17.9	3.86	0.0
2001	1.99	3.50	0.49	0.02	0.0	13.3	1.03	17.5

Year	Peak Flows (m^3/s)							
	West Whitemud Creek	Block Creek	Maskwa Creek	Haynes Creek	Bigknife Creek	Lloyd Creek	Waskasoo Creek	Whitemud Creek
2002	1.12	1.64	1.18	2.02	0.0	3.4	1.98	9.9
2003	3.08	11.10	2.51	8.29	2.2	18.6	19.21	9.2
2004	0.01	0.67	0.15	0.01	0.0	1.6	3.74	0.8
2005	3.55	5.20	2.86	3.91	10.1	17.7	8.38	31.8
2006	1.05	1.00	0.33	4.32	11.9	9.7	11.00	3.4
2007	7.10	18.80	0.74	8.57	22.0	33.3	24.20	35.5
2008	0.00	1.80	0.05	1.52	0.9	2.7	11.90	0.3
2009	0.00	1.63	0.09	0.40	0.1	2.0	6.90	0.2
2010	2.02	5.28	0.54	8.30	12.9	7.6	12.50	3.7
2011	5.40	2.20	2.81	15.19	6.2	24.5	22.77	15.3
2012	0.21	1.31	0.33	2.98	1.2	9.1	7.65	1.0
2013	1.01	4.60	0.95	3.42	7.8	8.0	9.71	10.0
2014	5.46	1.11	1.54	9.55	6.8	18.9	14.40	26.5
2015	1.30	0.00	0.00	0.82	3.1	0.0	8.22	11.5
2016	0.00	0.00	0.00	0.39	1.0	0.0	8.51	0.0
2017	1.79	0.00	0.00	0.00	6.2	0.0	0.00	0.0
2018	3.27	4.82	3.37	14.90	13.9	20.0	31.60	19.6
2019	2.48	1.72	1.6	4.77	5.8	6.5	11.10	20.4
2020	5.94		3.59	9.50		16.3	23.20	
2021	0.24		0.211	0.36				

Attachment B

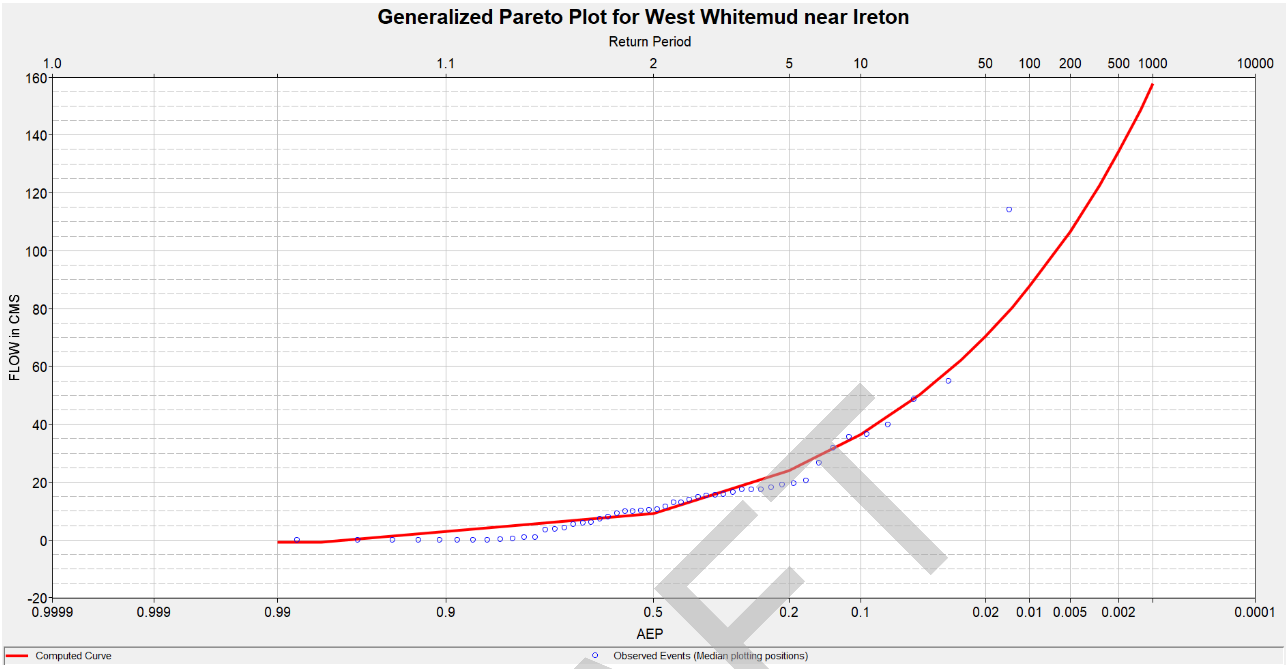


Figure B-1 Generalized Pareto Plot for West Whitemud near Ireton (05DF007)

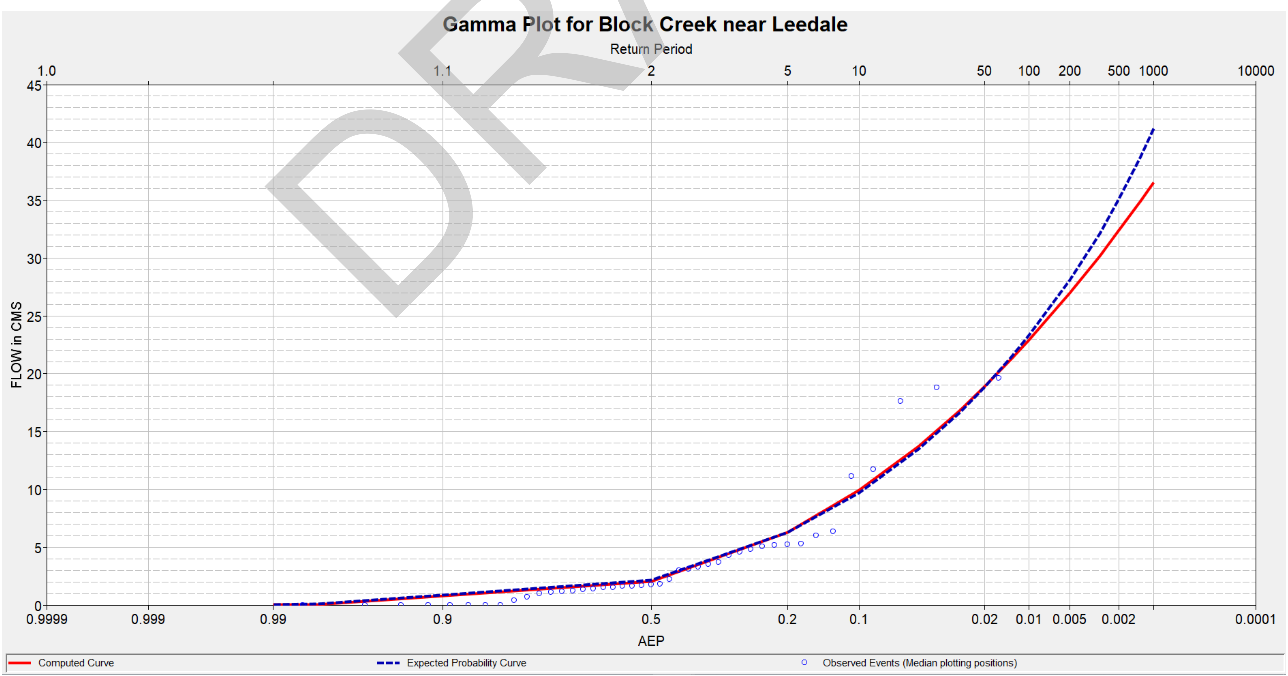


Figure B-2 Gamma Plot for Block Creek near Leedale (05CC010)

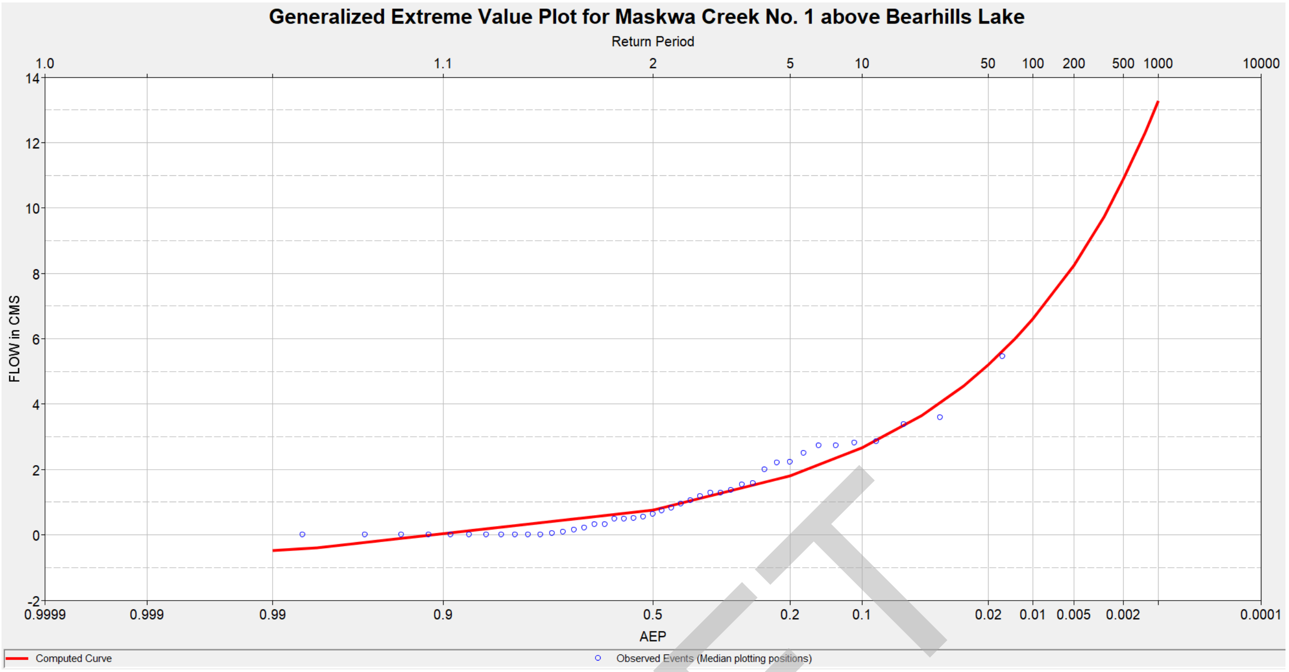


Figure B-3 **Generalized Extreme Value Plot for Maskwa Creek No. 1 above Bearhills Lake (05FA014)**

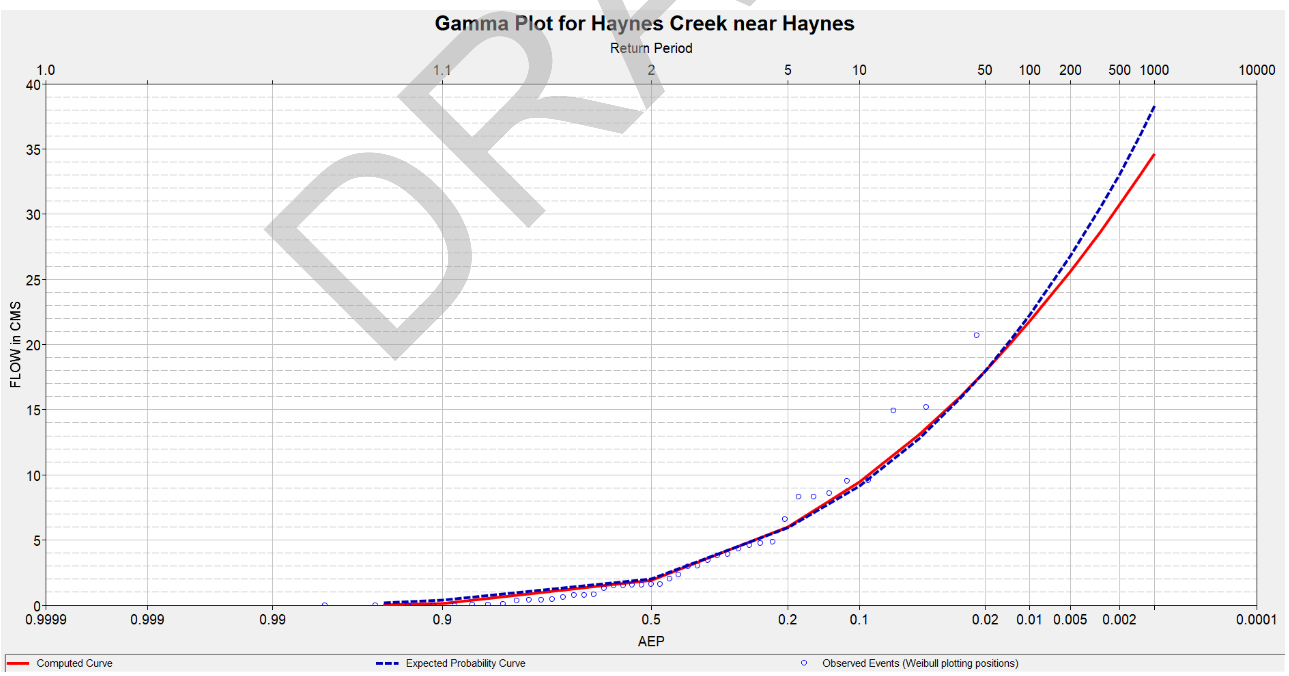


Figure B- 4 **Gamma Plot for Haynes Creek near Haynes (05CD006)**

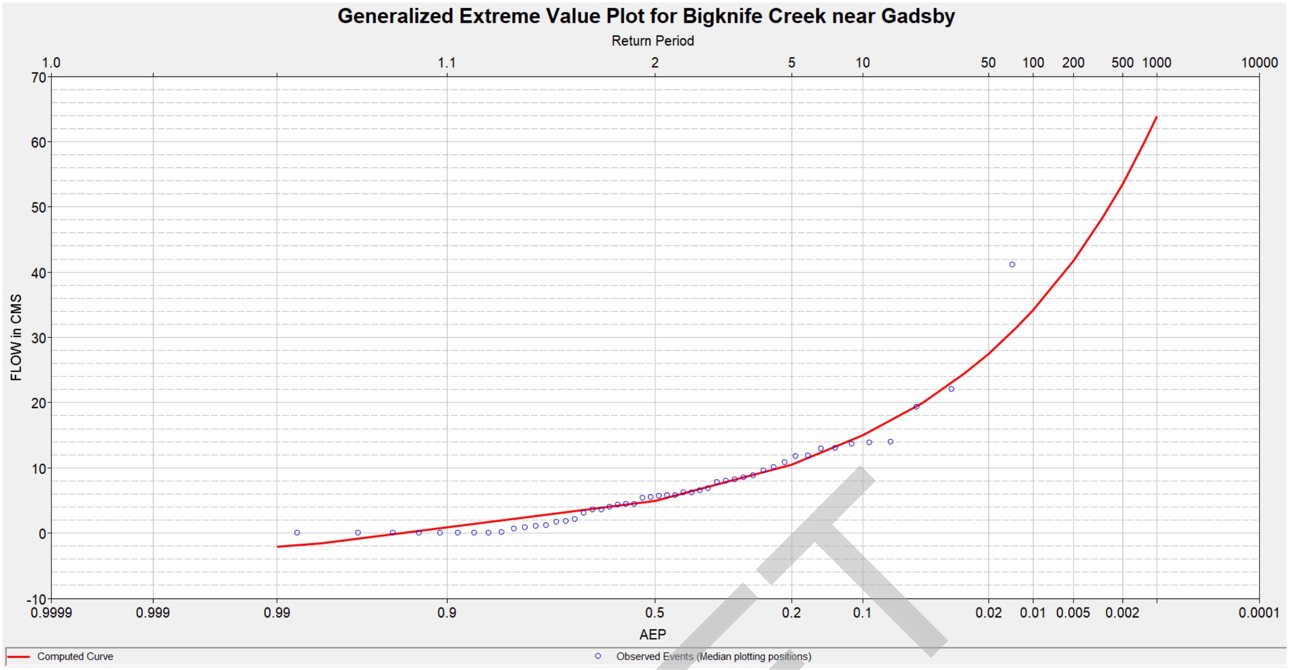


Figure B-5 Generalized Extreme Value Plot for Bigknife Creek near Gadsby (05FC002)

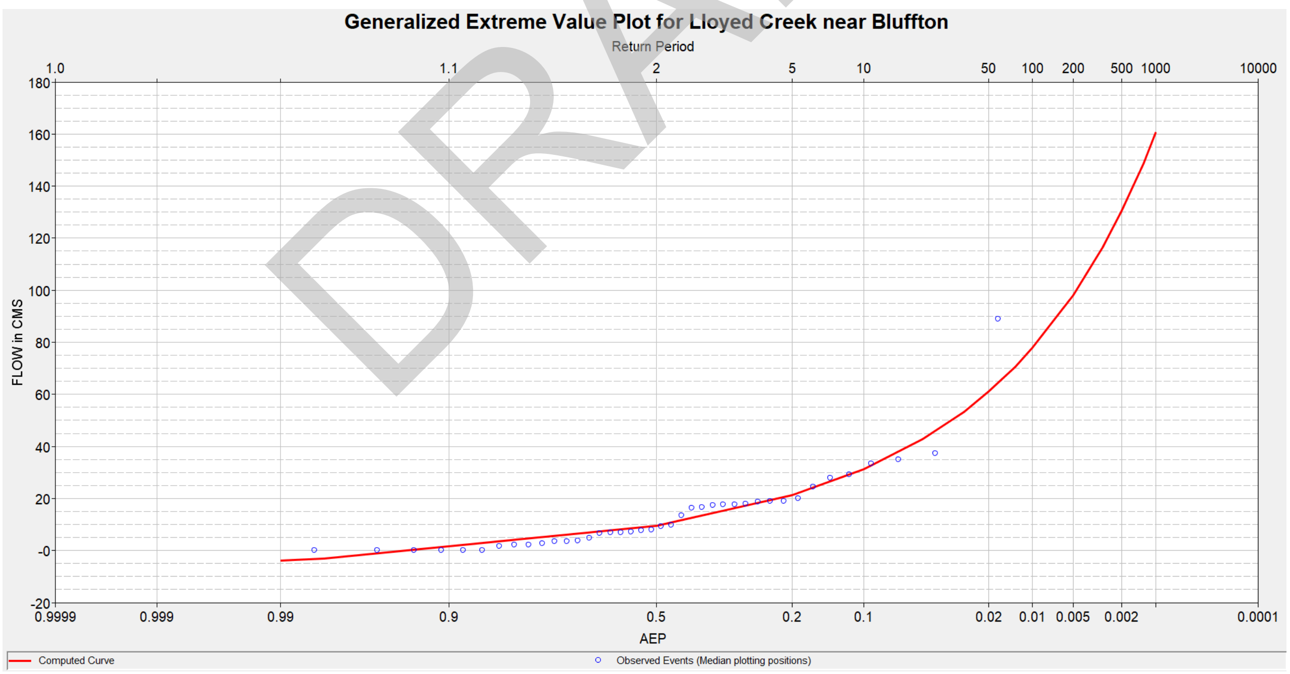


Figure B-6 Generalized Extreme Value Plot for Lloyd Creek near Bluffton (05CC009)

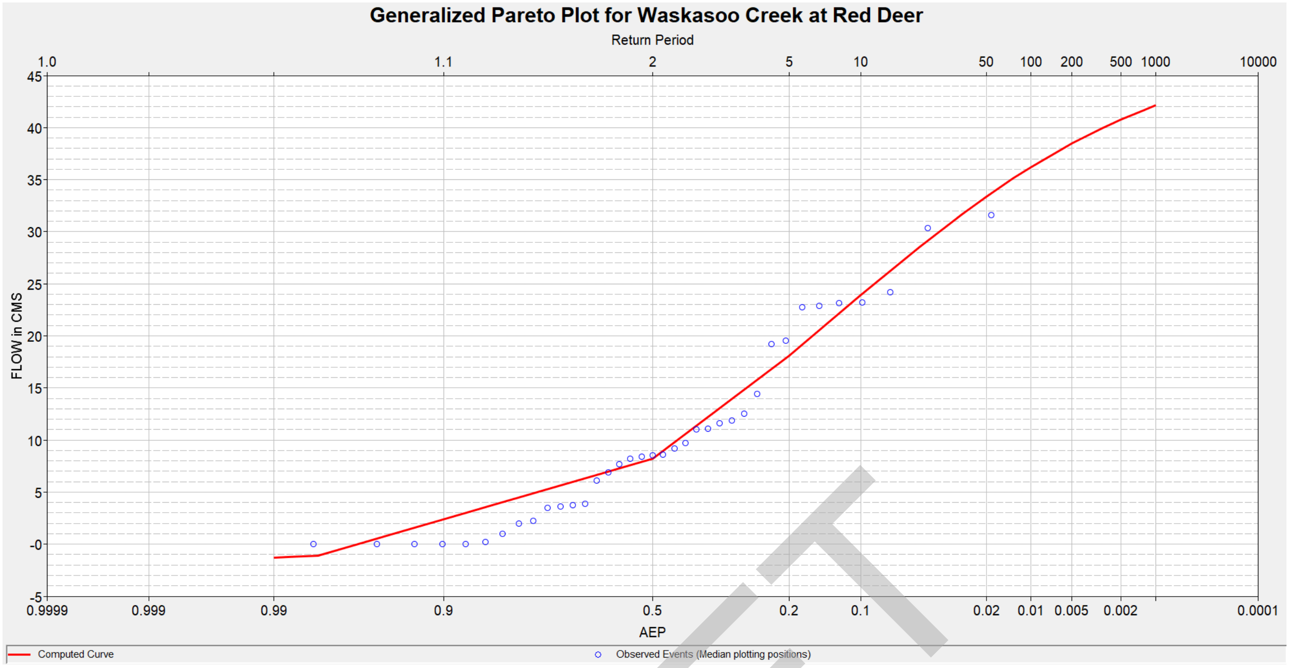


Figure B-7 **Generalized Pareto Plot for Waskasoo Creek at Red Deer (05CC011)**

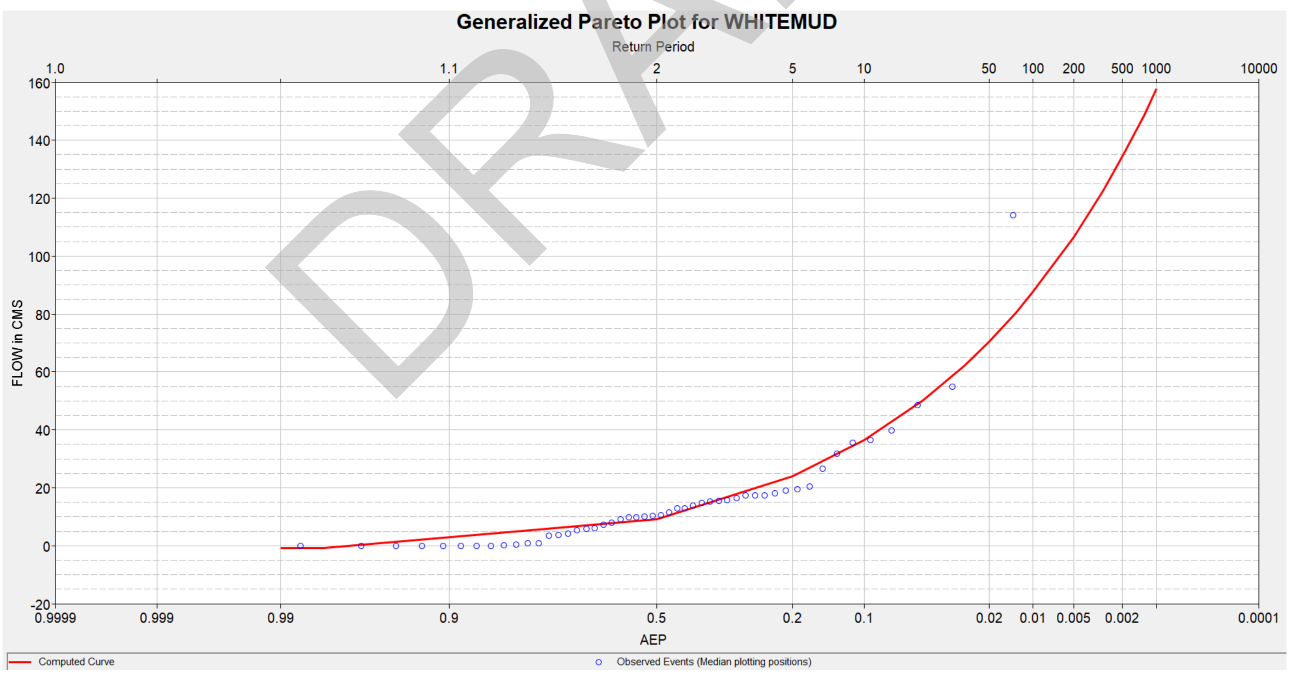


Figure B-8 **Generalized Flood Frequency Analysis Result for Whitemud Creek near Ellerslie (05DF006)**

Appendix F

Open Water Flood Profiles

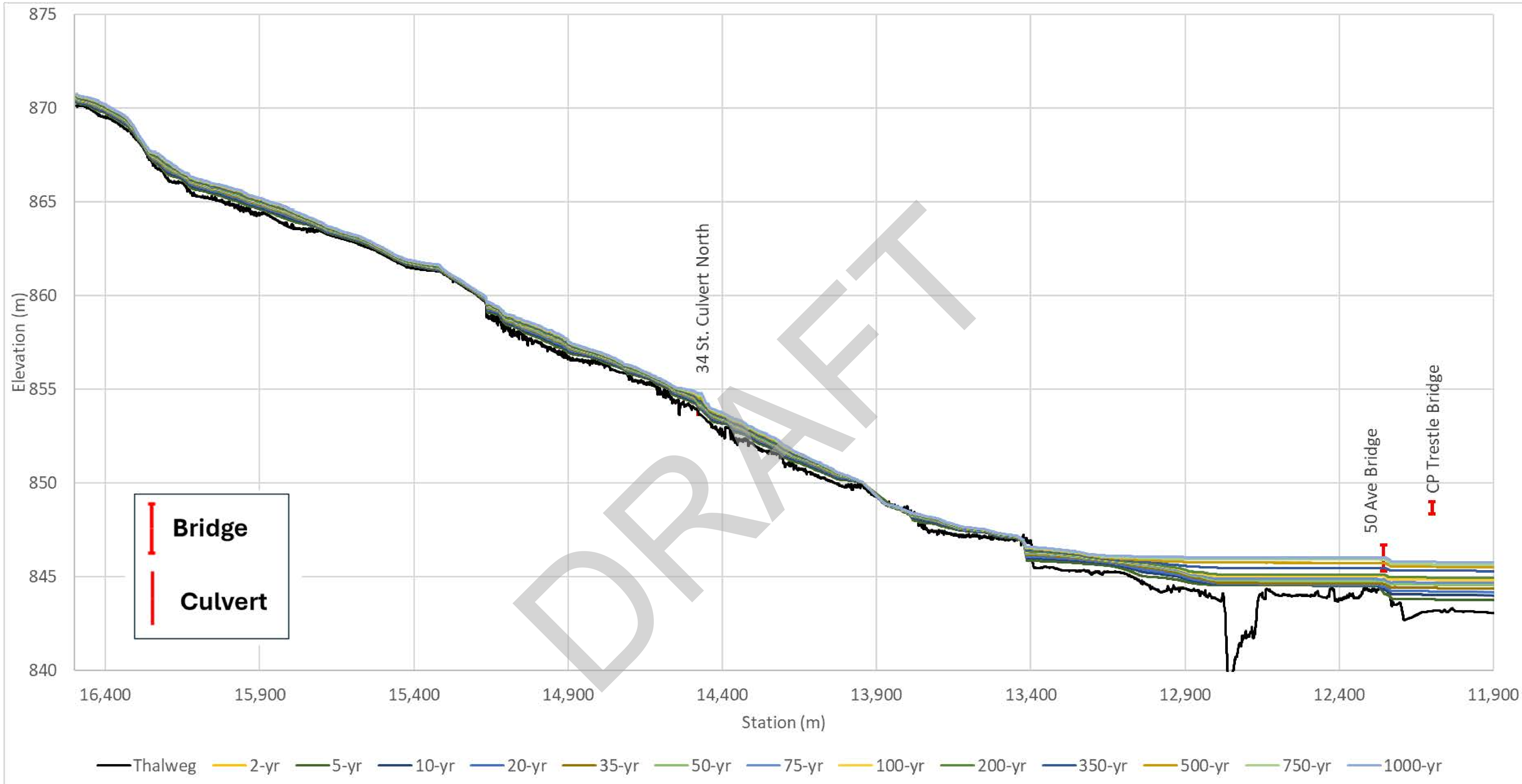


Figure F-1 Simulated Water Surface Profiles Along Upper Wolf Creek (Station 16,500 m to 11,900 m)

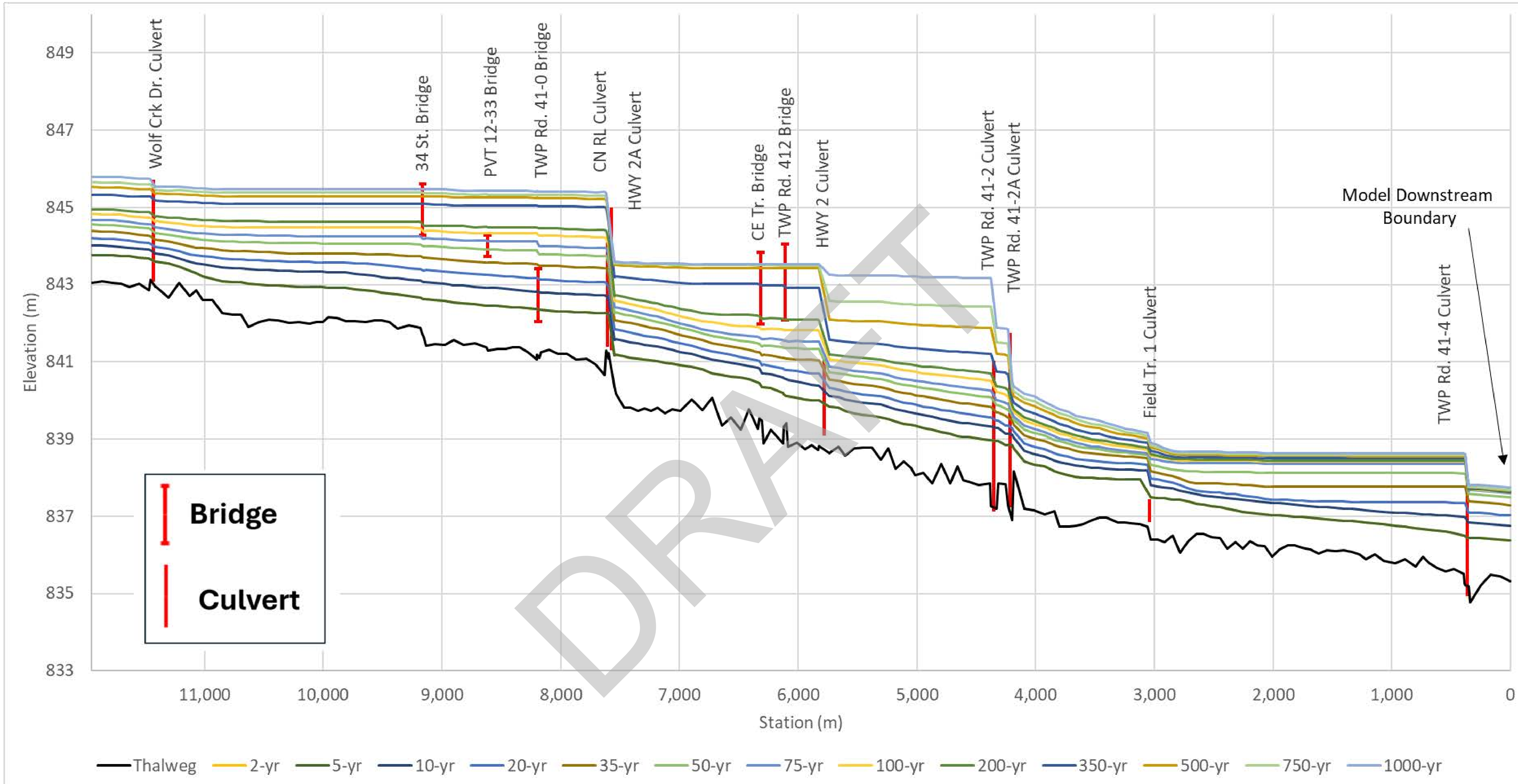


Figure F-2 Simulated Water Surface Profiles Along Lower Wolf Creek (Station 11,900 m to 0 m)

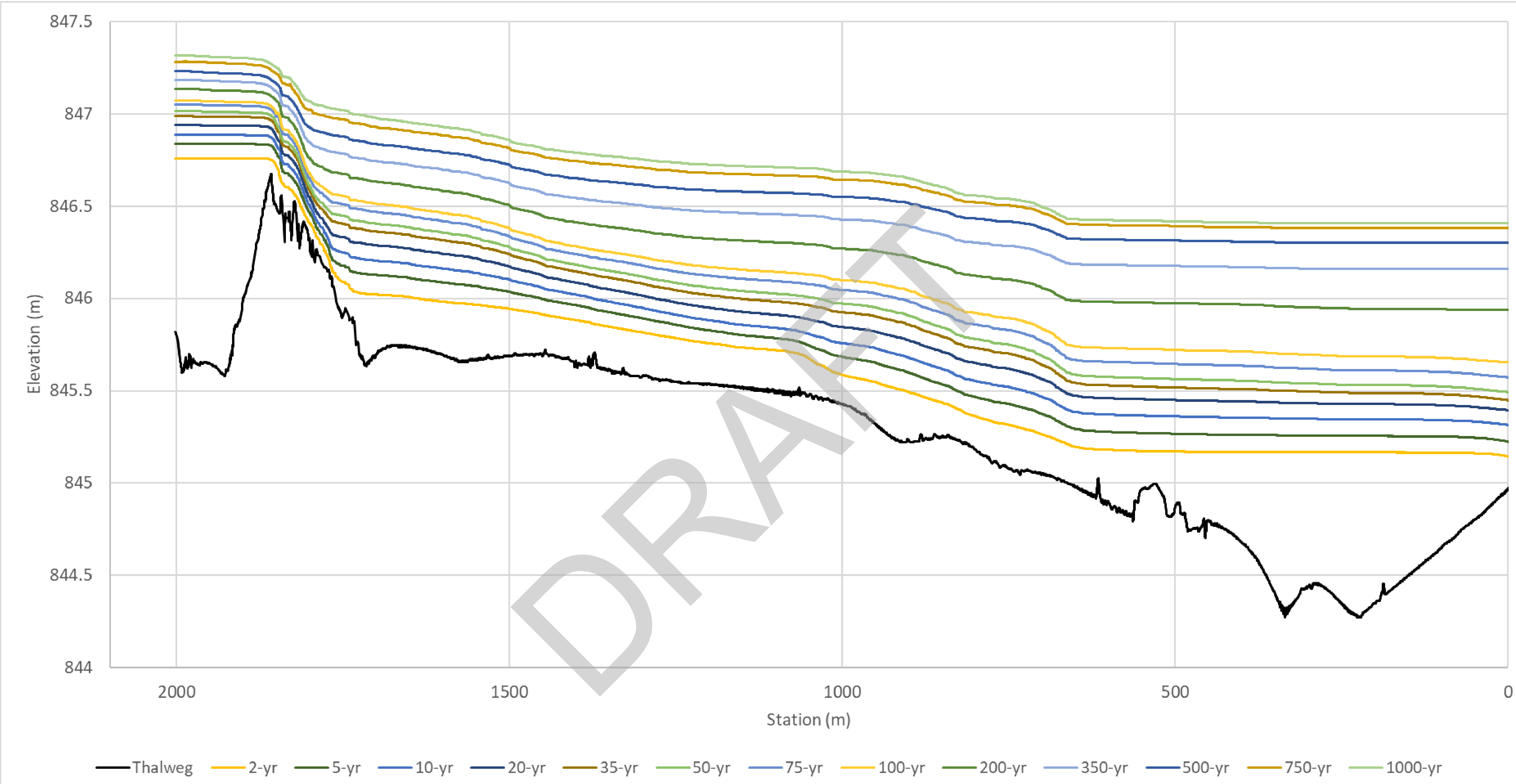


Figure F-3 Simulated Water Surface Profiles Along Unnamed Tributary 1

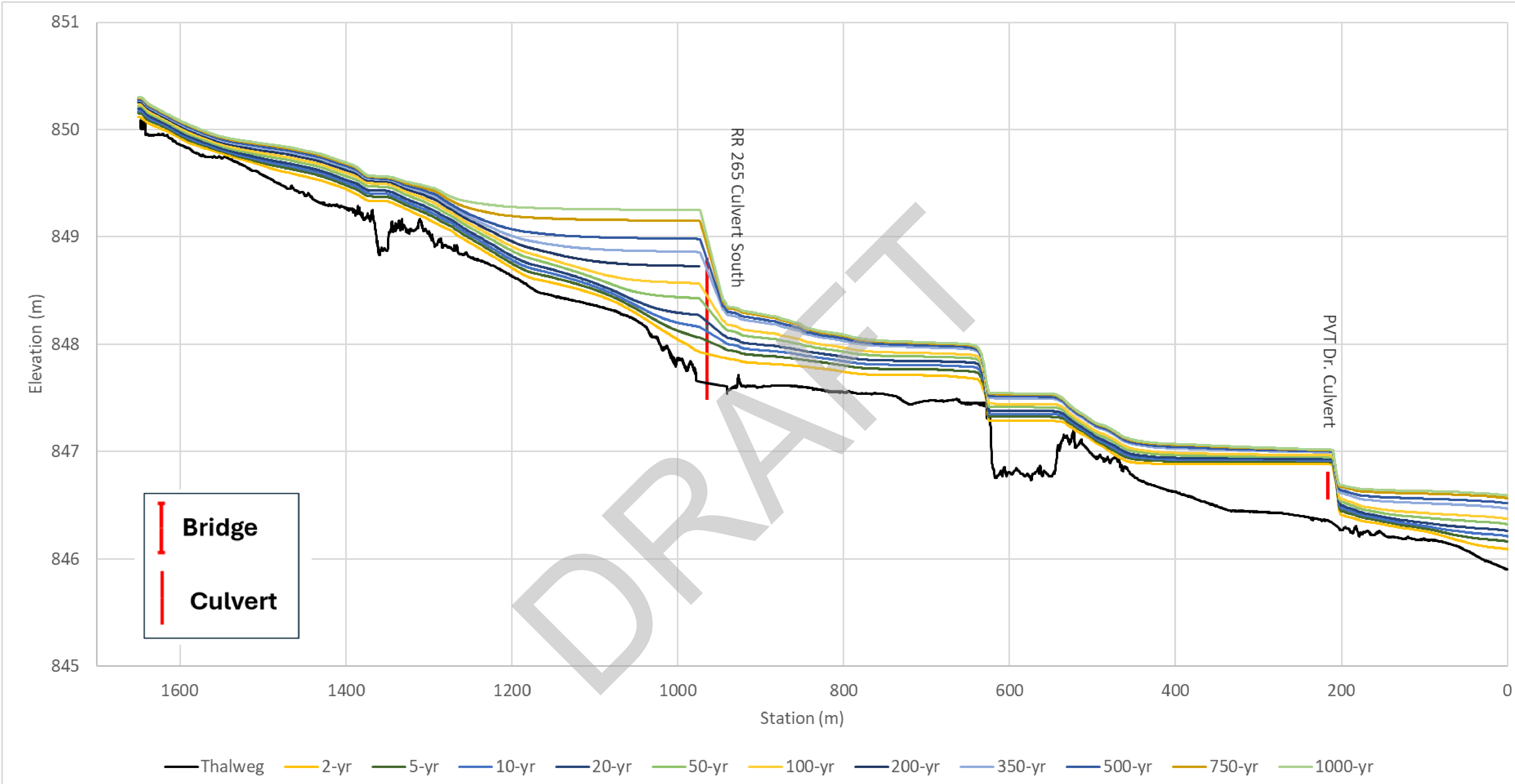


Figure F-4 Simulated Water Surface Profiles Along Unnamed Tributary 2

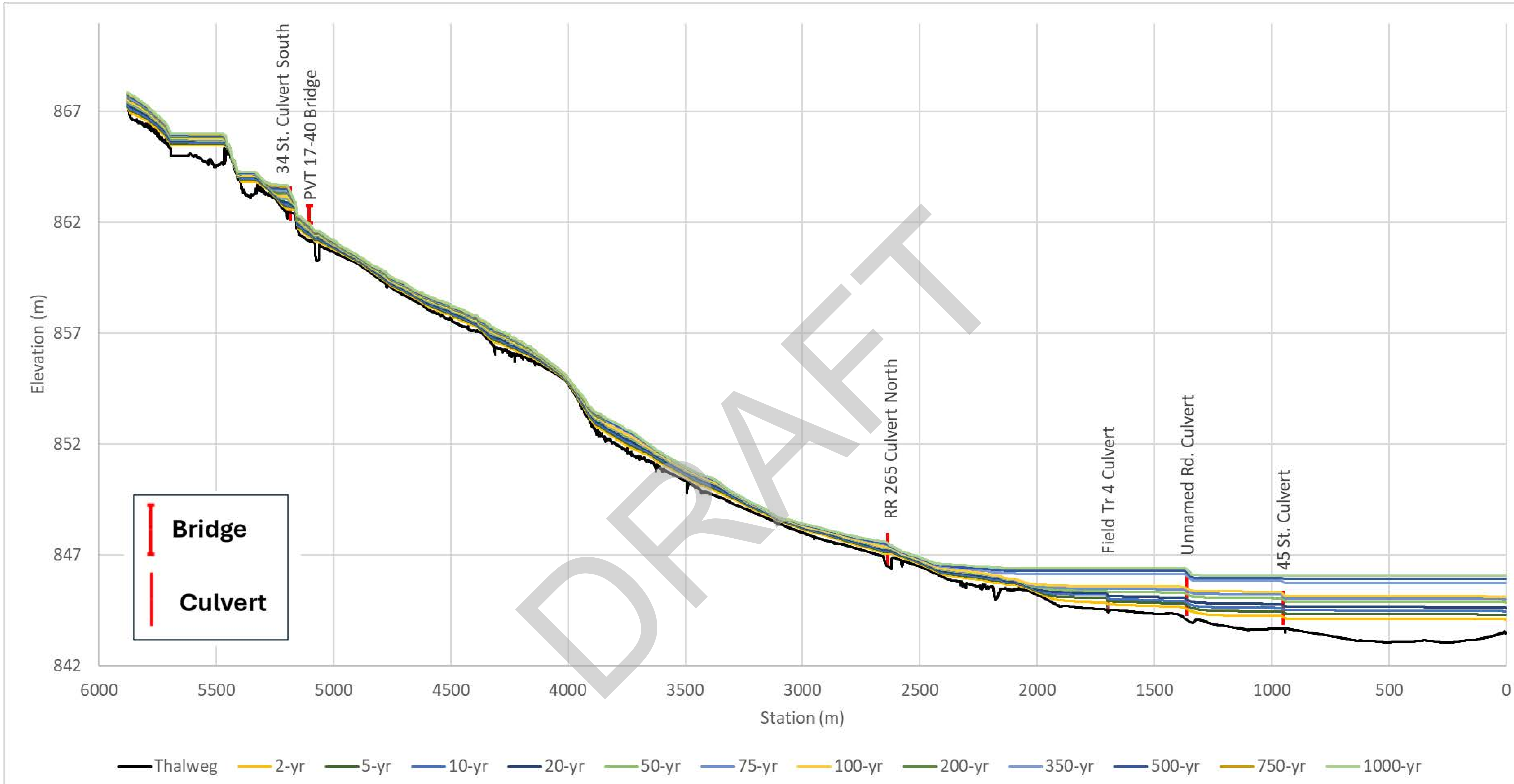


Figure F-5 Simulated Water Surface Profiles Along Unnamed Tributary 3

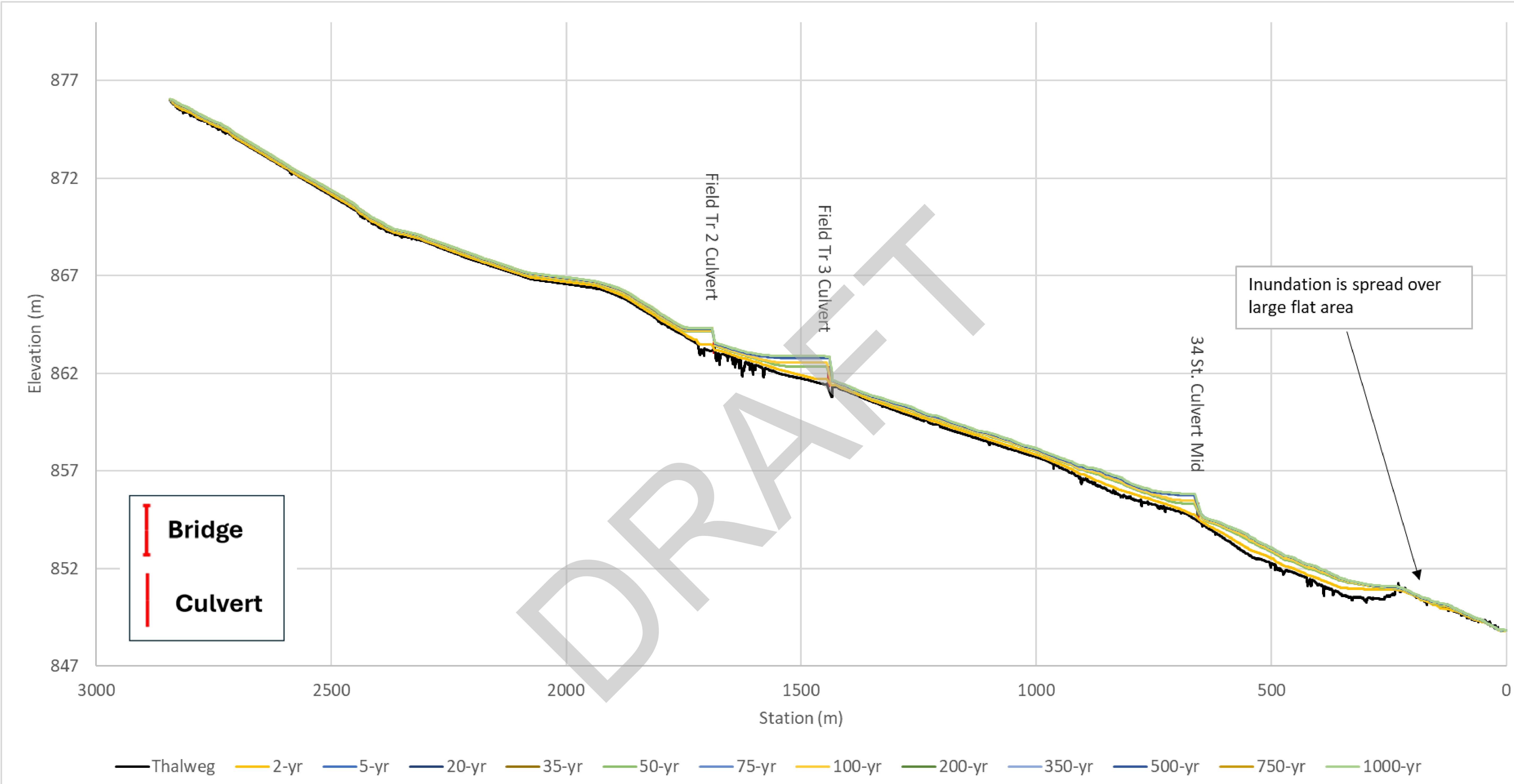


Figure F-6 Simulated Water Surface Profiles Along Unnamed Tributary 4

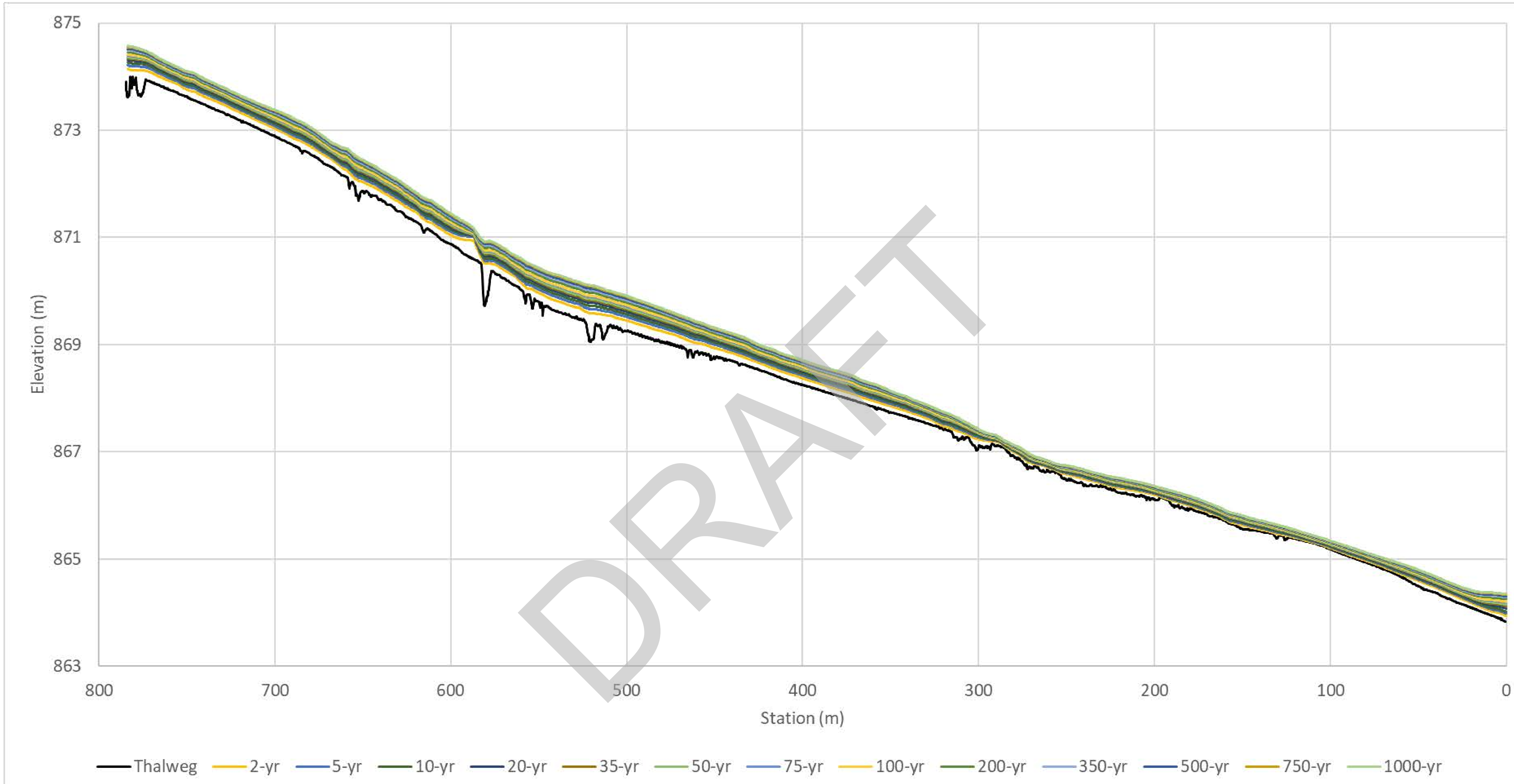


Figure F-7 Simulated Water Surface Profiles Along Unnamed Tributary 5

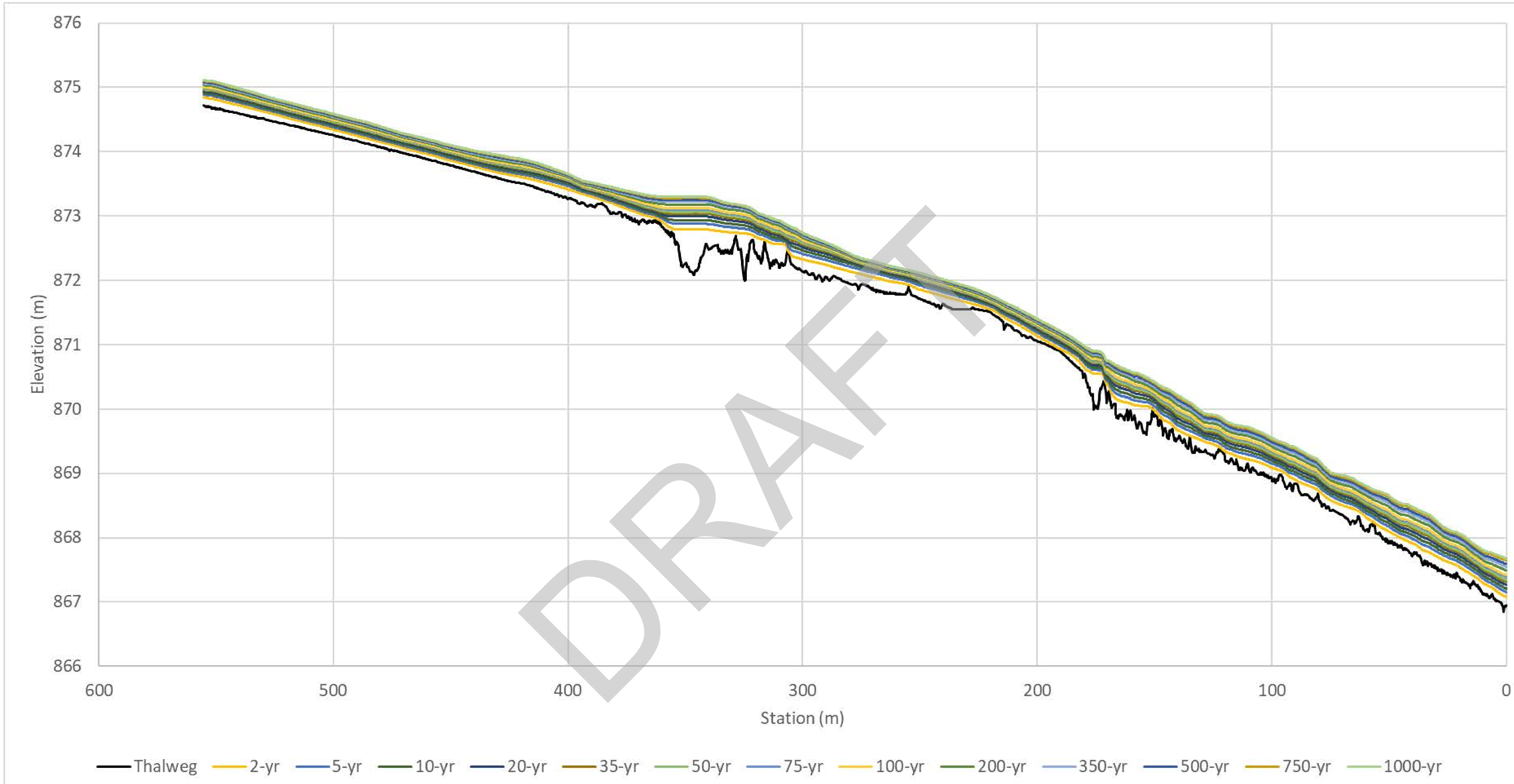


Figure F-8 Simulated Water Surface Profiles Along Unnamed Tributary 6

Table F-1 Upper Wolf Creek 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
16,500	870.14	870.22	870.28	870.33	870.37	870.41	870.43	870.47	870.49	870.54	870.59	870.62	870.66	870.68
16,400	869.47	869.68	869.74	869.80	869.84	869.89	869.91	869.95	869.97	870.02	870.07	870.10	870.13	870.15
16,300	868.29	868.36	868.40	868.43	868.45	868.48	868.49	868.51	868.52	868.56	868.58	868.60	868.63	868.64
16,200	866.13	866.44	866.56	866.64	866.72	866.79	866.83	866.88	866.91	866.99	867.05	867.09	867.14	867.17
16,100	865.27	865.61	865.71	865.78	865.85	865.89	865.92	865.96	865.99	866.06	866.11	866.16	866.20	866.23
16,000	864.88	865.14	865.25	865.32	865.38	865.43	865.47	865.51	865.54	865.61	865.67	865.71	865.76	865.79
15,900	864.33	864.59	864.69	864.75	864.82	864.88	864.91	864.96	864.99	865.06	865.11	865.15	865.19	865.21
15,800	863.79	863.98	864.10	864.19	864.26	864.32	864.35	864.40	864.43	864.48	864.52	864.55	864.59	864.61
15,700	863.39	863.50	863.54	863.58	863.62	863.65	863.67	863.70	863.72	863.77	863.81	863.84	863.87	863.89
15,600	862.85	862.96	863.00	863.04	863.08	863.11	863.12	863.14	863.16	863.19	863.21	863.23	863.25	863.26
15,500	862.14	862.26	862.29	862.32	862.35	862.37	862.38	862.40	862.41	862.44	862.47	862.49	862.51	862.52
15,400	861.43	861.57	861.61	861.64	861.67	861.69	861.71	861.73	861.74	861.77	861.80	861.82	861.84	861.85
15,300	861.09	861.15	861.17	861.19	861.20	861.21	861.22	861.23	861.24	861.26	861.27	861.28	861.30	861.30
15,200	860.04	860.09	860.11	860.13	860.15	860.16	860.17	860.18	860.19	860.21	860.22	860.23	860.25	860.25
15,100	858.30	845.85	858.53	858.58	858.64	858.69	858.72	858.77	858.79	858.86	858.91	858.95	858.99	859.02
15,000	857.50	857.74	857.85	857.92	858.00	858.06	858.10	858.16	858.19	858.25	858.31	858.35	858.40	858.43
14,900	856.65	856.93	857.04	857.11	857.19	857.24	857.28	857.32	857.34	857.40	857.45	857.49	857.53	857.55
14,800	856.45	856.55	856.62	856.67	856.72	856.76	856.78	856.81	856.83	856.88	856.91	856.94	856.97	856.99
14,700	855.53	855.80	855.89	855.94	856.00	856.04	856.07	856.10	856.12	856.17	856.21	856.24	856.27	856.29
14,600	854.84	855.16	855.23	855.28	855.31	855.34	855.36	855.39	855.40	855.44	855.46	855.48	855.50	855.51
14,500	854.05	854.30	854.40	854.46	854.52	854.56	854.59	854.63	854.65	854.71	854.79	854.85	854.93	855.00
14,400	852.60	853.16	853.23	853.28	853.33	853.37	853.40	853.43	853.45	853.51	853.59	853.65	853.73	853.77
14,300	852.03	852.26	852.36	852.42	852.48	852.53	852.56	852.61	852.64	852.70	852.78	852.84	852.91	852.94
14,200	850.95	851.33	851.44	851.51	851.57	851.62	851.65	851.69	851.72	851.79	851.87	851.92	851.98	852.00
14,100	850.43	850.69	850.80	850.86	850.93	850.98	851.01	851.04	851.06	851.09	851.12	851.14	851.15	851.16
14,000	849.89	850.15	850.23	850.28	850.31	850.34	850.35	850.37	850.38	850.39	850.40	850.40	850.41	850.41
13,900	850.04	850.02	850.04	850.05	850.06	850.06	850.06	850.07	850.07	850.07	850.08	850.08	850.08	850.08
13,800	848.50	848.35	848.37	848.39	848.40	848.41	848.42	848.43	848.43	848.45	848.46	848.47	848.48	848.49
13,700	847.47	847.73	847.84	847.89	847.93	847.96	847.97	847.99	848.01	848.03	848.05	848.07	848.08	848.09
13,600	847.16	847.43	847.48	847.50	847.52	847.54	847.55	847.56	847.57	847.59	847.61	847.62	847.63	847.64
13,500	847.01	847.13	847.17	847.19	847.22	847.23	847.24	847.25	847.26	847.27	847.28	847.29	847.31	847.31
13,400	846.05	845.86	845.99	846.08	846.18	846.25	846.29	846.33	846.36	846.43	846.50	846.54	846.60	846.62
13,300	845.35	845.78	845.91	846.00	846.08	846.14	846.17	846.21	846.24	846.30	846.35	846.39	846.44	846.47
13,200	845.22	845.67	845.78	845.85	845.91	845.96	845.98	846.01	846.03	846.07	846.11	846.15	846.20	846.22
13,100	845.18	845.41	845.55	845.63	845.71	845.76	845.78	845.82	845.84	845.90	845.96	846.04	846.11	846.13
13,000	844.35	844.98	845.18	845.31	845.44	845.53	845.57	845.63	845.66	845.76	845.87	845.98	846.07	846.10

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
12,900	844.36	844.74	844.89	844.99	845.10	845.18	845.24	845.31	845.36	845.58	845.80	845.95	846.06	846.08
12,800	843.80	844.56	844.64	844.67	844.73	844.82	844.91	845.04	845.15	845.49	845.76	845.93	846.04	846.07
12,700	841.87	844.56	844.63	844.66	844.71	844.81	844.90	845.04	845.14	845.49	845.76	845.93	846.04	846.07
12,600	843.99	844.54	844.59	844.60	844.66	844.80	844.89	845.03	845.14	845.49	845.75	845.93	846.04	846.07
12,500	844.00	844.54	844.59	844.60	844.66	844.80	844.89	845.03	845.14	845.49	845.75	845.93	846.04	846.07
12,400	843.78	844.52	844.55	844.56	844.65	844.79	844.89	845.03	845.14	845.49	845.75	845.93	846.04	846.07
12,300	844.30	844.52	844.55	844.55	844.65	844.79	844.89	845.03	845.14	845.49	845.75	845.93	846.04	846.07
12,200	843.13	843.82	844.07	844.26	844.45	844.61	844.72	844.87	844.99	845.35	845.55	845.67	845.81	845.90
12,100	843.20	843.80	844.05	844.23	844.42	844.58	844.70	844.85	844.97	845.34	845.55	845.67	845.81	845.89
12,000	843.15	843.78	844.03	844.21	844.40	844.56	844.68	844.83	844.95	845.32	845.53	845.65	845.78	845.87

Table F-2 Lower Wolf Creek Profiles

Cross-Section	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
1	11955	843.05	843.77	844.02	844.20	844.39	844.56	844.67	844.83	844.94	845.32	845.53	845.65	845.78	845.87
2	11856	843.08	843.76	844.01	844.19	844.38	844.55	844.67	844.82	844.94	845.32	845.52	845.64	845.78	845.86
3	11767	843.05	843.76	844.00	844.18	844.37	844.54	844.66	844.82	844.94	845.32	845.52	845.64	845.78	845.86
4	11700	843.02	843.75	843.98	844.16	844.35	844.53	844.65	844.81	844.93	845.31	845.52	845.64	845.78	845.86
5	11634	842.93	843.73	843.96	844.14	844.33	844.50	844.62	844.78	844.90	845.29	845.50	845.62	845.76	845.84
6	11549	843.02	843.69	843.92	844.10	844.29	844.47	844.59	844.76	844.88	845.28	845.48	845.60	845.74	845.82
7	11465	842.86	843.67	843.90	844.08	844.27	844.45	844.57	844.74	844.87	845.27	845.48	845.60	845.74	845.82
8	11451	843.12	843.66	843.88	844.06	844.25	844.43	844.56	844.73	844.86	845.27	845.47	845.59	845.73	845.81
9	11415	842.94	843.60	843.81	843.98	844.16	844.34	844.47	844.63	844.76	845.17	845.35	845.44	845.53	845.58
10	11404	842.94	843.60	843.81	843.98	844.16	844.34	844.47	844.64	844.77	845.17	845.36	845.45	845.54	845.58
11	11305	842.67	843.56	843.76	843.93	844.11	844.29	844.43	844.60	844.74	845.15	845.34	845.43	845.53	845.57
12	11217	843.05	843.47	843.68	843.87	844.06	844.25	844.40	844.58	844.73	845.15	845.34	845.44	845.53	845.57
13	11128	842.71	843.36	843.59	843.79	843.99	844.20	844.35	844.54	844.69	845.14	845.33	845.42	845.51	845.56
14	11071	842.86	843.29	843.55	843.76	843.96	844.18	844.34	844.53	844.68	845.13	845.32	845.41	845.50	845.55
15	11014	842.61	843.22	843.52	843.74	843.94	844.16	844.32	844.52	844.67	845.12	845.31	845.40	845.49	845.54
16	10933	842.59	843.15	843.48	843.71	843.92	844.14	844.31	844.50	844.66	845.11	845.30	845.39	845.48	845.52
17	10852	842.27	843.09	843.45	843.68	843.89	844.12	844.29	844.49	844.64	845.10	845.29	845.38	845.47	845.51
18	10755	842.21	843.07	843.43	843.66	843.87	844.11	844.28	844.48	844.64	845.10	845.29	845.38	845.47	845.51
19	10692	842.22	843.06	843.42	843.65	843.87	844.10	844.28	844.48	844.64	845.10	845.29	845.38	845.47	845.51
20	10628	841.91	843.03	843.40	843.64	843.86	844.10	844.28	844.48	844.64	845.10	845.29	845.38	845.47	845.51
21	10542	842.02	843.00	843.39	843.63	843.85	844.09	844.27	844.48	844.64	845.10	845.29	845.38	845.47	845.51
22	10457	842.09	842.98	843.38	843.62	843.84	844.08	844.26	844.47	844.63	845.10	845.29	845.38	845.47	845.51
23	10373	842.07	842.97	843.37	843.61	843.83	844.08	844.26	844.47	844.63	845.10	845.29	845.38	845.47	845.51
24	10288	842.00	842.96	843.35	843.60	843.81	844.07	844.26	844.47	844.63	845.10	845.29	845.38	845.46	845.51
25	10203	842.03	842.94	843.34	843.59	843.81	844.07	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
26	10117	841.99	842.94	843.33	843.59	843.81	844.07	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
27	10061	842.02	842.93	843.33	843.58	843.81	844.07	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
28	10005	842.03	842.93	843.33	843.58	843.81	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
29	9955	842.15	842.92	843.32	843.58	843.81	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
30	9880	842.13	842.92	843.32	843.58	843.80	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
31	9805	842.05	842.91	843.31	843.57	843.80	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
32	9722	842.05	842.88	843.28	843.56	843.80	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
33	9640	842.03	842.85	843.25	843.54	843.79	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
34	9574	842.08	842.83	843.23	843.52	843.79	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
35	9507	842.07	842.80	843.20	843.50	843.78	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
36	9440	842.02	842.77	843.18	843.48	843.78	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51

Cross-Section	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
37	9372	841.86	842.75	843.16	843.46	843.77	844.06	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
38	9275	841.95	842.71	843.13	843.43	843.75	844.05	844.25	844.47	844.63	845.10	845.29	845.38	845.46	845.51
39	9179	841.88	842.66	843.10	843.41	843.74	844.04	844.24	844.46	844.62	845.10	845.29	845.38	845.46	845.51
40	9169	841.74	842.64	843.08	843.39	843.71	844.01	844.20	844.42	844.58	845.09	845.29	845.38	845.46	845.51
41	9153	841.66	842.63	843.06	843.37	843.69	843.99	844.19	844.38	844.53	845.08	845.28	845.37	845.46	845.50
42	9136	841.42	842.63	843.07	843.38	843.70	844.00	844.20	844.39	844.53	845.08	845.28	845.37	845.46	845.50
43	9055	841.46	842.60	843.04	843.35	843.68	843.99	844.19	844.39	844.53	845.07	845.28	845.37	845.46	845.50
44	8974	841.43	842.57	843.02	843.33	843.66	843.97	844.18	844.38	844.53	845.07	845.28	845.37	845.46	845.50
45	8898	841.57	842.54	842.99	843.31	843.64	843.95	844.16	844.36	844.51	845.05	845.26	845.35	845.44	845.48
46	8821	841.44	842.52	842.97	843.29	843.62	843.94	844.15	844.35	844.51	845.05	845.26	845.35	845.43	845.47
47	8723	841.48	842.49	842.94	843.27	843.60	843.92	844.13	844.33	844.48	845.04	845.25	845.33	845.42	845.46
48	8624	841.38	842.46	842.92	843.25	843.58	843.91	844.13	844.33	844.49	845.04	845.25	845.34	845.42	845.46
49	8612	841.29	842.46	842.92	843.25	843.58	843.90	844.12	844.33	844.48	845.04	845.25	845.33	845.42	845.46
50	8536	841.34	842.45	842.91	843.23	843.57	843.90	844.12	844.32	844.48	845.04	845.25	845.33	845.42	845.46
51	8466	841.34	842.43	842.89	843.22	843.56	843.89	844.12	844.32	844.48	845.04	845.25	845.33	845.42	845.46
52	8405	841.37	842.42	842.88	843.21	843.55	843.89	844.12	844.32	844.48	845.04	845.25	845.33	845.42	845.46
53	8344	841.38	842.40	842.86	843.19	843.55	843.89	844.11	844.32	844.48	845.04	845.25	845.33	845.42	845.46
54	8273	841.25	842.39	842.84	843.18	843.55	843.89	844.12	844.32	844.48	845.04	845.25	845.33	845.42	845.46
55	8202	841.06	842.36	842.82	843.16	843.53	843.88	844.11	844.32	844.48	845.04	845.24	845.33	845.41	845.46
56	8197	841.18	842.36	842.83	843.16	843.53	843.87	844.09	844.31	844.48	845.04	845.25	845.33	845.42	845.46
57	8182	841.10	842.35	842.81	843.14	843.49	843.79	844.00	844.27	844.46	845.03	845.24	845.33	845.41	845.45
58	8169	841.26	842.34	842.80	843.13	843.49	843.79	844.00	844.27	844.46	845.03	845.24	845.33	845.41	845.46
59	8094	841.31	842.33	842.78	843.12	843.49	843.79	844.00	844.27	844.46	845.03	845.24	845.33	845.41	845.45
60	8019	841.21	842.31	842.77	843.11	843.48	843.79	843.99	844.26	844.45	845.03	845.24	845.33	845.41	845.45
61	7943	841.21	842.30	842.76	843.09	843.46	843.77	843.98	844.25	844.44	845.02	845.24	845.33	845.41	845.45
62	7867	841.07	842.29	842.74	843.08	843.45	843.76	843.97	844.24	844.43	845.02	845.23	845.32	845.40	845.44
63	7784	841.08	842.28	842.74	843.07	843.44	843.76	843.96	844.24	844.42	845.01	845.22	845.31	845.40	845.44
64	7707	840.93	842.27	842.73	843.07	843.44	843.75	843.96	844.23	844.42	845.00	845.22	845.30	845.39	845.43
65	7630	840.66	842.27	842.72	843.06	843.43	843.75	843.96	844.23	844.42	845.01	845.22	845.31	845.40	845.44
66	7616	841.29	842.26	842.71	843.05	843.42	843.73	843.94	844.21	844.40	844.99	845.20	845.29	845.37	845.42
67	7598	841.09	842.22	842.64	842.94	843.28	843.56	843.74	843.99	844.15	844.58	844.71	844.76	844.81	844.84
68	7593	841.22	842.21	842.62	842.93	843.27	843.55	843.74	843.98	844.15	844.58	844.71	844.76	844.81	844.83
69	7546	840.36	841.17	841.57	841.83	842.08	842.27	842.40	842.57	842.71	843.20	843.50	843.56	843.59	843.75
70	7536	840.17	841.18	841.58	841.83	842.08	842.28	842.40	842.58	842.72	843.21	843.50	843.56	843.59	843.75
71	7468	839.81	841.14	841.54	841.79	842.04	842.23	842.36	842.54	842.68	843.19	843.49	843.55	843.58	843.75
72	7409	839.81	841.11	841.51	841.76	842.00	842.20	842.32	842.50	842.65	843.17	843.48	843.54	843.57	843.74
73	7350	839.72	841.08	841.48	841.72	841.96	842.15	842.28	842.46	842.61	843.14	843.47	843.53	843.57	843.74
74	7295	839.80	841.06	841.45	841.68	841.92	842.11	842.24	842.42	842.57	843.13	843.47	843.53	843.56	843.73

Cross-Section	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
75	7240	839.74	841.04	841.42	841.65	841.89	842.08	842.20	842.38	842.54	843.12	843.46	843.53	843.56	843.73
76	7182	839.82	841.02	841.39	841.62	841.86	842.04	842.17	842.35	842.51	843.10	843.46	843.53	843.56	843.73
77	7125	839.67	840.98	841.35	841.58	841.81	841.99	842.11	842.29	842.46	843.08	843.45	843.52	843.55	843.73
78	7058	839.78	840.95	841.31	841.53	841.76	841.94	842.06	842.25	842.43	843.07	843.45	843.51	843.55	843.72
79	6990	839.72	840.92	841.26	841.48	841.70	841.88	841.99	842.18	842.37	843.05	843.44	843.51	843.54	843.72
80	6897	840.03	840.87	841.21	841.42	841.64	841.81	841.92	842.12	842.32	843.03	843.43	843.50	843.53	843.72
81	6804	839.76	840.80	841.13	841.34	841.56	841.73	841.85	842.06	842.27	843.02	843.43	843.50	843.53	843.72
82	6723	840.07	840.71	841.05	841.27	841.49	841.67	841.80	842.02	842.24	843.02	843.43	843.50	843.53	843.72
83	6642	839.35	840.65	841.01	841.22	841.44	841.62	841.75	841.98	842.22	843.02	843.42	843.50	843.53	843.72
84	6563	839.56	840.62	840.98	841.18	841.40	841.58	841.71	841.95	842.22	843.02	843.42	843.50	843.53	843.72
85	6483	839.24	840.59	840.94	841.13	841.35	841.54	841.69	841.93	842.21	843.02	843.42	843.50	843.53	843.72
86	6412	839.77	840.55	840.89	841.09	841.31	841.52	841.68	841.93	842.21	843.02	843.42	843.50	843.53	843.72
87	6340	839.26	840.47	840.84	841.04	841.26	841.48	841.65	841.91	842.20	843.02	843.42	843.49	843.53	843.71
88	6324	839.55	840.45	840.83	841.02	841.24	841.46	841.63	841.89	842.17	843.01	843.43	843.50	843.53	843.72
89	6306	839.48	840.34	840.70	840.91	841.17	841.40	841.58	841.85	842.12	842.98	843.42	843.50	843.53	843.71
90	6294	838.89	840.35	840.71	840.93	841.19	841.42	841.59	841.85	842.12	842.98	843.42	843.50	843.53	843.72
91	6228	839.25	840.32	840.68	840.90	841.17	841.42	841.60	841.86	842.13	842.98	843.42	843.50	843.53	843.72
92	6128	838.89	840.19	840.59	840.83	841.11	841.37	841.56	841.84	842.12	842.98	843.42	843.49	843.53	843.71
93	6117	839.32	840.16	840.57	840.81	841.10	841.35	841.54	841.81	842.09	842.96	843.42	843.49	843.53	843.71
94	6100	839.41	840.11	840.55	840.79	841.09	841.35	841.54	841.81	842.09	842.92	843.42	843.49	843.52	843.71
95	6083	838.81	840.10	840.54	840.79	841.09	841.35	841.53	841.81	842.09	842.92	843.42	843.49	843.52	843.71
96	6012	838.91	840.06	840.50	840.76	841.07	841.35	841.54	841.81	842.09	842.91	843.42	843.49	843.52	843.71
97	5941	838.74	840.03	840.44	840.73	841.05	841.34	841.53	841.81	842.09	842.92	843.42	843.49	843.52	843.71
98	5887	838.85	840.01	840.41	840.71	841.05	841.34	841.53	841.81	842.09	842.91	843.42	843.49	843.52	843.71
99	5834	838.71	840.00	840.39	840.70	841.04	841.33	841.53	841.81	842.09	842.92	843.42	843.49	843.52	843.71
100	5822	838.82	840.00	840.39	840.70	841.04	841.33	841.52	841.80	842.08	842.91	843.41	843.48	843.52	843.71
101	5735	838.63	839.84	840.12	840.32	840.54	840.73	840.86	841.05	841.19	841.56	842.10	842.58	843.25	843.67
102	5720	838.68	839.84	840.12	840.32	840.54	840.73	840.86	841.05	841.19	841.56	842.09	842.57	843.25	843.67
103	5659	838.81	839.81	840.08	840.28	840.51	840.70	840.84	841.03	841.17	841.54	842.08	842.56	843.24	843.67
104	5604	838.57	839.74	840.03	840.24	840.47	840.67	840.80	841.00	841.14	841.52	842.07	842.56	843.24	843.67
105	5526	838.76	839.67	839.98	840.19	840.43	840.63	840.77	840.97	841.12	841.51	842.06	842.55	843.24	843.67
106	5455	838.78	839.63	839.94	840.16	840.40	840.61	840.75	840.95	841.10	841.49	842.06	842.55	843.24	843.67
107	5379	838.78	839.60	839.92	840.14	840.38	840.58	840.73	840.93	841.08	841.48	842.05	842.55	843.24	843.67
108	5303	838.46	839.57	839.89	840.11	840.35	840.56	840.70	840.91	841.06	841.47	842.06	842.55	843.24	843.67
109	5240	838.77	839.53	839.84	840.06	840.30	840.51	840.65	840.86	841.02	841.43	842.02	842.53	843.24	843.67
110	5176	838.24	839.46	839.77	840.00	840.24	840.45	840.60	840.82	840.98	841.40	842.00	842.51	843.23	843.67
111	5112	838.43	839.40	839.72	839.95	840.19	840.41	840.56	840.78	840.95	841.38	841.98	842.50	843.22	843.66
112	5049	838.26	839.37	839.69	839.92	840.17	840.38	840.54	840.76	840.93	841.36	841.97	842.49	843.21	843.66

Cross-Section	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
113	5014	838.07	839.35	839.67	839.89	840.14	840.36	840.52	840.74	840.91	841.35	841.96	842.48	843.21	843.65
114	4943	838.13	839.29	839.62	839.84	840.10	840.32	840.48	840.71	840.88	841.33	841.95	842.48	843.20	843.65
115	4873	837.86	839.25	839.58	839.81	840.06	840.29	840.45	840.69	840.86	841.32	841.94	842.47	843.20	843.65
116	4794	838.36	839.19	839.53	839.76	840.02	840.25	840.42	840.66	840.84	841.30	841.93	842.46	843.19	843.64
117	4716	837.86	839.13	839.48	839.72	839.98	840.21	840.38	840.63	840.81	841.28	841.92	842.45	843.19	843.64
118	4659	838.29	839.08	839.44	839.68	839.95	840.19	840.36	840.61	840.79	841.27	841.91	842.45	843.19	843.64
119	4606	837.93	839.06	839.42	839.66	839.92	840.17	840.34	840.59	840.78	841.25	841.90	842.44	843.18	843.63
120	4560	837.89	839.05	839.41	839.65	839.91	840.16	840.33	840.58	840.77	841.25	841.90	842.44	843.18	843.63
121	4476	837.82	839.02	839.37	839.61	839.87	840.12	840.29	840.55	840.74	841.23	841.89	842.44	843.18	843.63
122	4382	837.86	838.98	839.33	839.57	839.83	840.08	840.25	840.51	840.71	841.21	841.88	842.43	843.17	843.63
123	4373	837.27	838.98	839.34	839.57	839.84	840.08	840.26	840.52	840.71	841.21	841.88	842.43	843.17	843.62
124	4327	837.20	838.96	839.29	839.48	839.69	839.88	840.01	840.21	840.37	840.75	841.20	841.51	841.88	842.11
125	4317	837.85	838.96	839.28	839.48	839.68	839.87	840.00	840.21	840.36	840.75	841.20	841.51	841.88	842.11
126	4254	837.83	838.85	839.15	839.36	839.60	839.80	839.94	840.15	840.32	840.72	841.18	841.49	841.87	842.11
127	4245	837.66	838.85	839.15	839.36	839.59	839.78	839.92	840.14	840.30	840.71	841.17	841.48	841.86	842.10
128	4234	837.28	838.85	839.14	839.35	839.57	839.77	839.91	840.12	840.28	840.69	841.16	841.47	841.85	842.08
129	4196	836.90	838.84	839.11	839.29	839.47	839.60	839.69	839.80	839.88	840.05	840.23	840.35	840.49	840.56
130	4181	838.16	838.76	839.03	839.20	839.37	839.50	839.59	839.70	839.77	839.94	840.12	840.24	840.37	840.45
131	4095	837.20	838.42	838.70	838.89	839.10	839.25	839.35	839.48	839.56	839.75	839.94	840.05	840.18	840.25
132	4012	837.15	838.34	838.61	838.81	839.01	839.17	839.27	839.40	839.48	839.67	839.86	839.98	840.10	840.17
133	3922	837.05	838.29	838.55	838.74	838.94	839.09	839.18	839.30	839.38	839.56	839.73	839.84	839.96	840.02
134	3841	837.13	838.17	838.44	838.63	838.84	838.98	839.07	839.20	839.28	839.45	839.62	839.72	839.84	839.90
135	3799	836.73	838.12	838.41	838.60	838.80	838.94	839.02	839.14	839.22	839.39	839.56	839.66	839.78	839.85
136	3727	836.74	838.07	838.36	838.55	838.75	838.88	838.97	839.09	839.16	839.33	839.49	839.60	839.71	839.78
137	3659	836.76	838.02	838.31	838.49	838.69	838.82	838.90	839.01	839.09	839.25	839.41	839.51	839.61	839.68
138	3599	836.79	838.00	838.29	838.47	838.66	838.78	838.86	838.97	839.05	839.20	839.36	839.46	839.56	839.62
139	3526	836.91	837.99	838.26	838.44	838.63	838.75	838.81	838.93	839.00	839.15	839.30	839.40	839.51	839.57
140	3463	836.96	837.98	838.25	838.43	838.62	838.73	838.80	838.91	838.98	839.13	839.28	839.37	839.47	839.53
141	3400	836.97	837.97	838.24	838.41	838.59	838.70	838.76	838.87	838.94	839.08	839.23	839.32	839.41	839.46
142	3307	836.83	837.96	838.22	838.39	838.57	838.66	838.72	838.83	838.89	839.02	839.15	839.24	839.32	839.37
143	3246	836.84	837.95	838.21	838.38	838.55	838.65	838.70	838.80	838.86	838.99	839.11	839.19	839.27	839.31
144	3185	836.81	837.95	838.21	838.37	838.54	838.63	838.68	838.78	838.84	838.97	839.10	839.17	839.25	839.29
145	3122	836.79	837.95	838.20	838.35	838.52	838.61	838.66	838.75	838.81	838.93	839.05	839.13	839.20	839.24
146	3059	836.74	#N/A	838.19	838.34	838.51	838.59	838.63	838.72	838.78	838.90	839.01	839.08	839.16	839.20
147	3028	836.39	837.50	837.80	837.98	838.16	838.34	838.49	838.57	838.61	838.70	838.79	838.84	838.91	838.94
148	2967	836.39	837.48	837.77	837.95	838.13	838.30	838.46	838.54	838.57	838.65	838.74	838.79	838.85	838.88
149	2912	836.34	837.47	837.75	837.92	838.09	838.26	838.43	838.50	838.53	838.60	838.68	838.72	838.77	838.80
150	2846	836.50	837.44	837.72	837.88	838.04	838.21	838.40	838.46	838.49	838.54	838.61	838.65	838.69	838.71

Cross-Section	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
151	2780	836.05	837.42	837.67	837.81	837.97	838.18	838.39	838.45	838.48	838.53	838.60	838.64	838.68	838.70
152	2713	836.36	837.38	837.62	837.73	837.90	838.17	838.38	838.45	838.48	838.53	838.59	838.64	838.68	838.70
153	2646	836.54	837.33	837.57	837.67	837.86	838.16	838.38	838.45	838.47	838.53	838.59	838.63	838.67	838.69
154	2581	836.55	837.30	837.54	837.64	837.85	838.15	838.38	838.45	838.47	838.52	838.59	838.63	838.67	838.69
155	2515	836.46	837.27	837.52	837.63	837.85	838.15	838.38	838.44	838.47	838.52	838.59	838.63	838.67	838.69
156	2450	836.43	837.24	837.50	837.61	837.85	838.15	838.38	838.44	838.47	838.52	838.59	838.63	838.67	838.69
157	2384	836.16	837.20	837.47	837.58	837.84	838.15	838.38	838.44	838.47	838.52	838.58	838.62	838.66	838.68
158	2319	836.34	837.16	837.45	837.57	837.84	838.15	838.38	838.44	838.47	838.52	838.58	838.62	838.66	838.68
159	2253	836.16	837.12	837.43	837.53	837.82	838.15	838.38	838.44	838.47	838.52	838.58	838.62	838.66	838.68
160	2193	836.35	837.09	837.40	837.51	837.80	838.14	838.37	838.44	838.46	838.52	838.58	838.62	838.66	838.68
161	2133	836.24	837.07	837.39	837.49	837.79	838.13	838.37	838.43	838.46	838.51	838.57	838.61	838.65	838.67
162	2071	836.23	837.06	837.37	837.45	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.60	838.64	838.65
163	2009	835.96	837.04	837.35	837.44	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.60	838.63	838.65
164	1944	836.14	837.03	837.34	837.44	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.60	838.63	838.65
165	1878	836.25	837.01	837.32	837.42	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.60	838.63	838.65
166	1816	836.24	836.99	837.30	837.41	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.59	838.63	838.65
167	1753	836.18	836.98	837.28	837.40	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.59	838.63	838.65
168	1686	836.14	836.96	837.26	837.39	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.59	838.63	838.65
169	1618	836.03	836.95	837.25	837.39	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.59	838.63	838.65
170	1546	836.12	836.93	837.24	837.38	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.59	838.63	838.65
171	1475	836.11	836.91	837.21	837.38	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.59	838.63	838.65
172	1404	836.12	836.89	837.20	837.38	837.77	838.12	838.36	838.43	838.45	838.50	838.56	838.59	838.63	838.65
173	1333	836.08	836.88	837.19	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
174	1275	836.02	836.87	837.18	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
175	1216	835.90	836.84	837.16	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
176	1141	836.02	836.81	837.14	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
177	1065	835.84	836.79	837.12	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
178	970	835.79	836.76	837.10	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
179	886	835.89	836.73	837.09	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
180	801	835.71	836.70	837.07	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
181	740	835.95	836.68	837.06	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
182	680	835.78	836.66	837.05	837.37	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
183	613	835.65	836.63	837.04	837.36	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
184	545	835.58	836.60	837.02	837.36	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
185	475	835.63	836.56	837.00	837.35	837.77	838.12	838.36	838.43	838.45	838.50	838.55	838.59	838.63	838.65
186	397	835.52	836.50	836.98	837.34	837.76	838.11	838.36	838.42	838.45	838.50	838.55	838.59	838.63	838.65
187	387	835.25	836.50	836.98	837.34	837.76	838.11	838.35	838.42	838.44	838.49	838.55	838.59	838.62	838.64
188	378	835.22	836.49	836.97	837.33	837.75	838.10	838.35	838.41	838.43	838.48	838.54	838.58	838.61	838.63

Cross-Section	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
189	353	835.20	836.44	836.83	837.10	837.38	837.57	837.67	837.70	837.70	837.72	837.74	837.76	837.81	837.86
190	337	834.78	836.44	836.84	837.10	837.38	837.58	837.68	837.70	837.71	837.73	837.74	837.76	837.82	837.87
191	253	835.21	836.43	836.82	837.09	837.37	837.56	837.66	837.69	837.70	837.72	837.74	837.75	837.81	837.86
192	169	835.48	836.41	836.80	837.07	837.34	837.54	837.64	837.67	837.68	837.69	837.71	837.73	837.79	837.84
193	85	835.44	836.39	836.78	837.04	837.32	837.51	837.62	837.64	837.65	837.67	837.69	837.71	837.76	837.81
194	0	835.32	836.37	836.75	837.02	837.29	837.49	837.59	837.62	837.62	837.64	837.66	837.68	837.74	837.79

Table F-3 Unnamed Tributary 1 Profiles

River	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
Unnamed Tributary 1	2,000	845.80	846.76	846.84	846.89	846.94	846.99	847.01	847.05	847.07	847.14	847.19	847.23	847.28	847.32
Unnamed Tributary 1	1,900	846.00	846.76	846.84	846.89	846.94	846.98	847.01	847.04	847.06	847.12	847.17	847.22	847.27	847.30
Unnamed Tributary 1	1,800	846.30	846.41	846.47	846.51	846.55	846.59	846.61	846.65	846.68	846.76	846.85	846.93	847.02	847.07
Unnamed Tributary 1	1,700	845.70	846.02	846.13	846.20	846.29	846.36	846.41	846.47	846.51	846.63	846.74	846.84	846.93	846.98
Unnamed Tributary 1	1,600	845.69	845.98	846.09	846.16	846.24	846.31	846.36	846.42	846.46	846.58	846.70	846.79	846.88	846.93
Unnamed Tributary 1	1,500	845.69	845.94	846.04	846.10	846.17	846.24	846.28	846.34	846.38	846.50	846.63	846.72	846.81	846.86
Unnamed Tributary 1	1,400	845.66	845.88	845.96	846.02	846.09	846.15	846.18	846.24	846.28	846.41	846.54	846.65	846.74	846.79
Unnamed Tributary 1	1,300	845.58	845.82	845.89	845.95	846.02	846.08	846.12	846.18	846.22	846.37	846.50	846.62	846.71	846.75
Unnamed Tributary 1	1,200	845.54	845.76	845.83	845.88	845.95	846.02	846.06	846.12	846.17	846.32	846.47	846.59	846.68	846.72
Unnamed Tributary 1	1,100	845.49	845.72	845.78	845.84	845.91	845.98	846.03	846.09	846.14	846.30	846.46	846.57	846.67	846.71
Unnamed Tributary 1	1,000	845.43	845.59	845.68	845.76	845.85	845.93	845.97	846.05	846.10	846.27	846.43	846.55	846.64	846.69
Unnamed Tributary 1	900	845.23	845.49	845.60	845.68	845.77	845.86	845.91	845.99	846.04	846.23	846.39	846.52	846.61	846.65
Unnamed Tributary 1	800	845.18	845.36	845.47	845.55	845.65	845.73	845.78	845.86	845.92	846.12	846.30	846.43	846.52	846.56
Unnamed Tributary 1	700	845.05	845.26	845.37	845.47	845.56	845.64	845.69	845.77	845.84	846.06	846.25	846.38	846.47	846.50
Unnamed Tributary 1	600	844.90	845.18	845.28	845.37	845.46	845.53	845.58	845.66	845.73	845.98	846.18	846.32	846.40	846.42
Unnamed Tributary 1	500	844.87	845.17	845.27	845.36	845.45	845.52	845.56	845.65	845.72	845.97	846.18	846.31	846.39	846.42
Unnamed Tributary 1	400	844.68	845.17	845.26	845.36	845.44	845.51	845.55	845.64	845.71	845.97	846.17	846.31	846.39	846.41
Unnamed Tributary 1	300	844.44	845.17	845.26	845.35	845.43	845.50	845.54	845.62	845.70	845.95	846.16	846.30	846.38	846.41
Unnamed Tributary 1	200	844.35	845.17	845.26	845.35	845.43	845.49	845.53	845.61	845.69	845.95	846.16	846.30	846.38	846.41
Unnamed Tributary 1	100	844.65	845.17	845.25	845.34	845.42	845.48	845.52	845.60	845.68	845.94	846.16	846.30	846.38	846.41
Unnamed Tributary 1	0	844.97	845.14	845.22	845.31	845.39	845.45	845.49	845.57	845.65	845.94	846.16	846.30	846.38	846.41

Table F-4 Unnamed Tributary 2 Profiles

River	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
Unnamed Tributary 2	1,600	849.86	849.92	849.95	849.96	849.98	849.99	850.00	850.01	850.02	850.04	850.05	850.06	850.08	850.09
Unnamed Tributary 2	1,500	849.58	849.66	849.69	849.71	849.73	849.75	849.76	849.77	849.78	849.81	849.83	849.84	849.86	849.87
Unnamed Tributary 2	1,400	849.27	849.45	849.48	849.51	849.53	849.55	849.57	849.59	849.60	849.63	849.65	849.66	849.68	849.69
Unnamed Tributary 2	1,300	849.03	849.16	849.21	849.24	849.27	849.29	849.31	849.33	849.34	849.37	849.40	849.42	849.44	849.47
Unnamed Tributary 2	1,200	848.64	848.71	848.76	848.79	848.83	848.85	848.87	848.90	848.91	848.96	849.01	849.07	849.20	849.28
Unnamed Tributary 2	1,100	848.36	848.47	848.51	848.54	848.57	848.60	848.62	848.65	848.67	848.77	848.89	849.00	849.16	849.26
Unnamed Tributary 2	1,000	847.87	848.05	848.13	848.20	848.29	848.38	848.44	848.52	848.57	848.73	848.86	848.98	849.15	849.25
Unnamed Tributary 2	900	847.60	847.82	847.90	847.95	848.00	848.04	848.06	848.09	848.11	848.17	848.21	848.23	848.27	848.28
Unnamed Tributary 2	800	847.56	847.75	847.80	847.84	847.88	847.91	847.93	847.95	847.97	848.01	848.03	848.05	848.08	848.09
Unnamed Tributary 2	700	847.47	847.71	847.77	847.81	847.84	847.87	847.89	847.90	847.92	847.95	847.97	847.99	848.01	848.02
Unnamed Tributary 2	600	846.81	847.29	847.32	847.35	847.38	847.40	847.41	847.43	847.44	847.47	847.50	847.52	847.53	847.54
Unnamed Tributary 2	500	846.97	847.11	847.13	847.15	847.17	847.18	847.19	847.21	847.21	847.24	847.25	847.27	847.28	847.29
Unnamed Tributary 2	400	846.63	846.89	846.91	846.93	846.94	846.96	846.97	846.98	846.99	847.01	847.03	847.05	847.06	847.07
Unnamed Tributary 2	300	846.44	846.89	846.91	846.92	846.94	846.95	846.96	846.97	846.97	846.99	847.01	847.02	847.03	847.04
Unnamed Tributary 2	200	846.27	846.41	846.45	846.48	846.50	846.52	846.53	846.55	846.56	846.59	846.62	846.64	846.67	846.69
Unnamed Tributary 2	100	846.19	846.26	846.29	846.31	846.34	846.37	846.39	846.41	846.43	846.48	846.52	846.56	846.61	846.63
Unnamed Tributary 2	0	845.91	846.09	846.16	846.21	846.26	846.30	846.32	846.35	846.37	846.42	846.47	846.52	846.57	846.59

Table F-5 Unnamed Tributary 3 Profiles

River	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
Unnamed Tributary 3	5,800	866.41	866.63	866.73	866.80	866.87	866.93	866.97	867.02	867.05	867.13	867.20	867.24	867.29	867.31
Unnamed Tributary 3	5,700	865.41	865.65	865.74	865.80	865.86	865.91	865.94	865.98	866.00	866.07	866.11	866.15	866.18	866.21
Unnamed Tributary 3	5,600	865.02	865.49	865.56	865.61	865.66	865.70	865.73	865.76	865.79	865.85	865.89	865.93	865.97	866.00
Unnamed Tributary 3	5,500	864.55	865.49	865.56	865.61	865.66	865.70	865.72	865.76	865.78	865.84	865.89	865.92	865.96	865.99
Unnamed Tributary 3	5,400	864.07	863.99	864.08	864.08	864.10	864.12	864.13	864.15	864.16	864.20	864.23	864.25	864.28	864.29
Unnamed Tributary 3	5,300	863.56	863.64	863.71	863.75	863.78	863.81	863.82	863.83	863.84	863.87	863.89	863.90	863.92	863.93
Unnamed Tributary 3	5,200	862.46	862.63	862.73	862.82	862.91	863.00	863.05	863.12	863.17	863.31	863.42	863.52	863.63	863.70
Unnamed Tributary 3	5,100	861.17	861.36	861.43	861.49	861.55	861.60	861.63	861.66	861.69	861.76	861.82	861.86	861.90	861.93
Unnamed Tributary 3	5,000	860.72	860.81	860.87	860.91	860.95	860.98	861.00	861.03	861.05	861.10	861.13	861.16	861.19	861.21
Unnamed Tributary 3	4,900	860.19	860.27	860.31	860.33	860.36	860.39	860.40	860.42	860.43	860.47	860.50	860.52	860.54	860.55
Unnamed Tributary 3	4,800	859.41	859.53	859.57	859.61	859.65	859.68	859.70	859.73	859.75	859.79	859.83	859.86	859.89	859.91
Unnamed Tributary 3	4,700	858.73	858.87	858.92	858.96	859.01	859.04	859.06	859.10	859.12	859.17	859.21	859.24	859.27	859.30
Unnamed Tributary 3	4,600	858.10	858.24	858.31	858.36	858.41	858.45	858.47	858.50	858.53	858.58	858.63	858.66	858.70	858.72
Unnamed Tributary 3	4,500	857.65	857.83	857.90	857.95	858.00	858.05	858.07	858.10	858.12	858.17	858.21	858.24	858.27	858.29
Unnamed Tributary 3	4,400	857.13	857.35	857.42	857.46	857.50	857.54	857.56	857.60	857.62	857.67	857.71	857.74	857.78	857.81
Unnamed Tributary 3	4,300	856.33	856.57	856.66	856.73	856.80	856.85	856.89	856.93	856.95	857.01	857.06	857.09	857.13	857.15
Unnamed Tributary 3	4,200	856.01	856.14	856.21	856.26	856.31	856.36	856.39	856.42	856.45	856.51	856.56	856.59	856.62	856.63
Unnamed Tributary 3	4,100	855.47	855.60	855.64	855.68	855.71	855.73	855.75	855.77	855.78	855.82	855.84	855.86	855.87	855.88
Unnamed Tributary 3	4,000	854.73	854.78	854.81	854.83	854.86	854.87	854.89	854.90	854.91	854.93	854.95	854.96	854.96	854.97
Unnamed Tributary 3	3,900	852.81	853.11	853.19	853.24	853.30	853.35	853.37	853.41	853.44	853.49	853.54	853.57	853.60	853.62
Unnamed Tributary 3	3,800	852.05	852.32	852.41	852.49	852.56	852.63	852.67	852.71	852.75	852.83	852.89	852.93	852.97	852.99
Unnamed Tributary 3	3,700	851.42	851.70	851.81	851.89	851.96	852.03	852.06	852.11	852.14	852.22	852.27	852.31	852.34	852.36
Unnamed Tributary 3	3,600	850.84	851.13	851.22	851.29	851.35	851.40	851.43	851.47	851.49	851.54	851.57	851.59	851.60	851.60
Unnamed Tributary 3	3,500	850.35	850.55	850.62	850.68	850.74	850.79	850.82	850.86	850.88	850.93	850.95	850.96	850.97	850.98
Unnamed Tributary 3	3,400	849.81	850.03	850.12	850.19	850.26	850.30	850.33	850.37	850.39	850.44	850.47	850.50	850.52	850.53
Unnamed Tributary 3	3,300	849.33	849.55	849.62	849.67	849.72	849.75	849.77	849.79	849.80	849.81	849.82	849.83	849.84	849.84
Unnamed Tributary 3	3,200	848.89	849.04	849.10	849.14	849.18	849.20	849.22	849.23	849.24	849.25	849.26	849.27	849.28	849.29
Unnamed Tributary 3	3,100	848.40	848.57	848.61	848.63	848.65	848.66	848.66	848.67	848.67	848.67	848.68	848.68	848.69	848.69
Unnamed Tributary 3	3,000	848.02	848.18	848.22	848.26	848.28	848.30	848.31	848.32	848.33	848.36	848.38	848.39	848.41	848.42
Unnamed Tributary 3	2,900	847.66	847.89	847.94	847.98	848.01	848.03	848.05	848.06	848.07	848.10	848.12	848.14	848.15	848.16
Unnamed Tributary 3	2,800	847.40	847.55	847.61	847.65	847.69	847.72	847.74	847.76	847.78	847.82	847.85	847.87	847.89	847.90
Unnamed Tributary 3	2,700	847.09	847.26	847.32	847.36	847.40	847.43	847.46	847.48	847.50	847.55	847.59	847.63	847.66	847.69
Unnamed Tributary 3	2,600	846.84	847.00	847.06	847.10	847.14	847.16	847.18	847.20	847.22	847.25	847.27	847.28	847.30	847.31
Unnamed Tributary 3	2,500	846.49	846.61	846.65	846.68	846.71	846.74	846.76	846.78	846.79	846.82	846.85	846.87	846.89	846.91
Unnamed Tributary 3	2,400	846.01	846.13	846.19	846.23	846.28	846.32	846.34	846.37	846.39	846.44	846.49	846.53	846.58	846.61
Unnamed Tributary 3	2,300	845.73	845.97	846.05	846.11	846.16	846.20	846.22	846.26	846.28	846.33	846.39	846.45	846.51	846.53
Unnamed Tributary 3	2,200	845.60	845.80	845.89	845.95	846.00	846.05	846.07	846.10	846.12	846.18	846.26	846.36	846.43	846.46

River	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
Unnamed Tributary 3	2,100	845.41	845.67	845.74	845.79	845.83	845.86	845.88	845.91	845.92	846.00	846.17	846.31	846.39	846.41
Unnamed Tributary 3	2,000	845.22	845.33	845.38	845.43	845.48	845.52	845.55	845.61	845.68	845.94	846.16	846.30	846.38	846.41
Unnamed Tributary 3	1,900	844.68	844.97	845.13	845.26	845.34	845.40	845.44	845.53	845.62	845.93	846.16	846.30	846.38	846.41
Unnamed Tributary 3	1,800	844.62	844.89	845.09	845.23	845.31	845.35	845.40	845.50	845.60	845.93	846.16	846.30	846.38	846.41
Unnamed Tributary 3	1,700	844.51	844.79	844.94	845.04	845.15	845.27	845.35	845.48	845.60	845.93	846.16	846.30	846.38	846.41
Unnamed Tributary 3	1,600	844.46	844.74	844.89	845.00	845.13	845.26	845.34	845.48	845.60	845.93	846.16	846.30	846.38	846.41
Unnamed Tributary 3	1,500	844.36	844.71	844.86	844.97	845.11	845.24	845.33	845.47	845.59	845.93	846.15	846.30	846.38	846.41
Unnamed Tributary 3	1,400	844.34	844.67	844.82	844.94	845.08	845.22	845.31	845.46	845.58	845.92	846.15	846.30	846.38	846.40
Unnamed Tributary 3	1,300	844.07	844.36	844.54	844.68	844.85	845.00	845.11	845.26	845.38	845.69	845.86	845.98	846.07	846.09
Unnamed Tributary 3	1,200	843.81	844.29	844.49	844.65	844.83	844.98	845.09	845.25	845.37	845.68	845.86	845.98	846.07	846.09
Unnamed Tributary 3	1,100	843.63	844.28	844.47	844.64	844.81	844.97	845.08	845.24	845.36	845.68	845.86	845.97	846.07	846.09
Unnamed Tributary 3	1,000	843.67	844.27	844.46	844.63	844.80	844.96	845.07	845.23	845.35	845.67	845.86	845.97	846.06	846.09
Unnamed Tributary 3	900	843.62	844.14	844.36	844.53	844.69	844.83	844.91	845.04	845.15	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	800	843.45	844.13	844.35	844.52	844.68	844.82	844.91	845.04	845.14	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	700	843.26	844.13	844.35	844.51	844.68	844.81	844.90	845.04	845.14	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	600	843.15	844.13	844.34	844.51	844.67	844.81	844.90	845.04	845.14	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	500	843.08	844.13	844.34	844.50	844.67	844.81	844.90	845.04	845.14	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	400	843.10	844.12	844.34	844.50	844.66	844.80	844.90	845.04	845.14	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	300	843.10	844.12	844.34	844.50	844.66	844.80	844.89	845.03	845.14	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	200	843.11	844.12	844.33	844.49	844.65	844.80	844.89	845.03	845.14	845.49	845.76	845.93	846.04	846.07
Unnamed Tributary 3	100	843.25	844.12	844.33	844.48	844.65	844.79	844.89	845.03	845.14	845.49	845.75	845.93	846.04	846.07
Unnamed Tributary 3	0	843.52	844.11	844.31	844.46	844.62	844.77	844.87	845.01	845.12	845.48	845.75	845.92	846.04	846.07

Table F-6 Unnamed Tributary 4 Profiles

River	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
Unnamed Tributary 4	2,800	875.27	875.35	875.38	875.40	875.43	875.44	875.46	875.47	875.48	875.50	875.52	875.53	875.55	875.55
Unnamed Tributary 4	2,700	873.98	874.03	874.06	874.08	874.10	874.12	874.13	874.14	874.15	874.18	874.20	874.21	874.22	874.23
Unnamed Tributary 4	2,600	872.55	872.59	872.61	872.63	872.65	872.67	872.68	872.69	872.70	872.72	872.74	872.75	872.76	872.77
Unnamed Tributary 4	2,500	871.11	871.18	871.21	871.23	871.26	871.27	871.28	871.30	871.31	871.33	871.35	871.36	871.38	871.39
Unnamed Tributary 4	2,400	869.52	869.63	869.67	869.69	869.72	869.74	869.75	869.76	869.77	869.79	869.81	869.82	869.83	869.84
Unnamed Tributary 4	2,300	868.74	868.79	868.81	868.83	868.85	868.86	868.87	868.89	868.89	868.92	868.93	868.95	868.96	868.97
Unnamed Tributary 4	2,200	867.83	867.91	867.94	867.96	867.98	868.00	868.01	868.03	868.03	868.06	868.08	868.09	868.11	868.12
Unnamed Tributary 4	2,100	867.04	867.11	867.14	867.16	867.17	867.19	867.20	867.21	867.22	867.24	867.26	867.27	867.28	867.29
Unnamed Tributary 4	2,000	866.58	866.69	866.72	866.75	866.77	866.79	866.80	866.82	866.83	866.85	866.87	866.89	866.91	866.92
Unnamed Tributary 4	1,900	866.07	866.18	866.22	866.25	866.28	866.30	866.32	866.34	866.35	866.38	866.41	866.43	866.45	866.46
Unnamed Tributary 4	1,800	864.68	864.77	864.82	864.85	864.88	864.91	864.92	864.94	864.96	864.99	865.01	865.03	865.06	865.07
Unnamed Tributary 4	1,700	863.20	863.48	863.67	863.85	864.04	864.10	864.13	864.16	864.18	864.23	864.26	864.28	864.31	864.32
Unnamed Tributary 4	1,600	862.25	862.60	862.66	862.69	862.73	862.76	862.78	862.81	862.83	862.89	862.94	862.97	863.01	863.03
Unnamed Tributary 4	1,500	861.74	861.90	861.95	862.03	862.15	862.27	862.35	862.46	862.55	862.72	862.78	862.82	862.85	862.87
Unnamed Tributary 4	1,400	861.07	861.12	861.15	861.17	861.20	861.21	861.23	861.24	861.25	861.28	861.30	861.32	861.34	861.35
Unnamed Tributary 4	1,300	860.11	860.22	860.25	860.28	860.31	860.33	860.34	860.36	860.38	860.41	860.44	860.46	860.48	860.50
Unnamed Tributary 4	1,200	859.24	859.40	859.45	859.48	859.52	859.54	859.56	859.58	859.59	859.63	859.66	859.69	859.72	859.73
Unnamed Tributary 4	1,100	858.48	858.61	858.66	858.70	858.74	858.77	858.79	858.81	858.83	858.87	858.90	858.92	858.94	858.95
Unnamed Tributary 4	1,000	857.72	857.83	857.88	857.91	857.95	857.98	858.00	858.02	858.04	858.07	858.10	858.12	858.15	858.16
Unnamed Tributary 4	900	856.61	856.83	856.92	856.97	857.01	857.04	857.06	857.09	857.11	857.16	857.20	857.23	857.26	857.27
Unnamed Tributary 4	800	855.68	855.88	855.98	856.04	856.10	856.14	856.17	856.20	856.22	856.28	856.32	856.34	856.37	856.39
Unnamed Tributary 4	700	854.95	855.10	855.15	855.19	855.25	855.32	855.37	855.46	855.52	855.69	855.76	855.80	855.83	855.85
Unnamed Tributary 4	600	853.54	853.77	853.86	853.93	854.00	854.05	854.08	854.12	854.15	854.21	854.23	854.24	854.25	854.26
Unnamed Tributary 4	500	852.23	852.54	852.63	852.70	852.78	852.83	852.87	852.92	852.95	853.02	853.05	853.06	853.07	853.07
Unnamed Tributary 4	400	851.14	851.50	851.60	851.68	851.76	851.82	851.86	851.91	851.94	852.01	852.04	852.05	852.06	852.06
Unnamed Tributary 4	300	850.40	850.95	851.00	851.05	851.09	851.12	851.14	851.16	851.17	851.19	851.20	851.20	851.21	851.21
Unnamed Tributary 4	200	850.57	850.58	850.59	850.60	850.61	850.62	850.62	850.63	850.63	850.65	850.74	850.75	850.76	850.77
Unnamed Tributary 4	100	849.73	849.76	849.78	849.79	849.80	849.81	849.81	849.82	849.83	849.84	849.85	849.86	849.87	849.87
Unnamed Tributary 4	0	849.28	849.34	849.34	849.34	849.34	849.34	849.34	849.34	849.34	849.34	849.34	849.34	849.34	849.34

Table F-7 Unnamed Tributary 5 Profiles

River	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
Unnamed Tributary 5	700	872.90	873.04	873.09	873.12	873.16	873.19	873.21	873.23	873.25	873.29	873.32	873.35	873.37	873.39
Unnamed Tributary 5	600	870.88	871.05	871.11	871.16	871.20	871.23	871.25	871.27	871.29	871.34	871.38	871.40	871.43	871.45
Unnamed Tributary 5	500	869.25	869.45	869.52	869.57	869.62	869.66	869.69	869.72	869.74	869.79	869.83	869.86	869.90	869.92
Unnamed Tributary 5	400	868.25	868.38	868.43	868.47	868.50	868.53	868.55	868.57	868.59	868.63	868.66	868.68	868.70	868.72
Unnamed Tributary 5	300	867.05	867.24	867.28	867.31	867.33	867.35	867.36	867.37	867.38	867.39	867.40	867.41	867.42	867.43
Unnamed Tributary 5	200	866.12	866.21	866.23	866.24	866.26	866.27	866.28	866.29	866.30	866.32	866.33	866.34	866.36	866.36
Unnamed Tributary 5	100	865.19	865.21	865.23	865.25	865.26	865.27	865.28	865.29	865.29	865.31	865.32	865.33	865.34	865.35
Unnamed Tributary 5	0	863.84	863.95	863.99	864.02	864.09	864.13	864.16	864.19	864.21	864.26	864.29	864.31	864.33	864.35

Table F-8 Unnamed Tributary 6 Profiles

River	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
Unnamed Tributary 6	500	874.26	874.35	874.39	874.41	874.44	874.46	874.47	874.49	874.50	874.53	874.55	874.56	874.58	874.59
Unnamed Tributary 6	400	873.27	873.42	873.47	873.50	873.53	873.55	873.56	873.58	873.59	873.61	873.63	873.64	873.65	873.59
Unnamed Tributary 6	300	872.15	872.33	872.42	872.47	872.52	872.56	872.59	872.62	872.64	872.68	872.70	872.72	872.74	872.64
Unnamed Tributary 6	200	871.07	871.15	871.20	871.23	871.26	871.28	871.29	871.31	871.32	871.35	871.37	871.38	871.40	871.32
Unnamed Tributary 6	100	868.94	869.10	869.16	869.21	869.25	869.29	869.32	869.35	869.37	869.43	869.47	869.50	869.54	869.37
Unnamed Tributary 6	0	866.95	867.08	867.16	867.21	867.27	867.32	867.35	867.40	867.42	867.50	867.55	867.60	867.65	867.42

Appendix G

Open Water Sensitivity Analysis

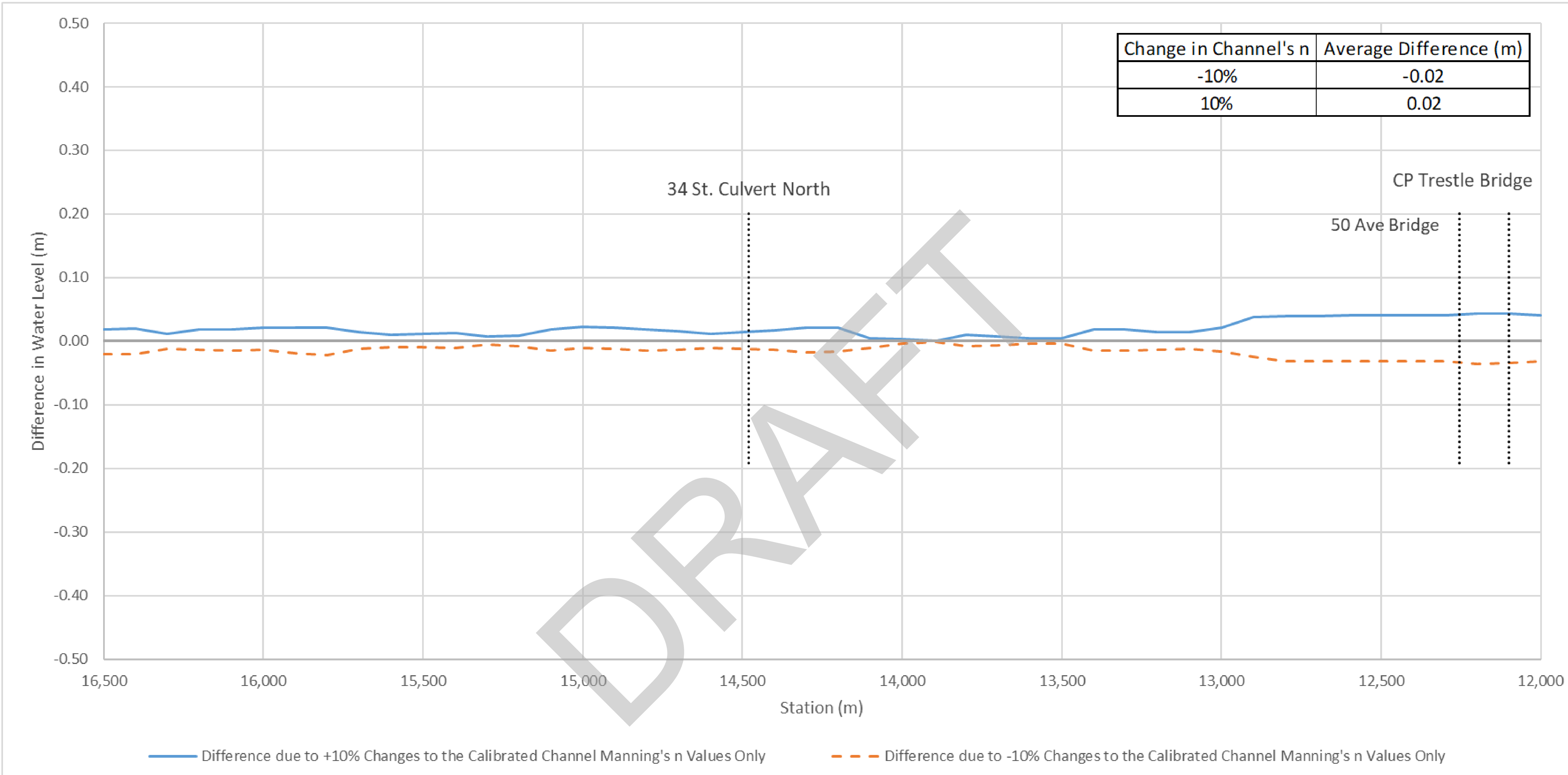


Figure G-1 Sensitivity of Simulated Water Level Along Upper Wolf Creek (Station 16,500 m to 11,900 m) (Channel Manning's n Only)

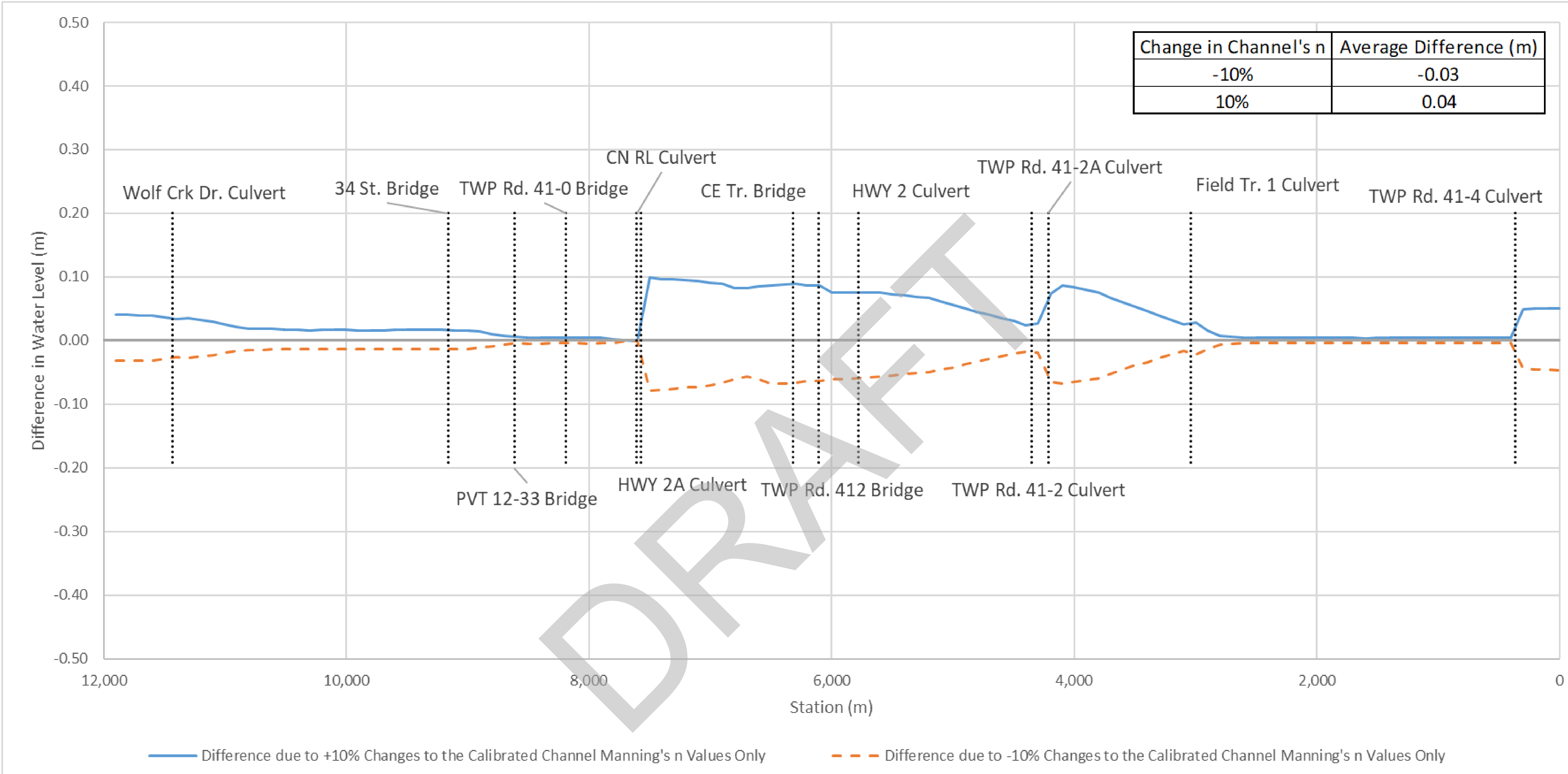


Figure G-2 Sensitivity of Simulated Water Level Along Lower Wolf Creek (Station 11,900 m to 0 m) (Channel Manning's n Only)

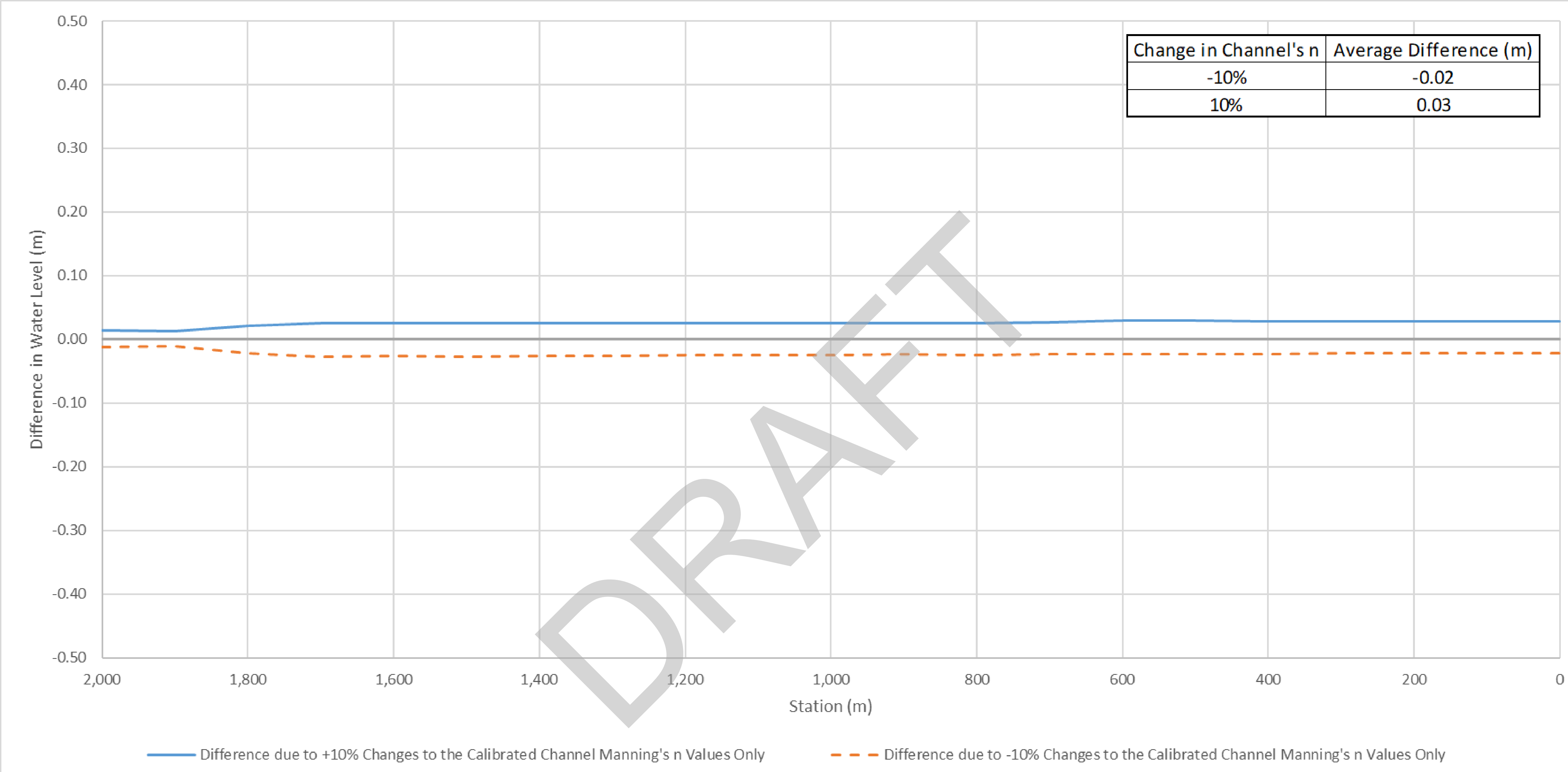


Figure G-3 Sensitivity of Simulated Water Level Along Unnamed Tributary 1 (Channel Manning's n Only)

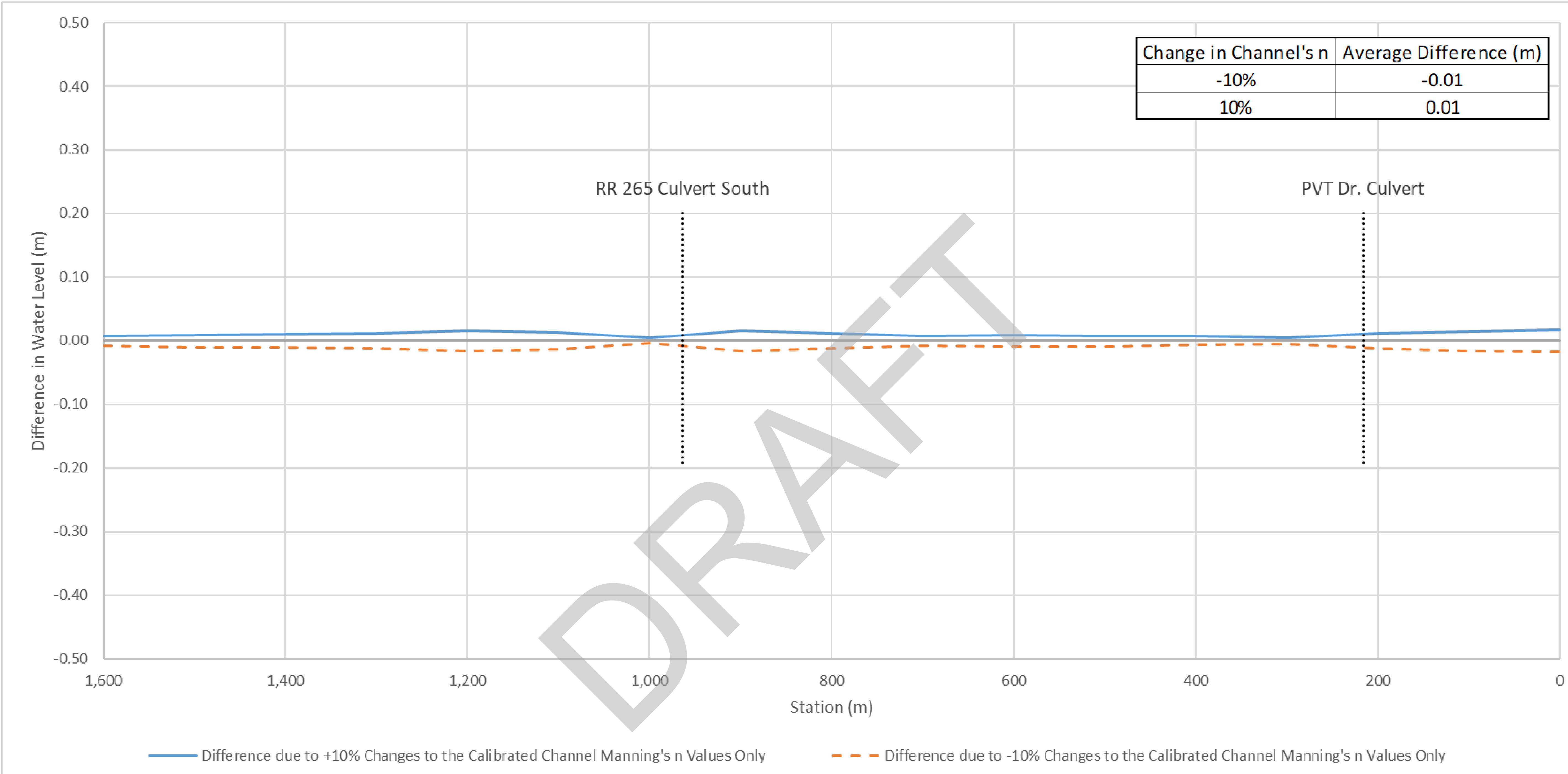


Figure G-4 Sensitivity of Simulated Water Level Along Unnamed Tributary 2 (Channel Manning's n Only)

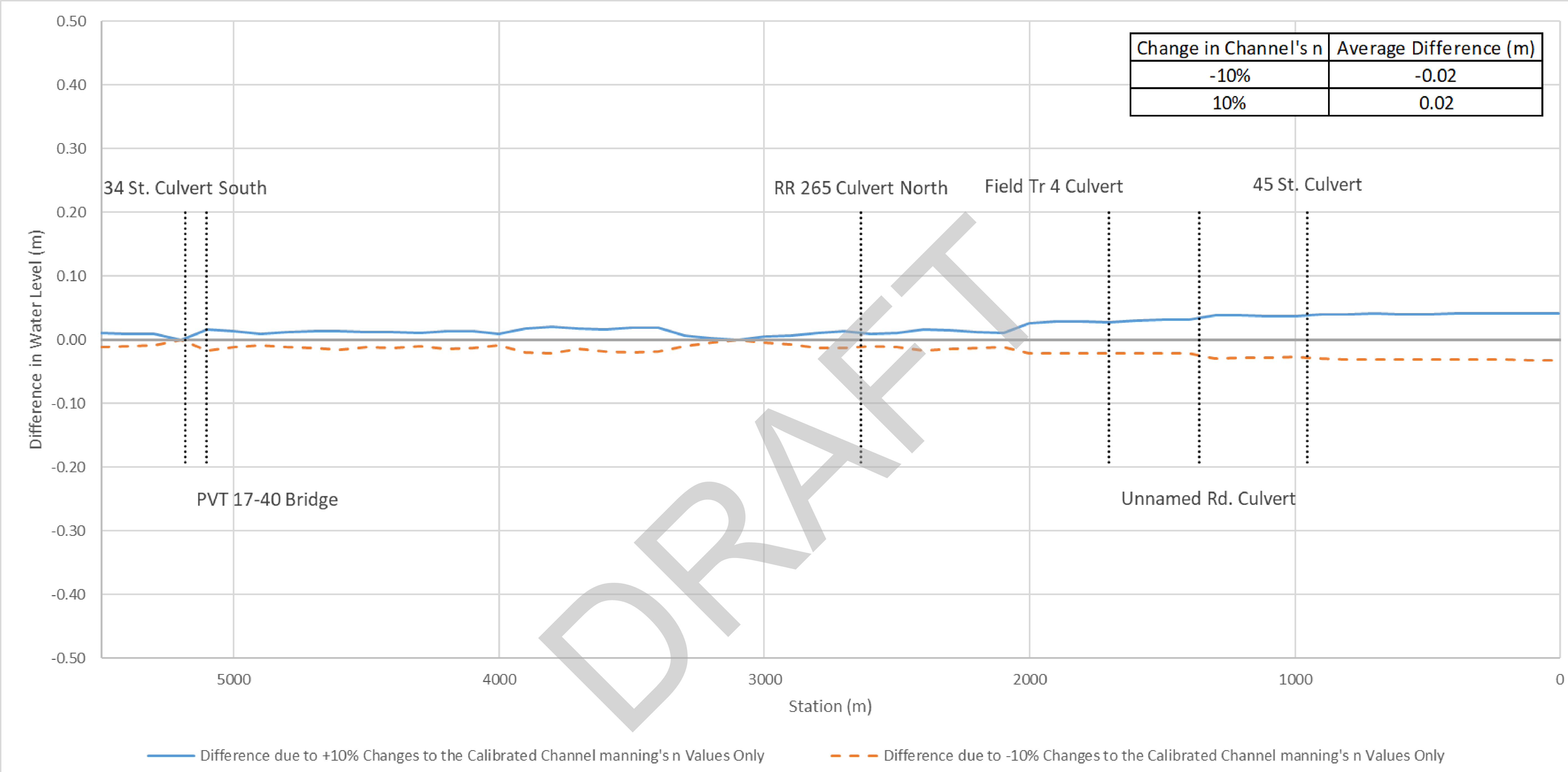


Figure G-5 Sensitivity of Simulated Water Level Along Unnamed Tributary 3 (Channel Manning's n Only)

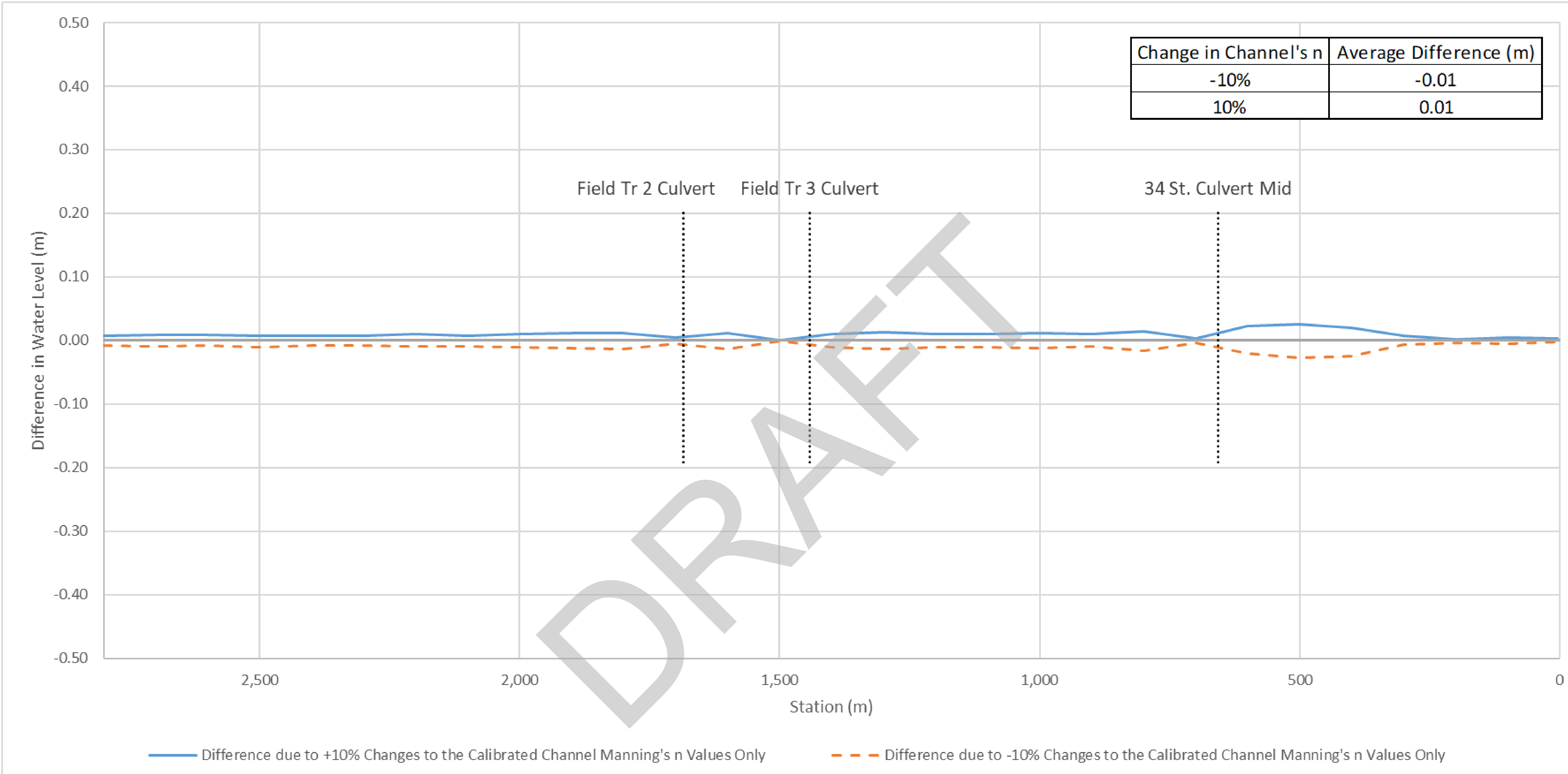


Figure G-6 Sensitivity of Simulated Water Level Along Unnamed Tributary 4 (Channel Manning's n Only)

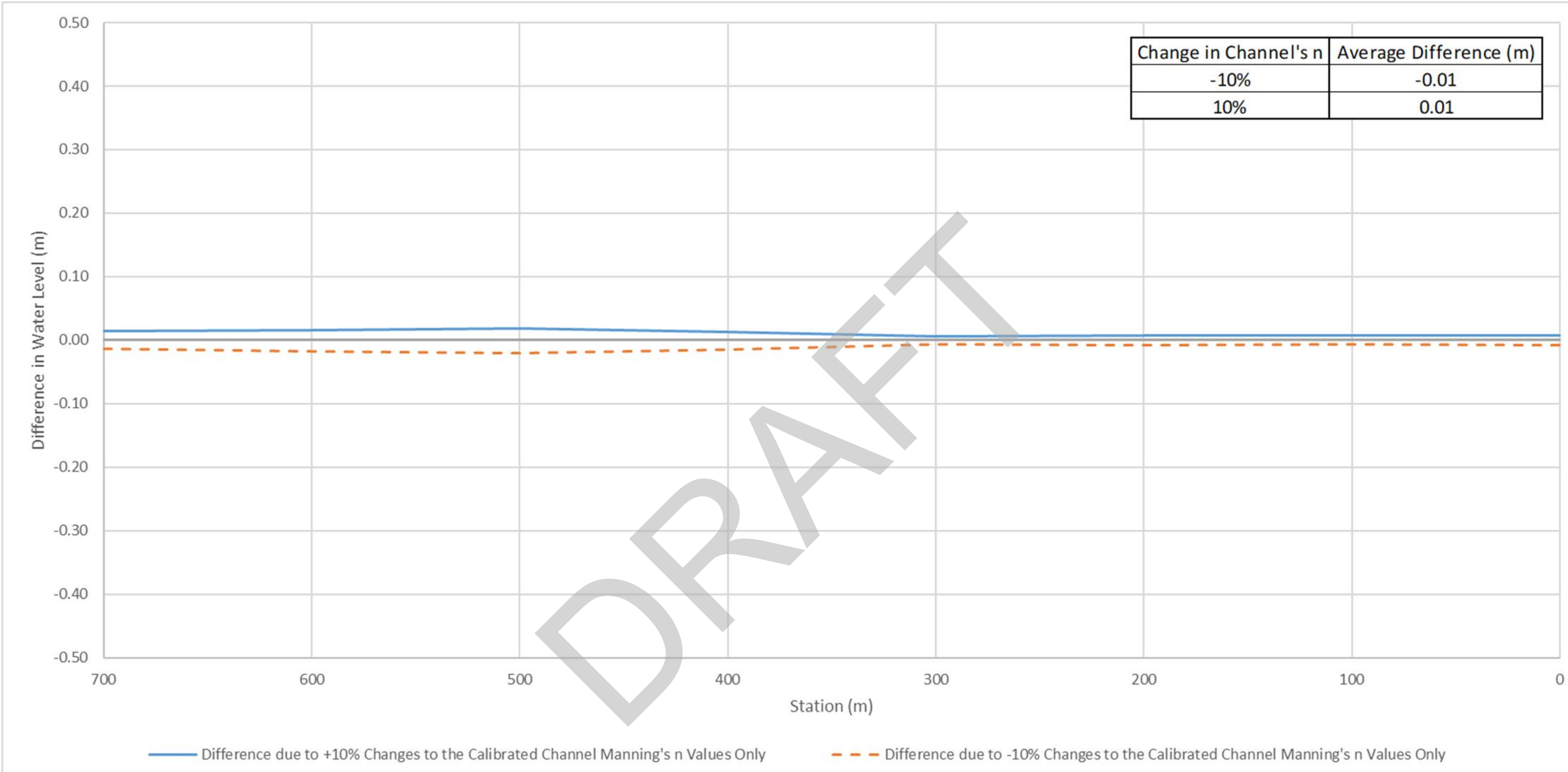


Figure G-7 Sensitivity of Simulated Water Level Along Unnamed Tributary 5 (Channel Manning's n Only)

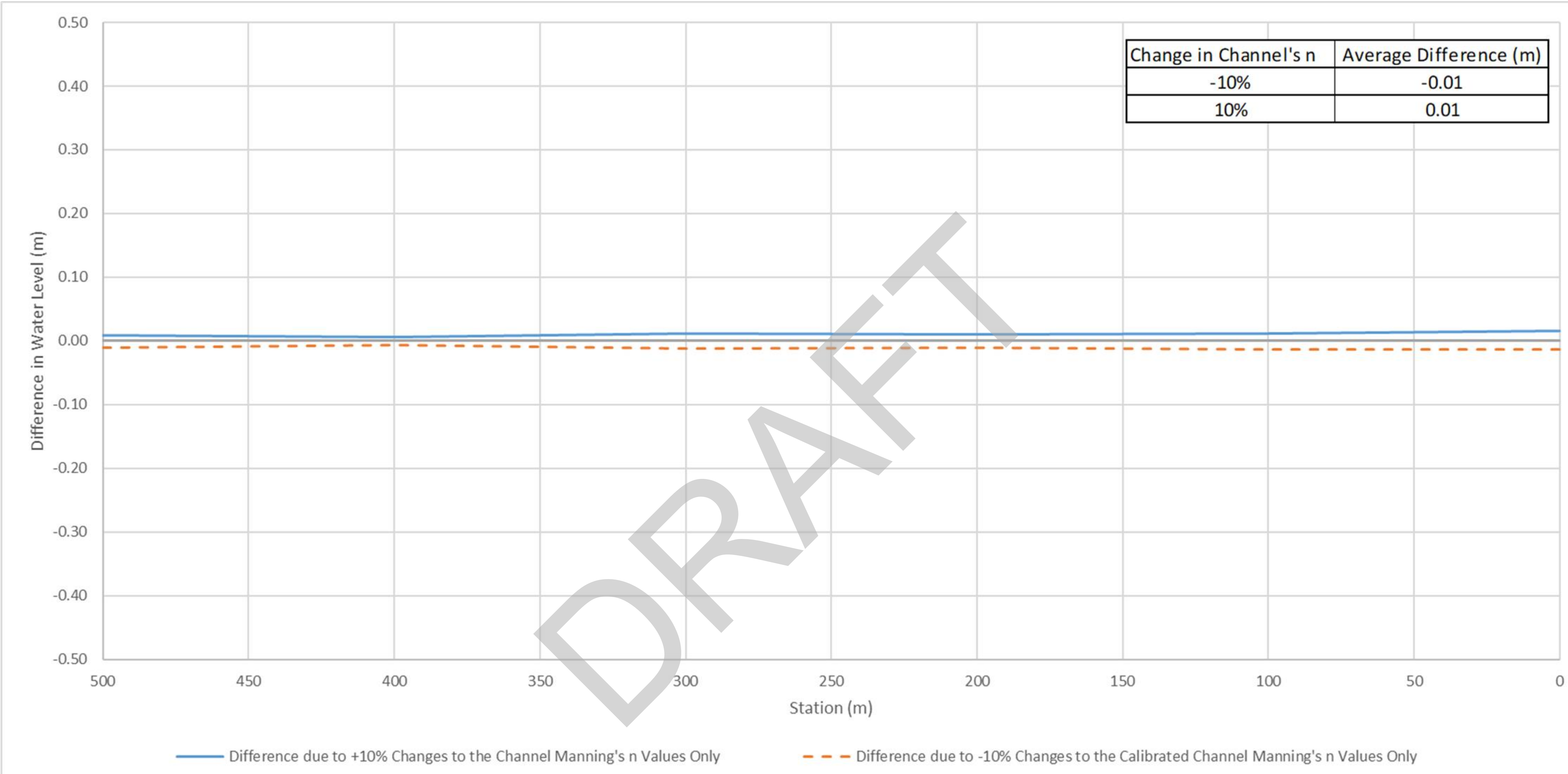


Figure G-8 Sensitivity of Simulated Water Level Along Unnamed Tributary 6 (Channel Manning's n Only)

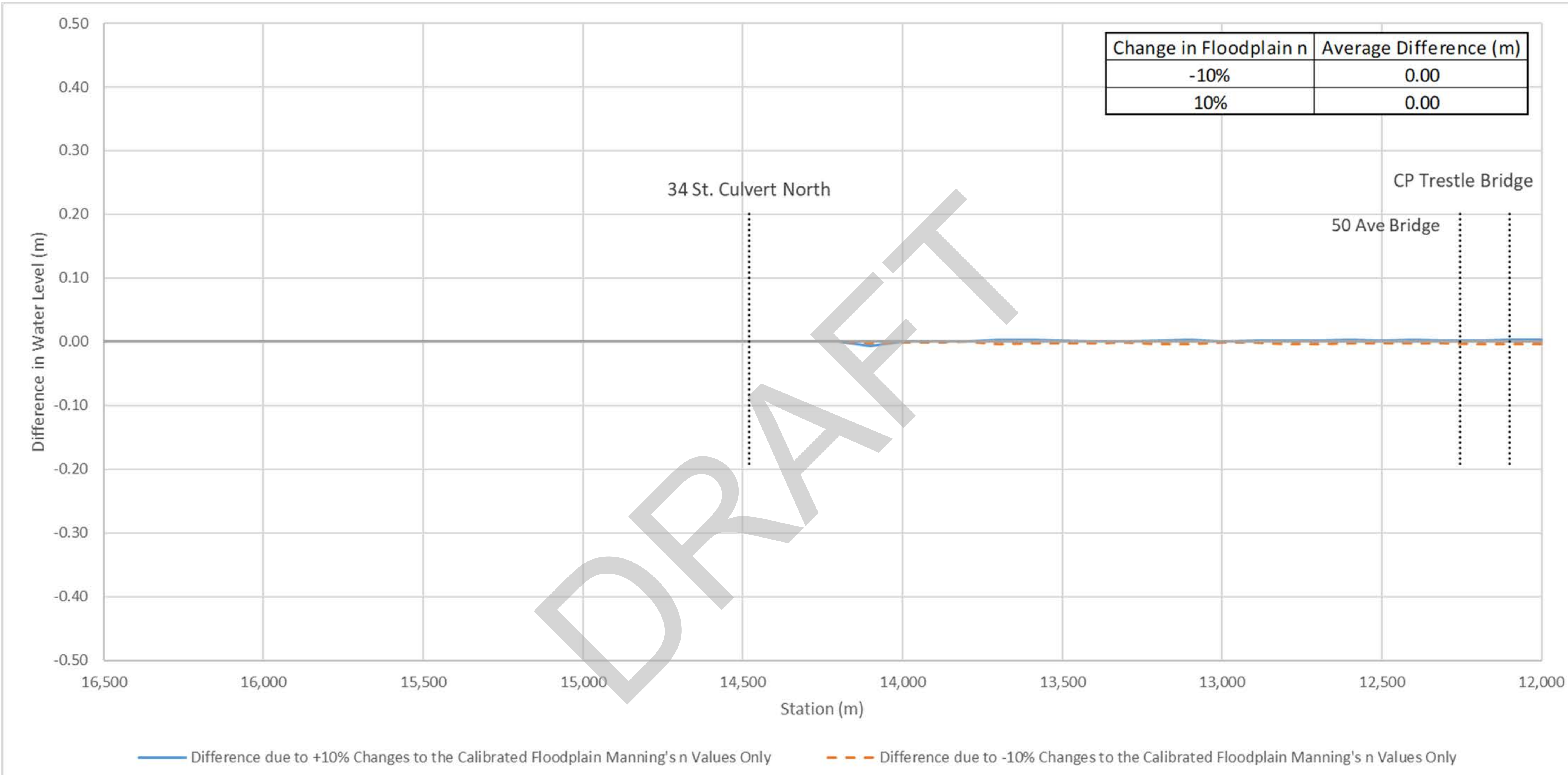


Figure G-9 Sensitivity of Simulated Water Level Along Upper Wolf Creek (Station 16,500 m to 11,900 m) (Floodplain Manning's n Only)

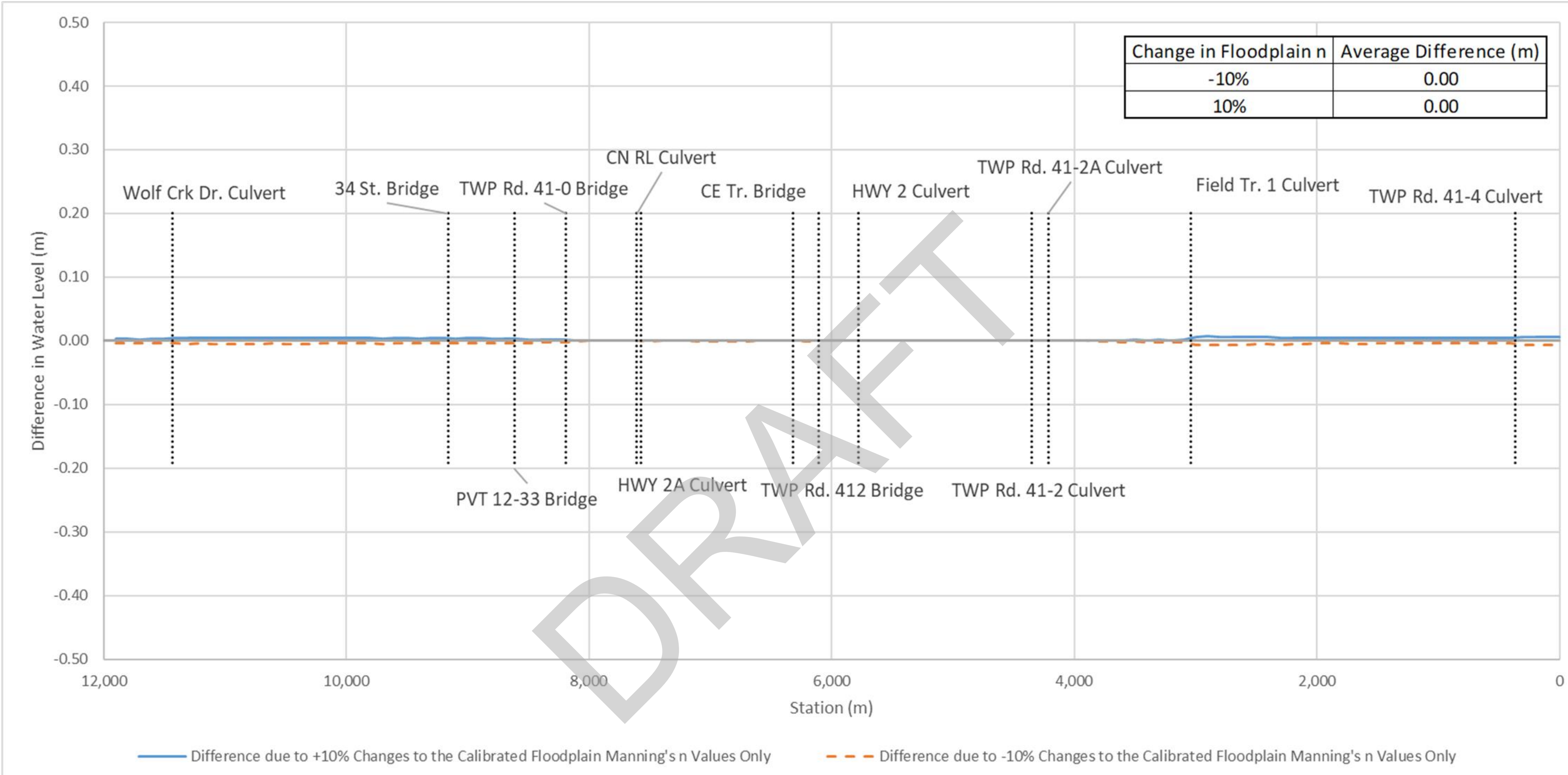


Figure G-10 Sensitivity of Simulated Water Level Along Lower Wolf Creek (Station 11,900 m to 0 m) (Floodplain Manning's n Only)

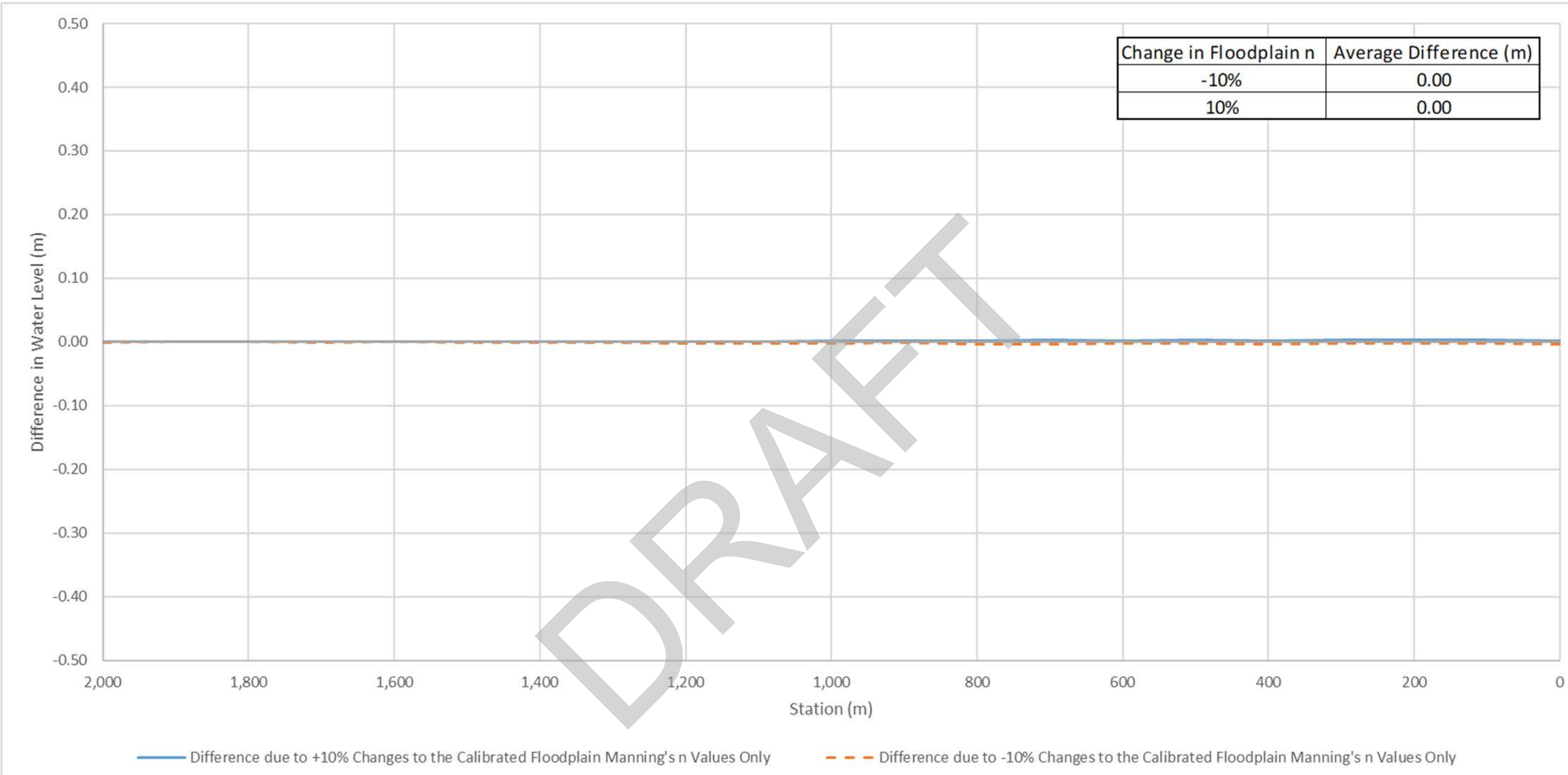


Figure G-11 Sensitivity of Simulated Water Level Along Unnamed Tributary 1 (Floodplain Manning's n Only)

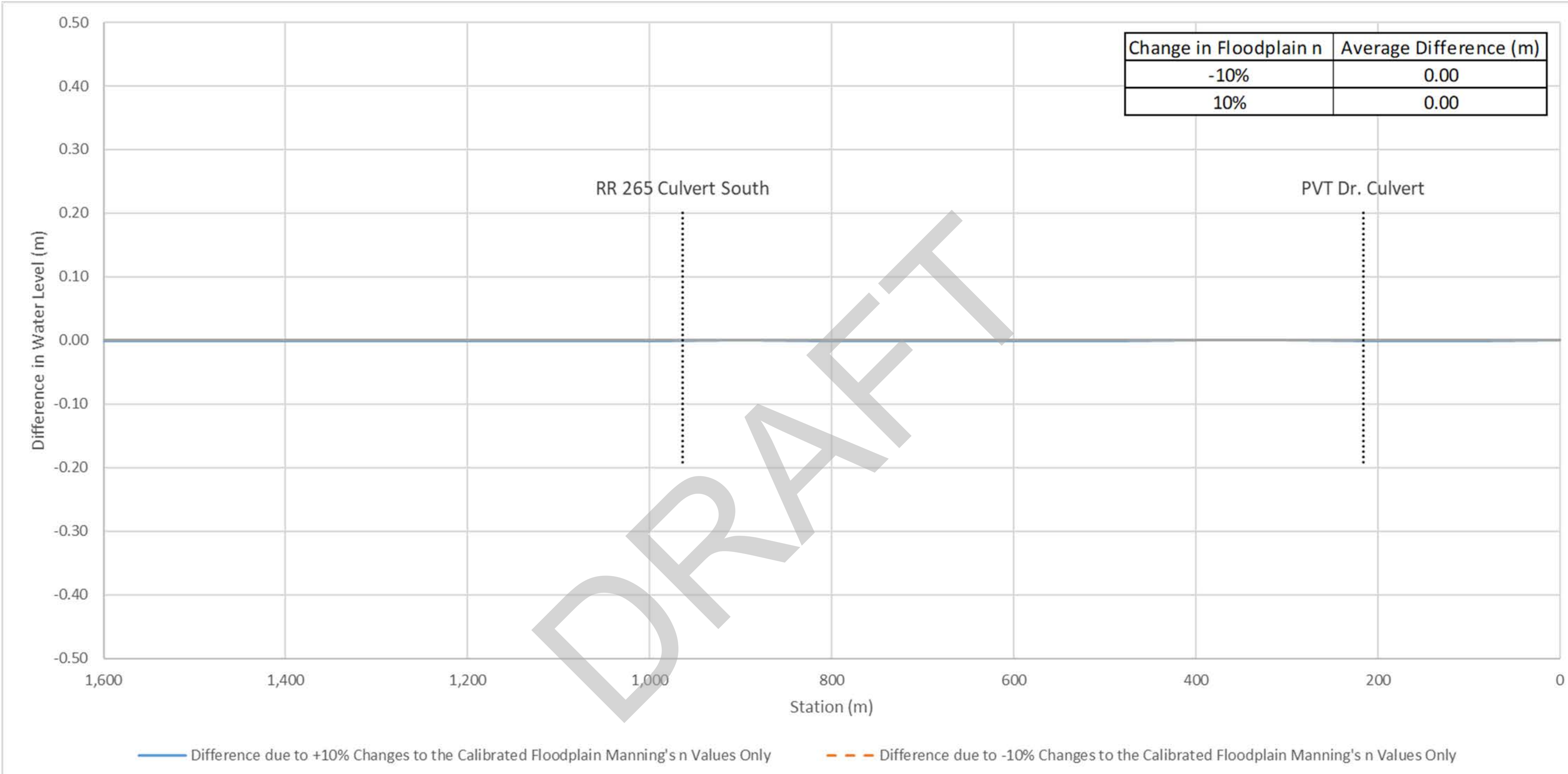


Figure G-12 Sensitivity of Simulated Water Level Along Unnamed Tributary 2 (Floodplain Manning's n Only)

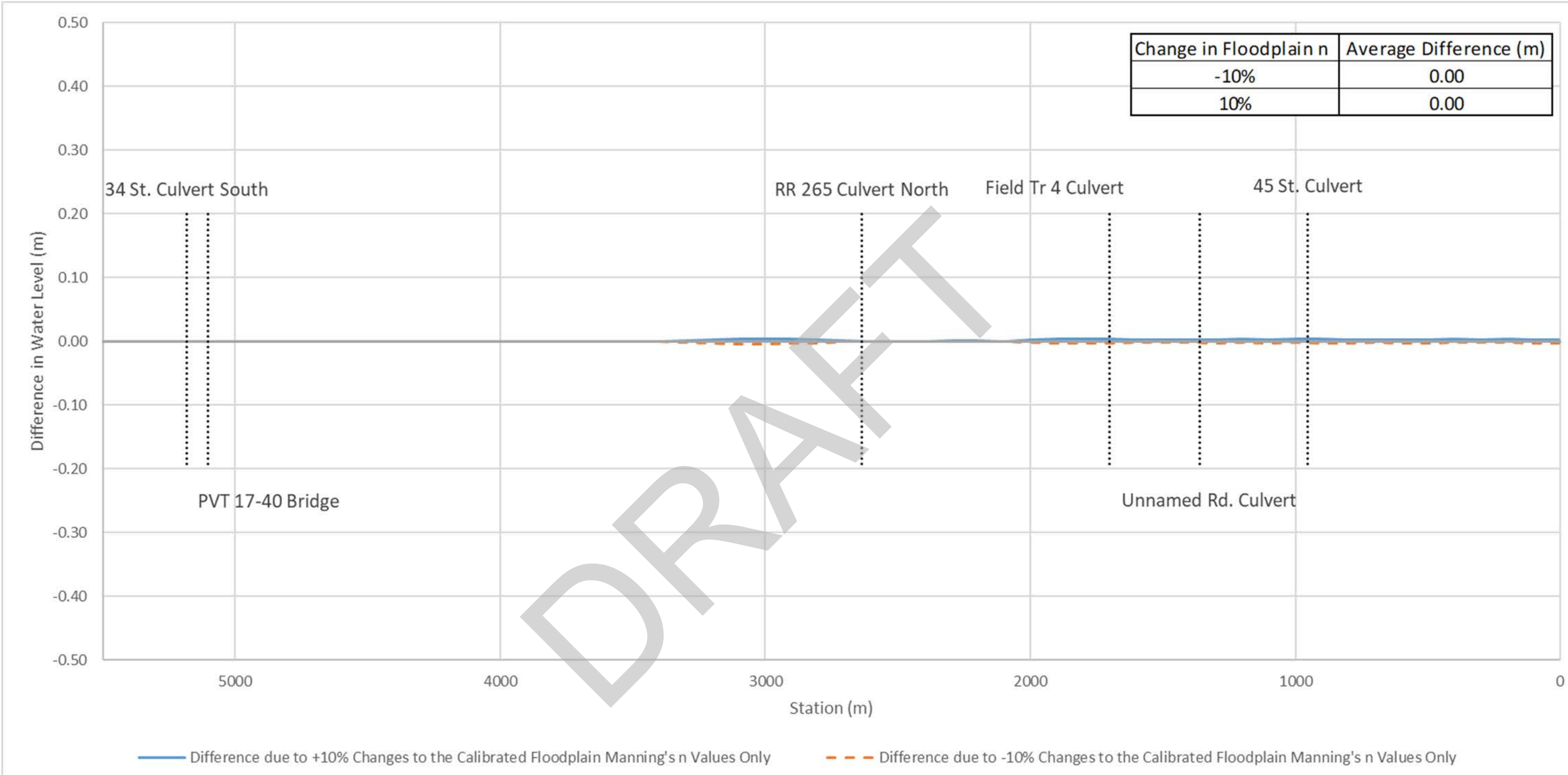


Figure G-13 Sensitivity of Simulated Water Level Along Unnamed Tributary 3 (Floodplain Manning's n Only)

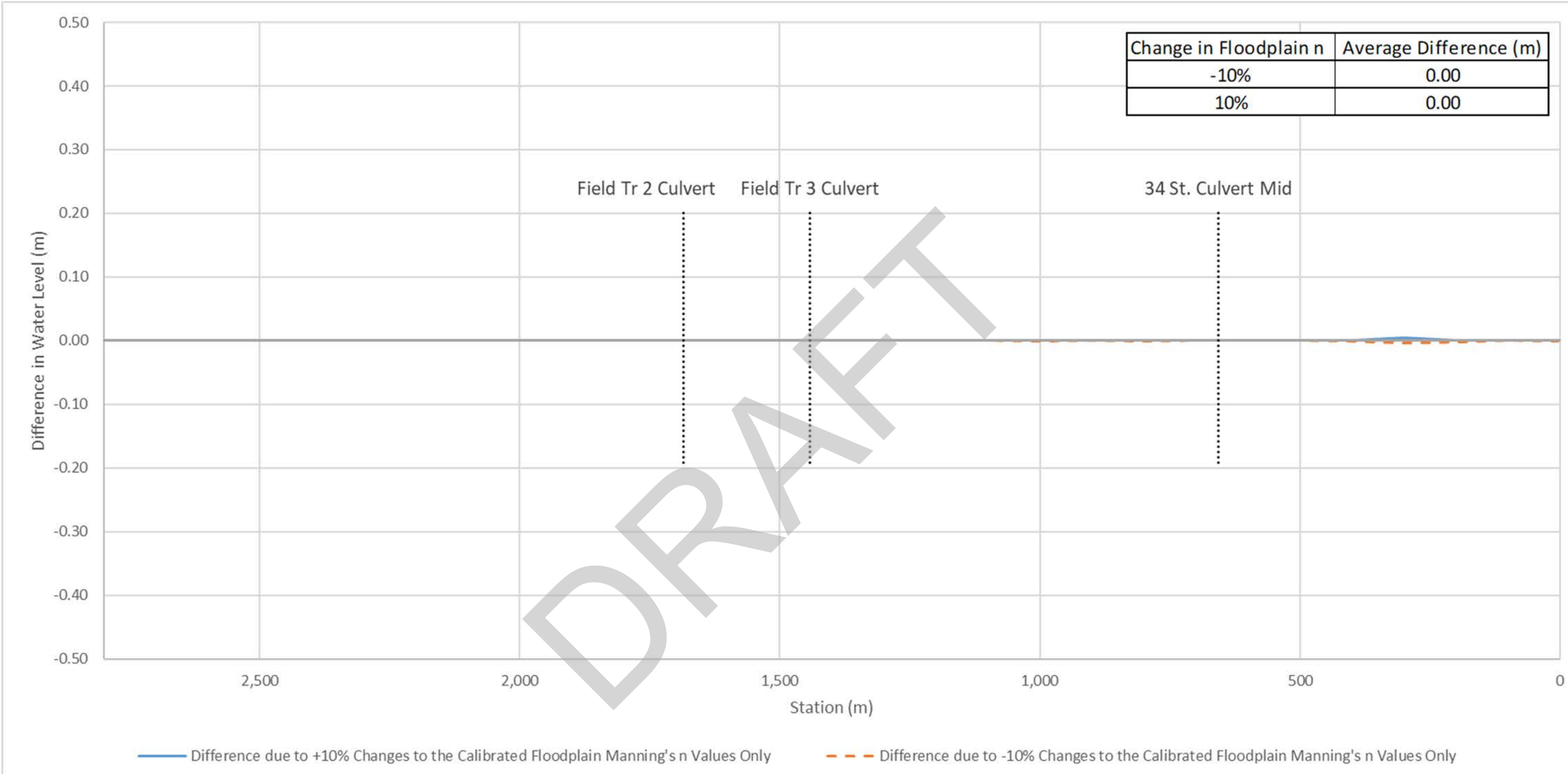


Figure G-14 Sensitivity of Simulated Water Level Along Unnamed Tributary 4 (Floodplain Manning's n Only)

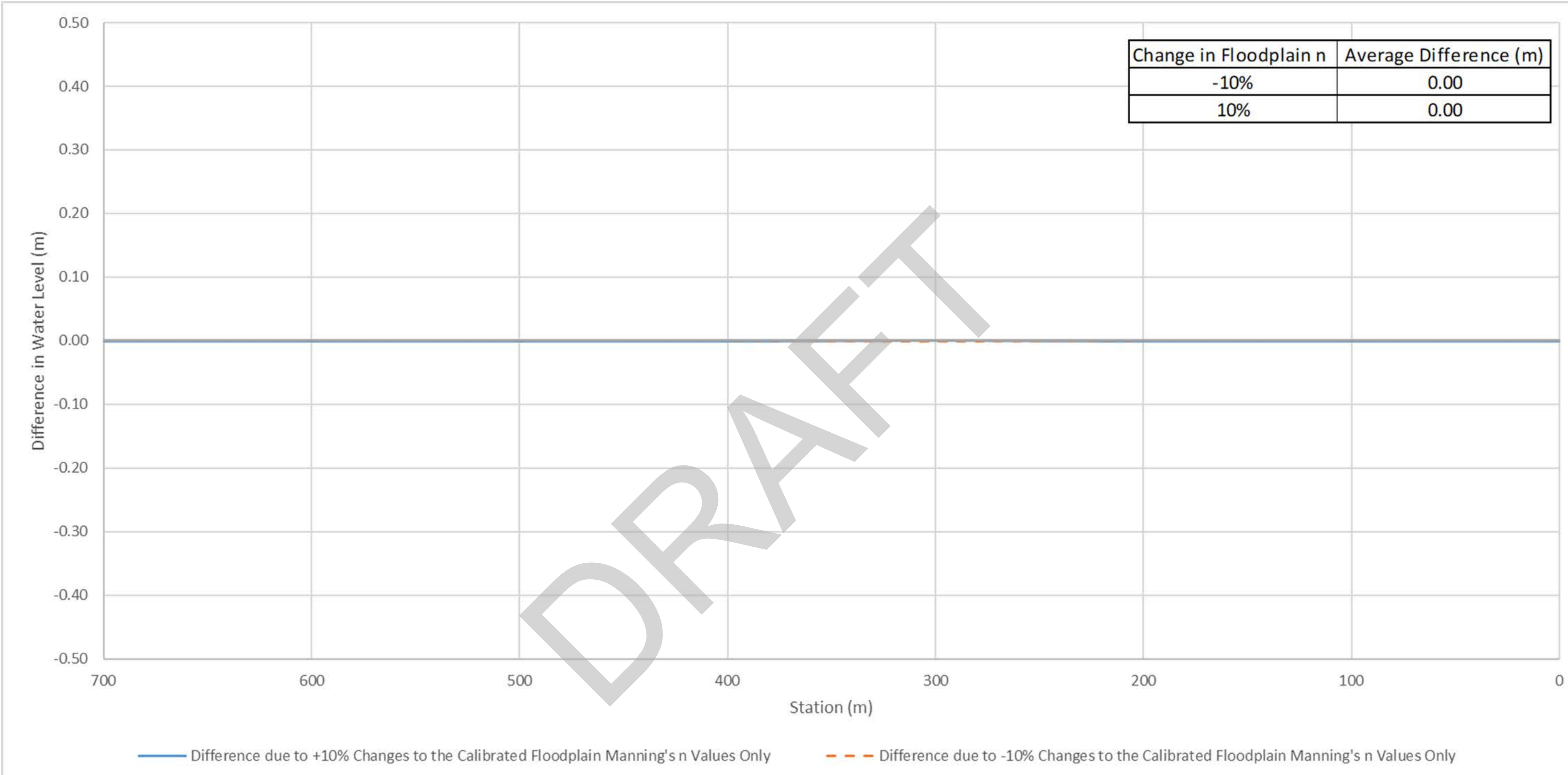


Figure G-15 Sensitivity of Simulated Water Level Along Unnamed Tributary 5 (Floodplain Manning's n Only)

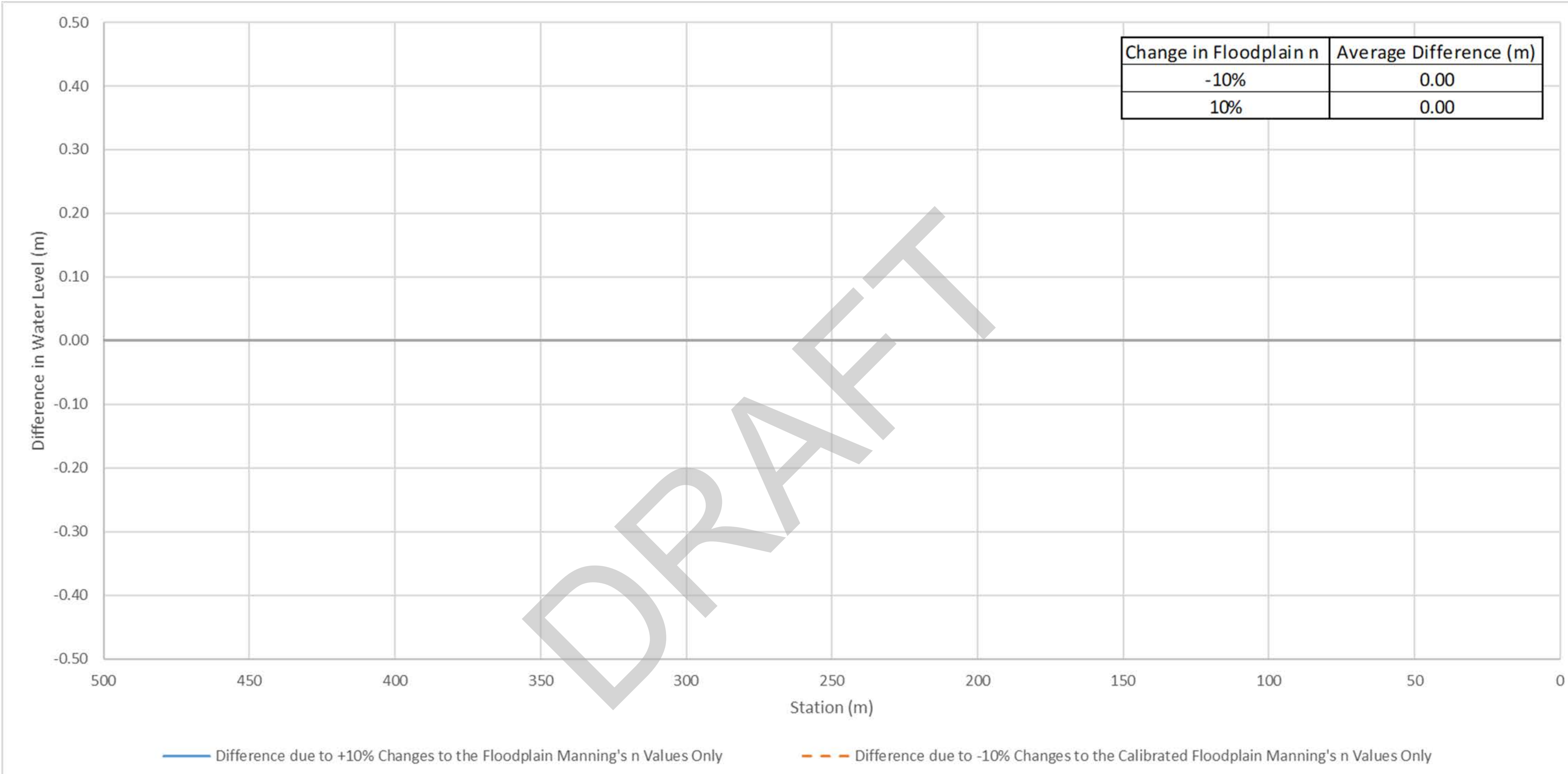


Figure G-16 Sensitivity of Simulated Water Level Along Unnamed Tributary 6 (Floodplain Manning's n Only)

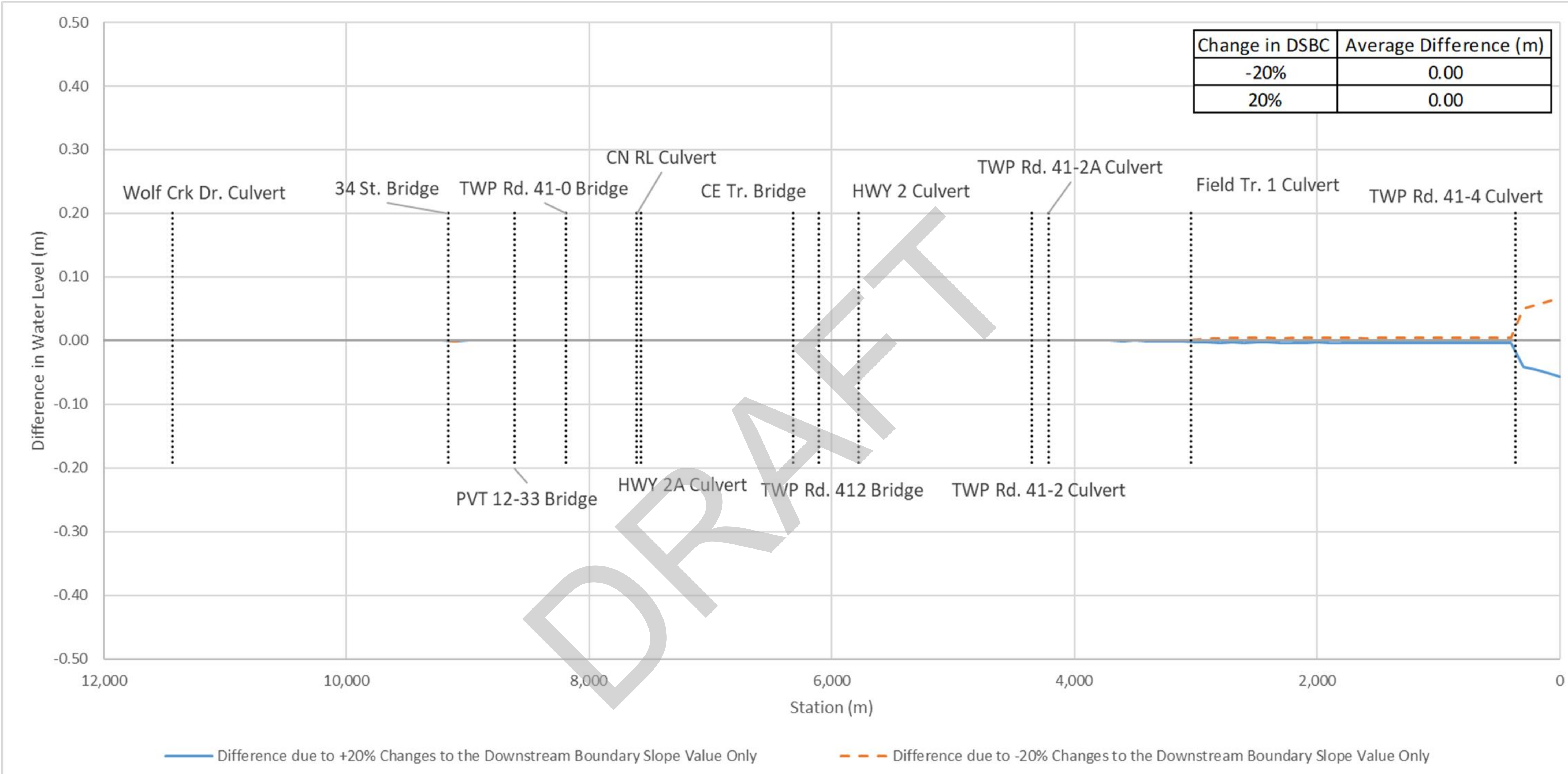


Figure G-17 Sensitivity of Simulated Water Level Along Lower Wolf Creek (Station 11,900 m to 0 m) (Downstream Boundary)

Appendix H

Open Water Inundation Maps

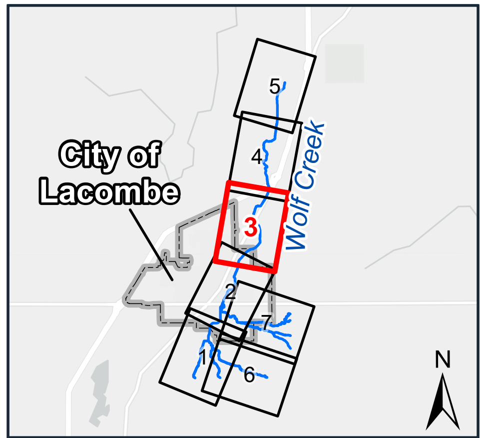
Provided separately in the map library

Appendix I

Floodway Criteria Maps and Flood Hazard Maps

Classification: Public

Classification: Public



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- MODEL CROSS SECTION
- BANK STATION
- CITY OF LACOMBE BOUNDARY
- PREVIOUS FLOODWAY
- PROPOSED FLOODWAY BOUNDARY
- PROTECTED FLOOD AREA
- 100-YEAR OPEN WATER DESIGN FLOOD EXTENT
- DEPTH ≥ 1M
- VELOCITY ≥ 1M/S

Alberta

Canada

DISCHARGE

Wolf Creek u/s of RS 9,805 = 10.62 m^3/s

Wolf Creek d/s of RS 9,805 = 17.91 m^3/s

0 100 200 300

Metres

Scale: 1:10,000

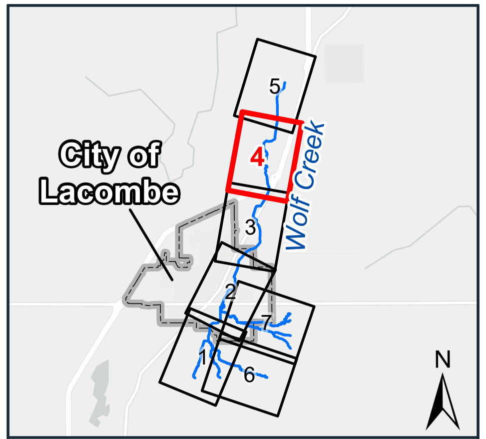
Open Water Floodway Criteria Map

Lacombe Flood Study

SHEET 3 OF 7

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
MODEL CROSS SECTION
BANK STATION
CITY OF LACOMBE BOUNDARY
PREVIOUS FLOODWAY
PROPOSED FLOODWAY BOUNDARY
PROTECTED FLOOD AREA
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

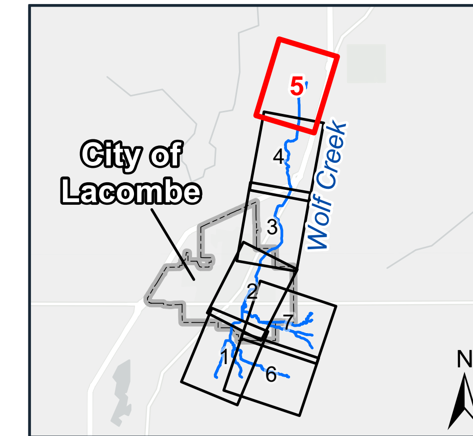
DISCHARGE
Wolf Creek u/s of RS 5,303 = 17.91 m^3/s
Wolf Creek d/s of RS 5,303 = 23.48 m^3/s

0 100 200 300
Metres
Scale: 1:10,000

Open Water Floodway Criteria Map
Lacombe Flood Study

SHEET 4 OF 7

BARR



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
MODEL CROSS SECTION
BANK STATION
CITY OF LACOMBE BOUNDARY
PREVIOUS FLOODWAY
PROPOSED FLOODWAY BOUNDARY
PROTECTED FLOOD AREA
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Wolf Creek = 23.48 m^3/s

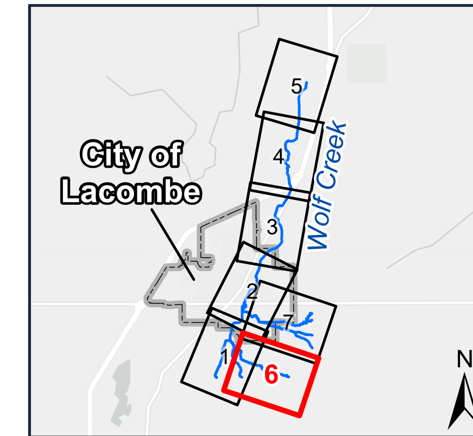
0 100 200 300
Metres
Scale: 1:10,000

Open Water Floodway Criteria Map
Lacombe Flood Study

SHEET 5 OF 7

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
BANK STATION
CITY OF LACOMBE BOUNDARY
PREVIOUS FLOODWAY
PROPOSED FLOODWAY BOUNDARY
PROTECTED FLOOD AREA
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Unnamed Tributary 2 = 1.34 m^3/s
Unnamed Tributary 3 = 1.34 m^3/s

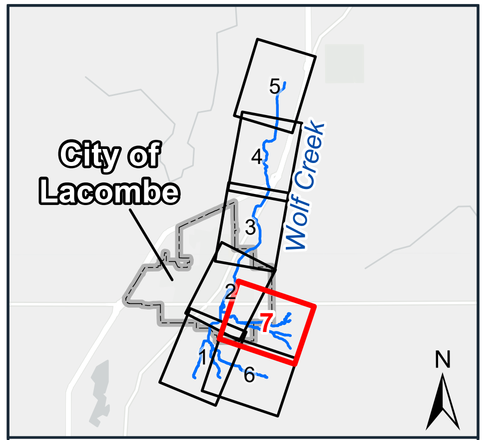
0 100 200 300
Metres
Scale: 1:10,000

Open Water Floodway Criteria Map
Lacombe Flood Study

SHEET 6 OF 7

BARR

Classification: Public



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- 2D MODEL PROFILE STATION
- BANK STATION
- CITY OF LACOMBE BOUNDARY
- PREVIOUS FLOODWAY
- PROPOSED FLOODWAY BOUNDARY
- PROTECTED FLOOD AREA
- 100-YEAR OPEN WATER DESIGN FLOOD EXTENT
- DEPTH ≥ 1M
- VELOCITY ≥ 1M/S

Alberta

Canada

DISCHARGE

Unnamed Tributary 4 u/s of RS 1,740 = 1.12 m^3/s
Unnamed Tributary 4 d/s of RS 1,740 = 2.24 m^3/s
Unnamed Tributary 5 = 1.12 m^3/s
Unnamed Tributary 6 = 0.84 m^3/s
Wolf Creek u/s of RS 16,250 = 0.84 m^3/s
Wolf Creek RS 16,250 to 13,880 = 1.68 m^3/s
Wolf Creek RS 13,880 to 13,700 = 3.92 m^3/s
Wolf Creek d/s of RS 13,700 = 4.61 m^3/s

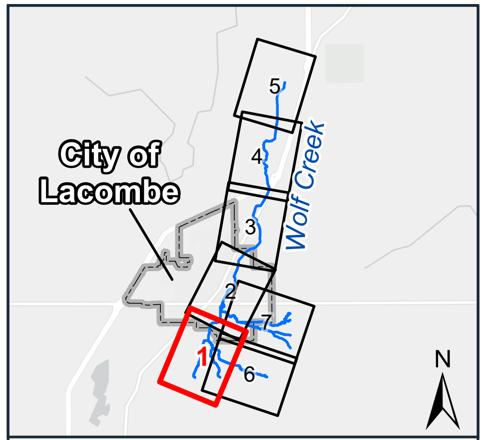
0 100 200 300
Metres
Scale: 1:10,000

Open Water Floodway Criteria Map
Lacombe Flood Study

SHEET 7 OF 7

BARR

Classification: Public



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- 2D MODEL PROFILE STATION
- CITY OF LACOMBE BOUNDARY
- FLOODWAY
- PROTECTED FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta

Canada

DISCHARGE

Unnamed Tributary 1 = 1.01 m^3/s
Unnamed Tributary 2 = 1.34 m^3/s
Unnamed Tributary 3 u/s of RS 2,380 = 1.34 m^3/s
Unnamed Tributary 3 RS 2,380 to 1,957 = 2.68 m^3/s
Unnamed Tributary 3 RS 1,957 = 3.69 m^3/s
Unnamed Tributary 3 d/s of RS 1,500 = 4.41 m^3/s

0 100 200 300 Metres

Scale: 1:10,000

Governing Design Flood Hazard Map

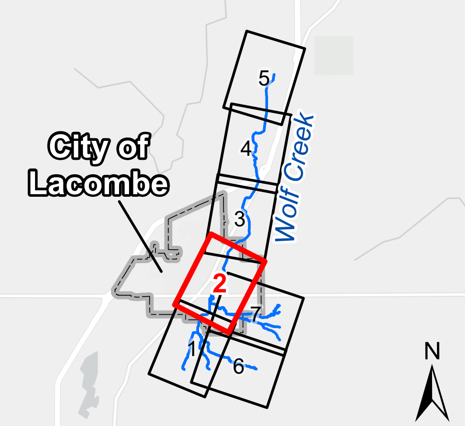
Lacombe Flood Study

SHEET 1 OF 7

BARR

Classification: Public

Barr Footer: ArcGISPro 3.3.2, 2025-03-19 11:28 File: I:\Client\Alberta_AEP\Work_Orders\61011343_Lacombe_Flood_Study\Maps\Final_Inundation_Maps\Lacombe Inundation Maps.aprx Layout: Flood Hazard Map User: EMA



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- MODEL CROSS SECTION
- 2D MODEL PROFILE STATION
- CITY OF LACOMBE BOUNDARY
- FLOODWAY
- PROTECTED FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta

Canada

DISCHARGE

Unnamed Tributary 3 = 4.41 m^3/s
Unnamed Tributary 4 = 2.24 m^3/s
Wolf Creek u/s of RS 13,880 = 1.68 m^3/s
Wolf Creek RS 13,880 to 13,700 = 3.92 m^3/s
Wolf Creek RS 13,700 to 12,220 = 4.61 m^3/s
Wolf Creek RS 12,220 to 11,767 = 9.02 m^3/s
Wolf Creek d/s of RS 11,767 = 10.62 m^3/s

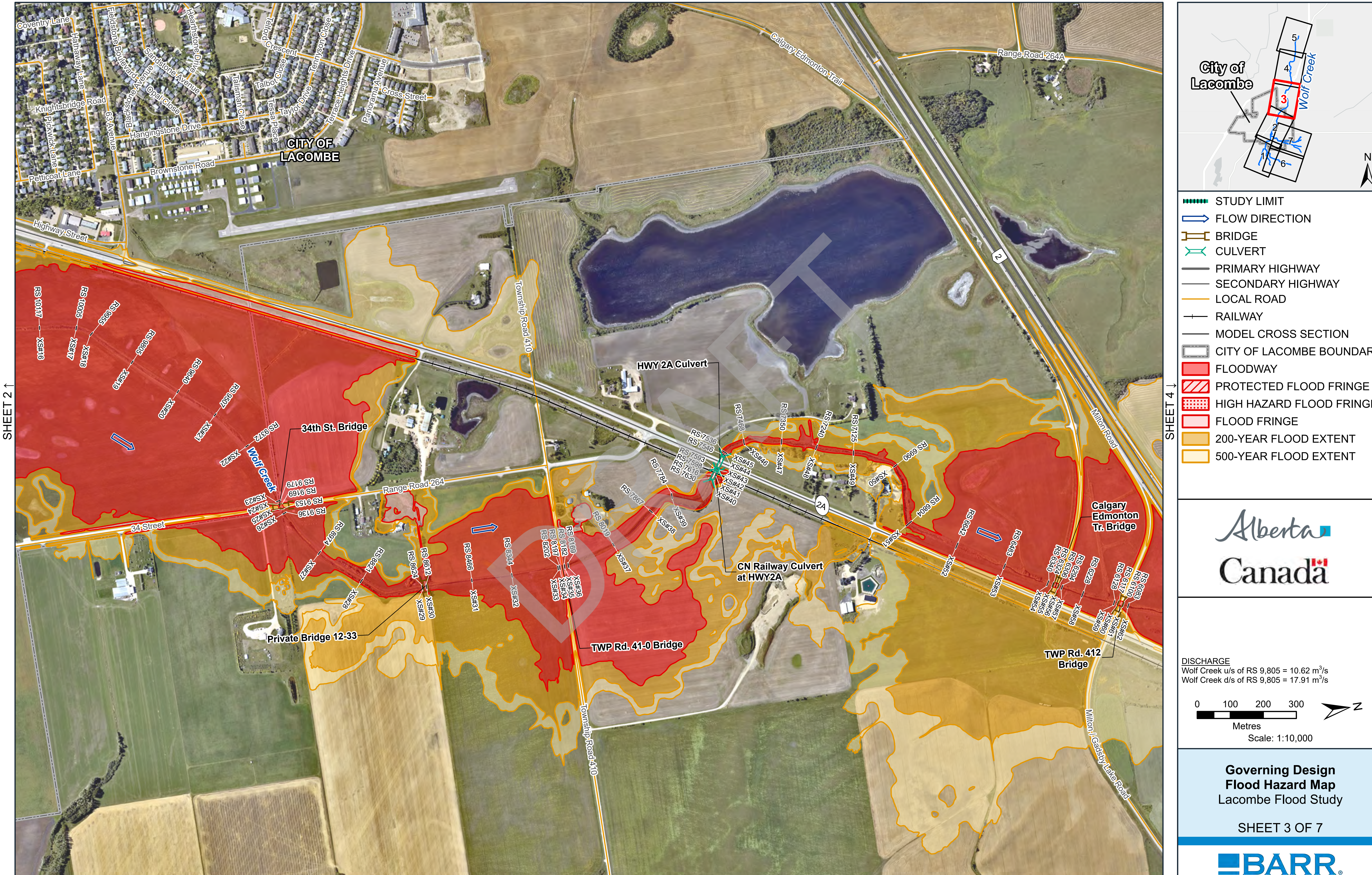
0 100 200 300 Metres

Scale: 1:10,000

Governing Design Flood Hazard Map
Lacombe Flood Study

SHEET 2 OF 7

BARR



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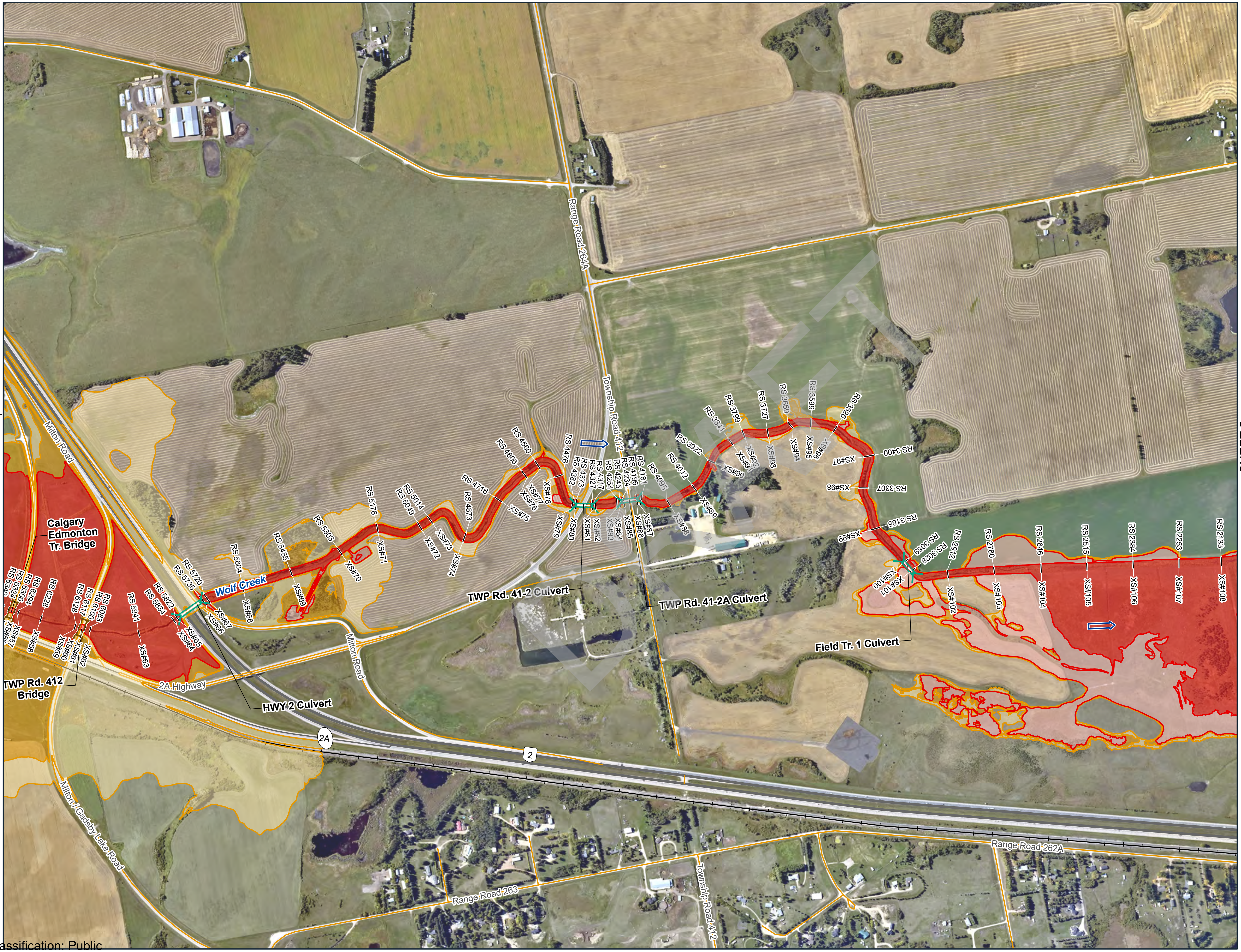
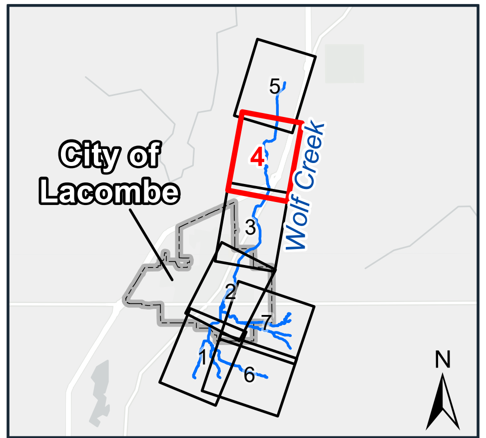




STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
MODEL CROSS SECTION
CITY OF LACOMBE BOUNDARY
FLOODWAY
PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE
Wolf Creek u/s of RS 5,303 = 17.91 m^3/s
Wolf Creek d/s of RS 5,303 = 23.48 m^3/s

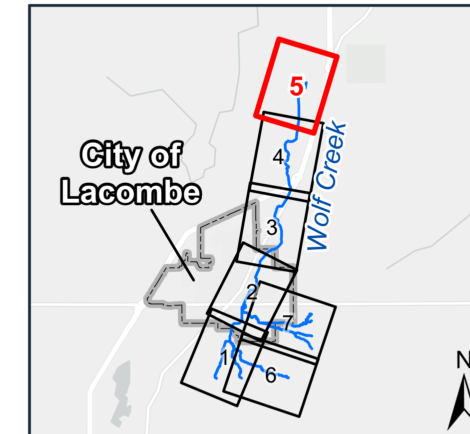
0 100 200 300
Metres
Scale: 1:10,000

Governing Design Flood Hazard Map
Lacombe Flood Study

SHEET 4 OF 7

BARR

Classification: Public



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- MODEL CROSS SECTION
- CITY OF LACOMBE BOUNDARY
- FLOODWAY
- PROTECTED FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE
Wolf Creek = 23.48 m^3/s

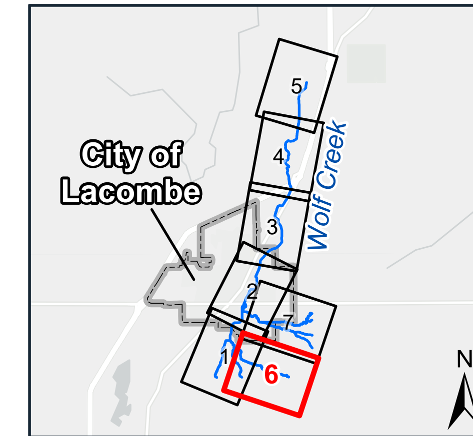
0 100 200 300
Metres
Scale: 1:10,000

Governing Design Flood Hazard Map
Lacombe Flood Study

SHEET 5 OF 7

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
CITY OF LACOMBE BOUNDARY
FLOODWAY
PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta

Canada

DISCHARGE
Unnamed Tributary 2 = 1.34 m^3/s
Unnamed Tributary 3 = 1.34 m^3/s

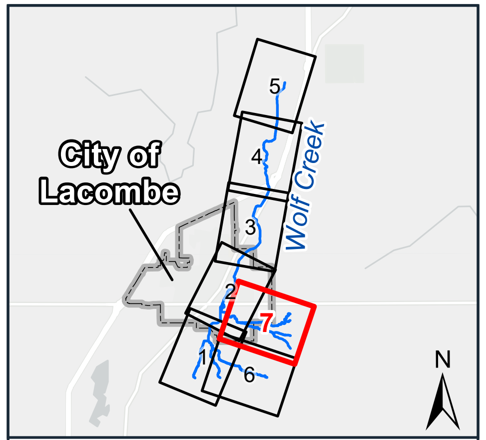
0 100 200 300
Metres
Scale: 1:10,000

Governing Design Flood Hazard Map
Lacombe Flood Study

SHEET 6 OF 7

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
CITY OF LACOMBE BOUNDARY
FLOODWAY
PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE

Unnamed Tributary 4 u/s of RS 1,740 = 1.12 m^3/s
Unnamed Tributary 4 d/s of RS 1,740 = 2.24 m^3/s
Unnamed Tributary 5 = 1.12 m^3/s
Unnamed Tributary 6 = 0.84 m^3/s
Wolf Creek u/s of RS 16,250 = 0.84 m^3/s
Wolf Creek RS 16,250 to 13,880 = 1.68 m^3/s
Wolf Creek RS 13,880 to 13,700 = 3.92 m^3/s
Wolf Creek d/s of RS 13,700 = 4.61 m^3/s

0 100 200 300
Metres
Scale: 1:10,000

Governing Design Flood Hazard Map
Lacombe Flood Study

SHEET 7 OF 7

BARR

Classification: Public

Appendix J

Climate Change Flood Profiles

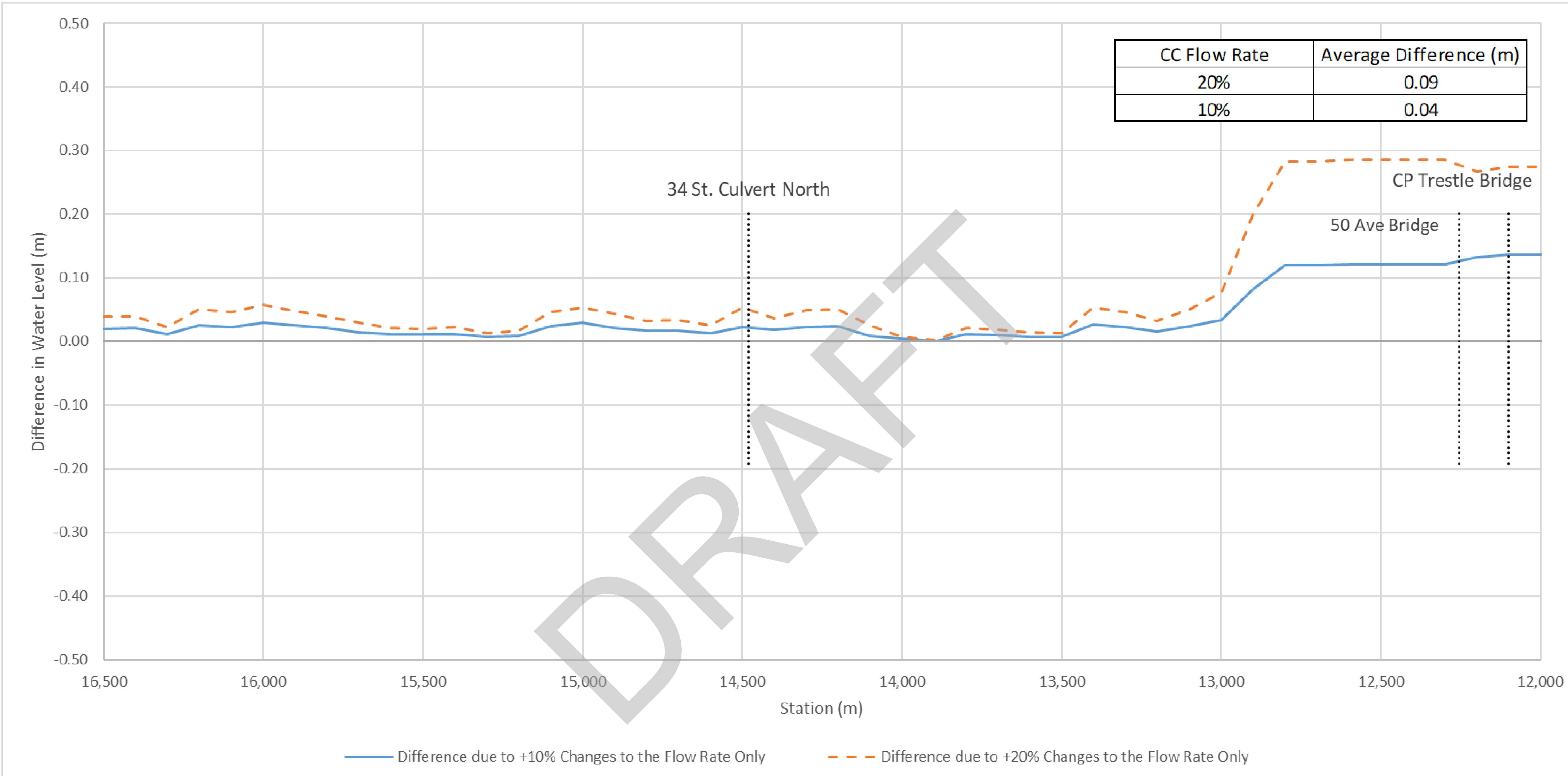


Figure J-1 Simulated Climate Change Water Surface Profiles Along Upper Wolf Creek (Station 16,500 m to 11,900 m)

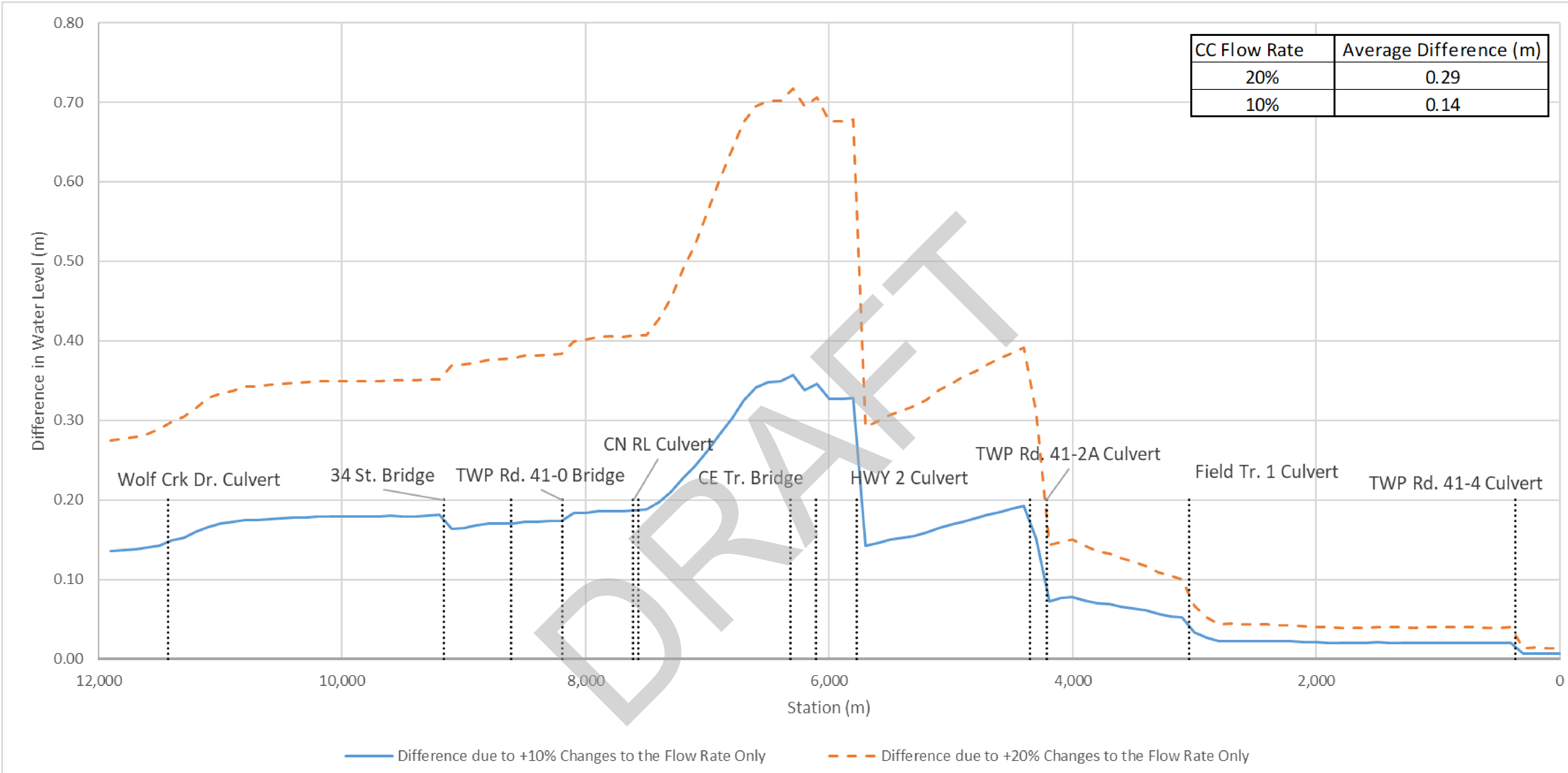


Figure J-2 Simulated Climate Change Water Surface Profiles Along Lower Wolf Creek (Station 11,900 m to 0 m)

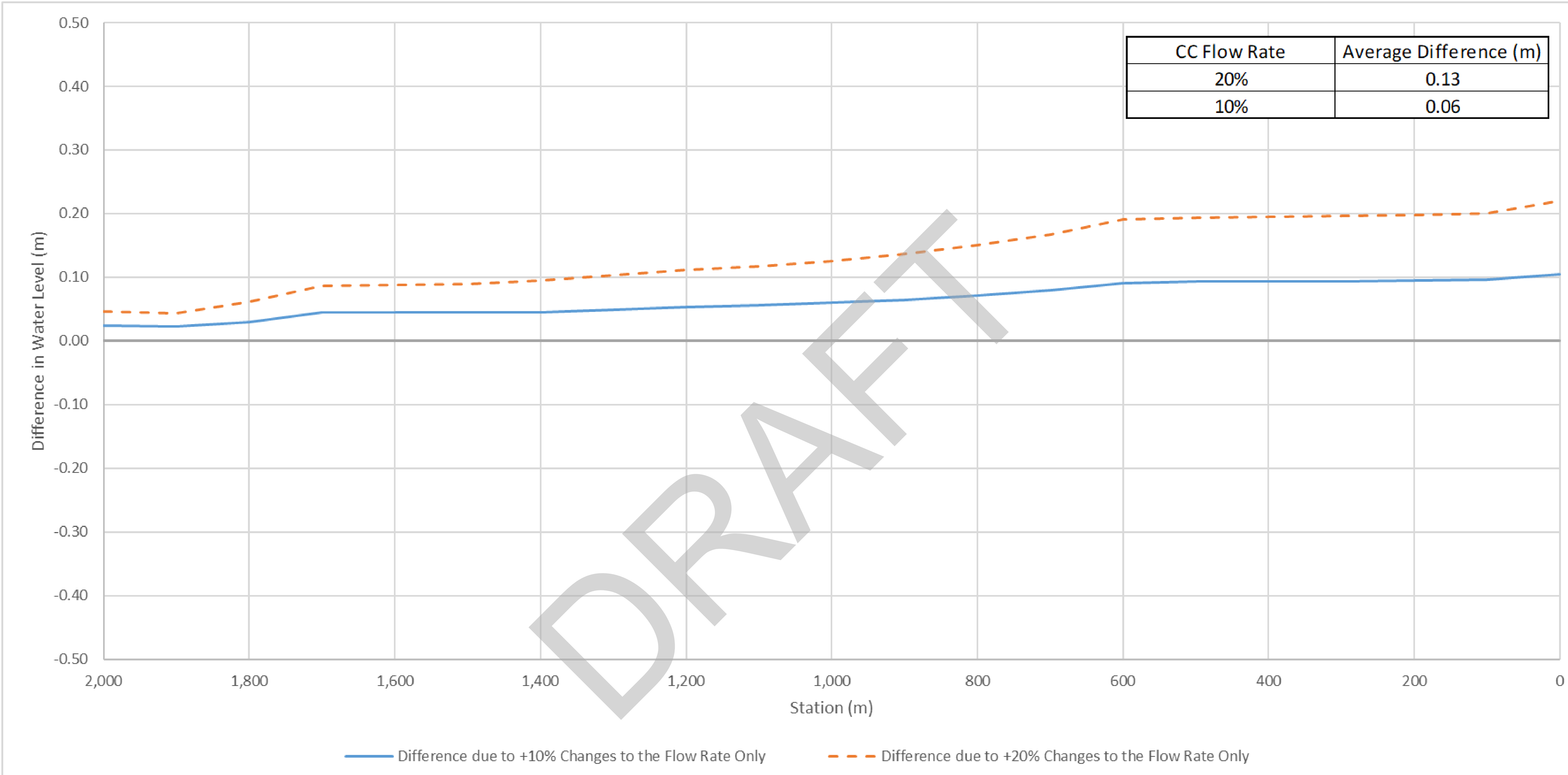


Figure J-3 Simulated Climate Change Water Surface Profiles Along Unnamed Tributary 1

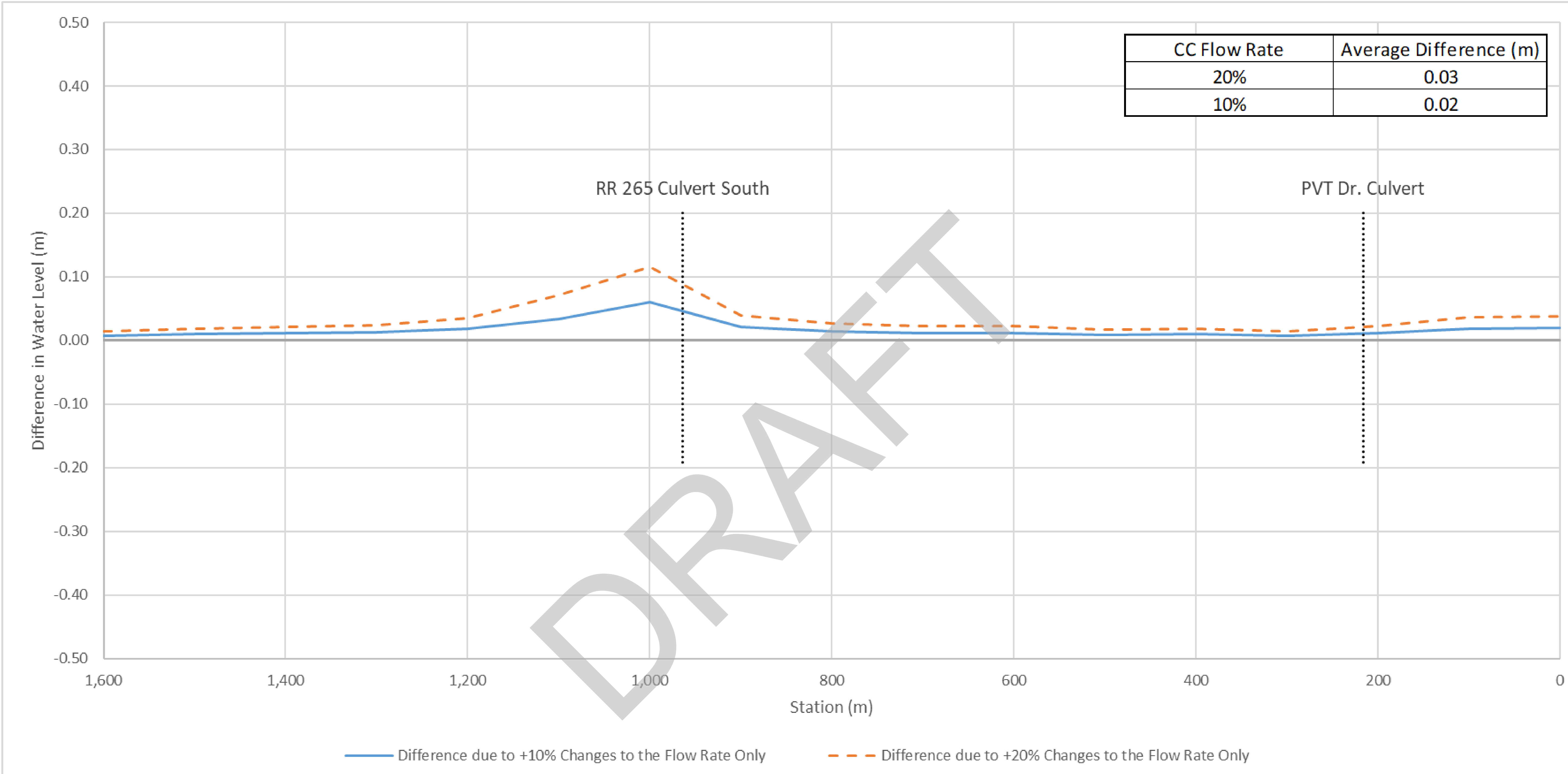


Figure J-4 Simulated Climate Change Water Surface Profiles Along Unnamed Tributary 2

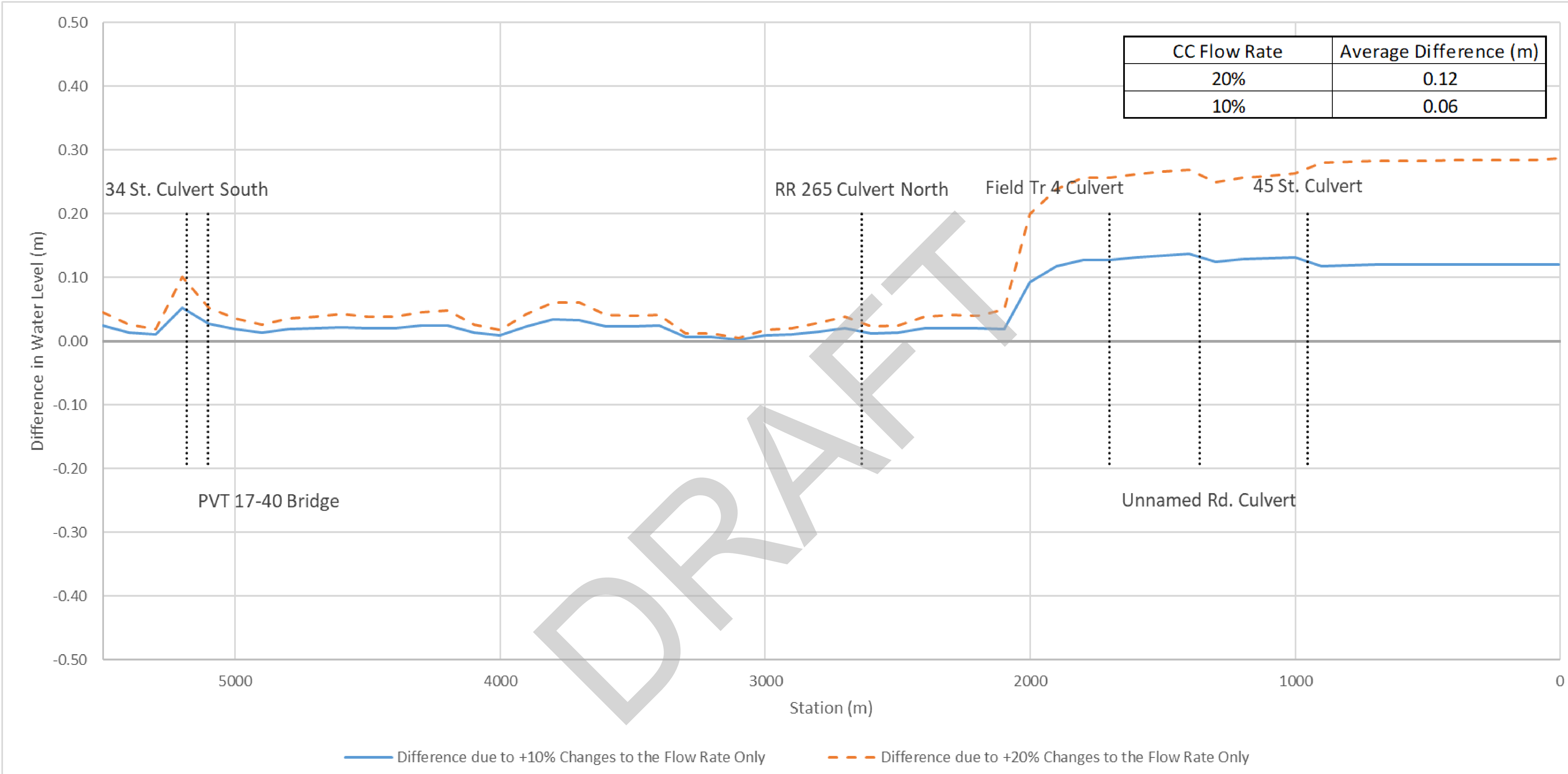


Figure J-5 Simulated Climate Change Water Surface Profiles Along Unnamed Tributary 3

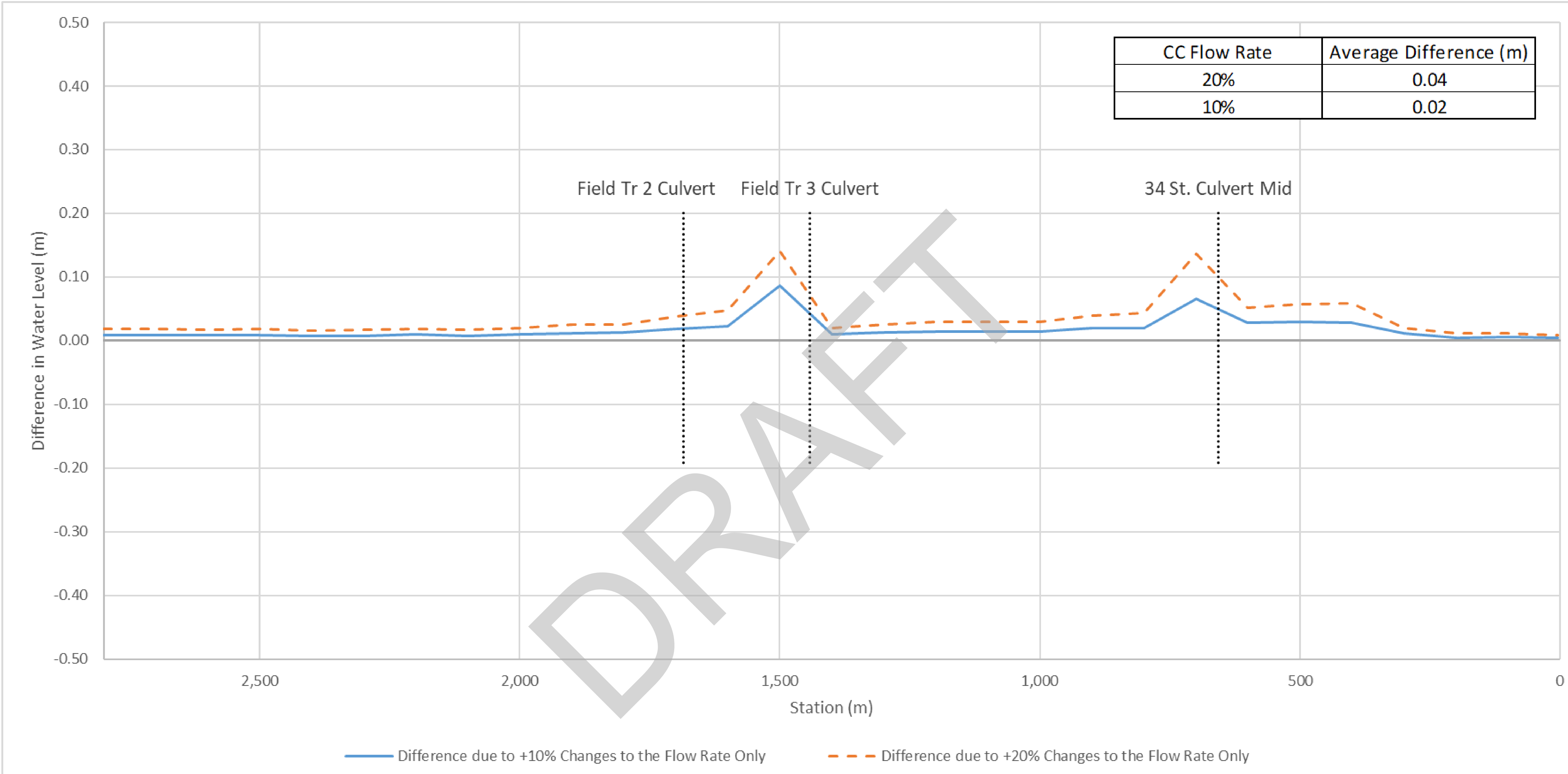
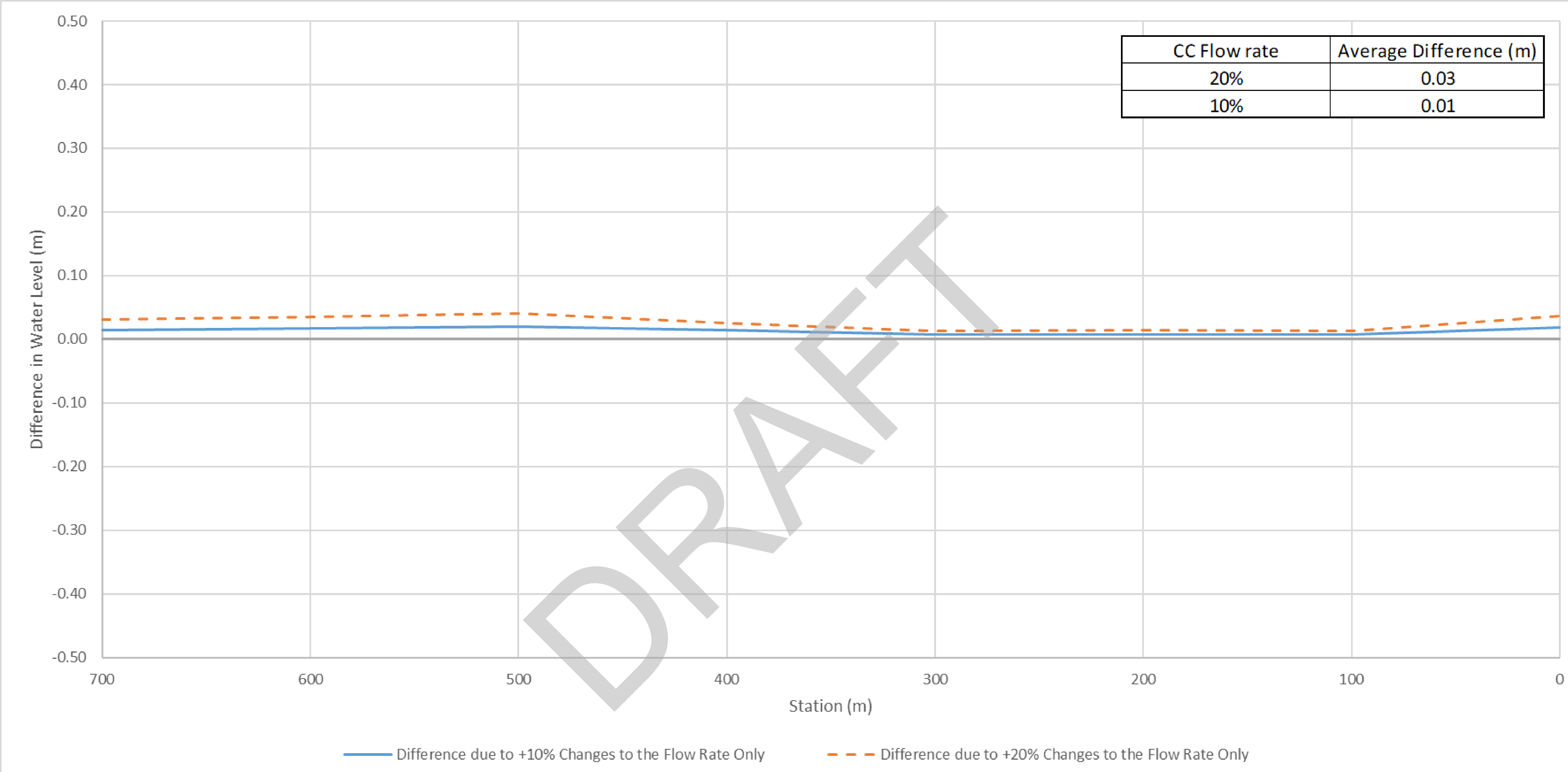


Figure J-6 Simulated Climate Change Water Surface Profiles Along Unnamed Tributary 4



CC Flow rate	Average Difference (m)
20%	0.03
10%	0.01

Figure J-7 Simulated Climate Change Water Surface Profiles Along Unnamed Tributary 5

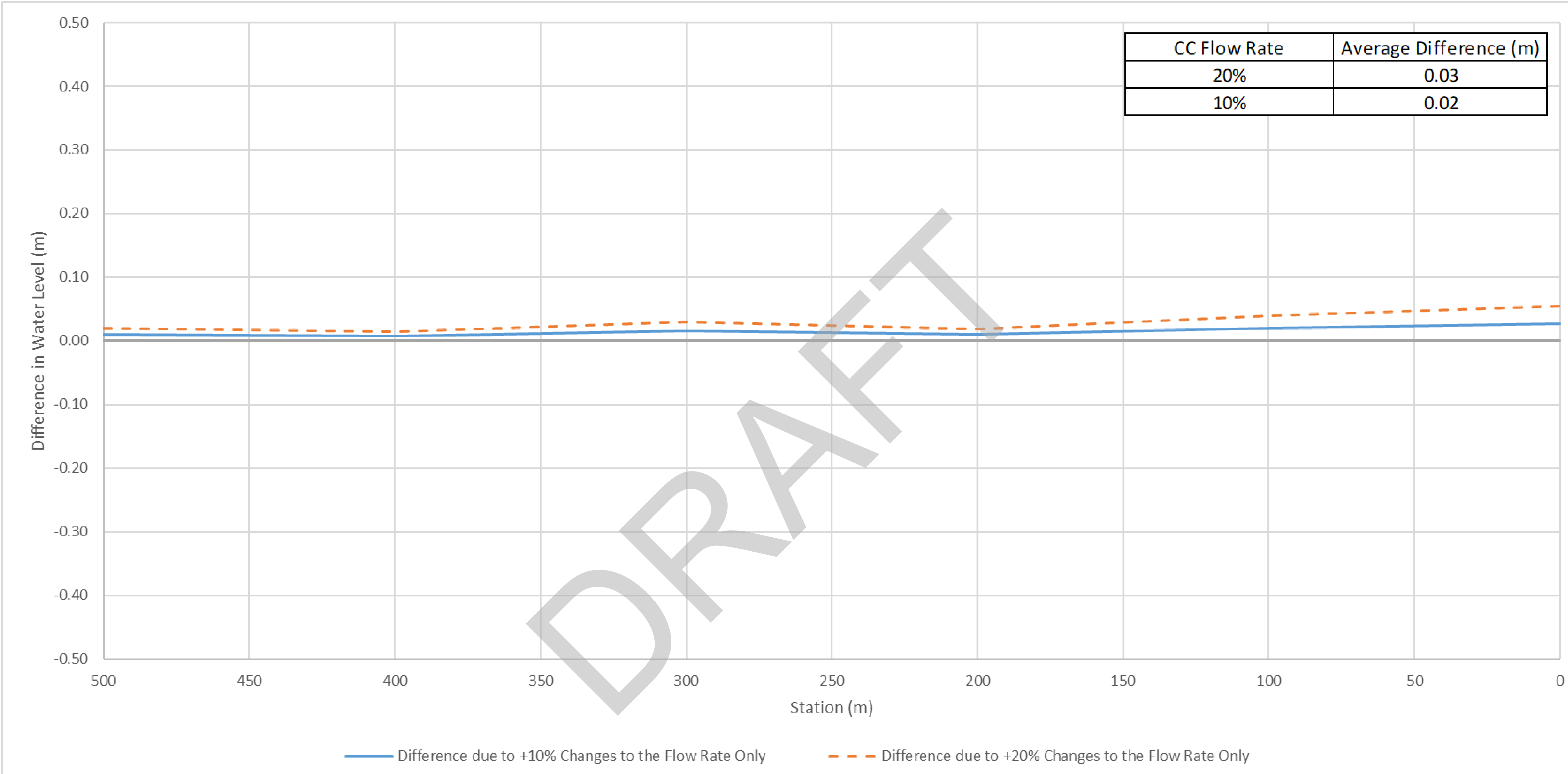


Figure J-8 Simulated Climate Change Water Surface Profiles Along Unnamed Tributary 6

Table J-1 Upper Wolf Creek Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
16,500	870.47	870.49	870.51	0.02	0.04
16,400	869.83	869.85	869.87	0.02	0.04
16,300	868.19	868.20	868.21	0.01	0.02
16,200	866.76	866.79	866.81	0.03	0.05
16,100	865.93	865.95	865.97	0.02	0.05
16,000	865.46	865.49	865.52	0.03	0.06
15,900	864.90	864.92	864.95	0.02	0.05
15,800	864.30	864.32	864.34	0.02	0.04
15,700	863.58	863.59	863.61	0.01	0.03
15,600	863.10	863.11	863.12	0.01	0.02
15,500	862.28	862.29	862.30	0.01	0.02
15,400	861.69	861.70	861.71	0.01	0.02
15,300	861.07	861.08	861.09	0.01	0.01
15,200	860.02	860.03	860.04	0.01	0.02
15,100	858.74	858.77	858.79	0.02	0.05
15,000	858.06	858.09	858.11	0.03	0.05
14,900	857.23	857.25	857.28	0.02	0.04
14,800	856.74	856.76	856.77	0.02	0.03
14,700	856.04	856.06	856.07	0.02	0.03
14,600	855.31	855.32	855.33	0.01	0.02
14,500	854.42	854.44	854.47	0.02	0.05
14,400	853.34	853.36	853.38	0.02	0.04
14,300	852.48	852.51	852.53	0.02	0.05
14,200	851.62	851.65	851.67	0.02	0.05
14,100	850.97	850.98	850.99	0.01	0.02
14,000	850.27	850.27	850.28	0.00	0.01
13,893	848.89	848.89	848.89	0.00	0.00
13,800	848.32	848.33	848.34	0.01	0.02
13,700	847.90	847.91	847.92	0.01	0.02
13,600	847.54	847.54	847.55	0.01	0.01
13,500	847.23	847.23	847.24	0.01	0.01
13,400	846.35	846.38	846.40	0.03	0.05
13,300	846.21	846.24	846.26	0.02	0.05
13,200	845.99	846.01	846.03	0.02	0.03
13,100	845.82	845.84	845.87	0.02	0.05
13,000	845.63	845.67	845.71	0.03	0.08
12,900	845.29	845.37	845.49	0.08	0.20
12,800	845.14	845.26	845.43	0.12	0.28
12,700	845.14	845.26	845.43	0.12	0.28
12,600	845.14	845.26	845.42	0.12	0.28
12,500	845.14	845.26	845.42	0.12	0.28
12,400	845.14	845.26	845.42	0.12	0.28
12,300	845.14	845.26	845.42	0.12	0.29
12,200	844.99	845.12	845.26	0.13	0.27
12,100	844.96	845.09	845.23	0.14	0.27
12,000	844.95	845.08	845.22	0.14	0.27

Table J-2 Lower Wolf Creek Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
11,900	844.95	845.08	845.22	0.14	0.27
11,800	844.94	845.08	845.22	0.14	0.28
11,700	844.94	845.07	845.21	0.14	0.28
11,600	844.91	845.05	845.19	0.14	0.28
11,500	844.88	845.03	845.17	0.14	0.29
11,400	844.85	845.00	845.15	0.15	0.30
11,300	844.75	844.90	845.05	0.15	0.30
11,200	844.73	844.89	845.05	0.16	0.32
11,100	844.70	844.86	845.03	0.17	0.33
11,000	844.67	844.84	845.01	0.17	0.33
10,900	844.66	844.83	844.99	0.17	0.34
10,800	844.64	844.82	844.99	0.17	0.34
10,700	844.64	844.82	844.98	0.18	0.34
10,600	844.64	844.82	844.98	0.18	0.35
10,500	844.64	844.81	844.98	0.18	0.35
10,400	844.63	844.81	844.98	0.18	0.35
10,300	844.63	844.81	844.98	0.18	0.35
10,200	844.63	844.81	844.98	0.18	0.35
10,100	844.63	844.81	844.98	0.18	0.35
10,000	844.63	844.81	844.98	0.18	0.35
9,900	844.63	844.81	844.98	0.18	0.35
9,800	844.63	844.81	844.98	0.18	0.35
9,700	844.63	844.81	844.98	0.18	0.35
9,600	844.63	844.81	844.98	0.18	0.35
9,500	844.63	844.81	844.98	0.18	0.35
9,400	844.63	844.81	844.98	0.18	0.35
9,300	844.63	844.81	844.98	0.18	0.35
9,200	844.63	844.81	844.98	0.18	0.35
9,100	844.53	844.70	844.90	0.16	0.37
9,000	844.53	844.70	844.90	0.16	0.37
8,900	844.52	844.69	844.89	0.17	0.37
8,800	844.51	844.68	844.88	0.17	0.38
8,700	844.49	844.66	844.87	0.17	0.38
8,600	844.49	844.66	844.87	0.17	0.38
8,500	844.48	844.65	844.86	0.17	0.38
8,400	844.48	844.65	844.86	0.17	0.38
8,300	844.48	844.65	844.86	0.17	0.38
8,200	844.48	844.65	844.86	0.17	0.38
8,100	844.46	844.64	844.86	0.18	0.40
8,000	844.45	844.64	844.85	0.18	0.40
7,900	844.44	844.62	844.84	0.19	0.40
7,800	844.43	844.61	844.83	0.19	0.41
7,700	844.42	844.61	844.83	0.19	0.41
7,600	844.42	844.61	844.83	0.19	0.41
7,500	842.72	842.91	843.13	0.19	0.41
7,400	842.66	842.86	843.09	0.20	0.43
7,300	842.60	842.81	843.05	0.21	0.45
7,200	842.54	842.77	843.03	0.23	0.49
7,100	842.47	842.71	842.99	0.24	0.52
7,000	842.40	842.67	842.97	0.26	0.56
6,900	842.34	842.62	842.94	0.28	0.60
6,800	842.28	842.59	842.92	0.30	0.64
6,700	842.24	842.57	842.92	0.32	0.67
6,600	842.22	842.56	842.92	0.34	0.70
6,500	842.22	842.56	842.92	0.35	0.70
6,400	842.21	842.56	842.92	0.35	0.70
6,300	842.19	842.54	842.90	0.36	0.72
6,200	842.13	842.47	842.82	0.34	0.69
6,100	842.12	842.47	842.83	0.35	0.71
6,000	842.09	842.42	842.77	0.33	0.68
5,900	842.09	842.42	842.77	0.33	0.68
5,800	842.08	842.41	842.76	0.33	0.68

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
5,700	841.19	841.33	841.48	0.14	0.29
5,600	841.15	841.30	841.45	0.15	0.30
5,500	841.12	841.27	841.42	0.15	0.31
5,400	841.09	841.24	841.40	0.15	0.31
5,300	841.07	841.22	841.38	0.15	0.32
5,200	841.00	841.16	841.33	0.16	0.33
5,100	840.95	841.12	841.29	0.16	0.34
5,000	840.91	841.08	841.26	0.17	0.35
4,900	840.87	841.05	841.23	0.17	0.36
4,800	840.84	841.02	841.21	0.18	0.36
4,700	840.81	840.99	841.18	0.18	0.37
4,600	840.78	840.96	841.15	0.19	0.38
4,500	840.75	840.94	841.13	0.19	0.38
4,400	840.72	840.91	841.11	0.19	0.39
4,300	840.36	840.51	840.67	0.15	0.31
4,200	839.90	839.97	840.04	0.07	0.14
4,100	839.59	839.67	839.74	0.08	0.15
4,000	839.48	839.56	839.63	0.08	0.15
3,900	839.36	839.44	839.50	0.07	0.14
3,800	839.23	839.30	839.37	0.07	0.14
3,700	839.14	839.21	839.27	0.07	0.13
3,600	839.05	839.12	839.18	0.07	0.13
3,500	838.99	839.06	839.11	0.06	0.12
3,400	838.94	839.01	839.06	0.06	0.12
3,300	838.89	838.95	839.00	0.06	0.11
3,200	838.85	838.90	838.95	0.05	0.11
3,100	838.80	838.85	838.90	0.05	0.10
3,000	838.60	838.63	838.66	0.03	0.07
2,900	838.53	838.55	838.58	0.03	0.05
2,800	838.48	838.50	838.53	0.02	0.04
2,700	838.47	838.50	838.52	0.02	0.04
2,600	838.47	838.49	838.51	0.02	0.04
2,500	838.47	838.49	838.51	0.02	0.04
2,400	838.47	838.49	838.51	0.02	0.04
2,300	838.47	838.49	838.51	0.02	0.04
2,200	838.46	838.49	838.51	0.02	0.04
2,100	838.45	838.48	838.50	0.02	0.04
2,000	838.45	838.47	838.49	0.02	0.04
1,900	838.45	838.47	838.49	0.02	0.04
1,800	838.45	838.47	838.49	0.02	0.04
1,700	838.45	838.47	838.49	0.02	0.04
1,600	838.45	838.47	838.49	0.02	0.04
1,500	838.45	838.47	838.49	0.02	0.04
1,400	838.45	838.47	838.49	0.02	0.04
1,300	838.45	838.47	838.49	0.02	0.04
1,200	838.45	838.47	838.49	0.02	0.04
1,100	838.45	838.47	838.49	0.02	0.04
1,000	838.45	838.47	838.49	0.02	0.04
900	838.45	838.47	838.49	0.02	0.04
800	838.45	838.47	838.49	0.02	0.04
700	838.45	838.47	838.49	0.02	0.04
600	838.45	838.47	838.49	0.02	0.04
500	838.45	838.47	838.49	0.02	0.04
400	838.45	838.47	838.49	0.02	0.04
300	837.70	837.71	837.72	0.01	0.01
200	837.68	837.69	837.70	0.01	0.01
100	837.66	837.66	837.67	0.01	0.01
0	837.63	837.63	837.64	0.01	0.01

Table J-3 Unnamed Tributary 1 Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
2,000	847.07	847.10	847.12	0.02	0.05
1,900	847.06	847.09	847.11	0.02	0.04
1,800	846.67	846.70	846.73	0.03	0.06
1,700	846.51	846.56	846.60	0.04	0.09
1,600	846.46	846.51	846.55	0.04	0.09
1,500	846.38	846.42	846.47	0.04	0.09
1,400	846.28	846.33	846.38	0.04	0.09
1,300	846.22	846.27	846.33	0.05	0.10
1,200	846.17	846.22	846.28	0.05	0.11
1,100	846.14	846.20	846.26	0.06	0.12
1,000	846.10	846.16	846.23	0.06	0.13
900	846.04	846.11	846.18	0.06	0.14
800	845.92	845.99	846.07	0.07	0.15
700	845.84	845.91	846.00	0.08	0.17
600	845.73	845.82	845.92	0.09	0.19
500	845.72	845.81	845.92	0.09	0.19
400	845.71	845.81	845.91	0.09	0.20
300	845.70	845.79	845.89	0.09	0.20
200	845.69	845.78	845.88	0.09	0.20
100	845.68	845.77	845.88	0.10	0.20
0	845.65	845.76	845.87	0.11	0.22

Table J-4 Unnamed Tributary 2 Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
1,600	850.02	850.03	850.03	0.01	0.01
1,500	849.78	849.79	849.80	0.01	0.02
1,400	849.60	849.61	849.62	0.01	0.02
1,300	849.34	849.35	849.36	0.01	0.02
1,200	848.91	848.93	848.95	0.02	0.03
1,100	848.67	848.71	848.74	0.03	0.07
1,000	848.57	848.63	848.69	0.06	0.12
900	848.11	848.14	848.15	0.02	0.04
800	847.97	847.98	848.00	0.01	0.03
700	847.92	847.93	847.94	0.01	0.02
600	847.44	847.46	847.47	0.01	0.02
500	847.21	847.22	847.23	0.01	0.02
400	846.99	847.00	847.01	0.01	0.02
300	846.97	846.98	846.99	0.01	0.01
200	846.56	846.57	846.58	0.01	0.02
100	846.43	846.45	846.46	0.02	0.04
0	846.37	846.39	846.41	0.02	0.04

Table J-5 Unnamed Tributary 3 Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
5,500	865.78	865.81	865.83	0.02	0.04
5,400	864.16	864.18	864.19	0.01	0.03
5,300	863.84	863.85	863.86	0.01	0.02
5,200	863.17	863.23	863.27	0.05	0.10
5,100	861.69	861.72	861.74	0.03	0.05
5,000	861.05	861.07	861.09	0.02	0.04
4,900	860.43	860.45	860.46	0.01	0.03
4,800	859.75	859.77	859.78	0.02	0.04
4,700	859.12	859.14	859.16	0.02	0.04
4,600	858.53	858.55	858.57	0.02	0.04
4,500	858.12	858.14	858.16	0.02	0.04
4,400	857.62	857.64	857.65	0.02	0.04
4,300	856.95	856.98	857.00	0.02	0.05
4,200	856.45	856.47	856.49	0.02	0.05
4,100	855.78	855.80	855.81	0.01	0.03
4,000	854.91	854.92	854.92	0.01	0.02
3,900	853.44	853.46	853.48	0.02	0.04
3,800	852.75	852.78	852.81	0.03	0.06
3,700	852.14	852.17	852.20	0.03	0.06
3,600	851.49	851.52	851.53	0.02	0.04
3,500	850.88	850.90	850.92	0.02	0.04
3,400	850.39	850.41	850.43	0.02	0.04
3,300	849.80	849.80	849.81	0.01	0.01
3,200	849.24	849.24	849.25	0.01	0.01
3,100	848.67	848.67	848.67	0.00	0.00
3,000	848.33	848.34	848.35	0.01	0.02
2,900	848.07	848.09	848.09	0.01	0.02
2,800	847.78	847.79	847.81	0.01	0.03
2,700	847.50	847.52	847.54	0.02	0.04
2,600	847.22	847.23	847.24	0.01	0.02
2,500	846.79	846.80	846.81	0.01	0.02
2,400	846.39	846.41	846.43	0.02	0.04
2,300	846.28	846.30	846.32	0.02	0.04
2,200	846.12	846.14	846.16	0.02	0.04
2,100	845.92	845.94	845.97	0.02	0.05
2,000	845.68	845.77	845.88	0.09	0.20
1,900	845.62	845.74	845.86	0.12	0.24
1,800	845.60	845.73	845.86	0.13	0.26
1,700	845.60	845.73	845.86	0.13	0.26
1,600	845.60	845.73	845.86	0.13	0.26
1,500	845.59	845.72	845.86	0.13	0.27
1,400	845.58	845.72	845.85	0.14	0.27
1,300	845.38	845.51	845.63	0.13	0.25
1,200	845.37	845.50	845.62	0.13	0.26
1,100	845.36	845.49	845.62	0.13	0.26
1,000	845.35	845.48	845.62	0.13	0.26
900	845.15	845.26	845.43	0.12	0.28
800	845.14	845.26	845.43	0.12	0.28
700	845.14	845.26	845.43	0.12	0.28
600	845.14	845.26	845.43	0.12	0.28
500	845.14	845.26	845.43	0.12	0.28
400	845.14	845.26	845.43	0.12	0.28
300	845.14	845.26	845.42	0.12	0.28
200	845.14	845.26	845.42	0.12	0.28
100	845.14	845.26	845.42	0.12	0.28
0	845.13	845.25	845.42	0.12	0.29

Table J-6 Unnamed Tributary 4 Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
2,800	875.48	875.49	875.50	0.01	0.02
2,700	874.15	874.16	874.17	0.01	0.02
2,600	872.70	872.71	872.71	0.01	0.02
2,500	871.31	871.32	871.33	0.01	0.02
2,400	869.77	869.78	869.79	0.01	0.02
2,300	868.89	868.90	868.91	0.01	0.02
2,200	868.03	868.04	868.05	0.01	0.02
2,100	867.22	867.23	867.24	0.01	0.02
2,000	866.83	866.84	866.85	0.01	0.02
1,900	866.35	866.36	866.37	0.01	0.02
1,800	864.96	864.97	864.98	0.01	0.03
1,700	864.18	864.20	864.22	0.02	0.04
1,600	862.83	862.85	862.88	0.02	0.05
1,500	862.55	862.64	862.69	0.09	0.14
1,400	861.25	861.26	861.27	0.01	0.02
1,300	860.38	860.39	860.40	0.01	0.03
1,200	859.59	859.61	859.62	0.01	0.03
1,100	858.83	858.84	858.86	0.01	0.03
1,000	858.04	858.05	858.07	0.01	0.03
900	857.11	857.13	857.15	0.02	0.04
800	856.22	856.24	856.27	0.02	0.04
700	855.52	855.59	855.66	0.07	0.14
600	854.15	854.17	854.20	0.03	0.05
500	852.95	852.98	853.01	0.03	0.06
400	851.94	851.97	852.00	0.03	0.06
300	851.17	851.18	851.19	0.01	0.02
200	850.68	850.69	850.70	0.00	0.01
100	849.83	849.83	849.84	0.01	0.01
0	848.80	848.81	848.81	0.00	0.01

Table J-7 Unnamed Tributary 5 Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
700	873.25	873.26	873.28	0.01	0.03
600	871.29	871.31	871.33	0.02	0.03
500	869.74	869.76	869.78	0.02	0.04
400	868.59	868.61	868.62	0.01	0.03
300	867.38	867.38	867.39	0.01	0.01
200	866.30	866.30	866.31	0.01	0.01
100	865.29	865.30	865.31	0.01	0.01
0	864.21	864.23	864.25	0.02	0.04

Table J-8 Unnamed Tributary 6 Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
500	874.50	874.51	874.52	0.01	0.02
400	873.59	873.60	873.60	0.01	0.01
300	872.64	872.65	872.67	0.02	0.03
200	871.32	871.33	871.34	0.01	0.02
100	869.37	869.39	869.41	0.02	0.04
0	867.42	867.45	867.48	0.03	0.05