Hydraulic Modelling and Flood Inundation Mapping Report

Red Deer River Hazard Study

Submitted to:

Alberta Environment and Parks

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Distribution List

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Executive Summary

Alberta Environment and Parks (AEP) retained Golder Associates Ltd. (Golder) in August 2017 to conduct the Red Deer River Hazard Study. The primary purpose of the study is to assess and identify river and flood hazards along the Red Deer River, Waskasoo Creek, and Piper Creek through the City of Red Deer, the Town of Penhold, Lacombe County, and Red Deer County.

The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. Project stakeholders include the Government of Alberta, the City of Red Deer, the Town of Penhold, Lacombe County, Red Deer County, and the public.

The Red Deer River Hazard Study includes multiple components and deliverables. This report documents the methodology and results of the hydraulic model creation and calibration component and the open water flood inundation map production component. These two components support the open water flood hazard identification, governing design flood hazard map production, and flood risk assessment and inventory components of this study. The tasks associated with the hydraulic model creation and calibration component include pertinent flood history documentation, description of river and valley features, model setup, model calibration, sensitivity analysis and generation of open water flood frequency profiles. The tasks associated with the open water flood inundation map production component include the generation of flood inundation maps for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods.

The study area includes the river reaches listed in Table i.

Table i: River Reaches in the Study Area

River	Reach Description	Length (km)
Red Deer River	From Township Road 380 to the Highway 11 Bridge	51
Waskasoo Creek	From the Highway 2A Bridge to its confluence with the Red Deer River	35
Piper Creek	From Township Road 374 to its confluence with Waskasoo Creek	20

Based on the flood inundation maps, flood impacts all land uses along the Red Deer River and the Waskasoo and Piper creeks, including residential areas, commercial and industrial areas, and recreation areas. A summary of these impacts is included below.

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

Red Deer River

- Riverside Meadows east of 54th Avenue at the 1000 years return period.
- McKenzie Trail at return periods 35 years and higher.
- Asooahum Crossing at return periods 100 years and higher.

Waskasoo Creek

- Residential areas in Penhold between Lincoln and Lucine Street and east of Newton Drive at return periods 350 years and higher.
- Residential buildings south of Township Road 374 (NE 19-37-27 W4M and NW 20-37-27 W4M) at return periods 750 years and 1000 years.
- Residential buildings on Range Road 275 (NE 6-38-27 W4M and NW 5-38-27 W4M) at return periods 750 years and 1000 years.
- Capstone at Riverlands south of 43rd Street at return periods 100 years and higher and north of 43rd Street at return periods 350 years and higher.
- Downtown east of 47th Avenue and north of 55th Street at return periods 350 years and higher.
- Parkvale east of 46th Avenue at return periods 350 years and higher.
- Woodlea west of 44th Avenue at return periods of 200 years and higher and remaining areas of Woodlea at return periods 500 years and higher.
- Limited areas of Waskasoo west of 45th Avenue and south of Waskasoo Crescent at return periods 200 years and higher. Low lying areas along 42A Avenue at return periods 750 years and 1000 years.

Piper Creek

- No residential areas were affected by flooding along Piper Creek.

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

Red Deer River

- Gravel pit on Township Road 382 (NW 12-38-28 W4M) at return periods of 200 years and higher and gravel pit on Range Road 280B (NW 13-38-28 W4M) at return periods of 35 years and higher.
- Railyards neighbourhood north of 52nd Street at return periods 350 years and higher.
- Campground in Riverside Light Industrial Park between Riverside Drive and the Red Deer River at return periods 35 years and higher. Other commercial buildings in the neighbourhood at return periods 200 years and higher.
- Riverside Heavy Industrial Park east of Riverside Drive at return periods 75 years and higher and west of Riverside Drive at return periods 500 years and higher. The Red Deer Waste Water treatment plant at return periods 350 years and higher.

Waskasoo Creek

- Capstone at Riverlands south of 43rd Street at return periods 100 years and higher and north of 43rd Street at return periods 350 years and higher.
- Downtown south of 45th Street at return periods 75 years and higher, between 45th Street and 50th Street at return periods 100 years and higher and north of 50th Street at return periods 500 years and higher.
- Parkvale east of 47th Avenue at return periods 350 years and higher.

Piper Creek

- No commercial and industrial areas were affected by flooding along Piper Creek.

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

Red Deer River

- Red Deer Golf and Country Club at return periods 35 years and higher.
- Bower Ponds Recreation area at return periods 35 years and higher.
- Great Chief Park at return periods 350 years and higher.
- Gaetz Lake Migratory Bird Sanctuary at return periods 350 years and higher.
- McKenzie Trail Recreation Area and Three Mile Bend Recreation Area at return periods 20 years and higher.
- River Bend Golf and Recreation Area at return periods 75 years and higher.

Waskasoo Creek

- Rotary Recreation Park at return periods 350 years and higher.

Piper Creek

No recreational areas were affected by flooding along Piper Creek.

Acknowledgements

These components of the Red Deer River Hazard Study were managed by Dr. Dejiang Long and Mr. Gaven Tang. The hydraulic modelling was conducted by Mr. Gaven Tang, Ms. Nancy Guo, Mr. Micah Richey and Mr. Amir Gharavi, with support from Mr. Wolf Ploeger. The open water flood inundation mapping was conducted by Mr. Peter Thiede and Mr. Brian Pendergast.

The authors express their special thanks to Mr. Abdullah Mamun & Ms. Jane Eaket, project managers for Alberta Environment and Parks (AEP), who provided overall study management, background data, and technical guidance to Golder's team throughout the hydraulic modelling and flood inundation mapping components.

The authors also express their gratitude to Peter Onyshko of AEP for his support, technical guidance, and for providing background information.

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1.0 INTRODUCTION

1.1 Study Background and Objectives

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in August 2017 to conduct the Red Deer River Hazard Study. The primary purpose of the study is to assess and identify river and flood hazards along the Red Deer River reach from Township Road 380 to the Highway 11 Bridge, the Waskasoo Creek reach from the Highway 2A Bridge to its confluence with the Red Deer River, and the Piper Creek reach from Township Road 374 to its confluence with Waskasoo Creek.

The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. Project stakeholders include the Government of Alberta, the City of Red Deer, the Town of Penhold, Lacombe County, Red Deer County, and the public.

The Red Deer River Hazard Study includes multiple components and deliverables. This report documents the methodology and results of the hydraulic model creation and calibration component and the open water flood inundation map production component. These two components support the open water flood hazard identification, governing design flood hazard map production, and flood risk assessment and inventory components of this study. The tasks associated with the hydraulic model creation and calibration component include pertinent flood history documentation, description of river and valley features, model setup, model calibration, sensitivity analysis and generation of open water flood frequency profiles. The tasks associated with the open water flood inundation mapping component include the generation of flood inundation maps for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods.

1.2 Study Area and Reaches

The study area covers approximately 51 km reach of the Red Deer River, 35 km reach of Waskasoo Creek, and 20 km reach of Piper Creek through the City of Red Deer, the Town of Penhold, Lacombe County, and Red Deer County. The study area is shown in Figure 1. The study reaches are summarized in Table 1.

Table 1: River Reaches in the Study Area

River	Reach Description	Length (km)
Red Deer River	From Township Road 380 to the Highway 11 Bridge	51
Waskasoo Creek	From the Highway 2A Bridge to its confluence with the Red Deer River	35
Piper Creek	From Township Road 374 to its confluence with Waskasoo Creek	20

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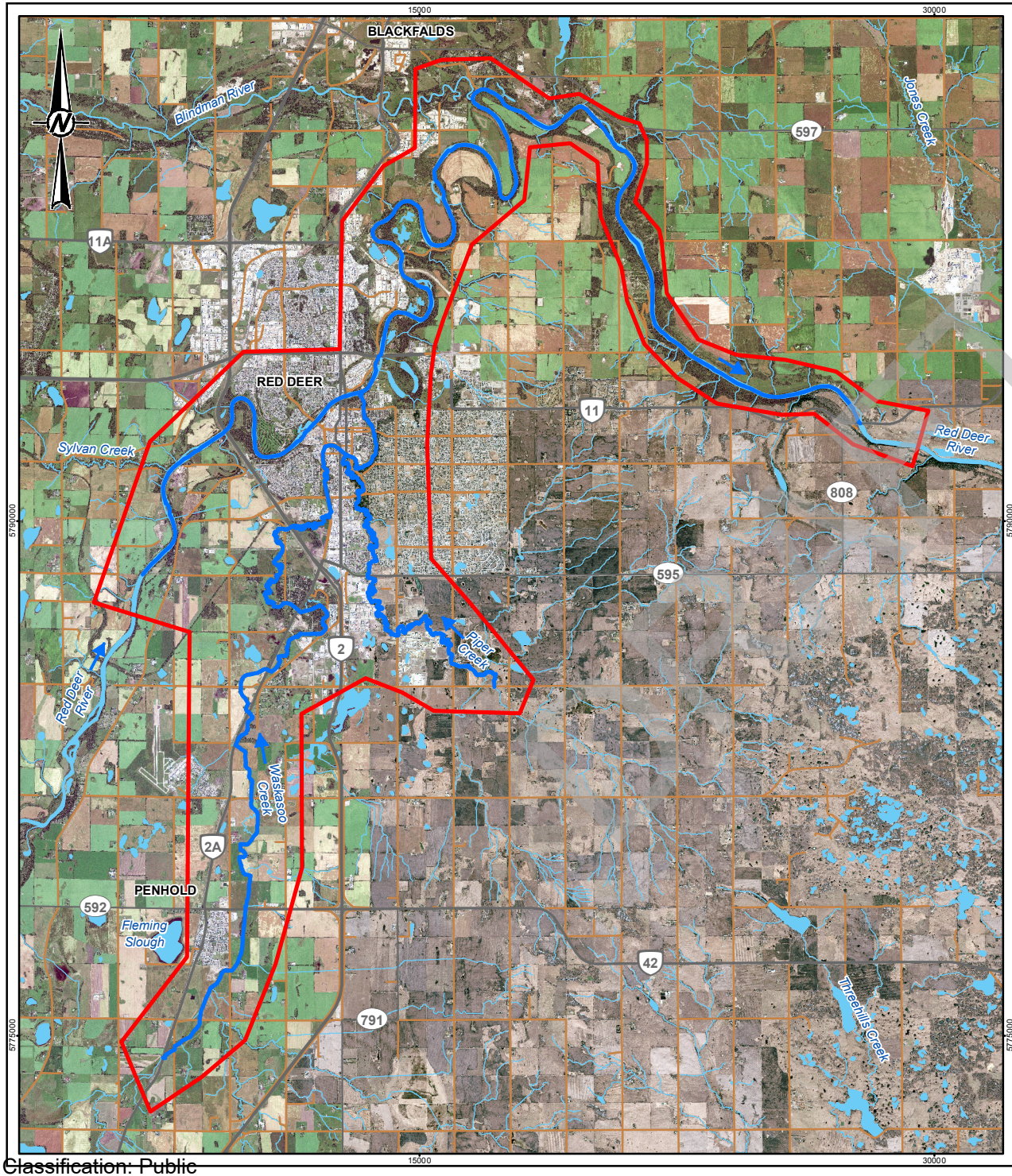

LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- FLOW DIRECTION
- WATERCOURSE
- WATERBODY
- SURVEY REACH
- RIVER HAZARD STUDY AREA

0 5 10

1:175,000 KILOMETRES

REFERENCE(S)

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
LOCATION MAP OF THE STUDY AREA

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-25
DESIGNED	GT
PREPARED	BP
REVIEWED	GT
APPROVED	DL

PROJECT NO.	CONTROL	REV.	FIGURE
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1.3 Scope of Work

The scope of the Hydraulic Model Creation and Calibration component and Open Water Flood Inundation Map Production Component of the study includes the following:

- Documentation of Flooding History;
- Summary of Available Data;
- Documentation of River and Valley Features;
- Model Setup;
- Model Calibration;
- Generation of Open-Water Flood Frequency Profiles;
- Model Sensitivity Analysis;
- Open Water Flood Inundation Map Production;
- Flood Water Surface TIN Development; and
- Flood Depth Grid Creation.

2.0 FLOODING HISTORY

2.1 General Information

The City of Red Deer covers the areas at and near the confluence of the Red Deer River and Waskasoo Creek, and the confluence of Waskasoo Creek and Piper Creek. The Town of Penhold is located along Waskasoo Creek upstream of the City of Red Deer.

The Red Deer River had a history of ice jam flooding prior to construction of Dickson Dam in 1983. Historic ice jam floods along the Red Deer River caused significant flooding in downtown Red Deer. Since construction of Dickson Dam, open water flooding has become the dominant flooding mechanism on the Red Deer River. However, ice jams do still occur on the Red Deer River.

Ice jams can occur on Waskasoo and Piper Creeks. Based on a review of available background information, there is no indication of these leading to significant ice jam flooding within the study reaches. Open water flooding is the dominant flooding mechanism on both creeks.

The Town of Penhold is historically susceptible to open water flooding along Waskasoo Creek. Several flood control structures were constructed in the town, as described by Golder (2021a). The downtown area in the City of Red Deer is also susceptible to flooding by Waskasoo Creek. Flood control structures along Waskasoo Creek were recently constructed in the city, as described by Golder (2021a).

The following sections describe the historic and recent floods in the study area.

2.2 Open Water Floods

2.2.1 Historic & Observed Floods

There is no record of severe historic open water flooding in the study area before systematic flood level recording.

2.2.2 Recent & Recorded Floods

Table 2 and Table 3 are summaries of the largest recorded floods on the Red Deer River and Waskasoo Creek. Highwater marks were available for the 1990, 2005, and 2013 floods on the Red Deer River, and the 1982, 2007, and 2018 floods on Waskasoo Creek.

There has been no systematic flood level recording on Piper Creek. However, highwater marks were collected for the 2018 flood on Piper Creek. The 2018 flood discharge on Piper Creek was estimated by assuming that the river characteristics are similar to those of Waskasoo Creek. The estimated flood peak discharge was 25.0 m^3/s for the 2018 flood event.

Table 2: Largest Open Water Floods on the Red Deer River at WSC Station No. 05CC002

Date	Maximum Instantaneous Discharge (m^3/s)
June 27, 1915[a]	1930[a]
August 26, 1954[a]	1480[a]
June 4, 1929[a]	1210[a]
June 3, 1932[a]	1180[a]
June 24, 1952[a]	1170[a]
June 2, 1923[a]	1130[a]
June 9, 1928[a]	1030[a]
June 17, 1970[a]	966[a]
June 4, 1990	908
June 19, 2005	1510
June 22, 2013	1290

a) Cited from W-E-R (1991).

Table 3: Largest Open Water Floods on Waskasoo Creek at WSC Station No. 05CC011

Date	Maximum Instantaneous Discharge (m^3/s)
April 6, 1969[a]	24.0[a]
April 15, 1982	23.9
April 9, 1996[a]	26.4[a]
May 5, 2007	24.2
April 25, 2018	32.0

a) Cited from UMA (2008).

In 2016 and 2017, the City of Red Deer engaged an engineering consultant for the Waskasoo Creek Channel Improvements project, with goals of stabilizing Waskasoo Creek banks and mitigating low-level flooding with engineered dikes. This project resulted in two dikes constructed near the Piper Creek and Waskasoo Creek confluence along Waskasoo Creek (i.e., the Safeway Dike and the Baymont Dike) (Golder, 2021a).

The Town of Penhold initiated a major channelization project along Waskasoo Creek following the 1969 flood event. It is described by UMA (2008) and is quoted below:

> *"As a result of this flood, a major channelization project for Waskasoo Creek was undertaken through the Penhold area in 1969 and 1970. Before the channelization, flooding in the Penhold area occurred frequently. The channelization of Waskasoo Creek near Penhold resulted in reducing overbank flooding in the Penhold area during small even storms."*

2.3 Ice Jam Floods

2.3.1 Historic and Observed Floods

Ice jams can occur on the Red Deer River, Waskasoo Creek, and Piper Creek. Based on a review of available background information, there is no indication that these lead to significant ice jam flooding within the study area. However, normal breakup conditions can result in ice jams or accumulations within the creeks, especially at the mouth of Waskasoo Creek and Piper Creek. The ice covers typically break up during low flow periods prior to spring freshet.

2.3.2 Recent and Recorded Floods

Table 4 presents the discharges and levels for the largest ice jam flood events on the Red Deer River. There is no record of severe historic ice jam related flooding on Waskasoo Creek and Piper Creek.

Table 4: Major Ice Jam Flood Events on the Red Deer River at the City of Red Deer (W-E-R, 1991)

Date	Maximum Instantaneous Discharge (m^3/s)	Stage (m)
April 9, 1913	113	5.84
April 6, 1925	340	5.73
April 4, 1943	275	7.10
March 19, 1947	16	5.61
April 15, 1954	205	4.36
April 6, 1955	255	6.01
April 11, 1956	282	4.35
April 10, 1958	242	5.10
March 26, 1960	326	4.69
March 10, 1968	30	4.50
April 8, 1970	142	4.46

W-E-R (1991) described the severity of ice jam flooding on the Red Deer River and its impact on the City of Red Deer as follows:

> *"…by far the worst floods involving highest flood levels have been caused by ice jams. Unlike summer floods, ice jam floods have generally occurred rapidly with little warning and under very inclement conditions. Ice jam floods have caused loss of life as well as significant loss of property.*
>
> *The worst Red Deer River flood recorded at the City of Red Deer occurred on April 4, 1943, and was caused by a sudden formation of an ice jam which caused the river level to rise some 4.6 m over a period of one hour."*

The ice jam floods listed in Table 4 were predominantly caused by dynamic breakups instead of thermal breakups. W-E-R (1991) further explained how the ice breakup regime has altered since operation of Dickson Dam began in 1983, as follows:

> *"…since operation of the Dickson Dam beginning in 1983, the ice regime between the City of Red Deer and the Dickson Dam has altered quite significantly. Breakup events on the Red Deer river since 1983 have been predominantly "thermal" breakup events."*

3.0 AVAILABLE DATA

3.1 Hydrology Summary

Red Deer River and its tributaries originate in the Rocky Mountains and traverse the foothills before reaching the City of Red Deer on the edge of the Prairies. The major tributaries along the study reach of Red Deer River are Waskasoo Creek, and Blindman River. The tributary feeding into Waskasoo Creek prior to Waskasoo Creek emptying into the Red Deer River is Piper Creek.

Red Deer River flows through a mixture of Alpine, Subalpine, Boreal Foothill, and Aspen Parkland eco-regions. Land use in the Red Deer River basin ranges from urban areas, to agricultural in parts of the foothills, and to forest in the remainder of the foothills and in the mountains.

The flood flow frequency estimates for the Red Deer River, Waskasoo Creek, and Piper Creek are documented in a separate report entitled "Red Deer River and Upper Red Deer River Hazard Studies – Open Water Flood Hydrology Assessment" (Golder 2021b). The regulated flood flow frequency estimates at key locations in the study area are summarized in Table 5.

3.2 DTM Data

The detailed Digital Terrain Model (DTM) for the study area was provided by AEP. It was developed using the 2017 LiDAR survey and is available as gridded raster with 0.5 m resolution, ESRI Terrain and Triangulated Irregular Network (TIN). The DTM was delivered in the local study coordinate system and datum (3TM 114°, NAD83 CSRS).

3.3 Survey Data

A detailed description of the survey data is provided in a separate report entitled "Red Deer River Hazard Study – Survey and Base Data Collection Report" (Golder 2021a).

3.4 Existing Models

The existing hydraulic models for the study area are listed in Table 6.

Table 5: Summary of Flood Flow Frequency Estimates for Regulated Flows

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Instantaneous Flood Peak Discharges for the Various Return Periods (m³/s)																							
				1000-year		750-year		500-year		350-year		200-year		100-year		75-year		50-year		35-year		20-year		10-year		5-year		2-year	
				Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower
RED DEER RIVER																											
Node 111	Red Deer River upstream of Red Deer	11,524	10,966	3,810	9,703 2,626	3,500	8,582 2,439	3,100	7,190 2,181	2,830	6,254 2,023	2,390	4,887 1,733	1,820	3,369 1,354	1,630	2,884 1,220	1,390	2,311 1,061	1,200	1,881 924	720	1,760 1,090	586	1,230 824	457	821 583	282	428 309
05CC002 / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11,609	11,052	3,810	6,884 2,531	3,500	6,179 2,351	3,100	5,323 2,129	2,830	4,742 1,981	2,390	3,805 1,712	1,820	2,710 1,343	1,630	2,363 1,217	1,390	1,948 1,062	1,200	1,632 932	720	1,770 1,100	586	1,240 830	457	827 588	282	431 311
Node 112	Red Deer River below Waskasoo Creek	12,096	11,302	3,910	6,845 2,658	3,590	6,160 2,466	3,190	5,317 2,239	2,910	4,725 2,077	2,460	3,819 1,813	1,870	2,744 1,411	1,680	2,413 1,288	1,430	1,995 1,114	1,230	1,659 971	721	1,810 1,120	587	1,270 849	458	846 601	283	441 318
Node 113	Red Deer River above Blindman River	12,096	11,302	3,870	6,517 2,565	3,570	5,908 2,401	3,150	5,067 2,165	2,880	4,538 2,015	2,440	3,704 1,759	1,860	2,670 1,381	1,670	2,346 1,271	1,430	1,949 1,110	1,230	1,627 973	721	1,810 1,120	587	1,270 849	458	846 601	283	441 318
Node 114	Red Deer River below Blindman River	14,010	13,336	4,440	7,491 2,936	4,130	6,859 2,781	3,630	5,873 2,488	3,310	5,237 2,316	2,810	4,276 2,036	2,180	3,153 1,635	1,980	2,782 1,507	1,720	2,345 1,336	1,490	1,971 1,179	782	2,140 1,320	647	1,500 1,000	512	998 709	320	520 375
Node 115	Red Deer River at Highway 11	14,128	13,454	4,420	7,457 2,922	4,110	6,826 2,768	3,610	5,841 2,474	3,290	5,205 2,302	2,790	4,246 2,022	2,180	3,153 1,635	1,970	2,768 1,499	1,710	2,331 1,328	1,490	1,971 1,179	770	2,160 1,330	640	1,510 1,010	508	1,010 715	318	525 378
RED DEER RIVER TRIBUTARIES																											
05CC011 / Node 307	Waskasoo Creek at Red Deer (WSC Station No. 05CC011)	487	250	107	264 39.9	99	231 38.5	88.7	192 36.7	80.2	161 35.1	67.7	122 31.9	53.9	87.3 27.9	48.7	75.3 26.4	41.8	61.7 24.2	36.3	51.5 21.7	28.3	38.9 17.6	19.8	27 12.4	12.7	18.3 7.91	5.16	8.05 3.14
Node 308	Waskasoo Creek above Piper Creek	326	166	72	175 26.5	67	154 25.6	60.2	128 24.4	54.6	107 23.3	46.3	81.1 21.2	37.1	58 18.5	33.5	50.1 17.5	28.9	41 16.1	25.1	34.2 14.4	19.6	25.9 11.7	13.7	17.9 8.24	8.71	12.2 5.26	3.47	5.35 2.09
Node 309	Waskasoo Creek below Highway 42	243	142	61.8	149 22.6	57.5	131 21.9	51.8	109 20.8	47	91.3 19.9	40	69.2 18.1	32.1	49.5 15.8	29	42.8 14.9	25	35 13.7	21.7	29.2 12.3	17	22.1 9.99	11.9	15.3 7.03	7.54	10.4 4.49	2.97	4.57 1.78
WASKASOO CREEK TRIBUTARIES																											
Node 310	Piper Creek above Waskasoo Creek	156	82	36.3	86.3 13	33.9	75.5 12.6	30.7	62.7 12	28	52.6 11.5	23.9	39.9 10.4	19.3	28.5 9.12	17.5	24.6 8.63	15.2	20.2 7.91	13.2	16.8 7.09	10.3	12.7 5.75	7.21	8.82 4.05	4.55	5.98 2.58	1.73	2.63 1.03
Node 311	Piper Creek below Highway 595	120	73	32.8	77.8 11.7	30.6	68 11.3	27.7	56.3 10.8	25.3	47.3 10.3	21.7	35.9 9.33	17.5	25.6 8.22	15.9	22.1 7.78	13.8	18.2 7.11	12	15.1 6.36	9.39	11.4 5.17	6.55	7.91 3.64	4.13	5.38 2.32	1.56	2.37 0.927
Node 312	Piper Creek below Township Road 374	81	59	26.4	62.3 9.37	24.7	54.2 9.03	22.4	45 8.65	20.5	37.8 8.22	17.6	28.7 7.46	14.3	20.5 6.56	13	17.7 6.23	11.2	14.5 5.7	9.79	12.1 5.09	7.68	9.13 4.14	5.36	6.32 2.91	3.37	4.3 1.85	1.26	1.9 0.742

Notes: (1) The flow change locations selected for the hydraulic modelling include: Red Deer River Nodes 202, 112 and 114; Red Deer Tributary Nodes 309, 308 and 307; and Waskasoo Creek Tributary Nodes 311 and 310.
(2) The flood peak discharges used in the hydraulic modelling are the values listed in the "Flood Est." column.
(3) The flood peak discharges used in the hydraulic modelling are for the regulated flow conditions.

Table 6: Existing Hydraulic Models for the Study Area

No.	Report	Program	Date	Author or Source
1	Red Deer River at Red Deer Hydraulics Study	HEC-2	June 1991	W-E-R Engineering Ltd.
2	Waskasoo Creek at Red Deer – Extension of Flood Risk Mapping study	HEC-2	March 1995	B.K. Hydrology Service
3	Flood Risk Mapping Study – Red Deer River, Dickson Dam to Red Deer Including Markerville	HEC-RAS	March 2007	AMEC Earth and Environmental
4	Waskasoo Creek at Penhold – Flood Hazard Mapping Study	HEC-RAS	December 2008	UMA Engineering Ltd.

3.5 Highwater Marks

The available highwater mark reports and data for open water flooding are listed in Table 7.

Table 7: Available Highwater Mark Reports and Data

No.	Report	Flood Event	Author or Source
1	Highwater Mark Report – Waskasoo Creek at Red Deer: 1982	April 1982	Alberta Environment
2	Highwater Mark Report – Red Deer River	June 1990	Alberta Environment
3	Highwater Mark Report – Red Deer River at Red Deer: June 7-13, 2005	June 2005	Alberta Environment
4	Highwater Mark Report – Waskasoo Creek at Penhold and Red Deer: May 4-9, 2007	May 2007	Alberta Environment
5	Highwater Mark Report – Red Deer River at Red Deer: June 23-25, 2013	June 2013	Alberta Environment and Sustainable Resource Development
6	Waskasoo Creek and Piper Creek Preliminary Highwater Mark Information with Photos	April 2018	Alberta Environment and Parks

3.6 Gauge Data and Rating Curves

The following active Water Survey of Canada (WSC) gauging stations are located within the study area:

- WSC Station No. 05CC002 - Red Deer River at Red Deer;
- WSC Station No. 05CC011 - Waskasoo Creek at Red Deer; and
- WSC Station No. 05CC001 - Blindman River Near Blackfalds.

3.7 Flood Photography

The available open water flood photography for the study area are listed in Table 8. These photographs were not useful to aid in calibration or verification where highwater mark information is limited.

Table 8: Available Open Water Flood Photography for the Study Area

No.	Report or Description	Flood Event	Author or Source
1	Red Deer River flood photographs taken from a helicopter on June 20, 2005	June 2005	City of Red Deer
2	Red Deer River flood photographs, presentations, and timeline for flood between June 18 and June 21, 2005	June 2005	Red Deer County
3	Lions Campground flood photographs taken on November 15, 2013	November 2013	City of Red Deer

4.0 RIVER AND VALLEY FEATURES

4.1 General Description

The Red Deer River, Waskasoo Creek and Piper Creek flow through the City of Red Deer. Waskasoo Creek flows through the Town of Penhold.

The Red Deer River starts in the Rocky Mountains of Banff National Park near Lake Louise and flows northeast for 145 km before reaching the City of Red Deer. At the WSC Station No. 05CC002 (Red Deer River at Red Deer), the total drainage area of the Red Deer River is 11,600 km^2. Within the study area, the Red Deer River flows in the northeast direction, from Township Road 380, through the City of Red Deer and then turns to flow in the southeast direction, to the Highway 11 Bridge.

Waskasoo Creek originates near Innisfail and flows mostly in a northeast direction until it joins with the Red Deer River. At the WSC Station No. 05CC011 (Waskasoo Creek at Red Deer), the total drainage area of Waskasoo Creek is 487 km^2. Within the study area, Waskasoo Creek flows from the Highway 2A bridge upstream of Penhold to its confluence with the Red Deer River.

Piper Creek originates at a location approximately 15 km southwest of the Waskasoo Creek and Red Deer River confluence. It flows in a northwest direction until it joins Waskasoo Creek in the City of Red Deer. At the Piper Creek and Waskasoo Creek confluence, the total drainage area of Piper Creek is 156 km^2. Within the study area, Piper Creek flows from Township Road 374 to its confluence with Waskasoo Creek.

4.2 Channel and Floodplain Characteristics

4.2.1 Red Deer River

Channel Characteristics

Within the study reach of the Red Deer River, the channel width ranges between 62 m and 300 m and the bankfull depth, which is approximated by the 2-year flood depth, ranges between 1.8 m and 4.6 m.

The Red Deer River at the City of Red Deer has an average slope of 0.12%. The channel pattern is one of irregular meanders with pool and riffle sequence, diagonal and mid-channel bars. The channel is partly entrenched and frequently confined with an average sinuosity of 1.4. The lateral activity of the river has a downstream progression and is slightly unstable. The channel bed consists predominantly of gravel with D_{50} of 48 mm and D_{90} of 95 mm. The channel bank consists of sand and gravels (Kellerhals et al. 1972).

W-E-R (1991) described the Red Deer River channel characteristics as follows:

"The Red Deer River channel along the study reach is set inside a broad river valley and is frequently deflected by the valley walls or by high terraces. The river exhibits a well defined meander pattern with higher sinuosity downstream of the 67th Street Bridge. There are several islands and mid-channel bars, the majority of which are also situated downstream of the 67th Street Bridge. The river profile features a regular sequence of shallow riffles and deep pools. The river valley bottom exhibits little evidence of meander progression or oxbow cut-offs. The channel banks are slightly unstable with localized bank erosion. The average sinuosity is about 1.4, the average meander wave length is about 2.3 km, and the meander amplitude is about 800 m. The channel bed materials is predominantly gravel with a median particle size (D_{50}) of approximately 48 mm and a 90 percentile particle size (D_{90}) of about 95 mm. About 90 percent of the riverbanks are alluvial, consisting of sands and gravels and about 10 percent are non-alluvial banks consisting of bed rock or glacial deposits."

Floodplain Characteristics

The Red Deer River floodplain is discontinuous within the study area. At the upstream boundary of the study area, the floodplain width is approximately equal to the channel width at about 150 m. Through the City of Red Deer, between the 67th Street Bridge and the Riverbend Pedestrian Bridge, the floodplain width increases substantially to be approximately 14 times the channel width at about 2,100 m. However, further downstream, after the Red Deer River turns southward until the downstream boundary, the river channel is incised, and the floodplain is confined.

A large part of the downtown area of the City of Red Deer is located within the Red Deer River floodplain. The City of Red Deer Wastewater Treatment Plant is also located within the Red Deer River floodplain. The two dikes that were constructed along the Red Deer River for flood mitigation purposes, are described in Golder (2021a).

AMEC (2007) described the Red Deer River floodplain characteristics as follows:

"The Red Deer River is situated in a broad river valley and is confined by valley walls with an average width of approximately 400 to 1000 m. The valley contains the river floodplain which is composed mainly of alluvial sand and gravel (Kellerhals et al. 1972). […] The floodplain of the Red Deer River along the study reach is clearly identifiable but is discontinuous. The land within the floodplain is partly cultivated, with some trees and brush present."

W-E-R (1991) described the Red Deer River floodplain characteristics as follows:

"The active floodplain along the river is clearly identifiable but relatively small, narrow, and discontinuous. The vegetation on the floodplain consists of pasture, bushes and shrubs ranging from light to high density. Several relatively large areas subject to flooding are located downstream of the 67th Street Bridge on the right bank of the Red Deer River. The maximum extent of flooding at this location during the 100 year design flood is about 600 m from the riverbank, but this is mainly shallow water."

4.2.2 Waskasoo Creek

Channel Characteristics

Within the study reach of the Waskasoo Creek, the channel width ranges between 5.1 m and 27.8 m and the bankfull depth, which is approximated by the 2-year flood depth, ranges between 0.4 m and 3.3 m. The average channel slope of Waskasoo Creek ranges between 0.06% to 0.10% upstream of the Red Deer River valley, increases to 0.50% as it descends the Red Deer River valley, and decreases to 0.06% on the Red Deer River floodplain before its confluence with the Red Deer River.

UMA (2008) described the Waskasoo Creek channel characteristics near the Town of Penhold as follows:

> *"…Most of the creek has been channelized adjacent to, and downstream of the Town of Penhold. This channelized system has not been well maintained and is overgrown with brush in various areas. The remaining channel is grassed. The natural channel varies from a meandering shallow streambed with a number of oxbows to undefined in wetland or flat areas."*

Floodplain Characteristics

The Waskasoo Creek floodplain is generally wide and flat within the study area. The floodplains are mostly of farmland along the upper reach and include urban development area within the City of Red Deer. The floodplain width ranges from 5 times the channel width to 100 times the channel width, particularly for the large flood events. The floodplain is generally unconfined from the upstream boundary until Waskasoo Creek begins descending into the Red Deer River valley. In the area of the descent into the Red Deer River valley, the Waskasoo Creek floodplain is confined. The floodplain is relatively unconfined again after Waskasoo Creek reaches the bottom of the Red Deer River valley.

The Town of Penhold and a large part of the downtown area of the City of Red Deer are located within the Waskasoo Creek floodplains. Two dikes along the Town of Penhold, and two dikes in the City of Red Deer were constructed along Waskasoo Creek for flood mitigation as described in Golder (2021a).

UMA (2018) described the Waskasoo Creek floodplain characteristics near the Town of Penhold as follows:

> *"The floodplain is mostly undeveloped, with farm cropland and grazing land. A small section of the floodplain adjacent to the Town of Penhold, has been developed and future development is proposed in this area. Along the channel banks there is brush and grass, with some trees."*

4.2.3 Piper Creek

Channel Characteristics

Within the study reach of the Piper Creek, the channel width ranges between 5.9 m and 37.6 m and the bankfull depth, which is approximated by the 2-year flood depth, ranges between 0.3 m and 1.9 m. The average channel slope of Piper Creek is 0.10% upstream of the Red Deer River valley, and increases to 0.45% before its confluence with Waskasoo Creek.

Based on field observations, Piper Creek was estimated to have similar hydraulic characteristics as Waskasoo Creek. Based on this estimation, the hydraulic model for the Waskasoo Creek and Piper Creek was calibrated using the same roughness coefficient.

Floodplain Characteristics

The Piper Creek floodplain is generally confined within the study area. The floodplains are mostly urban forested parkland with some farmland near the upstream boundary. The floodplain width ranges from 2 times the channel width to 100 times the channel width, particularly for the large flood events. The floodplain is unconfined between the upstream boundary and the Range Road 272 Bridge. Downstream of this bridge, the floodplain is confined in a small valley until Piper Creek reaches its confluence with Waskasoo Creek.

4.3 Large Tributary

The Blindman River enters the Red Deer River at a location approximately 20 km downstream of the Waskasoo Creek confluence. The Blindman River has a catchment area of approximately 1,796 km^2 according to WSC Station No. 05CC001 (Blindman River near Blackfalds), which is located approximately 2.5 km west of the Red Deer River confluence.

4.4 Bridges, Culverts, and Weirs

There are 9 bridges along the Red Deer River study reach, 35 bridges along the Waskasoo Creek study reach, and 8 bridges along the Piper Creek study reach. The pertinent information of these bridges is summarized in Table 9.

There are no culverts along the Red Deer River study reach, 12 culverts along the Waskasoo Creek study reach, and 7 culverts along the Piper Creek study reach. These culverts are summarized in Table 10.

There are no weirs along the Red Deer River, Waskasoo Creek or Piper Creek study reach.

Table 9: List of Bridges Within the Study Reach

No.	River	River Station (m)	Name	Bridge Type	No. of Spans
1	Red Deer River	45385.27	CP Rail Bridge	Railway	3
2	Red Deer River	45318.97	Red Deer Bypass (Queen Elizabeth II Highway) Northbound and Southbound Bridges	Traffic	4
3	Red Deer River	42454.7	Heritage Ranch Pedestrian Bridge	Pedestrian	4
4	Red Deer River	40179.64	Taylor Drive Northbound and Southbound Bridges	Traffic	5
5	Red Deer River	39395.52	CP Rail (58 Street) Pedestrian Bridge	Pedestrian	4
6	Red Deer River	39161.54	50 Avenue (Gaetz Avenue) Bridge	Traffic	6
7	Red Deer River	38992.8	49 Avenue Bridge	Traffic	5
8	Red Deer River	37289.75	67 Street (David Thompson Highway) Bridge	Traffic	5
9	Red Deer River	32422.86	Riverbend (Discovery Canyon) Pedestrian Bridge	Pedestrian	3
10	Waskasoo Creek	33004.05	Township Road 264 Bridge	Traffic	1
11	Waskasoo Creek	31177.97	Range Road 280 Bridge	Traffic	1
12	Waskasoo Creek	29248.34	Highway 42 Bridge	Traffic	2
13	Waskasoo Creek	26835.45	Private Bridge	Traffic	1
14	Waskasoo Creek	25201.05	Township Road 372 Bridge	Traffic	1
15	Waskasoo Creek	25125.59	Private Bridge	Traffic	1
16	Waskasoo Creek	22192.14	Highway 2A Bridge	Traffic	1
17	Waskasoo Creek	22128.42	CP Rail Bridge	Railway	1
18	Waskasoo Creek	21338.1	Township Road 374 Bridge	Traffic	1

Table 9: List of Bridges Within the Study Reach

No.	River	River Station (m)	Name	Bridge Type	No. of Spans
19	Waskasoo Creek	20288.78	CP Rail Bridge	Railway	1
20	Waskasoo Creek	20254.69	Highway 2A Bridge	Traffic	1
21	Waskasoo Creek	20000.1	Private Bridge	Traffic	1
22	Waskasoo Creek	19486.9	Private Bridge	Traffic	1
23	Waskasoo Creek	18681.57	Lantern Street Bridge	Traffic	1
24	Waskasoo Creek	17671.28	Township Road 375 Bridge	Traffic	2
25	Waskasoo Creek	15977	Highway 2A Bridge	Traffic	1
26	Waskasoo Creek	15944.57	CP Rail Bridge	Railway	1
27	Waskasoo Creek	15513.21	Range Road 275 Bridge	Traffic	2
28	Waskasoo Creek	12656.21	Township Road 380 Bridge	Traffic	1
29	Waskasoo Creek	11473.08	Private Bridge	Traffic	1
30	Waskasoo Creek	9610.085	Range Road 275 Bridge	Traffic	1
31	Waskasoo Creek	9406.597	Highway 2 Bridge	Traffic	1
32	Waskasoo Creek	8725.84	Private Bridge	Traffic	1
33	Waskasoo Creek	5210.98	ACR Trail South Pedestrian Bridge	Pedestrian	1
34	Waskasoo Creek	5005.23	ACR Trail North Pedestrian Bridge	Pedestrian	1
35	Waskasoo Creek	3801.724	50 Avenue (Gaetz Avenue) Bridge[1]	Traffic	1
36	Waskasoo Creek	3611.609	49 Avenue Bridge	Traffic	1
37	Waskasoo Creek	2468.093	Barrett Park South Pedestrian Bridge	Pedestrian	1
38	Waskasoo Creek	2004.915	Barrett Park North Pedestrian Bridge	Pedestrian	1
39	Waskasoo Creek	1331.213	Ross Street Eastbound and Westbound Bridges	Traffic	1
40	Waskasoo Creek	1253.214	Coronation Park South Pedestrian Bridge	Pedestrian	1
41	Waskasoo Creek	982.1014	Coronation Park North Pedestrian Bridge	Pedestrian	4
42	Waskasoo Creek	835.2544	53 Street Bridge	Traffic	3
43	Waskasoo Creek	600.8005	55 Street Bridge	Traffic	1
44	Waskasoo Creek	153.1458	Gaetz Park Pedestrian Bridge	Pedestrian	1
45	Piper Creek	17514.25	Range Road 272 Bridge	Traffic	1
46	Piper Creek	6532.337	Bannerman Close Pedestrian Bridge	Pedestrian	1
47	Piper Creek	3764.79	Bower Woods East-West Pedestrian Bridge	Pedestrian	1

Table 9: List of Bridges Within the Study Reach

No.	River	River Station (m)	Name	Bridge Type	No. of Spans
48	Piper Creek	3178.546	Bower Woods North-South Pedestrian Bridge	Pedestrian	1
49	Piper Creek	1825.649	Kin Canyon South Pedestrian Bridge	Pedestrian	1
50	Piper Creek	1343.162	Kin Canyon North Pedestrian Bridge	Pedestrian	1
51	Piper Creek	635.7696	Rotary Picnic Park South Pedestrian Bridge	Pedestrian	1
52	Piper Creek	390.0081	Rotary Picnic Park North Pedestrian Bridge	Pedestrian	1

(1) The 50 Avenue (Gaetz Avenue) Bridge on the Waskasoo Creek was surveyed and modelled as a bridge in the Study. It is acknowledged that the City of Red Deer recognizes this structure as a culvert.

Table 10: List of Culverts Within the Study Reach

No.	River	River Station (m)	Name	No. of Culverts	Inside Diameter (m)	Culvert Type
1	Waskasoo Creek	34225.38	Range Road 281 Culvert	1	0.9	Pipe
2	Waskasoo Creek	32212.93	Private Culvert	1	2.5	Pipe
3	Waskasoo Creek	31431.8	Private Culvert	4	0.5	Pipe
					0.7	Pipe
					0.7	Pipe
					0.5	Pipe
4	Waskasoo Creek	22894.8	Private Culvert	1	1.5	Pipe
5	Waskasoo Creek	14586.2	Private Culvert	2	1.6	Pipe
					2.1	Pipe
6	Waskasoo Creek	9482.278	CP Rail Culvert	2	3	Pipe
					3	Pipe
7	Waskasoo Creek	6805.485	Taylor Drive Culvert	1	2.8	Pipe
8	Waskasoo Creek	6308.135	32 Street Culvert	1	3.4	Pipe
9	Waskasoo Creek	5893.377	34 Street Culvert	1	3.2	Pipe
10	Waskasoo Creek	4500.285	43 Street Culvert	1	2.4	Pipe
11	Waskasoo Creek	4142.467	52 Avenue & 45 Street Loop Culvert	2	3.0 (W) x 2.0 (H)	Box
					3.0 (W) x 2.0 (H)	Box
12	Waskasoo Creek	3387.566	48 Avenue Culvert	3	3.6 (W) x 2.8 (H)	Box
					3.6 (W) x 2.8 (H)	Box
					3.6 (W) x 2.8 (H)	Box
13	Piper Creek	18613.3	Private Culvert	1	1.4	Pipe
14	Piper Creek	12376.4	40 Avenue Culvert	2	2.2	Pipe
					2.2	Pipe
15	Piper Creek	12095.1	Private Culvert	2	1.8	Pipe
					1.8	Pipe
16	Piper Creek	11554.53	Private Culvert	1	2.2	Pipe
17	Piper Creek	7675.133	Delburne Road (19 Street) Culvert	2	2.2	Pipe
					2.2	Pipe
18	Piper Creek	2424.258	32 Street Culvert	3	3.0 (W) x 2.5 (H)	Box
					3.1 (W) x 2.8 (H)	Box
					3.1 (W) x 2.8 (H)	Box
19	Piper Creek	66.71176	43 Street Culvert	2	2	Pipe
					2	Pipe

4.5 Flood Control Structures

There is one flood control structure along the Red Deer River study reach, four flood control structures along the Waskasoo Creek study reach, and no flood control structures along the Piper Creek study reach. These flood control structures are summarized in Table 11.

Table 11: List of Flood Control Structures Within the Study Reach

River	Description	Name / Identifier	Approximate Length (m)	Side of River[a]	Type
Red Deer River	Retaining Structure North of 67 Street	McKenzie Trails Berm	280	Right	Retaining Structure
Red Deer River	Access Road Around Wastewater Treatment Cells	Red Deer Wastewater Treatment Plant Dike	1,514	Left	Roadway and Earthfill Barrier
Waskasoo Creek	Waskasoo Ave. Between Lucina St. and Robinson Ave.	Penhold Dike #1	998	Left	Roadway
Waskasoo Creek	East of Waskasoo Ave. Between Lucina St. and Hawkridge Blvd.	Penhold Dike #2	868	Left	Earthfill Barrier
Waskasoo Creek	South of Safeway Between 49 Ave. and 50 Ave.	Safeway Dike	160	Left	Earthfill Barrier
Waskasoo Creek	South of Baymont Inn & Suites Between 48 Ave. and 49 Ave.	Baymont Dike	80	Left	Earthfill Barrier

a) Left or right refers to directions as seen by an observer looking downstream.

4.6 Other Features

There are no other relevant features along the Red Deer River, Waskasoo Creek, and Piper Creek study reaches.

5.0 MODEL CONSTRUCTION

5.1 HEC-RAS Program

5.1.1 Theoretical Aspects

The HEC-RAS program (Version 5.0.6) was used as the software platform for developing the one-dimensional (1D) hydraulic model in the study area. The HEC-RAS program was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE). The River Analysis System (RAS) software has a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, and graphics and reporting facilities. HEC-RAS is a commonly-used program in North America and around the world (USACE 2016).

The HEC-RAS program was designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. HEC-RAS is capable of simulating steady and unsteady flow conditions. The program can be used to calculate water surface profiles for gradually varied flow. The program is capable of calculating the water surface profiles associated with subcritical, supercritical and mixed flow regimes. In this study, the program is used in steady-state mode.

The basic computational procedure for steady-state simulation is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion. The momentum equation is utilized in situation where the water surface profile is rapidly varied. The program can be used to simulate the effects of various obstructions such as bridges, culverts, weirs, spillways, and other structures in the floodplain. For this study, HEC-RAS is run in steady state mode only.

The main assumptions in 1D modelling are listed below:

- The variation of the river channel and floodplain geometries is represented by a series of cross sections.
- The water level is constant at each cross section.
- The flow is perpendicular to the cross section alignment.

The HEC-GeoRAS module (Version 10.2) was used to prepare cross section data based on the LiDAR DEM and river survey data (Golder, 2021a). HEC-GeoRAS is an ArcGIS extension tool specifically designed to create a HEC-RAS import file from geospatial data.

5.1.2 General Model Setup

Reaches

All reaches in the study area are included into one integrated model setup. The model consists of five reaches, which are summarized in Table 12.

Table 12: Reaches in the Hydraulic Model

Stream	Reach	Length (km)
Red Deer River	Upper Reach	12.4
	Lower Reach	38.5
Waskasoo Creek	Upper Reach	31.2
	Lower Reach	3.5
Piper Creek	Entire Reach	19.7

Cross Sections

The cross section alignments and extents were selected following the general approach listed below:

- The cross sections should be approximately perpendicular to the flow direction both in the main channel and the floodplains. This resulted in some cross sections bended using multiple vertices.
- The cross sections must not cross each other.
- The cross sections should have sufficient lengths on the floodplains to extend beyond the limits of all simulated open-water floods.

A conceptual two-dimensional hydraulic analysis was performed for the entire study area to understand the flood flow paths on the floodplains for the 100-year and 1000-year flood events. This analysis was used to complement the professional judgement used to inform selection of the cross section alignments.

Boundary Conditions

The HEC-RAS model requires specification of boundary conditions at all open and internal boundaries. The open boundaries specified in the hydraulic model are listed below:

- Discharge at the upstream end of the Red Deer River study reach;
- Discharge at the upstream end of the Waskasoo Creek study reach;
- Discharge at the upstream end of the Piper Creek study reach; and
- Normal flow condition at the downstream end of the Red Deer River study reach.

A schematic of the model setup is presented in Figure 2.

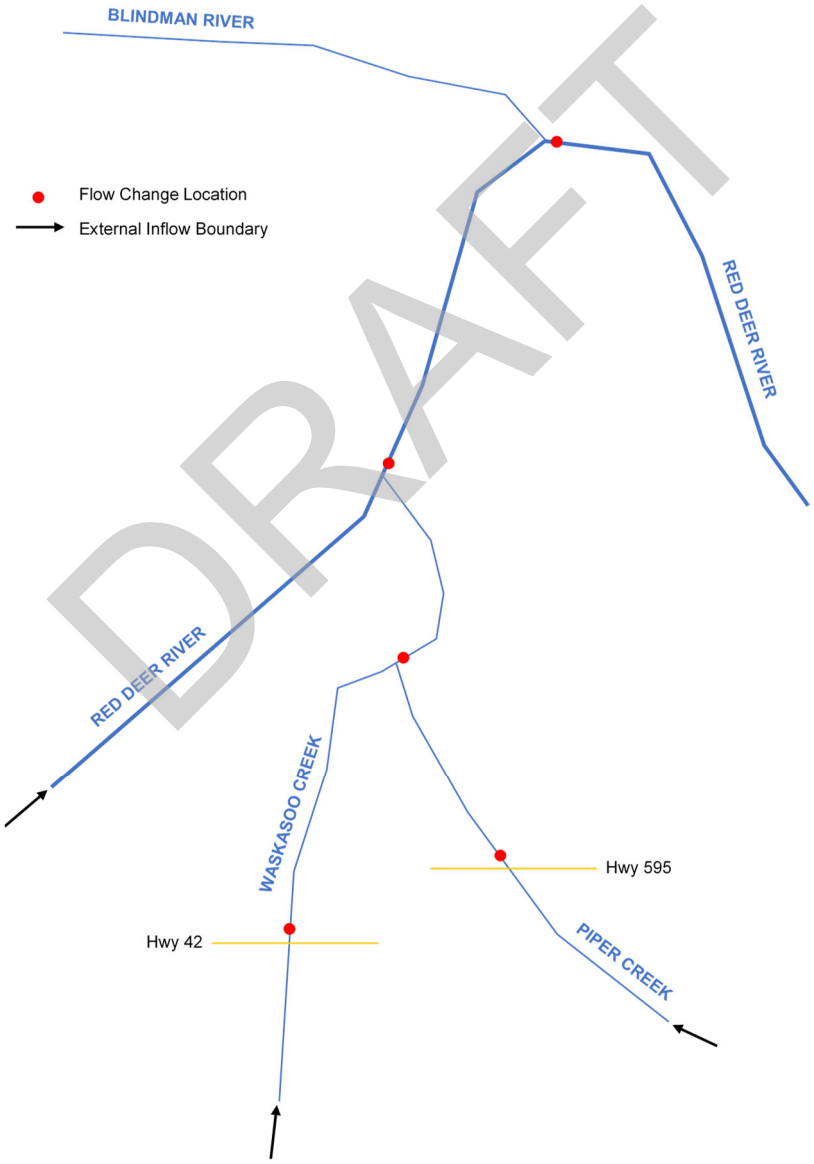


Figure 2: Flow Change Locations used in the Model Setup

5.2 Geometric Data Base

5.2.1 Cross Section Data

Locations of the cross sections in the model were selected based on the locations of surveyed cross sections and modelling requirements. The cross section data were extracted from the following sources:

- River survey data collected in 2017 (Golder 2021a); and
- 2017 LiDAR data provided by AEP.

The alignments of the cross sections on the floodplains were selected based an examination of the topography and professional judgement, which was supplemented with the results of a conceptual two-dimensional hydraulic analysis. Hydraulic divides were introduced at appropriate locations under close consultation with AEP to serve as breaklines for cross sections. HEC-GeoRAS was used to define the main channels, overbank flow paths, bank stations, and cross section river stations.

The cross section counts and river reaches are summarized in Table 13 and Table 14.

Table 13: Number of Cross Sections in Model Reaches

Stream Name in HEC-RAS	Reach Name in HEC-RAS	Description of Reach	From Station (m)	To Station (m)	Length (km)	Number of Cross Sections
Red Deer River	Upper Reach	Upstream study end to Waskasoo Creek confluence	50,826	38,495	12.4	48
	Lower Reach	Waskasoo Creek confluence to downstream study end	38,495	0	38.5	105
Waskasoo Creek	Upper Reach	Upstream study end to Piper Creek confluence	34,636	3,525	31.2	254
	Lower Reach	Piper Creek confluence to Red Deer River confluence	3,525	0	3.5	49
Piper Creek	Piper Creek	Upstream study end to Waskasoo Creek confluence	19,702	0	19.7	134
					Total	**590**

Table 14: Summary of Study Reaches

Stream Reach	Reach Length (km)	Number of Cross Sections	Average Cross Section Spacing (m)
Red Deer River	50.9	153	335
Waskasoo Creek	34.7	303	115
Piper Creek	19.7	134	148

5.2.1.1 Roughness Distribution

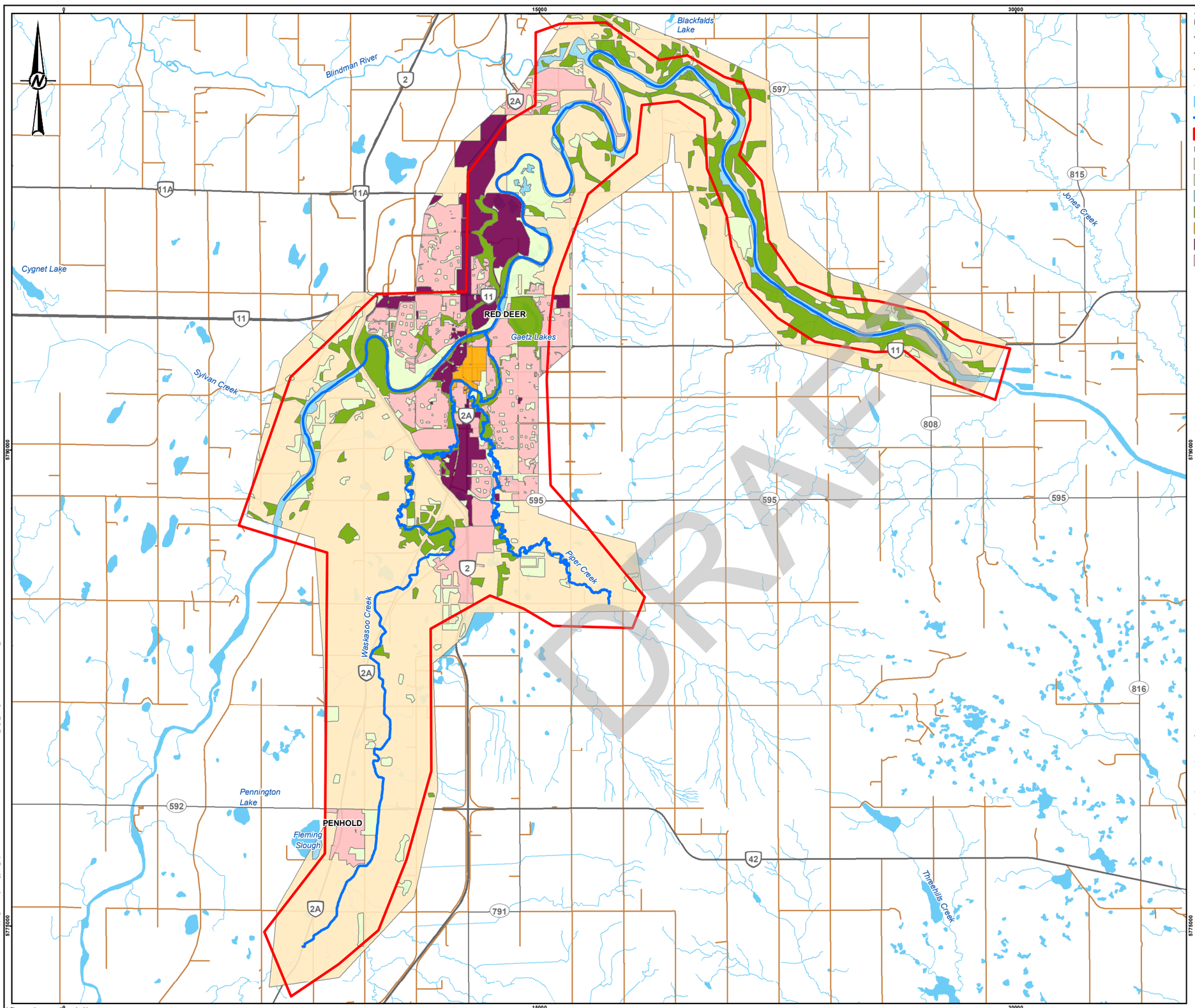
The left and right bank stations defining the main channels were determined using HEC-GeoRAS based on the 2017 LiDAR data, aerial imagery, and survey data. Manning's n roughness values were specified using the distributed roughness approach, which allows for multiple, varying roughness values within each cross section. The initial roughness distribution was specified based on the following data:

- bank lines established from the LiDAR data, aerial imagery and surveyed data to identify the main channels;
- land use information provided by the City of Red Deer and Town of Penhold; and
- information collected during the site reconnaissance in August 2017.

These data sources were used to define seven roughness classes. The initial roughness (Manning's n) values assigned to the classes are provided in Table 15. These initial values were selected based on literature and professional judgement. The roughness values were applied to the cross sections using HEC-GeoRAS and modified at some locations during the model calibration process (see Section 5.4.1). The roughness distribution is shown in Figure 3.

Table 15: Roughness Classes and Initial Manning's n Values

Number	Description	Initial Manning's n
1	River and Creeks	0.030
2	Urban Mixture (Residential and Small Commercial)	0.080
3	Urban Mixture (Industrial and Large Commercial)	0.050
4	Urban Mixture (Downtown)	0.060
5	Agriculture	0.045
6	Grassland and Open Space	0.038
7	Trees and Bushes	0.100



LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERCOURSE
- WATERBODY
- SURVEY REACH
- RIVER HAZARD STUDY AREA

LAND USE CLASSES

- AGRICULTURE
- GRASSLAND AND OPEN SPACE
- WATER
- TREES AND BUSHES
- URBAN MIXTURE (DOWNTOWN)
- URBAN MIXTURE (INDUSTRIAL AND LARGE COMMERCIAL)
- URBAN MIXTURE (RESIDENTIAL AND SMALL COMMERCIAL)

0 3 6

1:120,000 KILOMETRES

REFERENCE(S)

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
ROUGHNESS CLASS DISTRIBUTION

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-25
DESIGNED	NG
PREPARED	PT
REVIEWED	GT
APPROVED	DL

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	3000	0	3

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5.2.2 Bridges, Culverts & Weirs

Bridges

The bridge geometries used in the HEC-RAS model were defined based on the following data:

- River and bridge surveys completed in 2017 (Golder 2021a); and
- As-built drawings provided by Alberta Transportation and the City of Red Deer.

All existing bridges are represented in the HEC-RAS model. They include those which may not affect water levels during floods (e.g., clear span bridges with sufficient freeboards). Losses through bridges are calculated in the model using the energy equation (i.e., standard step method).

Bridges are modelled using upstream and downstream cross sections. Internal cross sections cut along the centerlines of the bridges are used only for bridges with defined embankments that are higher than surrounding ground elevations. This is because the lengths of upstream and downstream cross sections are different in some cases, which would result in levees and ineffective flow areas being misplaced along the bridge cross sections.

The cross sections tend to have long lengths. To properly model overland flows that can bypass bridges, the multiple flow analysis is implemented. This allows the HEC-RAS model to calculate a distribution of flows that are conveyed through the bridge openings and bypassed around the bridges. Not using the multiple flow analysis would result in bypassed flows being treated as flows over a broad-crested weir.

There are variations of bridge types, abutments, approaches, and embankments within the study area. For each bridge, ineffective areas upstream and downstream of the bridges were carefully selected on a case-by-case basis including the selection of permanent and non-permanent ineffective areas where appropriate.

All bridges within the study area are approximately perpendicular to the main channel flow direction, so that it was not necessary to include any skew in the model.

The initial values of the contraction and expansion coefficients at the bridges were selected to be 0.3 and 0.5, respectively. These are typical values listed in the HEC-RAS user manual. One exception is the Riverbend (Discovery Canyon) Pedestrian Bridge where contraction and expansion coefficients were selected to be 0.8 and 1.0, respectively, because the bridge opening is small, compared with other Red Deer River bridges, resulting in greater energy losses in flow through the bridge.

Culverts

The culvert geometries used in the HEC-RAS model were defined based on the river and culvert survey data collected in 2017 (Golder 2021a). All existing culverts are represented in the HEC-RAS model. Losses through culverts are calculated in the model using the energy equation (i.e., standard step method).

Culverts are modelled using upstream and downstream cross sections. Internal cross sections cut along the centerlines of the culverts are used only for a few culverts to help better define the embankments. There are no manually defined internal cross sections, because the lengths of upstream and downstream cross sections are different in some cases, and because having the internal cross sections would result in levees and ineffective flow areas being misplaced along the culvert cross sections.

Similar to the bridge modelling approach, the multiple flow analysis is implemented to properly simulate overland flows that bypass the culverts. This allows the HEC-RAS model to calculate a distribution of flows that are conveyed through the culvert openings and bypassed around the culverts as overland flows. Not using the multiple flow analysis would result in bypassed flows being treated as flows over a broad-crested weir.

There are variations of culvert shapes, approaches and embankments within the study area. For each culvert, ineffective areas upstream and downstream of the culverts were carefully selected on a case-by-case basis including the selection of permanent and non-permanent ineffective areas where appropriate.

The initial values of the entrance loss coefficient were selected to range between 0.5 and 0.9 based on the recommended values listed in the HEC-RAS user manual. The exit loss coefficient value of 1.0 was specified.

Weirs

There is no weir included in the model setup.

Summary

The total number of bridges, culverts, weirs and other features included in the model are summarized in Table 16.

Table 16: Number of Hydraulic Structures Included in the Hydraulic Model

Stream	Total Number			
	Bridges[a]	Culverts	Weirs	Other Features
Red Deer River	9	None	None	None
Waskasoo Creek	35	12	None	None
Piper Creek	8	7	None	None

a) The Queen Elizabeth II Highway Northbound and Southbound bridges, Taylor Drive Northbound and Southbound bridges, and David Thompson Westbound and Eastbound bridges on the Red Deer River are simulated each as one bridge in the hydraulic model.

5.2.3 Flood Control Structures

The flood control structures considered in this study were based on the survey data collected by Golder (2021a), as-built drawings provided by the City of Red Deer, and feedback from the stakeholders. Only structures that are regularly maintained by the stakeholders and designed to provide a certain level of protection were included in this study. This does not include private flood protection berms.

The flood control structures were represented in the HEC-RAS model using one (or a combination) of the two methods listed below:

- Levees; and/or
- Ineffective flow areas.

The method selection was based on professional judgement and suitability for use along a particular cross section. If one method was selected for a particular flood control structure, it was consistently used for the entire length of that flood control structure.

The flood control structures included in the hydraulic model are summarized in Table 17.

Table 17: Flood Control Structures in the Study Area

Stream	Description	Name or Identifier	Approximate Length (m)	Side of River[a]	Type
Red Deer River	Retaining Structure North of 67 Street	McKenzie Trails Berm	280	Right	Retaining Structure
Red Deer River	Access Road Around Wastewater Treatment Cells	Red Deer Wastewater Treatment Plant Dike	1,514	Left	Roadway and Earthfill Barrier
Waskasoo Creek	Waskasoo Ave. Between Lucina St. and Robinson Ave.	Penhold Dike #1	998	Left	Roadway
Waskasoo Creek	East of Waskasoo Ave. Between Lucina St. and Hawkridge Blvd.	Penhold Dike #2	868	Left	Earthfill Barrier
Waskasoo Creek	South of Safeway Between 49 Ave. and 50 Ave.	Safeway Dike	160	Left	Earthfill Barrier
Waskasoo Creek	South of Baymont Inn & Suites Between 48 Ave. and 49 Ave.	Baymont Dike	80	Left	Earthfill Barrier

a) Left or right refers to directions as seen by an observer looking downstream.

5.2.4 Other Features

There are no other hydraulically relevant features included in the model setup.

5.3 Model Calibration

5.3.1 Methodology

The Manning's roughness n value and the bridge contraction/expansion coefficients are the two primary model parameters used in calibrating the HEC-RAS model. Selection of the initial Manning's n values included consideration of river bed/bank materials, vegetation cover, site information collected during the field inspection, and Golder's past experience with the Red Deer River and other similar rivers.

Manning's n value may reduce with increased stage. Model calibration was conducted based on the pertinent flow and water level information of the low flow and high flow conditions, and the WSC gauging station rating curves to determine appropriate roughness values across a wide range of flows, as described below:

- **Low Flow Calibration:** The surveyed water levels and measured flows during the river surveys were used for the low flow calibration.
- **High Flow Calibration:** Available highwater marks and peak flow estimates for the 1990, 2005 and 2013 floods were used for high flow calibration of Red Deer River. Available highwater marks and peak flow estimates for the 1982, 2007 and 2018 floods were used for high flow calibration of Waskasoo Creek. Available highwater marks for the 2018 flood were used for high flow validation of Piper Creek.
- **Rating Curve Calibration:** The flow-stage rating curves for the two WSC gauging stations (i.e., 05CC002, Red Deer River at Red Deer; and 05CC011, Waskasoo Creek at Red Deer) within the study area were used in the model calibration to understand and quantify the potential variation of effective roughness at various water stages. There is no WSC gauging station on Piper Creek.

The model calibration process involved multiple iterations to adjust the model parameter values, conduct simulations, and compare the simulated water levels with the highwater marks (for high flow calibration), surveyed water levels (for low flow calibration), and gauging station rating curve data. The objective of the model calibration was to achieve good matches between the simulated water levels and the highwater marks, surveyed water levels and gauged water levels.

The results of the model calibration are described in the following sections.

5.3.2 Low Flow Calibration

The water level and discharge measurements collected in the fall of 2017 on Red Deer River, Waskasoo Creek and Piper Creek were used to support the low flow calibration. The measured flows used in the model calibration are summarized in Table 18.

Table 18: Measured Discharges and Corresponding WSC Gauge Data

Stream	Date	WSC Gauging Station	Discharge (m^3/s)		Difference	
			WSC Gauge	Measured during Survey	(m^3/s)	(%)
Red Deer River	Sept.24, 2017	05CC002	21.1	20.76	0.34	1.6%
	Sept.27, 2017	05CC002, 05CC011	22.12	21.37	0.76	3.5%
	Sept.25, 2017	05CC002, 05CC011	22.13	23.27	-1.14	-4.9%
	Sept.17, 2017	05CC002, 05CC011	22.72	24.05	-1.33	-5.5%
	Sept.18, 2017	05CC002, 05CC011, 05CC001	23.74	24.32	-0.58	-2.4%
	Sept.19, 2017	05CC002, 05CC011, 05CC001	21.52	21.87	-0.36	-1.6%
	Sept.16, 2017	05CC002, 05CC011, 05CC001	22.83	22.65	0.18	0.8%
Waskasoo Creek	Sept. 14, 2017	N/A	N/A	0.02	N/A	N/A
	Sept. 15, 2017	N/A	N/A	0.02	N/A	N/A
	Sept. 16, 2017	05CC011	0.034	0.038	-0.004	-10.5%
	Sept. 13, 2017	05CC011	0.74	1.37	-0.63	-46.1%
Piper Creek	Sept. 20, 2017	N/A	N/A	0.11	N/A	N/A
	Sept. 21, 2017	N/A	N/A	0.27	N/A	N/A

a) Discharge on Waskasoo Creek and Piper Creek was measured using an ADV.

b) Discharge on Red Deer River was measured using an ADP.

c) Discharge values for the WSC gauge reading were based on real-time data posted online by AEP. Data obtained from AEP are provisional and preliminary, and may be subject to change when manually reviewed and corrected.

5.3.2.1 Red Deer River

The Red Deer River channel roughness values were calibrated based on the measured discharge and water level data collected during the low flow conditions at various locations along the river, as discharges varied from upstream to downstream with the inflows from Waskasoo Creek and Blindman River. The surveyed river discharges from September 16 to September 27 ranged from 20.76 m^3/s (above the Waskasoo Creek confluence) and 24.32 m^3/s (below the Blindman River confluence). These flows are less than 10% of the estimated 2-year flood peak flow (Golder 2021b).

The calibrated channel Manning's *n* value for the low flow conditions is 0.045, and it is uniform for the entire Red Deer River study reach, which is within the typical range of roughness for gravel bed rivers (Chow 1959). This value is higher than the calibrated channel Manning's *n* value for high flow conditions, because the effective roughness increase as discharge decreases.

Figure 4 shows a comparison between the simulated water surface profile and measured water levels for the low flow conditions. Table A.1 in Appendix A lists the differences between the simulated and measured water levels.

The average difference between the simulated and measured water level is -0.09 m, with individual differences ranging from -0.66 m to +0.14 m (see Figure 5).

5.3.2.2 Waskasoo Creek

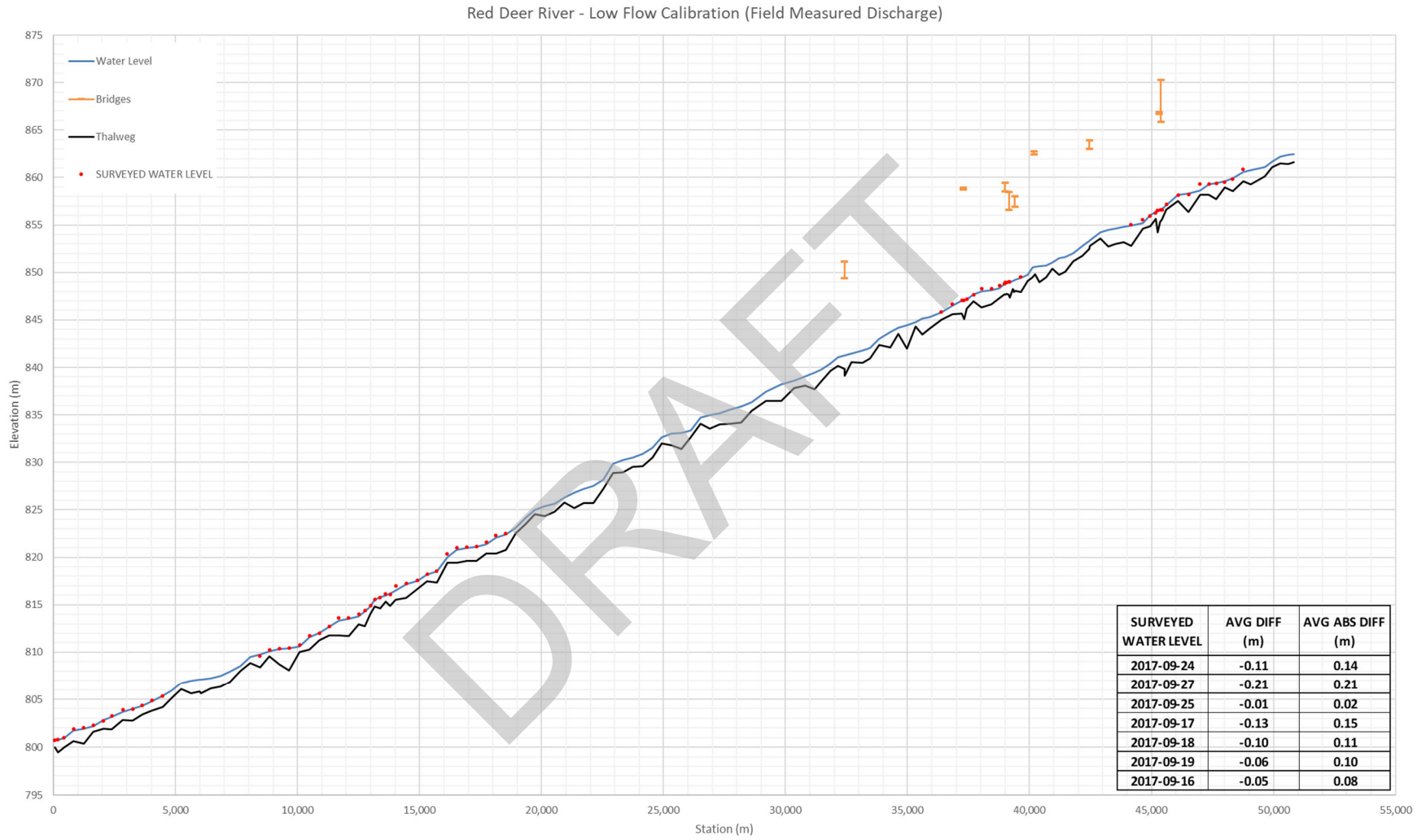
The Waskasoo Creek channel roughness values were calibrated based on the measured discharge and water level data collected during the low flow conditions on Waskasoo Creek near the Piper Creek confluence. The surveyed river discharges from September 13 to September 16 ranged from 0.02 m^3/s to 1.37 m^3/s.

Discharges measured for Waskasoo Creek capture not only the creek base flow, but also storm sewer drainage, and other local discharges. The beaver dams, and short rainfall events had relatively pronounced effects on the measured water levels. Taking this into consideration, the low flow measurements may not be representative of the flow conditions during the water level survey at individual cross sections. Therefore, the results of the low flow calibration were used to evaluate whether the low flow Manning's roughness is unchanged or higher compared against high flow conditions.

The selected calibrated channel Manning's *n* value for the low flow conditions is 0.05, which is uniform for the entire Waskasoo Creek study reach. The value is within the typical range of roughness for similar creeks (Chow 1959) and it is a reasonable increase from the high flow calibration (see Section 5.3.3.2)

Figure 6 shows a comparison between the simulated water surface profile and measured water levels for the low flow conditions. Table A.2 in Appendix A lists the differences between the simulated and measured water levels.

The average difference between the simulated and measured water level is -0.24 m, with individual differences ranging from -1.0 m to +0.08 m (see Figure 7).



SURVEYED WATER LEVEL	AVG DIFF (m)	AVG ABS DIFF (m)
2017-09-24	-0.11	0.14
2017-09-27	-0.21	0.21
2017-09-25	-0.01	0.02
2017-09-17	-0.13	0.15
2017-09-18	-0.10	0.11
2017-09-19	-0.06	0.10
2017-09-16	-0.05	0.08

Figure 4: Comparison of Simulated Red Deer River Water Surface Profile with Surveyed Water Levels for Low Flow Conditions

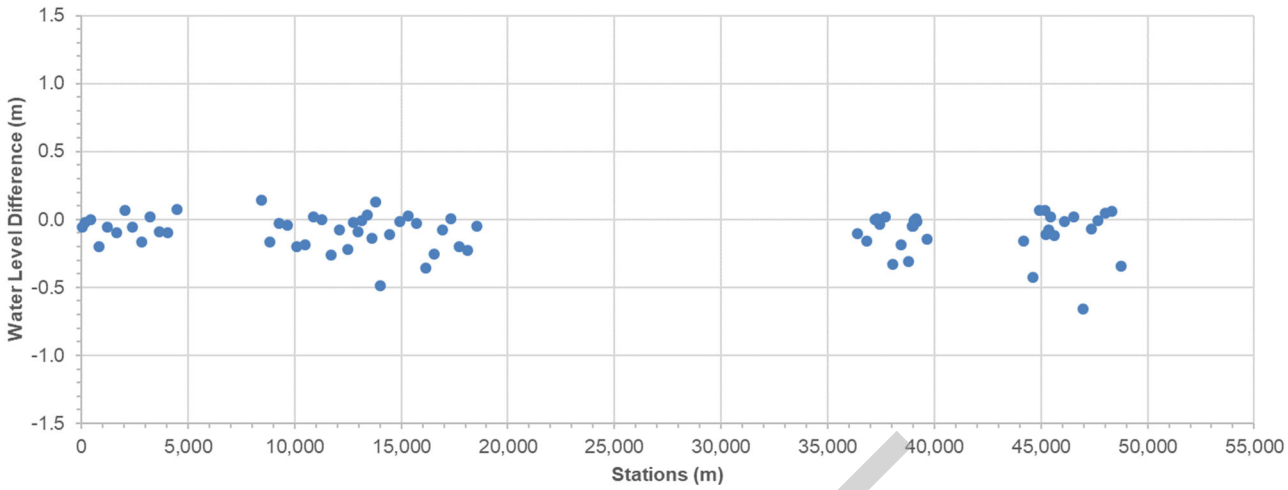


Figure 5: Difference of Simulated and Surveyed Red Deer River Water Levels for Low Flow Conditions

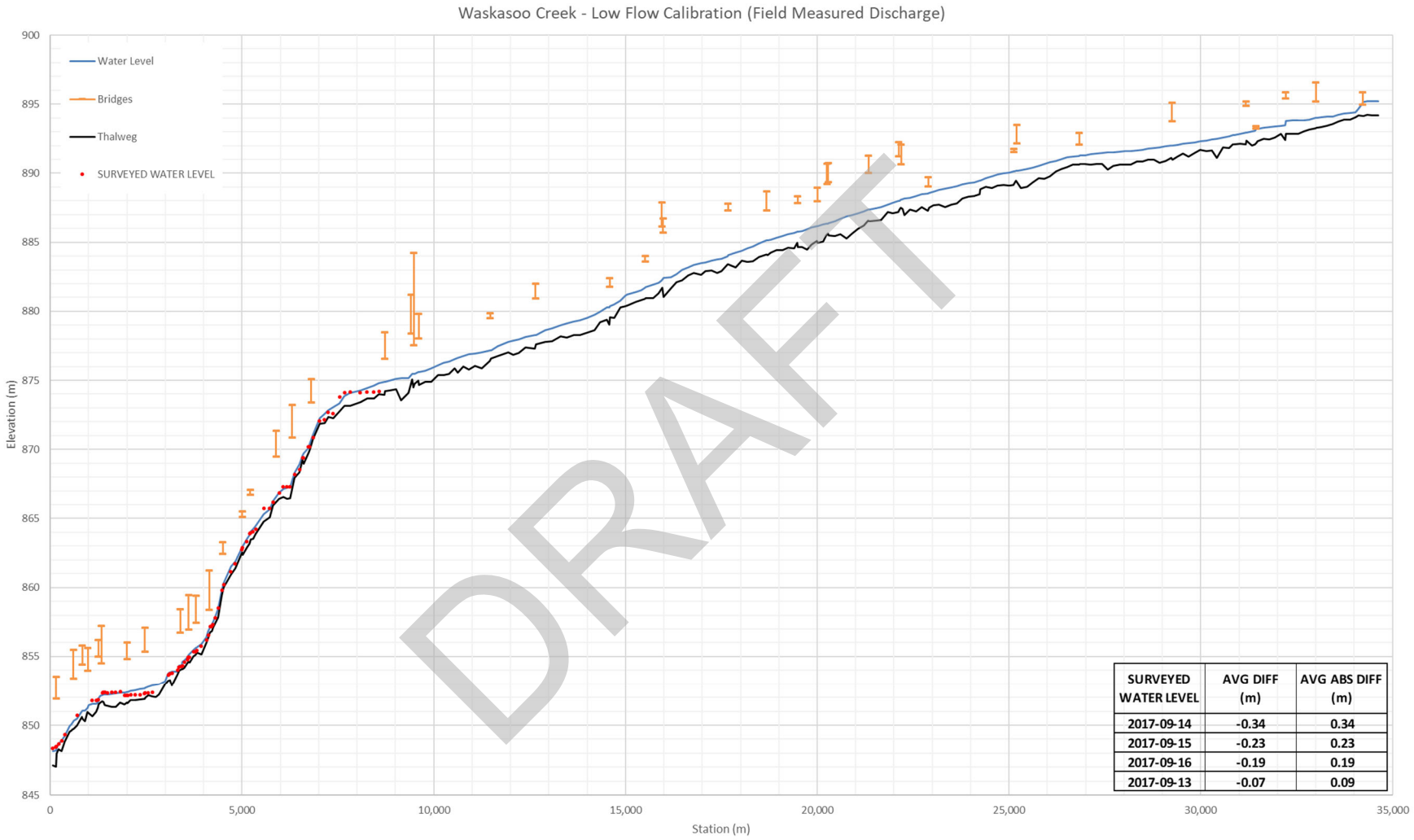


Figure 6: Comparison of Simulated Waskasoo Creek Water Surface Profile with Surveyed Water Levels for Low Flow Conditions

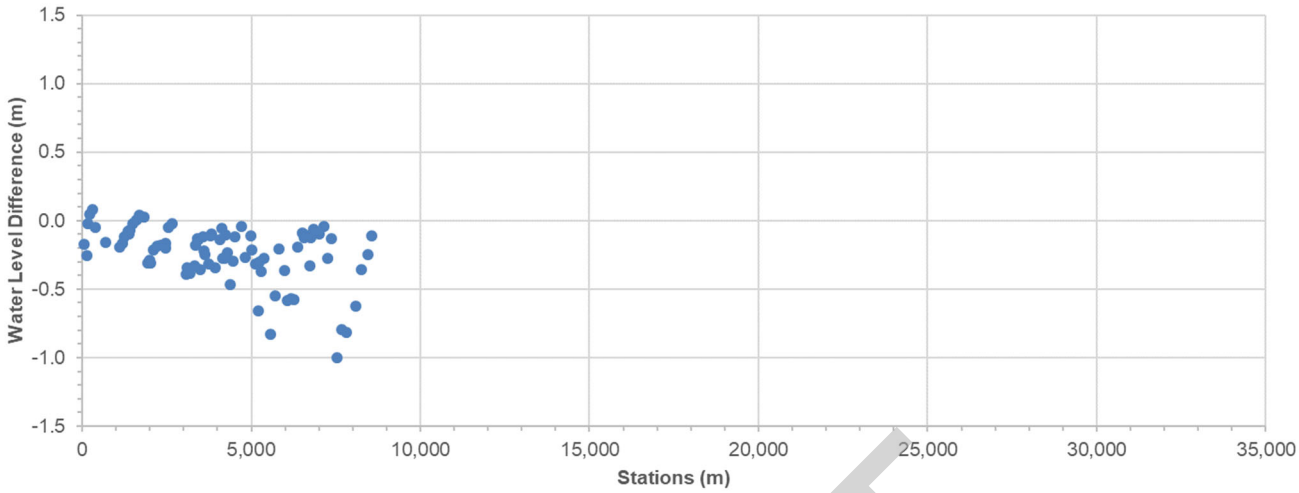


Figure 7: Difference of Simulated and Surveyed Waskasoo Creek Water Levels for Low Flow Conditions

5.3.2.3 Piper Creek

The Piper Creek channel roughness values were calibrated based on the measured discharge and water level data collected during the low flow conditions. The surveyed river discharges were 0.11 m^3/s on September 20 and 0.27 m^3/s on September 21.

Discharges measured for the Piper Creek capture not only the creek base flow, but also storm sewer drainage, and other local discharges. The beaver dams, and short rainfall events had relatively pronounced effects on the measured water levels. Taking this into consideration, the low flow measurements may not be representative of the flow conditions during the water level survey at individual cross sections. Therefore, the results of the low flow calibration were used to evaluate whether the low flow Manning's roughness is unchanged or higher compared against high flow conditions.

The selected calibrated channel Manning's *n* value for the low flow conditions is 0.05, which is uniform for the entire Piper Creek study reach. This is within the typical range of roughness for similar creeks (Chow 1959) and it is a reasonable increase from the high flow calibration (see Section 5.3.3.3).

Figure 8 shows a comparison between the simulated water surface profile and measured water levels for the low flow conditions. Table A.3 in Appendix A lists the differences between the simulated and measured water levels.

The average difference between the simulated and measured water level is -0.26 m, with individual differences ranging from -0.76 m to +0.07 m (see Figure 9).

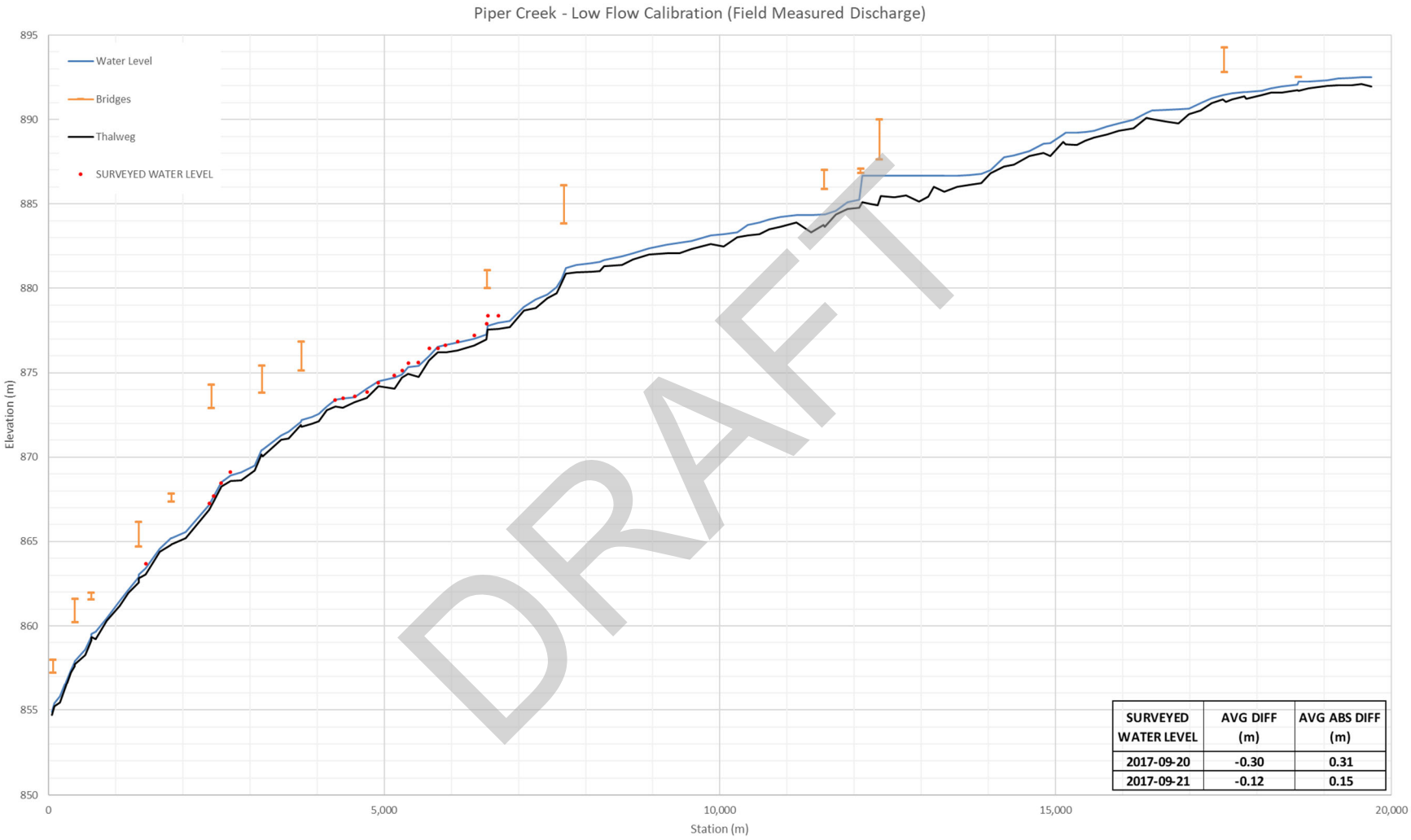


Figure 8: Comparison of Simulated Piper Creek Water Surface Profile with Surveyed Water Levels for Low Flow Conditions

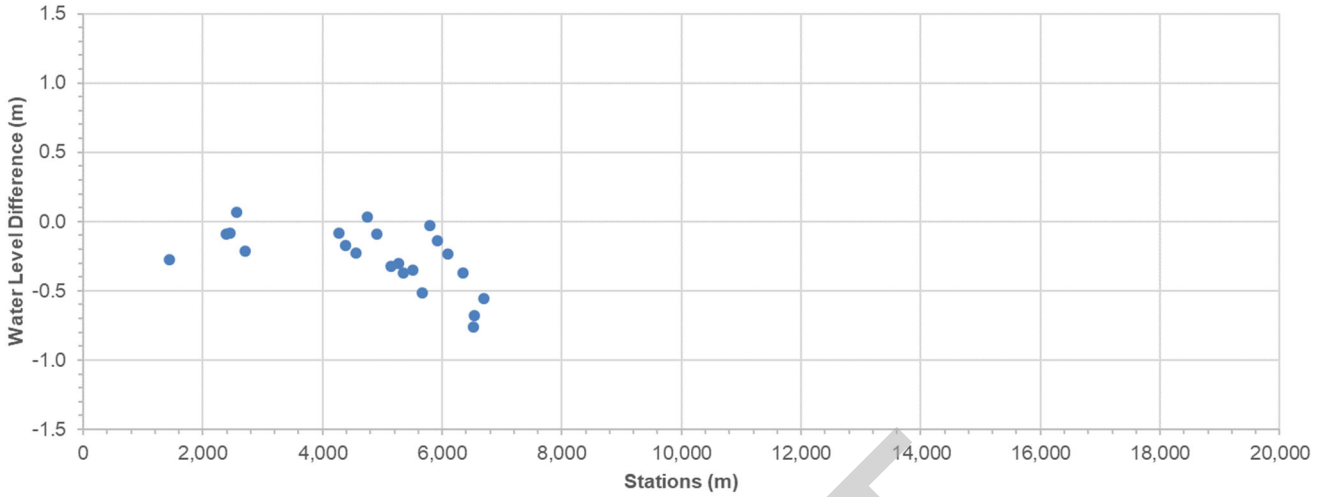


Figure 9: Difference of Simulated and Surveyed Piper Creek Water Levels for Low Flow Conditions

5.3.3 High Flow Calibration

5.3.3.1 Red Deer River

Highwater marks along the Red Deer River study reach are available for the three flood events (i.e., 1990, 2005, and 2013 floods). The largest flood event of the three is the 2005 flood event. The Manning's *n* values for Red Deer River during high flow conditions is calibrated based on the 2005 highwater marks associated with a flood peak discharge of 1,510 m^3/s, which is close to the 35-year flood peak flow of 1,580 m^3/s (Golder 2018b). The Manning's *n* selection was confirmed based on the highwater marks for the 1990 and 2013 flood events.

Flood peak discharges of Red Deer River were based on the recorded data by WSC at Station 05CC002 (i.e., Red Deer River at Red Deer). Concurrent average daily inflows from Waskasoo Creek at WSC Station No. 05CC011 and Blindman River at WSC Station No. 05CC001, were accounted for along the Red Deer River reaches downstream of their stream mouths. The 1990, 2005 and 2013 flood peak discharges used for the Red Deer River high flow calibration are summarized in Table 19.

Table 19: Flood Peak Discharges Used for the Red Deer River Model Calibration

Red Deer River Reach	Stations (m)	1990 Flood Peak Discharge (m^3/s)	2005 Flood Peak Discharge (m^3/s)	2013 Flood Peak Discharge (m^3/s)
Upper Reach	50,826 to 38,445	908	1,510	1,290
Lower Reach	38,445 to 18,535	915	1,513	1,292
	18,535 to 0	924	1,516	1,296

There was limited overland flooding along Red Deer River during the 1990, 2005 and 2013 flood events. Therefore, the overland roughness values have little effect on the simulated water levels for the events and no adjustment is made to the initial roughness (see Table 15) estimates for the floodplain areas. The model calibration was achieved by adjusting the main channel Manning's *n* values so that the simulated water levels are in good match with the 1990, 2005 and 2013 highwater marks.

The calibrated channel Manning's *n* values for the high flow conditions are 0.032 for the Red Deer River Upper Reach (i.e., upstream of the Waskasoo Creek confluence) and 0.036 for the Red Deer River Lower Reach (i.e., downstream of the Waskasoo Creek confluence). The simulated water levels match well with the 1990, 2005, and 2013 highwater marks. The selected roughness values are within the typical range of roughness for gravel bed rivers (Chow 1959) and comparable to the calibrated high flow Manning's *n* values in previous Red Deer Hydraulics Study (W-E-R 1991).

Figure 10, Figure 11 and Figure 12 show a comparison between the simulated water surface profile and measured water levels for the 1990, 2005 and 2013 flood conditions, respectively. Table A.4 in Appendix A lists the differences between the simulated and measured water levels.

The highwater mark comparison statistics for the Red Deer River high flow calibration are summarized in Table 20, Figure 13, Figure 14 and Figure 15.

Table 20: Red Deer River High Flow Calibration Statistics

Flood Event	Difference between Simulated Water Level and Highwater Marks (m)	
	Average Difference	Range of Individual Difference
1990	0.40	+0.18 to +0.53
2005	-0.06	-0.90 to +0.44
2013	-0.07	-0.63 to +0.85

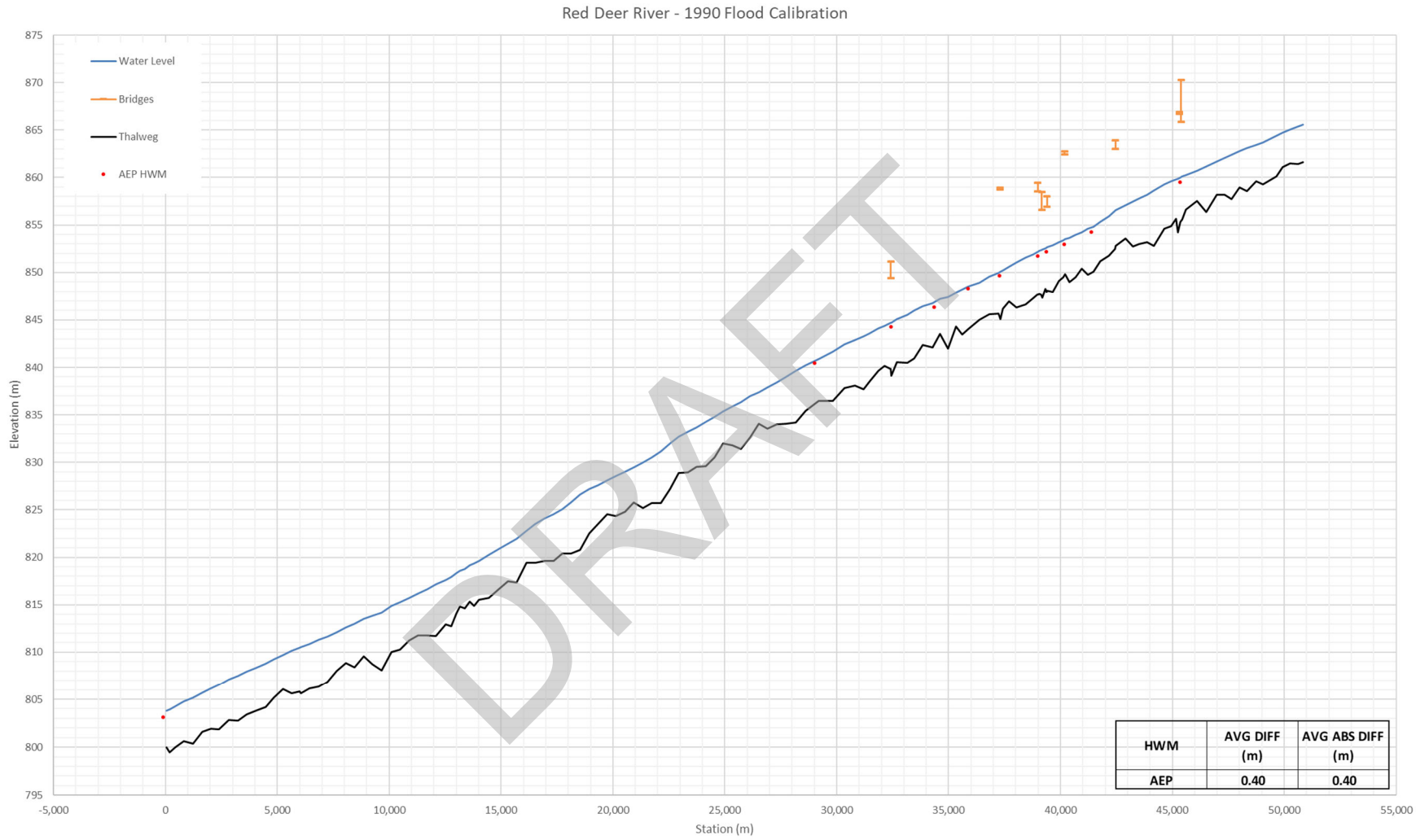


Figure 10: Comparison of Simulated Water Levels with Highwater Marks - 1990 Flood on Red Deer River

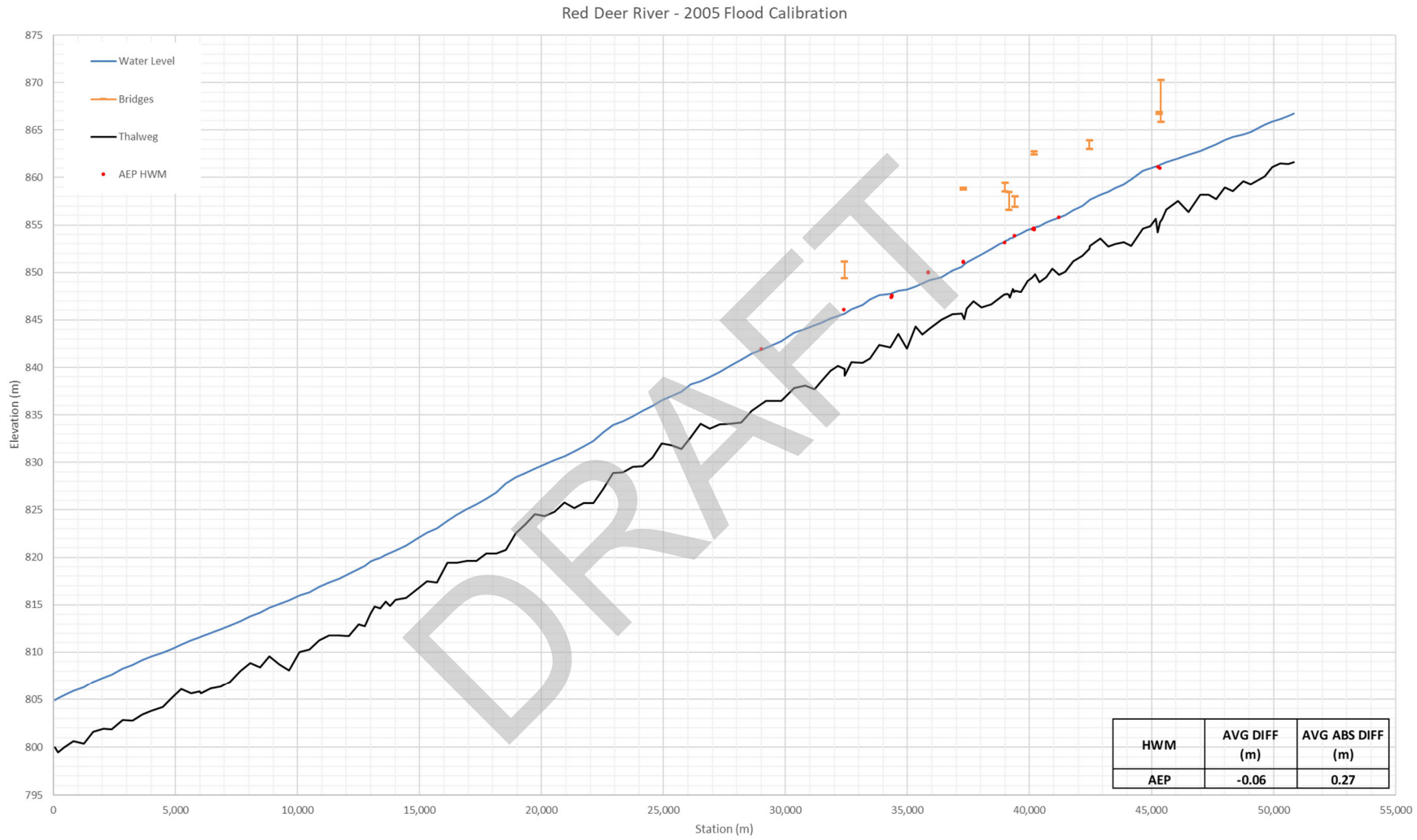


Figure 11: Comparison of Simulated Water Levels with Highwater Marks - 2005 Flood on Red Deer River

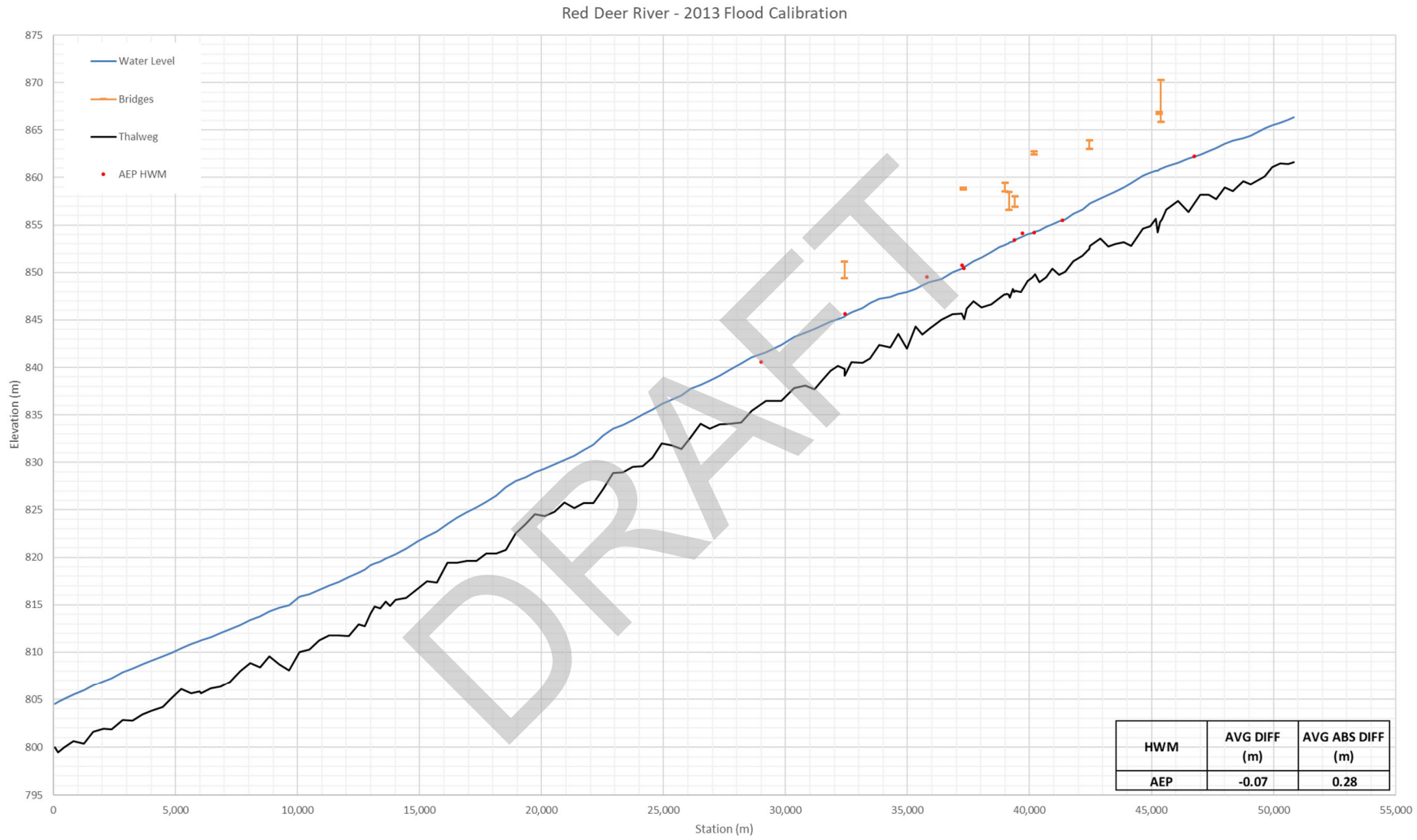


Figure 12: Comparison of Simulated Water Levels with Highwater Marks - 2013 Flood on Red Deer River

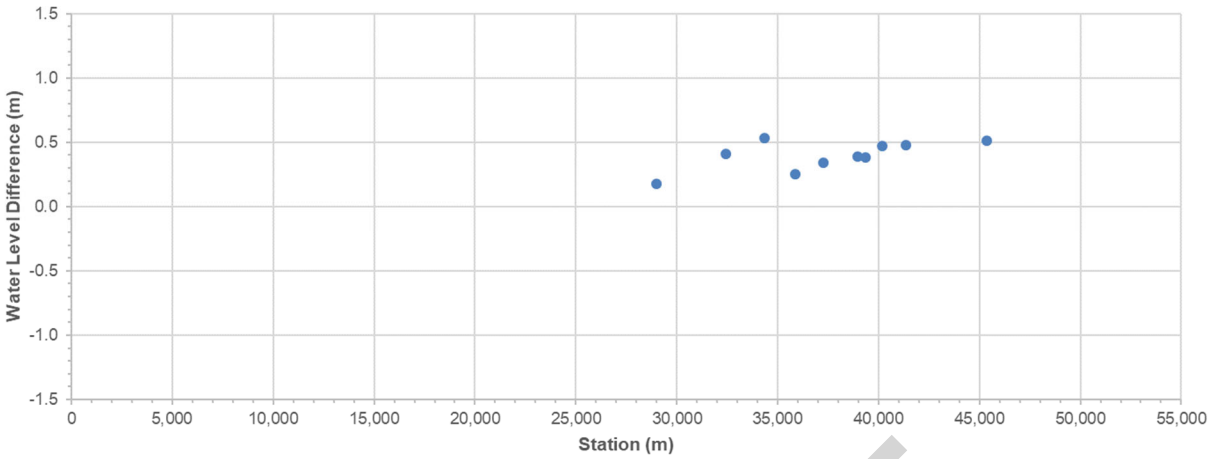


Figure 13: Difference between Simulated Water Levels and Highwater Marks - 1990 Flood on Red Deer River

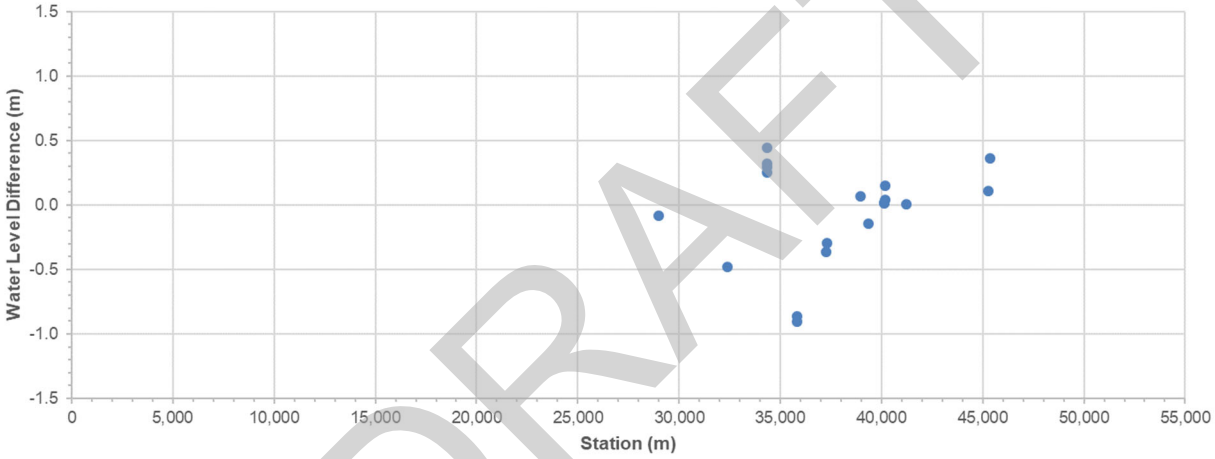


Figure 14: Difference between Simulated Water Levels and Highwater Marks - 2005 Flood on Red Deer River

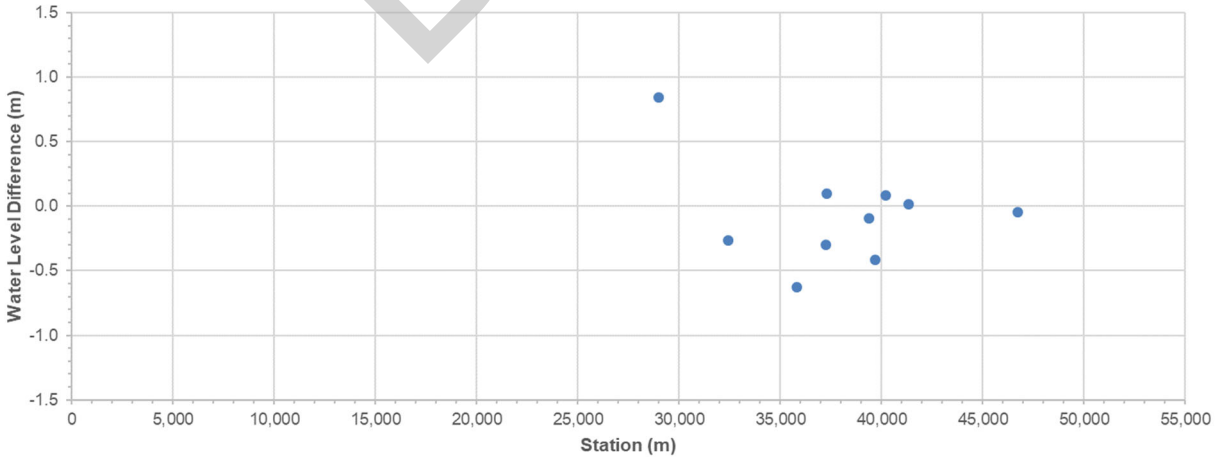


Figure 15: Difference between Simulated Water Levels and Highwater Marks - 2013 Flood on Red Deer River

5.3.3.2 Waskasoo Creek

Highwater marks along the Waskasoo Creek study reach are available for the three flood events (i.e., 1982, 2007 and 2018 floods). The largest flood event of the three is the 2018 flood event. The Manning's *n* value for Waskasoo Creek during high flow conditions is calibrated based on the 2018 highwater marks associated with estimated flood peak discharge of 32 m^3/s, which is close to the 35-year flood peak flow of 36 m^3/s (Golder, 2021b). The Manning's n selection was confirmed based on highwater marks of the 1982 and 2007 flood events.

The flood peak discharges on Waskasoo Creek are based on the recorded data by WSC at Station 05CC011 (i.e., Waskasoo Creek at Red Deer). Distributions of the peak discharges along the Waskasoo Creek study reach were estimated based on the hydrology assessment by Golder (2021b). The 1982, 2007 and 2018 flood peak discharges used for the Waskasoo Creek high flow calibration are summarized in Table 21.

Table 21: Flood Peak Discharges Used for the Waskasoo Creek Model Calibration

Waskasoo Creek Reach	Stations (m)	1982 Flood Peak Discharge (m^3/s)	2007 Flood Peak Discharge (m^3/s)	2018 Flood Peak Discharge (m^3/s)
Upper Reach	34,636 to 29,081	14.4	14.5	19.2
	29,081 to 3,498	16.6	16.8	22.1
Lower Reach	3,498 to 0	23.9	24.2	32.0

There was limited overland flooding along Waskasoo Creek during the 2018 flood event. Therefore, the overland roughness values have little effect on the simulated water levels for the flood event and no adjustment is made to the initial roughness (see Table 15) estimates for the floodplain areas. The model calibration was achieved by adjusting the main channel Manning's *n* values so that the simulated water levels are in good match with the 1982, 2007 and 2018 highwater marks.

The calibrated channel Manning's n value for the high flow conditions is 0.033, which is within the typical range of roughness for similar creeks (Chow 1959).

Figure 16, Figure 17 and Figure 18 show comparisons between the simulated water surface profiles and measured water levels for the three flood events. Table A.5 in Appendix A lists the differences between the simulated and measured water levels.

The highwater mark comparison statistics for Waskasoo Creek high flow calibration are summarized in Table 22, Figure 19, Figure 20 and Figure 21.

Table 22: Waskasoo Creek High Flow Calibration Statistics

Flood Event	Difference between Simulated Water Level and Highwater Marks (m)	
	Average Difference	Range of Individual Difference
1982	0.23	-0.31 to +0.93
2007	-0.02	-0.71 to +0.37
2018	0.10	-0.33 to +0.72

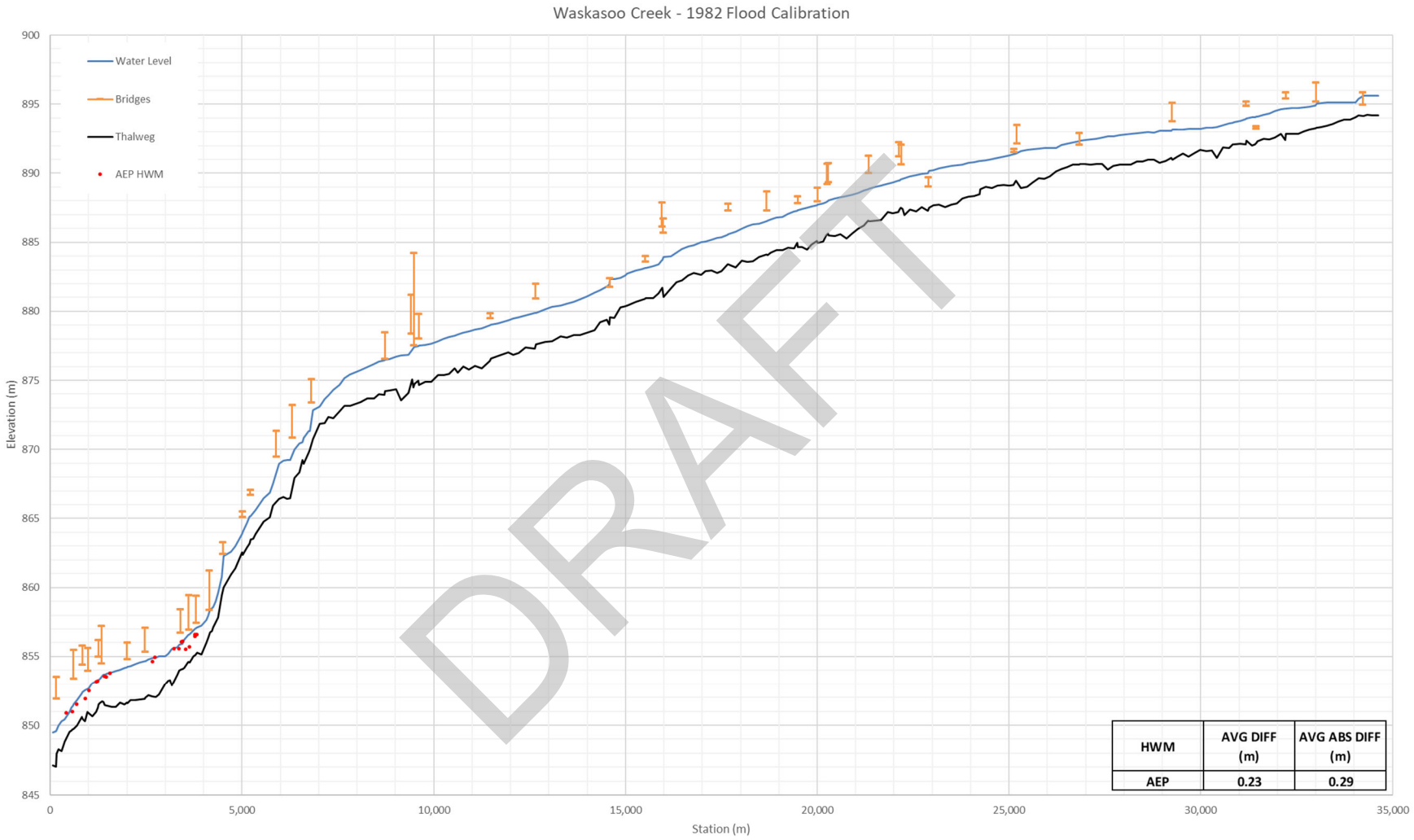


Figure 16: Comparison of Simulated Water Levels with Highwater Marks - 1982 Flood on Waskasoo Creek

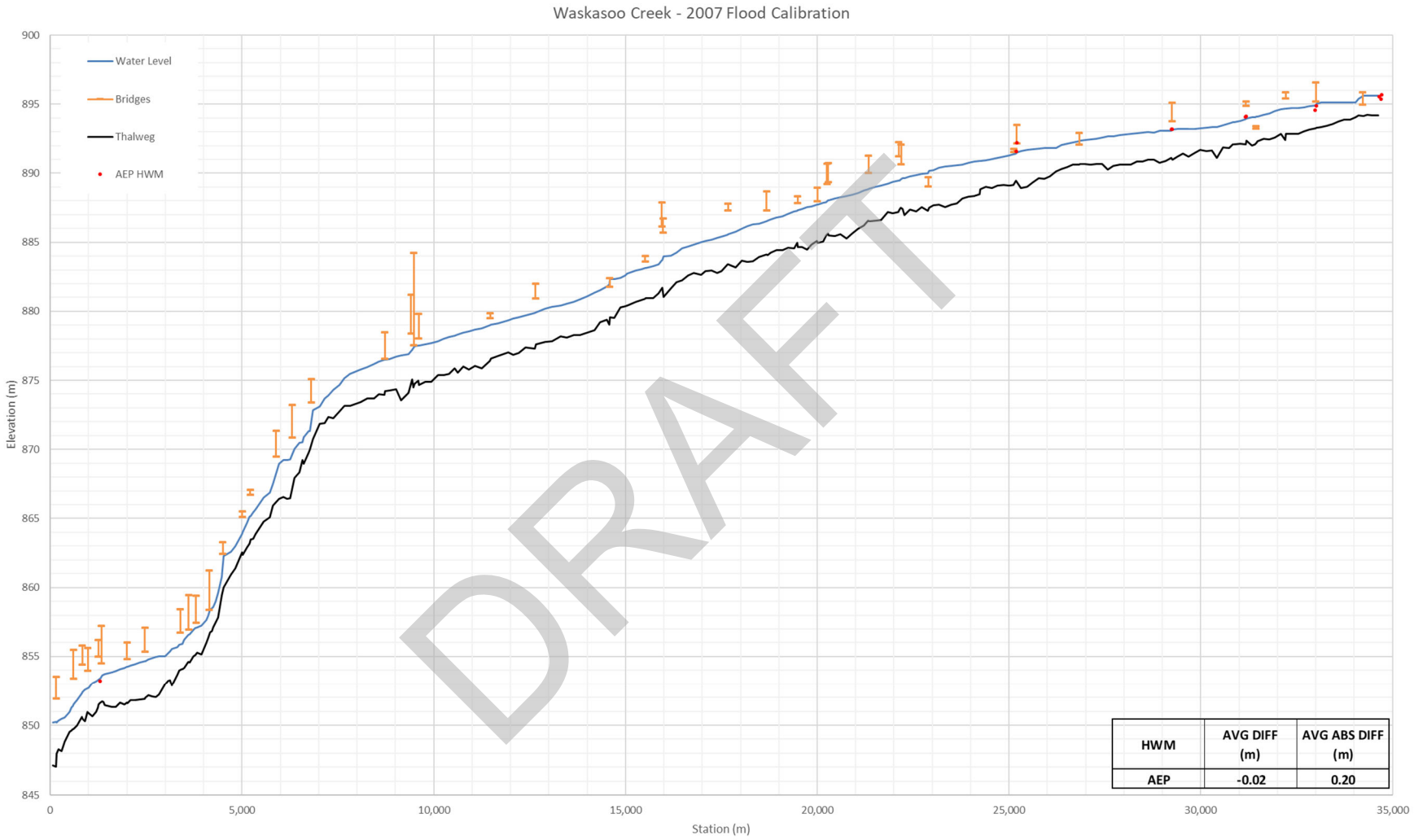


Figure 17: Comparison of Simulated Water Levels with Highwater Marks - 2007 Flood on Waskasoo Creek

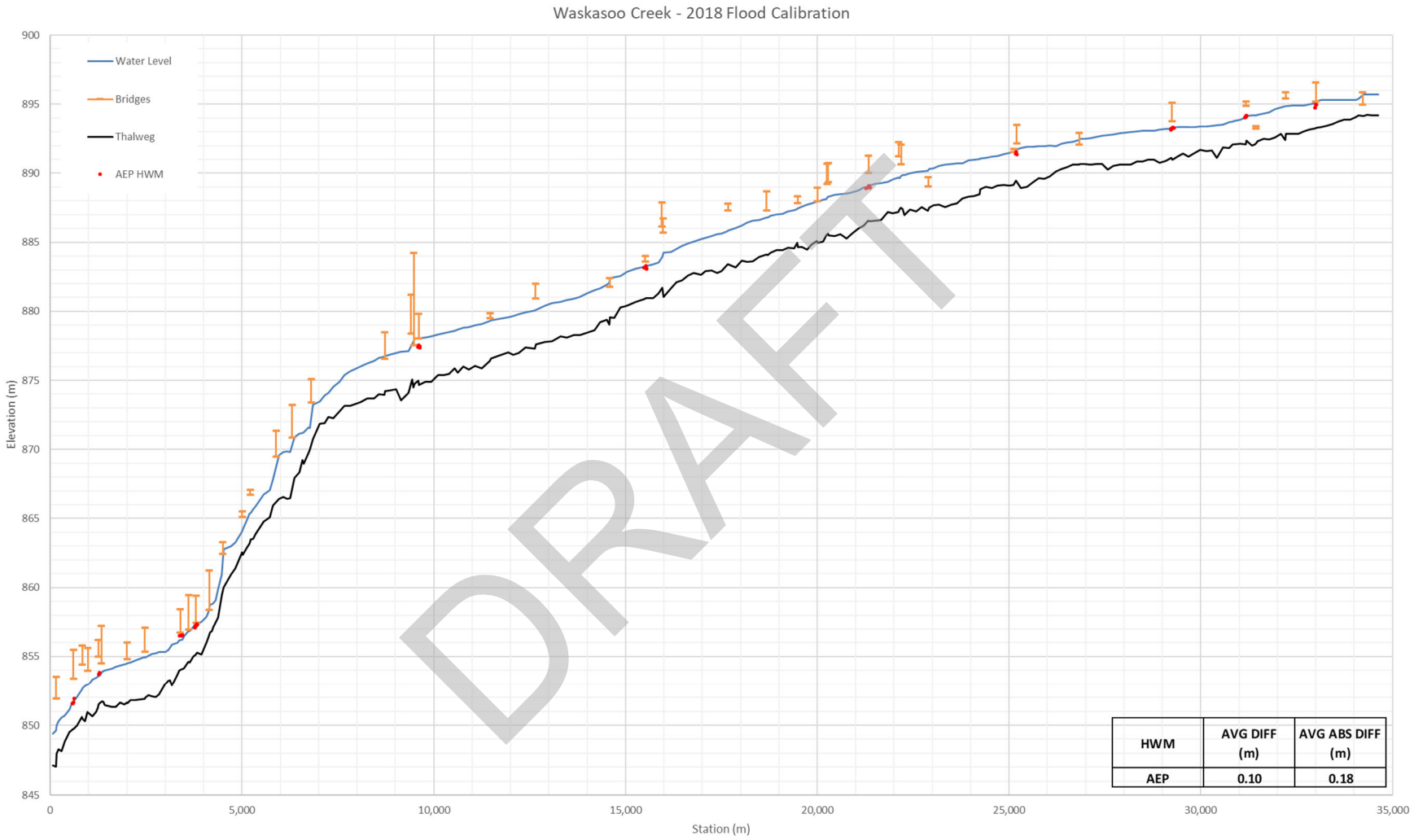


Figure 18: Comparison of Simulated Water Levels with Highwater Marks - 2018 Flood on Waskasoo Creek

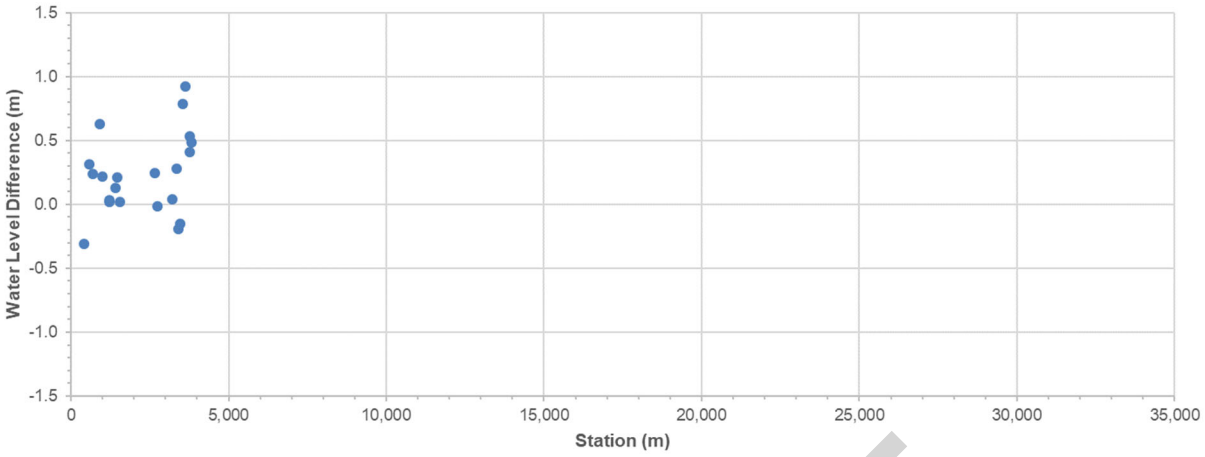


Figure 19: Difference between Simulated Water Levels and Highwater Marks - 1982 Flood on Waskasoo Creek

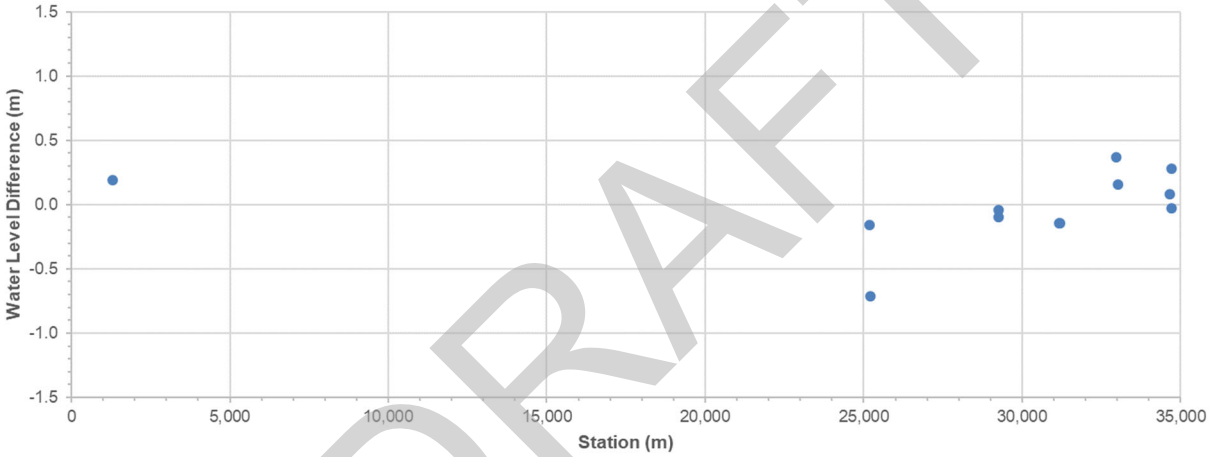


Figure 20: Difference between Simulated Water Levels and Highwater Marks - 2007 Flood on Waskasoo Creek

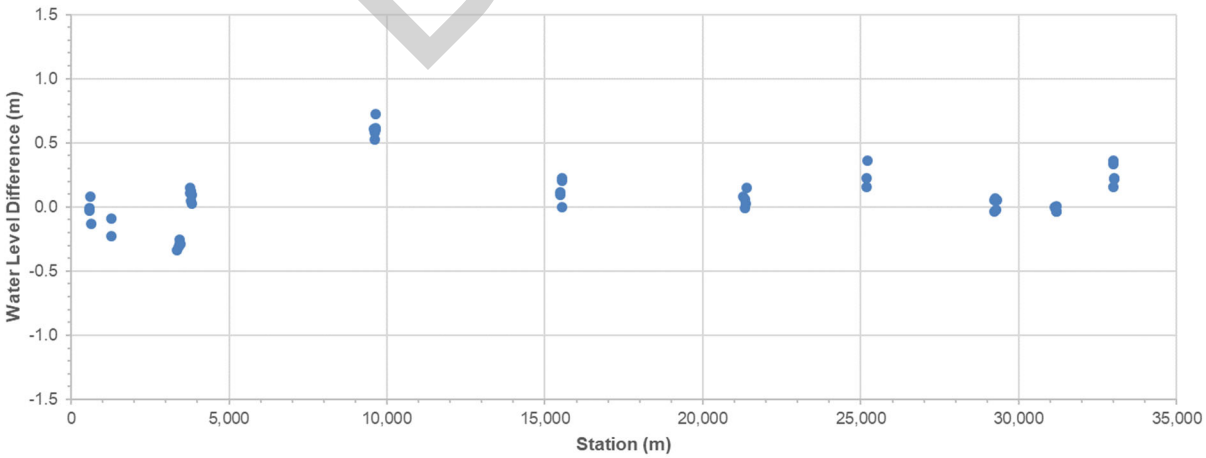


Figure 21: Difference between Simulated Water Levels and Highwater Marks - 2018 Flood on Waskasoo Creek

5.3.3.3 Piper Creek

Highwater marks were available along the Piper Creek study reach for only one flood event (i.e., 2018 flood). Piper Creek has no gauging station. No flow measurement was taken during the 2018 flood highwater mark survey. The Piper Creek channel Manning's *n* value was estimated to be the same as that of Waskasoo Creek, because they have similar physical and geomorphic characteristics. The calibrated channel Manning's *n* value for the high flow conditions is 0.033, which is within the typical range of roughness for similar creeks (Chow 1959).

The 2018 flood peak discharges on Piper Creek were estimated so that the downstream group of highwater marks match with the simulated flood levels. The flood peak discharges were estimated to be 22.8 m^3/s between the upstream boundary and Highway 595, and 25.0 m^3/s between Highway 595 and the Waskasoo Creek confluence. This distribution of the flood peak discharges along Piper Creek study reach was estimated based on the hydrology assessment by Golder (2021b). A detailed discussion of the 2018 flood peak discharge estimate for Piper Creek is in Appendix B.

The estimated 2018 flood peak discharges used for the Piper Creek high flow calibration run are summarized in Table 23.

Table 23: 2018 Flood Peak Discharges Used for the Piper Creek Model Calibration

Piper Creek Reach	Stations (m)	2018 Flood Peak Discharge (m^3/s)
Upstream Reach	19,702 to 7,570	22.8
Downstream Reach	7,570 to 0	25.0

Figure 22 shows a comparison between the simulated water surface profile and measured water levels for the 2018 flood event. Table A.6 in Appendix A lists the differences between the simulated and measured water levels.

The average difference between the simulated and measured water level is -0.20 m, with individual differences ranging from -0.57 m to +0.12 m (see Figure 23).

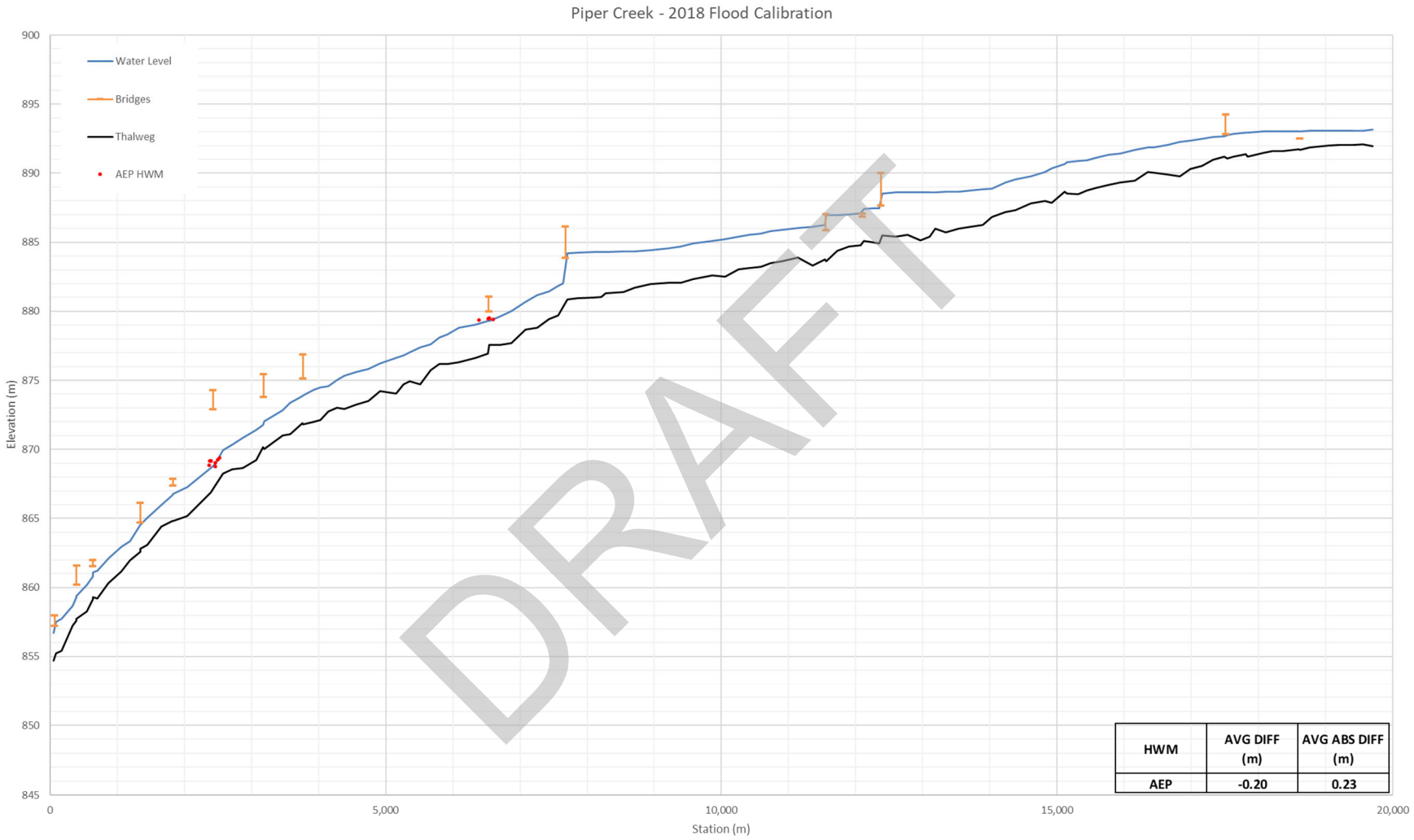


Figure 22: Comparison of Simulated Piper Creek Water Surface Profile with Highwater Marks for the 2018 High Flow Event

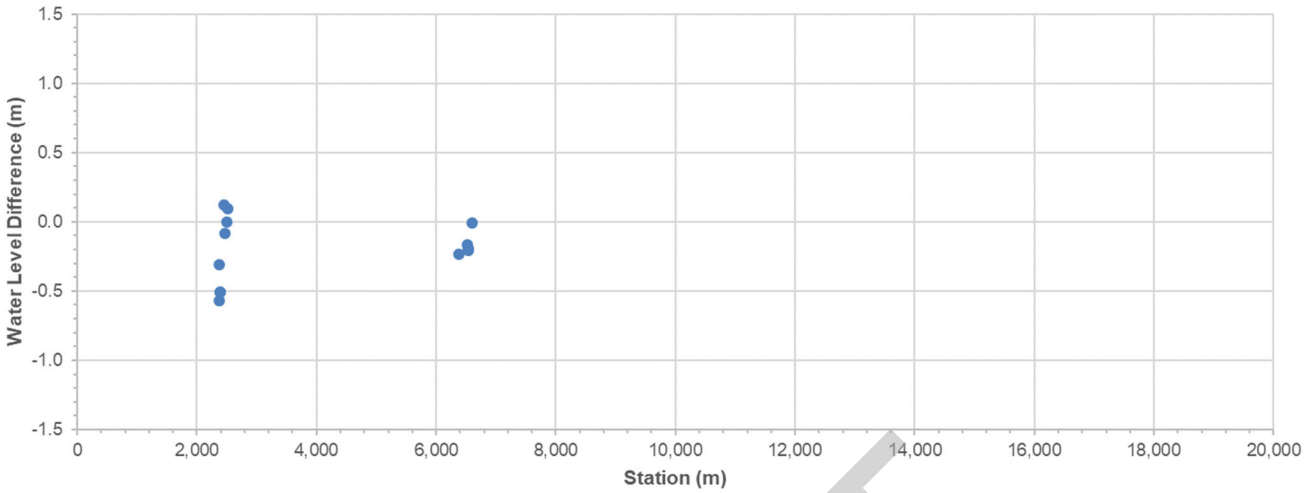


Figure 23: Difference of Simulated Piper Creek Water Levels and Highwater Marks for the 2018 High Flow Event

5.3.4 Gauging Station Rating Curves

The stage-discharge rating curve data available at the following WSC gauging stations were used to support the high flow model calibration and to quantify the variability of the main channel roughness over a range of flows:

- Red Deer River at Red Deer (WSC Station No. 05CC002); and
- Waskasoo Creek at Red Deer (WSC Station No. 05CC011).

Additional cross sections were interpolated in HEC-RAS to simulate the hydraulic conditions at the exact gauge locations. The model was calibrated based on the stage-discharge rating curves for these stations. Comparisons of the WSC rating curves (including individual measurements) and the simulated rating curves, are shown in Figure 24 and Figure 25. The findings are discussed:

- **Red Deer River:** The simulated rating curve matches well with the WSC rating curve. The high and low flow calibration results (see Section 5.3.3.1) also match well with the water levels based on the WSC rating curve. Therefore, the Manning's *n* values calibrated for the high and low flow conditions along the Red Deer River study reach are representative of the channel hydraulic characteristics.

- **Waskasoo Creek:** The shape of the simulated rating curve is similar to the WSC rating curve with a 0.2 m elevation shift. The elevation shift in the rating curve is potentially a result of incorrect datum provided by WSC for this gauge station. If this elevation shift is corrected, the simulated rating curve matches well with the WSC rating curve. The high and low flow calibration results (see Section 5.3.3.2) match well with the simulated rating curve, and the WSC rating curve if the elevation shift is corrected. Therefore, the Manning's *n* values calibrated for the high and low flow conditions along the Waskasoo Creek study reach are representative of the channel hydraulic characteristics.

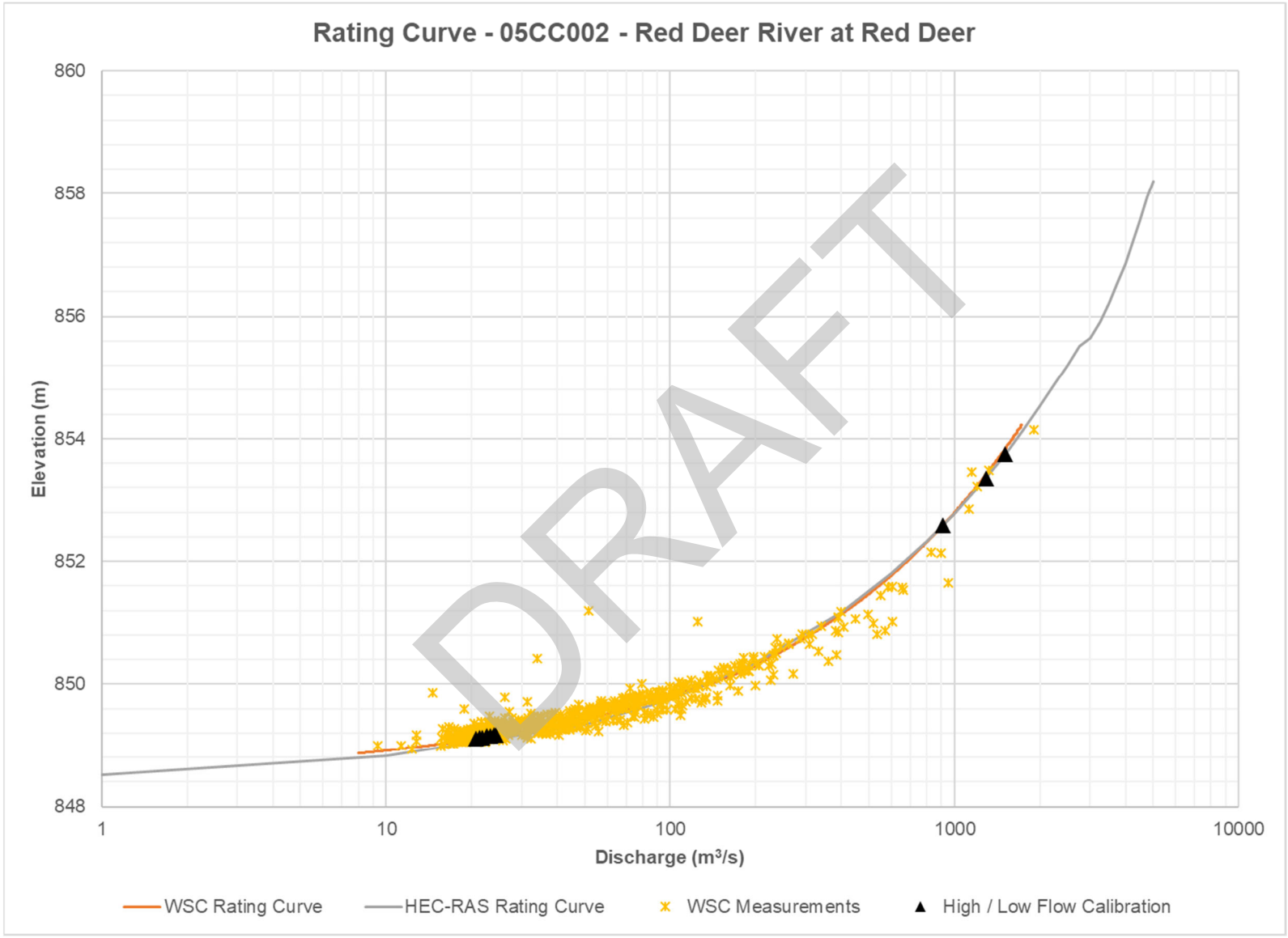


Figure 24: Red Deer River at Red Deer (WSC Station No. 05CC002) Rating Curve

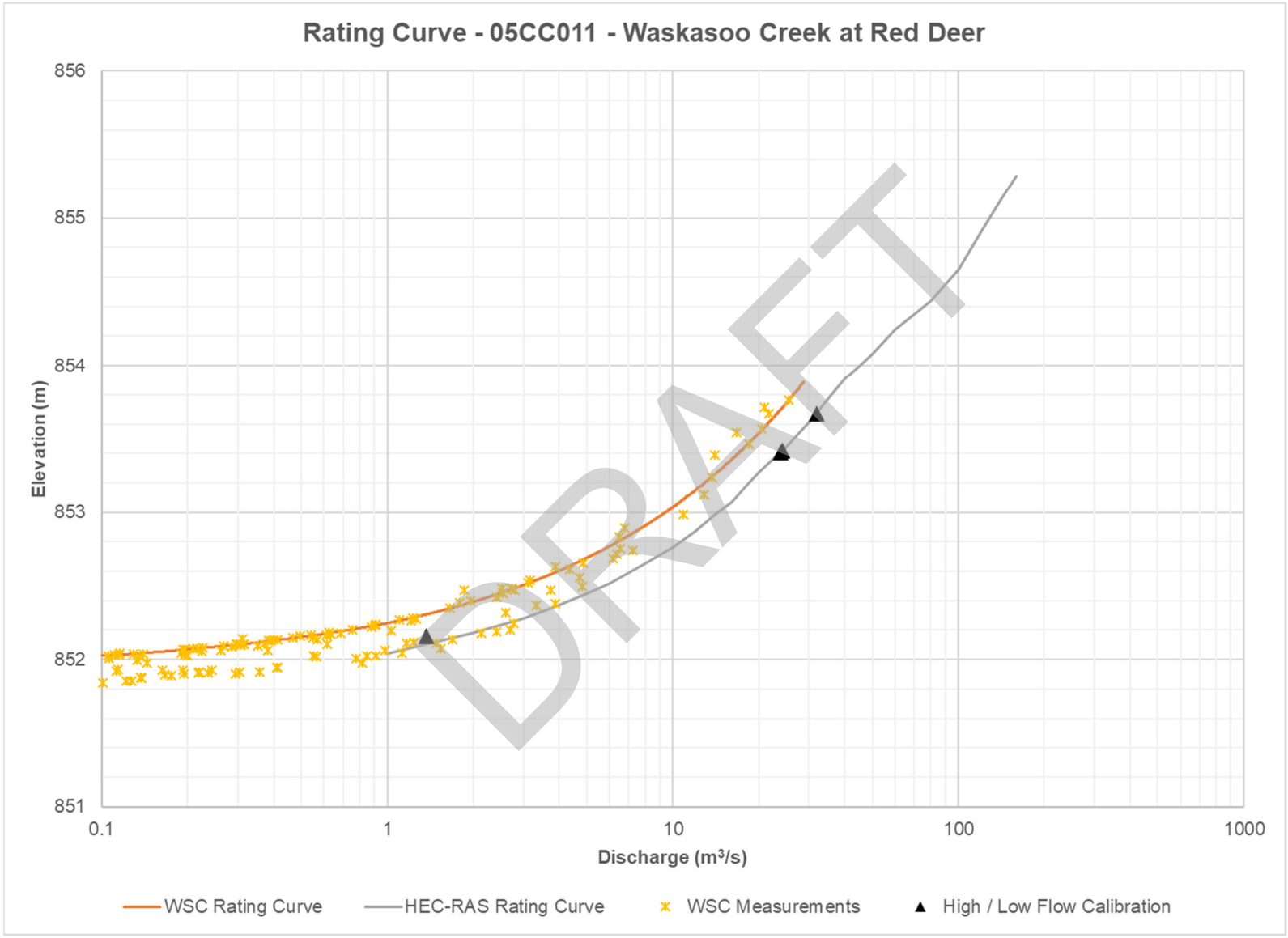


Figure 25: Waskasoo Creek at Red Deer (WSC Station No. 05CC011) Rating Curve

5.3.5 Calibration Results

The main purpose of this study is to identify river and flood hazards. Therefore, the focus of model calibration was on determination of appropriate Manning's n values for high flow conditions.

Red Deer River

Highwater mark measurements on Red Deer River are available for the 1990, 2005 and 2013 open water flood events. The Manning's *n* value for the upper Red Deer River study reach (i.e., Red Deer River upstream of the Waskasoo Creek confluence) was calibrated to be 0.032, and the lower Red Deer River study reach (i.e., Red Deer River downstream of the Waskasoo Creek confluence) was calibrated to be 0.036 based on the highwater marks. The calibration results show that the simulated water levels are in good agreement with the reported water levels.

The differences between the simulated water levels and measured highwater marks along the Red Deer River study reach during the 1990, 2005 and 2013 flood events are summarized in Table 24.

The model calibration results based on the stage-discharge rating curve for the Red Deer River WSC gauging station support selection of the calibrated Manning's n values.

Table 24: Red Deer River High Flow Calibration Results

Parameter	Difference between Simulated Water Levels and Highwater Marks (m)		
	1990 Flood	2005 Flood	2013 Flood
Mean difference	+0.40	-0.06	-0.07
Mean absolute difference	0.40	0.27	0.28
Minimum difference	+0.18	-0.90	-0.63
Maximum difference	+0.53	+0.44	+0.85

Waskasoo Creek

Highwater mark measurements along Waskasoo Creek are available for the 1982, 2007 and 2018 open water flood events. The Manning's *n* value for the Waskasoo Creek study reach is calibrated to be 0.033 based on the highwater marks. The results show that the simulated water levels are in good agreement with the highwater marks.

The differences between the simulated water levels and highwater marks along the Waskasoo Creek study reach during the 1982, 2007 and 2018 flood events are summarized in Table 25.

Table 25: Waskasoo Creek High Flow Calibration Results

Parameter	Difference between Simulated Water Levels and Highwater Marks (m)		
	1982 Flood	2007 Flood	2018 Flood
Mean difference	+0.23	-0.02	0.10
Mean absolute difference	0.29	+0.20	0.18
Minimum difference	-0.31	-0.71	-0.33
Maximum difference	+0.93	+0.37	+0.72

The model calibration results based on the stage-discharge rating curve for the Waskasoo WSC gauging station support selection of the calibrated Manning's n values.

Piper Creek

Highwater mark measurements along Piper Creek are available for the 2018 open water flood event. There is no hydrometric gauge station on Piper Creek, and no flow measurement was taken during the 2018 flood. The Piper Creek channel Manning's *n* value was selected to be the same as that for Waskasoo Creek, because the two creeks have similar hydraulic and geomorphic characteristics. The 2018 flood peak discharges along Piper Creek were estimated based on the simulation results.

The differences between the simulated water levels and highwater marks along the Piper Creek study reach during the 2018 flood event are summarized in Table 26.

Table 26: Piper Creek 2018 Flood Calibration Results

Parameter	Difference between Simulated Water Levels and Highwater Marks (m)
Mean difference	-0.20
Mean absolute difference	0.23
Minimum difference	-0.57
Maximum difference	+0.12

5.4 Model Parameters and Options

5.4.1 Manning's Roughness

5.4.1.1 Channel Roughness

The calibrated stream channel Manning's *n* values are summarized in Table 27.

Table 27: Calibrated Stream Channel Roughness Values for High Flow Conditions

Stream Reach	Calibrated Manning's n Value
Red Deer River Upper Reach (Upstream of Waskasoo Creek Confluence)	0.032
Red Deer River Lower Reach (Downstream of Waskasoo Creek Confluence)	0.036
Waskasoo Creek	0.033
Piper Creek	0.033

5.4.1.2 Overbank Roughness

There was insufficient data available to calibrate the overbank roughness values for open-water flood conditions. Therefore, no adjustment to the initially estimated Manning's *n* values for the overbank areas was made during the calibration process. However, the upper end of the rating curve comparisons in Figure 24 and Figure 25 suggest that the selected overbank roughness values are reasonable.

The selected overbank Manning's *n* values are summarized in Table 28.

Table 28: Selected Overbank Roughness Values

Number	Description	Manning's n Value
2	Urban Mixture (Residential and Small Commercial)	0.080
3	Urban Mixture (Industrial and Large Commercial)	0.050
4	Urban Mixture (Downtown)	0.060
5	Agriculture	0.045
6	Grassland and Open Space	0.038
7	Trees and Bushes	0.100

5.4.2 Expansion and Contraction Coefficients

During the calibration process, the values of the contraction/expansion coefficients were adjusted upstream and downstream of some bridges to match the highwater marks without using unrealistic channel bed roughness values. The calibrated contraction coefficient values range from 0.05 to 0.8, and the calibrated expansion coefficient values range from 0.1 to 1.0 (see Table 29). For all other cross sections, the default contraction and expansion coefficients values were used (0.1 and 0.3, respectively).

Table 29: Calibrated Contraction and Expansion Coefficients – High Flow Calibration

Cross Section	River	Reach	River Station	Contraction Coefficient	Expansion Coefficient
XS 16	Red Deer River	Upper Reach	45435.72	0.3	0.5
XS 17	Red Deer River	Upper Reach	45353.49	0.3	0.5
XS 18	Red Deer River	Upper Reach	45245.89	0.3	0.5
XS 27	Red Deer River	Upper Reach	42464.36	0.3	0.5
XS 28	Red Deer River	Upper Reach	42446.18	0.3	0.5
XS 37	Red Deer River	Upper Reach	40125.1	0.3	0.5
XS 40	Red Deer River	Upper Reach	39413.17	0.3	0.5
XS 41	Red Deer River	Upper Reach	39380.99	0.3	0.5
XS 43	Red Deer River	Upper Reach	39179.93	0.3	0.5
XS 44	Red Deer River	Upper Reach	39145.07	0.3	0.5
XS 46	Red Deer River	Upper Reach	39010.69	0.3	0.5
XS 47	Red Deer River	Upper Reach	38975.33	0.3	0.5
XS 53	Red Deer River	Lower Reach	37322.76	0.3	0.5
XS 54	Red Deer River	Lower Reach	37225.1	0.3	0.5
XS 67	Red Deer River	Lower Reach	32432.03	0.8	1.0
XS 68	Red Deer River	Lower Reach	32414.68	0.8	1.0
XS 160	Piper Creek	Piper Creek	18620.05	0.3	0.5
XS 161	Piper Creek	Piper Creek	18606.56	0.3	0.5
XS 168	Piper Creek	Piper Creek	17535.17	0.3	0.5
XS 169	Piper Creek	Piper Creek	17495.33	0.3	0.5

Table 29: Calibrated Contraction and Expansion Coefficients – High Flow Calibration

Cross Section	River	Reach	River Station	Contraction Coefficient	Expansion Coefficient
XS 200	Piper Creek	Piper Creek	12397.44	0.3	0.5
XS 201	Piper Creek	Piper Creek	12355.73	0.3	0.5
XS 203	Piper Creek	Piper Creek	12118.36	0.3	0.5
XS 204	Piper Creek	Piper Creek	12071.83	0.3	0.5
XS 207	Piper Creek	Piper Creek	11565.41	0.3	0.5
XS 208	Piper Creek	Piper Creek	11544.17	0.3	0.5
XS 228	Piper Creek	Piper Creek	7703.327	0.3	0.5
XS 229	Piper Creek	Piper Creek	7642.626	0.3	0.5
XS 236	Piper Creek	Piper Creek	6542.118	0.3	0.5
XS 237	Piper Creek	Piper Creek	6522.557	0.3	0.5
XS 255	Piper Creek	Piper Creek	3769.287	0.3	0.5
XS 256	Piper Creek	Piper Creek	3759.758	0.3	0.5
XS 259	Piper Creek	Piper Creek	3185.599	0.3	0.5
XS 260	Piper Creek	Piper Creek	3170.9	0.3	0.5
XS 265	Piper Creek	Piper Creek	2455.593	0.3	0.5
XS 266	Piper Creek	Piper Creek	2391.906	0.3	0.5
XS 268	Piper Creek	Piper Creek	1829.269	0.3	0.5
XS 269	Piper Creek	Piper Creek	1821.473	0.3	0.5
XS 272	Piper Creek	Piper Creek	1346.251	0.3	0.5
XS 273	Piper Creek	Piper Creek	1340.073	0.3	0.5
XS 279	Piper Creek	Piper Creek	638.8506	0.3	0.5
XS 280	Piper Creek	Piper Creek	632.6887	0.3	0.5
XS 282	Piper Creek	Piper Creek	392.0748	0.3	0.5
XS 283	Piper Creek	Piper Creek	387.9414	0.3	0.5
XS 286	Piper Creek	Piper Creek	84.98931	0.3	0.5
XS 287	Piper Creek	Piper Creek	48.70916	0.3	0.5
XS 291	Waskasoo Creek	Upper Reach	34246.47	0.3	0.5
XS 292	Waskasoo Creek	Upper Reach	34116.75	0.3	0.5
XS 300	Waskasoo Creek	Upper Reach	33017.5	0.3	0.5
XS 301	Waskasoo Creek	Upper Reach	32982.53	0.3	0.5
XS 306	Waskasoo Creek	Upper Reach	32223.84	0.3	0.5
XS 307	Waskasoo Creek	Upper Reach	32203.38	0.3	0.5
XS 313	Waskasoo Creek	Upper Reach	31442.97	0.3	0.5
XS 314	Waskasoo Creek	Upper Reach	31420.6	0.3	0.5

Table 29: Calibrated Contraction and Expansion Coefficients – High Flow Calibration

Cross Section	River	Reach	River Station	Contraction Coefficient	Expansion Coefficient
XS 316	Waskasoo Creek	Upper Reach	31187.78	0.3	0.5
XS 317	Waskasoo Creek	Upper Reach	31166.55	0.3	0.5
XS 331	Waskasoo Creek	Upper Reach	29265.61	0.3	0.5
XS 332	Waskasoo Creek	Upper Reach	29232.09	0.3	0.5
XS 348	Waskasoo Creek	Upper Reach	26844.8	0.3	0.5
XS 349	Waskasoo Creek	Upper Reach	26827.29	0.3	0.5
XS 360	Waskasoo Creek	Upper Reach	25212.6	0.5	0.8
XS 361	Waskasoo Creek	Upper Reach	25188.74	0.5	0.8
XS 362	Waskasoo Creek	Upper Reach	25132.22	0.5	0.8
XS 363	Waskasoo Creek	Upper Reach	25118.96	0.5	0.8
XS 379	Waskasoo Creek	Upper Reach	22908.11	0.3	0.5
XS 380	Waskasoo Creek	Upper Reach	22881.55	0.3	0.5
XS 385	Waskasoo Creek	Upper Reach	22219.55	0.05	0.1
XS 386	Waskasoo Creek	Upper Reach	22174.71	0.05	0.1
XS 387	Waskasoo Creek	Upper Reach	22140.9	0.05	0.1
XS 388	Waskasoo Creek	Upper Reach	22116	0.05	0.1
XS 417	Waskasoo Creek	Upper Reach	18700.24	0.3	0.5
XS 418	Waskasoo Creek	Upper Reach	18667.47	0.3	0.5
XS 424	Waskasoo Creek	Upper Reach	17682.69	0.3	0.5
XS 425	Waskasoo Creek	Upper Reach	17661.39	0.3	0.5
XS 436	Waskasoo Creek	Upper Reach	15994.03	0.3	0.5
XS 437	Waskasoo Creek	Upper Reach	15959.25	0.3	0.5
XS 438	Waskasoo Creek	Upper Reach	15931.12	0.3	0.5
XS 441	Waskasoo Creek	Upper Reach	15523.43	0.3	0.5
XS 442	Waskasoo Creek	Upper Reach	15503.48	0.3	0.5
XS 461	Waskasoo Creek	Upper Reach	12667.91	0.3	0.5
XS 462	Waskasoo Creek	Upper Reach	12641.14	0.3	0.5
XS 468	Waskasoo Creek	Upper Reach	11485.96	0.3	0.5
XS 469	Waskasoo Creek	Upper Reach	11460.21	0.3	0.5
XS 490	Waskasoo Creek	Upper Reach	8736.87	0.3	0.5
XS 491	Waskasoo Creek	Upper Reach	8714.813	0.3	0.5
XS 503	Waskasoo Creek	Upper Reach	6853.289	0.3	0.5
XS 504	Waskasoo Creek	Upper Reach	6764.342	0.3	0.5
XS 509	Waskasoo Creek	Upper Reach	6369.437	0.3	0.5

Table 29: Calibrated Contraction and Expansion Coefficients – High Flow Calibration

Cross Section	River	Reach	River Station	Contraction Coefficient	Expansion Coefficient
XS 510	Waskasoo Creek	Upper Reach	6250.98	0.3	0.5
XS 513	Waskasoo Creek	Upper Reach	5969.643	0.5	0.5
XS 514	Waskasoo Creek	Upper Reach	5812.234	0.5	0.5
XS 519	Waskasoo Creek	Upper Reach	5221.907	0.3	0.5
XS 520	Waskasoo Creek	Upper Reach	5200.053	0.3	0.5
XS 526	Waskasoo Creek	Upper Reach	4524.341	0.5	0.5
XS 527	Waskasoo Creek	Upper Reach	4472.177	0.5	0.5
XS 532	Waskasoo Creek	Upper Reach	4168.366	0.3	0.5
XS 533	Waskasoo Creek	Upper Reach	4120.058	0.3	0.5
XS 571	Waskasoo Creek	Lower Reach	1261.654	0.3	0.5
XS 572	Waskasoo Creek	Lower Reach	1244.775	0.3	0.5
XS 575	Waskasoo Creek	Lower Reach	994.8925	0.3	0.5
XS 576	Waskasoo Creek	Lower Reach	969.3104	0.3	0.5
XS 578	Waskasoo Creek	Lower Reach	843.7892	0.3	0.5
XS 579	Waskasoo Creek	Lower Reach	827.4989	0.3	0.5
XS 581	Waskasoo Creek	Lower Reach	616.0494	0.3	0.5
XS 582	Waskasoo Creek	Lower Reach	588.6684	0.3	0.5
XS 588	Waskasoo Creek	Lower Reach	164.6487	0.3	0.5
XS 589	Waskasoo Creek	Lower Reach	143.2944	0.3	0.5

5.4.3 Minor Losses

In consideration of the flood frequency profile generation, minor losses were introduced at some cross sections to eliminate or reduce the impact of unrealistic water level drops and profile crossings (i.e., where lower flood flows would result in higher water levels or higher flood flows would result in lower water levels). Minor losses were introduced at 13 cross sections (representing about 2% of all cross sections), as summarized in Table 30.

Table 30: Minor Losses at Cross Sections

Cross Section	River	Reach	River Station	Minor Loss Coefficient
XS 57	Red Deer River	Lower Reach	35880.01	0.5
XS 92	Red Deer River	Lower Reach	22538.81	0.1
XS 103	Red Deer River	Lower Reach	18130.02	0.3
XS 277	Piper Creek	Piper Creek	704.011	0.1
XS 301	Waskasoo Creek	Upper Reach	32982.53	0.5
XS 332	Waskasoo Creek	Upper Reach	29232.09	0.5

Table 30: Minor Losses at Cross Sections

Cross Section	River	Reach	River Station	Minor Loss Coefficient
XS 363	Waskasoo Creek	Upper Reach	25118.96	0.4
XS 394	Waskasoo Creek	Upper Reach	21324.33	0.3
XS 411	Waskasoo Creek	Upper Reach	19478.36	0.3
XS 533	Waskasoo Creek	Upper Reach	4120.058	0.3
XS 535	Waskasoo Creek	Upper Reach	3935.851	0.3
XS 537	Waskasoo Creek	Upper Reach	3782.856	0.3
XS 542	Waskasoo Creek	Lower Reach	3498.188	0.5

5.4.4 Obstructions and Ineffective Flow Areas

The following four types of ineffective flow areas were implemented in the model setup:

- **Topographical low areas in which standing water may occur:** Permanent ineffective flow areas were specified to block off low-lying areas that do not effectively convey flow.
- **Topographical low areas that can be activated:** Non-permanent ineffective flow areas were specified to block off low-lying areas that can become active after the water level is above a certain elevation.
- **Bridge decks and embankments:** Permanent ineffective flow areas were specified to block off flow through bridge embankments.
- **Flood control dikes:** Permanent ineffective flow areas were specified to block off flow behind flood control dikes.

Small residential buildings and houses are not specified as building blockage, because their effects on the hydraulic conditions in the overbank areas are represented by the composite or apparent Manning's value for residential areas.

5.4.5 Flow Splits, Islands and Diversions

There is no flow split, island or diversion included in the HEC-RAS model setup.

5.5 Open Water Flood Frequency Profiles

5.5.1 Hydrology Summary

Surface water profiles were simulated for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year regulated flood events using the calibrated HEC-RAS model. The estimated peak discharges for these flood events were determined in the hydrology analysis (Golder 2021b).

The boundary condition at the downstream end of the Red Deer River study reach was estimated based on normal flow depth with an energy slope of 0.1% for all flood discharges. The flood peak discharges for the study reaches are summarized in Table 31.

Table 31: Flood Peak Discharges along the Study Reaches

Flood Event	Flood Peak Discharge (m^3/s)							
	Red Deer River[a]			Waskasoo Creek[b]			Piper Creek[c]	
	Above Waskasoo Creek	Below Waskasoo Creek	Below Blindman River	Above Highway 42	Above Piper Creek	Above Red Deer River	Above Highway 595	Above Waskasoo Creek
2-Year	282	283	320	3.0	3.5	5.2	1.6	1.7
5-Year	457	458	512	7.5	8.7	12.7	4.1	4.6
10-Year	586	587	647	11.9	13.7	19.8	6.6	7.2
20-Year	720	721	782	17.0	19.6	28.3	9.4	10.3
35-Year	1,200	1,230	1,490	21.7	25.1	36.3	12.0	13.2
50-Year	1,390	1,430	1,720	25.0	28.9	41.8	13.8	15.2
75-Year	1,630	1,680	1,980	29.0	33.5	48.7	15.9	17.5
100-Year	1,820	1,870	2,180	32.1	37.1	53.9	17.5	19.3
200-Year	2,390	2,460	2,810	40.0	46.3	67.7	21.7	23.9
350-Year	2,830	2,910	3,310	47.0	54.6	80.2	25.3	28.0
500-Year	3,100	3,190	3,630	51.8	60.2	88.7	27.7	30.7
750-Year	3,500	3,590	4,130	57.5	67.0	99.0	30.6	33.9
1,000-Year	3,810	3,910	4,440	61.8	72.0	107.0	32.8	36.3

a) Red Deer River above Waskasoo Creek from station 50,826 to 38,445; below Waskasoo Creek from station 38,445 to 18,535; and below Blindman River from station 18,535 to 0 along the Red Deer River study reach. Flood peak discharges along the Red Deer River are based on regulated flows.

b) Waskasoo Creek above Highway 42 from station 34,636 to 29,081; above Piper Creek from station 29,081 to 3,498; and above Red Deer River from 3498 to 0 along the Waskasoo Creek study reach.

c) Piper Creek above 595 from station 19,702 to 7,570; and above Waskasoo Creek from station 7,570 to 0 along the Piper Creek study reach.

5.5.2 Red Deer River

The simulated open-water flood profiles of the various return periods for the Red Deer River are shown in Figure 26, Figure 27, and Figure 28. The open-water flood water levels for individual cross sections are listed in Table C.1 in Appendix C.

5.5.3 Waskasoo Creek

The simulated open-water flood profiles of the various return periods for the Waskasoo Creek are shown in Figure 29 and Figure 30. The open-water flood water levels for individual cross sections are listed in Table C.1 in Appendix C. Computed water levels for some flood scenarios at a very small subset of cross sections were manually adjusted to the nearest lower or higher flood level, or interpolated to avoid crossing water level profiles.

5.5.4 Piper Creek

The simulated open-water flood profiles of the various return periods for the Piper Creek are shown in Figure 31. The open-water flood water levels for individual cross sections are listed in Table C.1 in Appendix C. Computed water levels for some flood scenarios at a very small subset of cross sections were manually adjusted to the nearest lower or higher flood level, or interpolated to avoid crossing water level profiles.

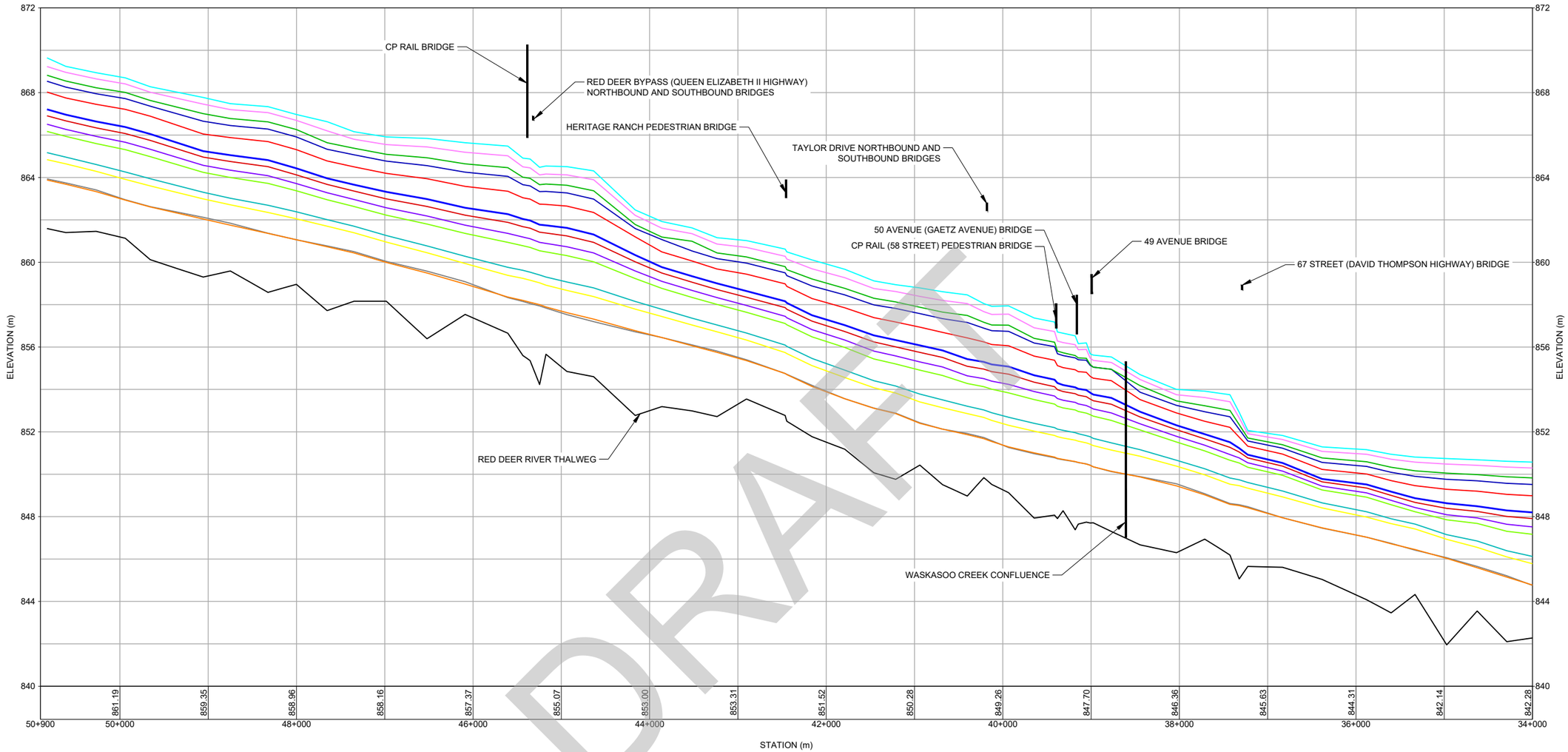
5.6 Model Sensitivity

5.6.1 Summary

Sensitivity analyses were conducted to evaluate the effects of changing model parameters on the simulated 100-year regulated-flow flood water levels. The model parameters included in the sensitivity analyses are the downstream boundary condition and Manning's *n* values for channels and floodplains. The results of the sensitivity analyses are used to quantify the level of uncertainty associated with the simulated 100-year flood levels. The sensitivity analysis results are summarized in Table 32.

Table 32: Summary of Sensitivity Analysis Results

Water Body	Parameter	Absolute Water Level Difference due to Various Percent Changes from the Base Values (m)							
		Channel Manning's *n*		Floodplain Manning's *n*		Channel and Floodplain Manning's *n*		Downstream Boundary Energy Slope	
		+10%	-10%	+10%	-10%	+10%	-10%	+20%	-20%
Red Deer River	Maximum	0.31	0.32	0.08	0.09	0.33	0.35	0.29	0.36
	Minimum	0.05	0.06	0.01	0.00	0.12	0.12	0.00	0.00
	Average	0.22	0.24	0.03	0.04	0.26	0.27	0.01	0.01
Waskasoo Creek	Maximum	0.39	0.38	0.03	0.04	0.40	0.39	0.00	0.00
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.07	0.07	0.01	0.02	0.09	0.08	0.00	0.00
Piper Creek	Maximum	0.09	0.10	0.02	0.02	0.09	0.10	0.00	0.00
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.04	0.05	0.01	0.01	0.05	0.05	0.00	0.00



LEGEND

- DESIGN FLOOD PROFILE - 2 YEAR
- DESIGN FLOOD PROFILE - 5 YEAR
- DESIGN FLOOD PROFILE - 10 YEAR
- DESIGN FLOOD PROFILE - 20 YEAR
- DESIGN FLOOD PROFILE - 35 YEAR
- DESIGN FLOOD PROFILE - 50 YEAR
- DESIGN FLOOD PROFILE - 75 YEAR
- DESIGN FLOOD PROFILE - 100 YEAR
- DESIGN FLOOD PROFILE - 200 YEAR
- DESIGN FLOOD PROFILE - 350 YEAR
- DESIGN FLOOD PROFILE - 500 YEAR
- DESIGN FLOOD PROFILE - 750 YEAR
- DESIGN FLOOD PROFILE - 1000 YEAR

REFERENCE

FLOOD PROFILES FROM HEC-RAS MODELLING, RIVER THALWEG FROM SURVEY DATA COLLECTED BY GOLDER FROM AUGUST 29 TO NOVEMBER 4, 2017 (RED DEER RIVER, WASKASOO CREEK AND PIPER CREEK).

0 1,000 2,000 METRES

HORIZONTAL SCALE 1:50,000
VERTICAL EXAGGERATION = 240X

CLIENT
ALBERTA ENVIRONMENT AND PARKS

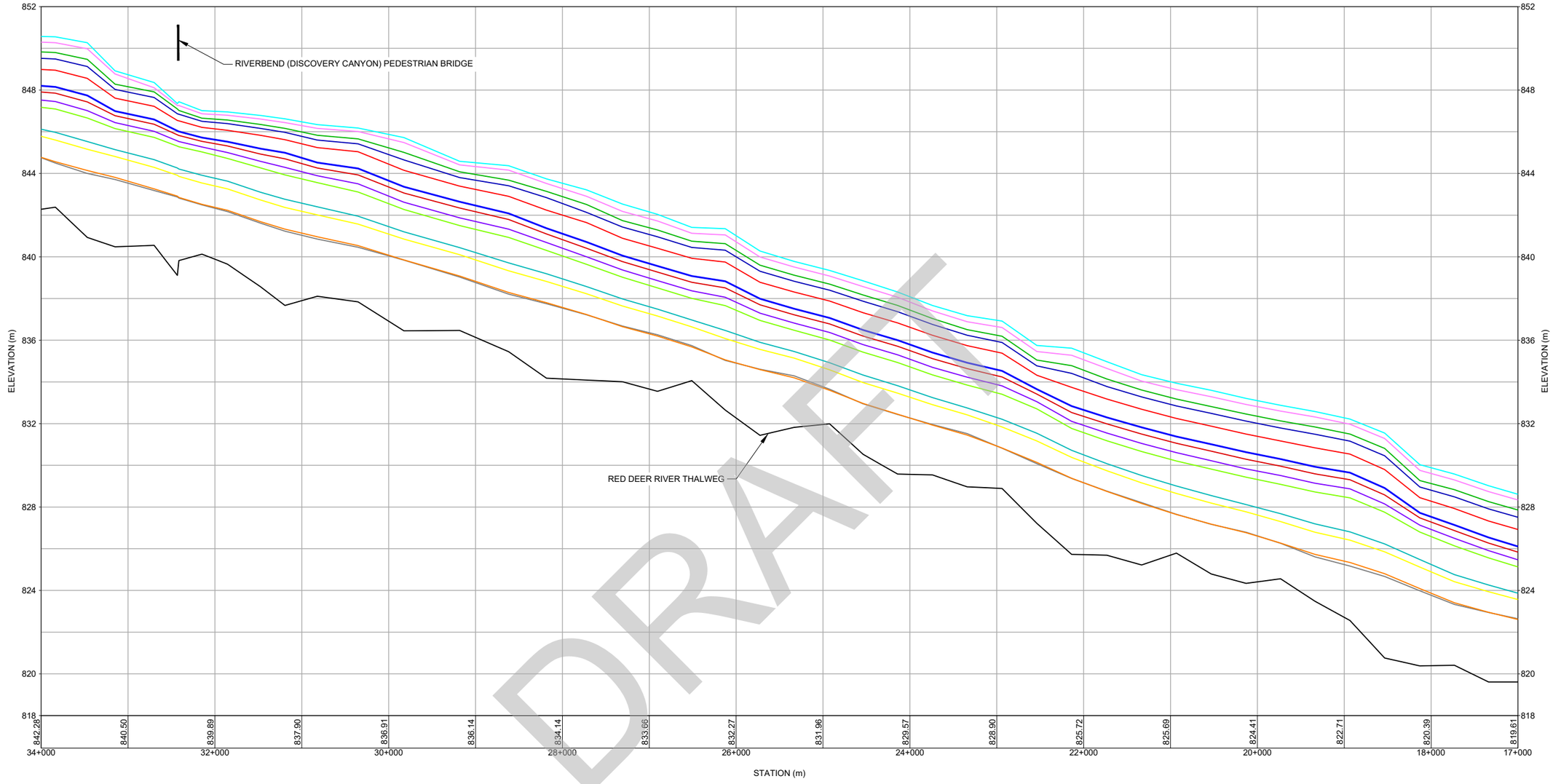
PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
OPEN WATER FLOOD PROFILES - RED DEER RIVER
(UPPER REACH)

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-05-17
PREPARED	T. FETENE
DESIGN	G. TANG
REVIEW	G. TANG
APPROVED	D. LONG

PROJECT No. 21452576
Rev. 1
FIGURE 26



LEGEND

- DESIGN FLOOD PROFILE - 2 YEAR
- DESIGN FLOOD PROFILE - 5 YEAR
- DESIGN FLOOD PROFILE - 10 YEAR
- DESIGN FLOOD PROFILE - 20 YEAR
- DESIGN FLOOD PROFILE - 35 YEAR
- DESIGN FLOOD PROFILE - 50 YEAR
- DESIGN FLOOD PROFILE - 75 YEAR
- DESIGN FLOOD PROFILE - 100 YEAR
- DESIGN FLOOD PROFILE - 200 YEAR
- DESIGN FLOOD PROFILE - 350 YEAR
- DESIGN FLOOD PROFILE - 500 YEAR
- DESIGN FLOOD PROFILE - 750 YEAR
- DESIGN FLOOD PROFILE - 1000 YEAR

REFERENCE

FLOOD PROFILES FROM HEC-RAS MODELLING, RIVER THALWEG FROM SURVEY DATA COLLECTED BY GOLDER FROM AUGUST 29 TO NOVEMBER 4, 2017 (RED DEER RIVER, WASKASOO CREEK AND PIPER CREEK).

0 1,000 2,000 METRES

HORIZONTAL SCALE 1:50,000
VERTICAL EXAGGERATION = 240X

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
OPEN WATER FLOOD PROFILES - RED DEER RIVER
(MIDDLE REACH)

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-05-17
PREPARED	T. FETENE
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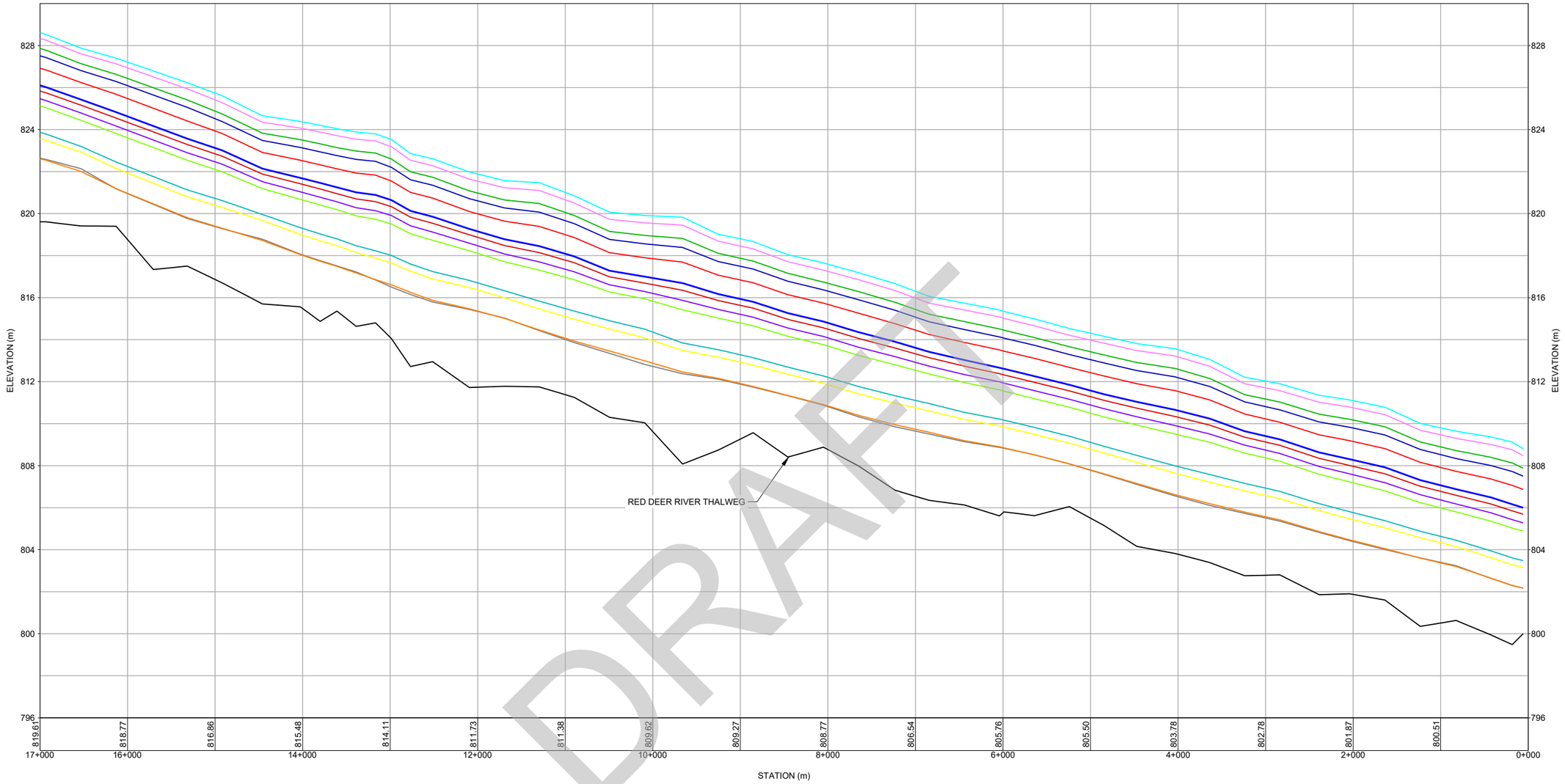
REVIEW	G. TANG
APPROVED	D. LONG

PROJECT No. 21452576 Rev. 1 FIGURE 27



LEGEND

- DESIGN FLOOD PROFILE - 2 YEAR
- DESIGN FLOOD PROFILE - 5 YEAR
- DESIGN FLOOD PROFILE - 10 YEAR
- DESIGN FLOOD PROFILE - 20 YEAR
- DESIGN FLOOD PROFILE - 35 YEAR
- DESIGN FLOOD PROFILE - 50 YEAR
- DESIGN FLOOD PROFILE - 75 YEAR
- DESIGN FLOOD PROFILE - 100 YEAR
- DESIGN FLOOD PROFILE - 200 YEAR
- DESIGN FLOOD PROFILE - 350 YEAR
- DESIGN FLOOD PROFILE - 500 YEAR
- DESIGN FLOOD PROFILE - 750 YEAR
- DESIGN FLOOD PROFILE - 1000 YEAR

REFERENCE

FLOOD PROFILES FROM HEC-RAS MODELLING, RIVER THALWEG FROM SURVEY DATA COLLECTED BY GOLDER FROM AUGUST 29 TO NOVEMBER 4, 2017 (RED DEER RIVER, WASKASOO CREEK AND PIPER CREEK).

0 1,000 2,000 METRES

HORIZONTAL SCALE 1:50,000
VERTICAL EXAGGERATION = 240X

CLIENT
ALBERTA ENVIRONMENT AND PARKS

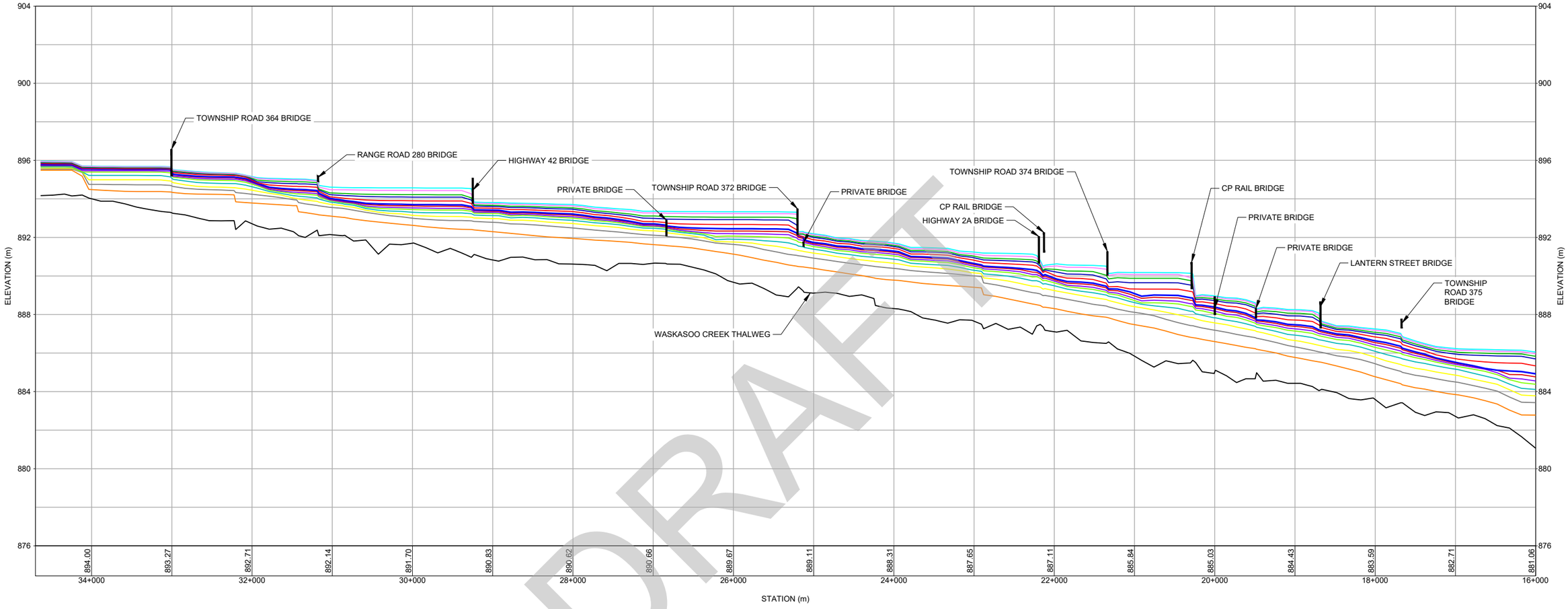
PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
OPEN WATER FLOOD PROFILES - RED DEER RIVER
(LOWER REACH)

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-05-17
PREPARED	T. FETENE
DESIGN	G. TANG
REVIEW	G. TANG
APPROVED	D. LONG

PROJECT No. 21452576
Rev. 1
FIGURE 28



LEGEND

- DESIGN FLOOD PROFILE - 2 YEAR
- DESIGN FLOOD PROFILE - 5 YEAR
- DESIGN FLOOD PROFILE - 10 YEAR
- DESIGN FLOOD PROFILE - 20 YEAR
- DESIGN FLOOD PROFILE - 35 YEAR
- DESIGN FLOOD PROFILE - 50 YEAR
- DESIGN FLOOD PROFILE - 75 YEAR
- DESIGN FLOOD PROFILE - 100 YEAR
- DESIGN FLOOD PROFILE - 200 YEAR
- DESIGN FLOOD PROFILE - 350 YEAR
- DESIGN FLOOD PROFILE - 500 YEAR
- DESIGN FLOOD PROFILE - 750 YEAR
- DESIGN FLOOD PROFILE - 1000 YEAR

REFERENCE

FLOOD PROFILES FROM HEC-RAS MODELLING, RIVER THALWEG FROM SURVEY DATA COLLECTED BY GOLDER FROM AUGUST 29 TO NOVEMBER 4, 2017 (RED DEER RIVER, WASKASOO CREEK AND PIPER CREEK).

0 1,000 2,000

HORIZONTAL SCALE 1:50,000 METRES
VERTICAL EXAGGERATION = 240X

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
OPEN WATER FLOOD PROFILES - WASKASOO CREEK
(UPPER REACH)

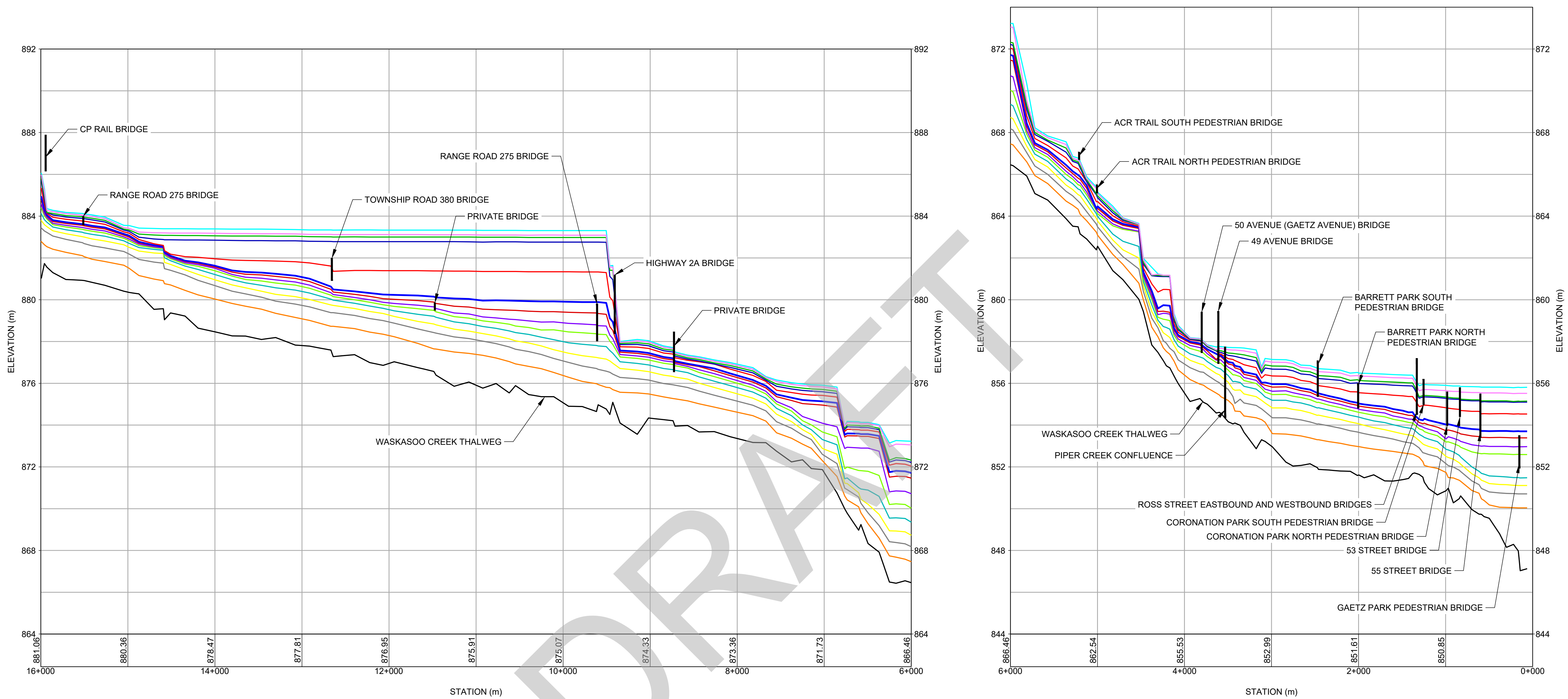
CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-05-17
PREPARED	T. FETENE
DESIGN	G. TANG
REVIEW	G. TANG
APPROVED	D. LONG

PROJECT No. 21452576 | Rev. 1 | FIGURE 29

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

25 mm



LEGEND

- DESIGN FLOOD PROFILE - 2 YEAR
- DESIGN FLOOD PROFILE - 5 YEAR
- DESIGN FLOOD PROFILE - 10 YEAR
- DESIGN FLOOD PROFILE - 20 YEAR
- DESIGN FLOOD PROFILE - 35 YEAR
- DESIGN FLOOD PROFILE - 50 YEAR
- DESIGN FLOOD PROFILE - 75 YEAR
- DESIGN FLOOD PROFILE - 100 YEAR
- DESIGN FLOOD PROFILE - 200 YEAR
- DESIGN FLOOD PROFILE - 350 YEAR
- DESIGN FLOOD PROFILE - 500 YEAR
- DESIGN FLOOD PROFILE - 750 YEAR
- DESIGN FLOOD PROFILE - 1000 YEAR

REFERENCE

FLOOD PROFILES FROM HEC-RAS MODELLING, RIVER THALWEG FROM SURVEY DATA COLLECTED BY GOLDER FROM AUGUST 29 TO NOVEMBER 4, 2017 (RED DEER RIVER, WASKASOO CREEK AND PIPER CREEK).

0 1,000 2,000 METRES

HORIZONTAL SCALE 1:50,000
VERTICAL EXAGGERATION = 240X

CLIENT
ALBERTA ENVIRONMENT AND PARKS

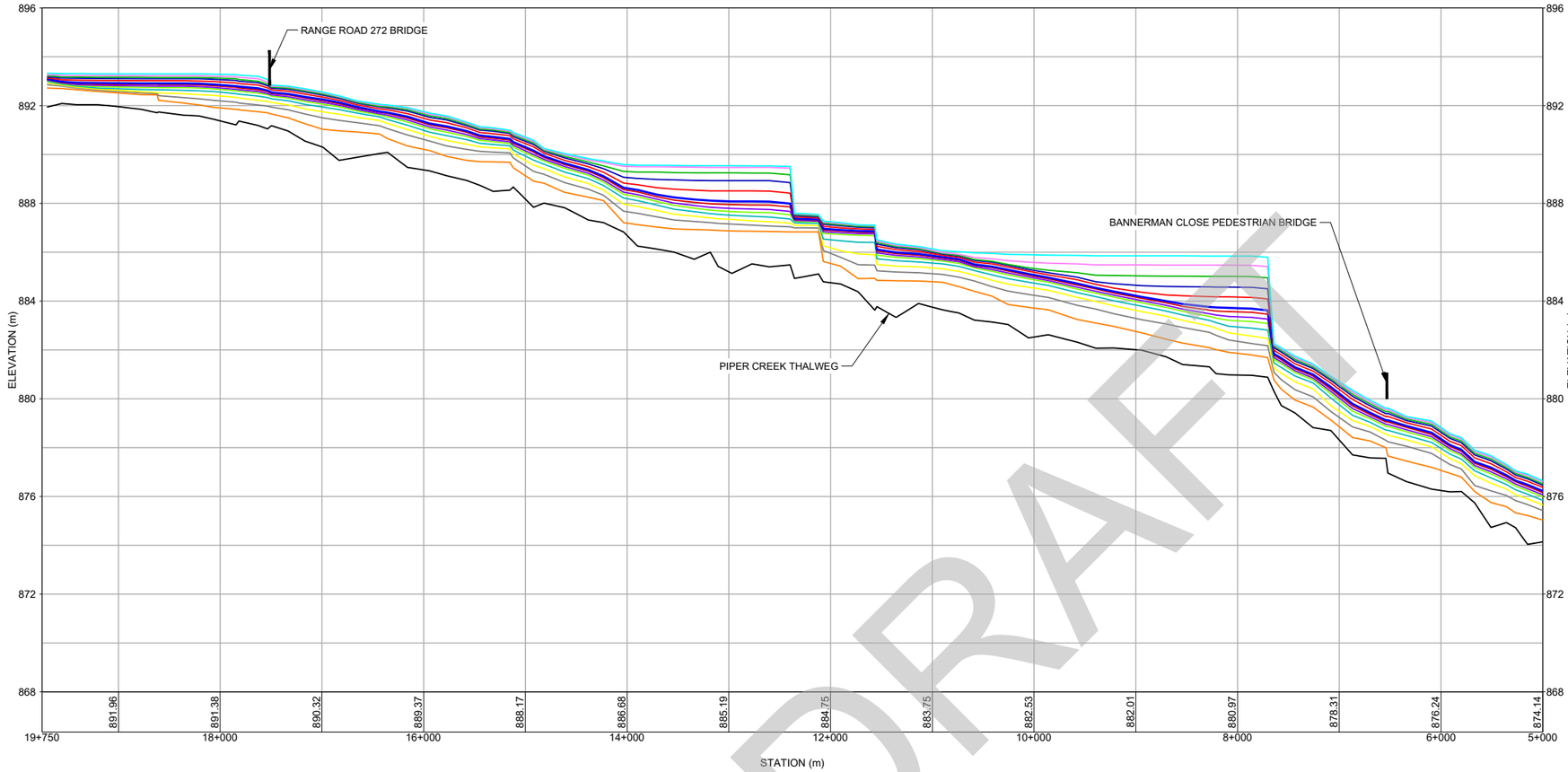
PROJECT
RED DEER RIVER HAZARD STUDY

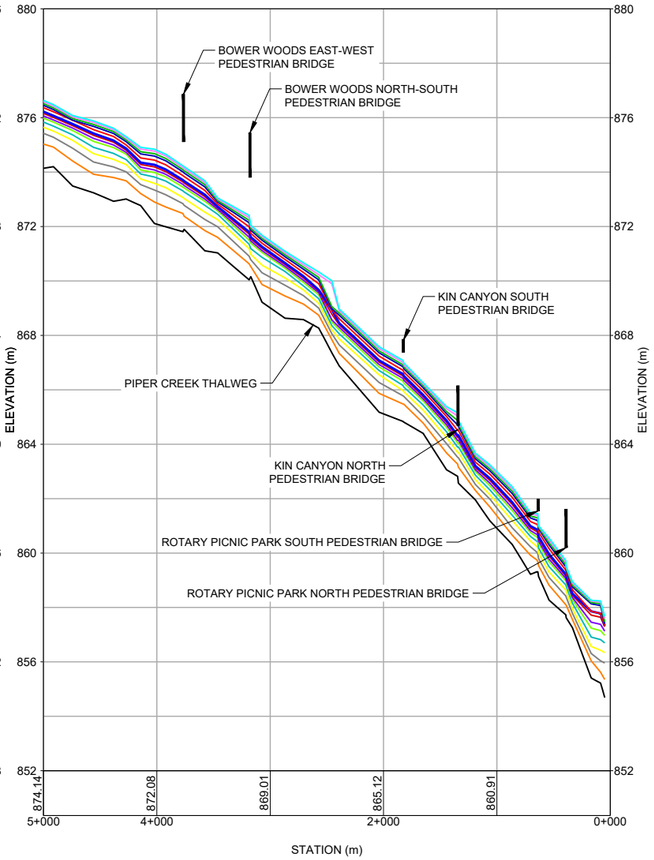
TITLE
OPEN WATER FLOOD PROFILES - WASKASOO CREEK
(LOWER REACH)

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-05-17
PREPARED	T. FETENE
DESIGN	G. TANG
REVIEW	G. TANG
APPROVED	D. LONG

PROJECT No. 21452576 | Rev. 1 | FIGURE 30





LEGEND

- DESIGN FLOOD PROFILE - 2 YEAR
- DESIGN FLOOD PROFILE - 5 YEAR
- DESIGN FLOOD PROFILE - 10 YEAR
- DESIGN FLOOD PROFILE - 20 YEAR
- DESIGN FLOOD PROFILE - 35 YEAR
- DESIGN FLOOD PROFILE - 50 YEAR
- DESIGN FLOOD PROFILE - 75 YEAR
- DESIGN FLOOD PROFILE - 100 YEAR
- DESIGN FLOOD PROFILE - 200 YEAR
- DESIGN FLOOD PROFILE - 350 YEAR
- DESIGN FLOOD PROFILE - 500 YEAR
- DESIGN FLOOD PROFILE - 750 YEAR
- DESIGN FLOOD PROFILE - 1000 YEAR

REFERENCE

FLOOD PROFILES FROM HEC-RAS MODELLING, RIVER THALWEG FROM SURVEY DATA COLLECTED BY GOLDER FROM AUGUST 29 TO NOVEMBER 4, 2017 (RED DEER RIVER, WASKASOO CREEK AND PIPER CREEK).

0 1,000 2,000 METRES

HORIZONTAL SCALE 1:50,000
VERTICAL EXAGGERATION = 240X

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
OPEN WATER FLOOD PROFILES - PIPER CREEK

CONSULTANT
wsp GOLDER

YYYY-MM-DD	2022-05-17
PREPARED	T. FETENE
DESIGN	G. TANG
REVIEW	G. TANG
APPROVED	D. LONG

PROJECT No. 21452576 | Rev. 1 | FIGURE 31

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

25 mm

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Path: \\golder.gds\comp\lexdata\office\Saskatoon\GGIS\2017\1783039 Red Deer River Hazard Study\Figures\30000\ | File Name: 1783039-30000 - Piper Creek_R1.dwg

5.6.2 Boundary Conditions

The normal flow condition was assumed as the downstream boundary condition in the HEC-RAS model. A sensitivity analysis was performed to assess the effects of varying the assumed downstream boundary slope on the upstream water levels. The downstream boundary energy slope was varied by ±20% from the base value of 0.001.

The results of the sensitivity analysis of the downstream boundary condition are presented in Figure D.1, Figure D.2 and Figure D.3 in Appendix D.

The water level at the downstream boundary increased by 0.36 m for decreasing the slope by 20% and reduced by 0.29 m by increasing the slope by 20%. The energy slope change at the downstream model boundary affects the water levels up to 6.8 km upstream of the downstream model boundary.

5.6.3 Manning Roughness

5.6.3.1 Channel Roughness

The results of the sensitivity analysis of the channel Manning's n values are presented in Figure D.4, Figure D.5 and Figure D.6 in Appendix D.

5.6.3.2 Overbank Roughness

The results of the sensitivity analysis of the overbank Manning's n values are presented in Figure D.7, Figure D.8 and Figure D.9 in Appendix D.

5.6.3.3 Combined Roughness

The results of the sensitivity analysis of the combined channel and overbank Manning's n values are presented in Figure D.10, Figure D.11 and Figure D.12 in Appendix D.

6.0 FLOOD INUNDATION MAPS

The Red Deer River Hazard Study flood inundation maps for the 2- to 1000-year floods are presented separately in the Open Water Flood Inundation Map Library. The following sections describe the inundation mapping methodology and flood impacts.

6.1 Methodology

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

- Simulated water levels at individual cross sections for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events.
- Locations and extents of individual cross sections.
- LiDAR DTM.
- Information about permanent flood control structures.

The purpose of the flood inundation mapping is to show the areas that are inundated by direct or potential flood control structure failure inundation.

6.1.1 Direct Flood Inundation Areas

Direct inundation is the flood inundation where there is a direct overland connection between the main river channels and flooded areas on the floodplains.

6.1.1.1 General Procedure

The following general procedure was used in ArcGIS to develop the inundation extent for the 13 open water flood events:

1) Assign water levels at each section for all flood events to the cross section polyline features as attributes. The result is one polyline feature that includes the simulated water levels for all flood events.
2) Create a continuous water level surface using a Triangulated Irregular Network (TIN) between cross sections.
3) Manually adjust the water level surface TIN in special areas (see details in Section 6.1.1.2). These adjustments are made by using 3D break lines to create areas of, for example, horizontal water levels and to separate the manually adjusted areas from the original water surface areas. Between the 3D break lines and the next upstream/downstream cross sections, the water surface was linearly interpolated (see Figure 32).
4) Convert the adjusted TIN into a water level raster with the same resolution and cell alignment as the DTM raster.
5) Subtract the DTM from the water level raster.
6) Assign “NoData” to dry cells (with water depths smaller than 0.01 m).
7) Remove areas that are not directly connected to the main river channels.
8) Polygons with an area smaller than 25 m^2 are deleted and holes smaller than 25 m^2 are filled.
9) The outline of the polygons is smoothed using the PEAK algorithm with a threshold of 15 m.

In addition to this general procedure, the following modifications were applied where appropriate:

- Backwater inundation for relatively large tributaries was included and based on the simulated water levels at the main channel at the confluences of those tributaries. This applies to the Blindman River (tributary to the Red Deer River).
- Some areas within the main river channels are not automatically delineated as inundated using ArcGIS because the DTM represents the elevation of the river water surface at the time of the data collection and not the river bed. Where the DTM elevations are higher than the modelled water levels, gaps in the inundation polygons are created. In these locations, inundation polygons were added manually to the river channels to close the gaps. This applies to some areas along Piper Creek and Waskasoo Creek for the 2-year and 5-year floods.
- Areas where no direct overland connection is delineated based on the DTM, but a hydraulic connection through culverts, permeable railway embankments or other features is known to exist, may be included in the inundation extent.

6.1.1.2 Manual Edits

In some areas, the water level surface TINs were manually edited to properly map water levels within the floodplain. Edits were made in the when the following inundation cases existed:

- Single Overtopping Point: At locations where inundated areas on the flood plain are connected to the main channel at a single overtopping point (spill point), the inundation extent was re-evaluated using a constant water level which is equal to that at the spill point. Often the inundated areas on the flood plain are located upstream of the overtopping point (backwater). In these cases, applying a constant water level reduced the size of the inundated area. Where the inundated areas are located downstream of the overtopping point, their size was increased.
- Multiple Overtopping Points: If there are multiple overtopping points related to a single overflow area, the inundation extent was based on the hydraulic gradient in the main channel between the overtopping points. The inundation extent upstream of the most upstream overtopping point and downstream of the most downstream overtopping point, were evaluated using the estimated water level at these bounding spill points.
- Single Overtopping Point Causing Overtopping Downstream: If the area behind the single overtopping location would be (after some time) completely inundated and pooled with a constant surface water elevation similar to the water level at the spill point, this may cause a second overtopping further downstream and flow back into the main channel, because at that point the water level behind the embankment may be higher than that in the main channel. In this case, the inundation extent was re-evaluated using a linear interpolation between the water level at the upstream spill point and the ground elevation at the downstream re-entry point.

Details of the manual edits for each flood event are discussed below.

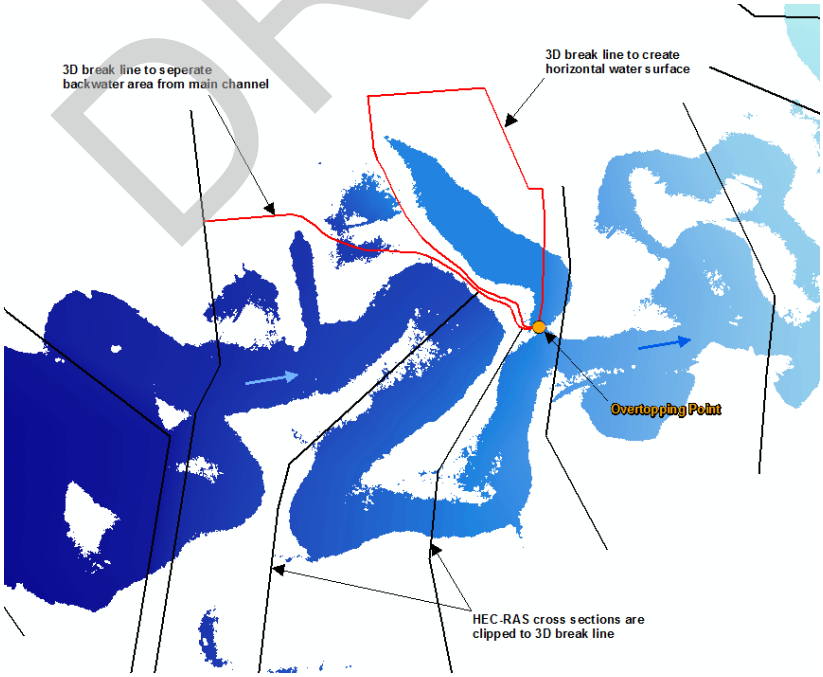

Figure 32: Example of Manual Edits to Water Level Surface TIN in Special Areas along the Waskasoo Creek (Scenario 1)

2-Year Flood

A summary of manual edits applied to the inundation extent for the 2-year flood event is provided in Table 33.

Table 33: Special Areas for the 2-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 59 and XS 60, right bank	1	846.25	Single overtopping point (backwater)
2	Red Deer River	Between XS 101 and XS 102, left bank	1	824.84	Single overtopping point (backwater) inundation for the Blindman River
3	Waskasoo Creek	XS 302, left bank	1	894.27	Single overtopping point (backwater)
4	Piper Creek	Between XS 159 and XS 160, left bank	1	892.45	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

5-Year Flood

A summary of manual edits applied to the inundation extent for the 5-year flood event is provided in Table 34.

Table 34: Special Areas for the 5-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 58 and XS 59, right bank	1	847.09	Single overtopping point (backwater). Potential flood control structure failure directly upstream of direct inundation.
2	Red Deer River	Between XS 101 and XS 102, left bank	1	825.6	Single overtopping point (backwater) inundation for the Blindman River
3	Waskasoo Creek	Between XS 325 and XS 326, left bank	1	893.00	Single overtopping point (backwater)
4	Waskasoo Creek	Between XS 355 and XS 356, left bank	1	891.59	Single overtopping point (backwater)
5	Piper Creek	Between XS 156 and XS 157, right bank	1	892.69	Single overtopping point (backwater)
6	Piper Creek	Between XS 158 and XS 159, left bank	1	892.53	Single overtopping point (backwater)
7	Piper Creek	Between XS 245 and XS 255, right bank	1	872.90	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

10-Year Flood

A summary of manual edits applied to the inundation extent for the 10-year flood event is provided in Table 35.

Table 35: Special Areas for the 10-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 58 and XS 59, right bank	1	847.52	Single overtopping point (backwater). Potential flood control structure failure directly upstream of direct inundation.
2	Red Deer River	Between XS 101 and XS 102, left bank	1	826.03	Single overtopping point (backwater) inundation for the Blindman River
3	Waskasoo Creek	XS 316, right bank	1	893.87	Single overtopping point (backwater)
4	Waskasoo Creek	Between XS 324 and XS 325, left bank	1	893.24	Single overtopping point (backwater)
5	Waskasoo Creek	Between XS 352 and 353, left bank	1	891.97	Single overtopping point (backwater)
6	Waskasoo Creek	Between XS 390 and XS 391, right bank	1	889.07	Single overtopping point (backwater)
7	Waskasoo Creek	Between XS 397 and XS 398, left bank	1	888.25	Single overtopping point (backwater)
8	Waskasoo Creek	Between XS 442 and XS 443, left bank	1	882.95	Single overtopping point (backwater)
9	Piper Creek	Between XS 156 and XS 157, right bank	1	892.73	Single overtopping point (backwater)
10	Piper Creek	Between XS 158 and XS 159, left bank	1	892.57	Single overtopping point (backwater)
11	Piper Creek	Between XS 245 and XS 255, right bank	1	873.13	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

20-Year Flood

A summary of manual edits applied to the inundation extent for the 20-year flood event is provided in Table 36.

Table 36: Special Areas for the 20-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 55 and XS 56, right bank, potential flood control structure failure	1	848.92	Single overtopping point (backwater)
2	Red Deer River	Between XS 58 and XS 59, right bank	1	847.78	Single overtopping point (backwater). Potential flood control structure failure directly upstream of direct inundation.
3	Red Deer River	Between XS 61 and XS 62, left bank	1	846.63	Single overtopping point (backwater)
4	Red Deer River	Between XS 101 and XS 102, left bank	1	826.41	Single overtopping point (backwater) inundation for the Blindman River
5	Waskasoo Creek	Between XS 311 and XS 312, right bank	1	894.24	Single overtopping point (backwater)
6	Waskasoo Creek	Between XS 324 and XS 325, left bank	1	893.36	Single overtopping point (backwater)
7	Waskasoo Creek	Between XS 397 and XS 398, left bank	1	888.47	Single overtopping point (backwater)
8	Piper Creek	Between XS 156 and XS 157, right bank	1	892.78	Single overtopping point (backwater)
9	Piper Creek	Between XS 158 and XS 159, left bank	1	892.68	Single overtopping point (backwater)
10	Piper Creek	Between XS 215 and XS 216, right bank	1	884.90	Single overtopping point (backwater)
11	Piper Creek	Between XS 245 and XS 255, right bank	1	873.37	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

35-Year Flood

A summary of manual edits applied to the inundation extent for the 35-year flood event is provided in Table 37.

Table 37: Special Areas for the 35-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 7 and XS 8, left bank	1	863.75	Single overtopping point (backwater)
2	Red Deer River	XS 21, left bank	1	860.02	Single overtopping point (backwater)
3	Red Deer River	Between XS 55 and XS 56, right bank	1	849.59	Single overtopping point (backwater)
4	Red Deer River	Between XS 61 and XS 62, left bank	1	847.52	Single overtopping point (backwater)
5	Red Deer River	Between XS 62 and XS 63, left bank	1	847.25	Single overtopping point (backwater)
6	Red Deer River	Between XS 101 and XS 102, left bank	1	827.94	Single overtopping point (backwater) inundation for the Blindman River
7	Waskasoo Creek	Between XS 311 and XS 312, right bank	1	894.33	Single overtopping point (backwater)
8	Waskasoo Creek	Between XS 318 and XS 319, left bank	1	893.85	Single overtopping point (backwater)
9	Waskasoo Creek	Between XS 324 and XS 325, left bank	1	893.48	Single overtopping point (backwater)
10	Waskasoo Creek	Between XS 397 and XS 398, left bank	1	888.61	Single overtopping point (backwater)
11	Waskasoo Creek	Between XS 416 and XS 417, left bank	1	886.96	Single overtopping point (backwater)
12	Waskasoo Creek	Between XS 432 and XS 433, right bank	1	884.90	Single overtopping point (backwater)
13	Piper Creek	Between XS 156 and XS 157, right bank	1	892.82	Single overtopping point (backwater)
14	Piper Creek	Between XS 158 and XS 159, left bank	1	892.76	Single overtopping point (backwater)
15	Piper Creek	Between XS 245 and XS 255, right bank	1	873.51	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

50-Year Flood

A summary of manual edits applied to the inundation extent for the 50-year flood event is provided in Table 38.

Table 38: Special Areas for the 50-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 7 and XS 8, left bank	1	864.12	Single overtopping point (backwater)
2	Red Deer River	XS 22, left bank	1	860.44	Single overtopping point (backwater)
3	Red Deer River	Between XS 34 and XS 35, left bank	1	854.825	Single overtopping point (backwater)
4	Red Deer River	Between XS 55 and XS 56, left bank	1	850.02	Single overtopping point (backwater)
5	Red Deer River	Between XS 61 and XS 62, left bank	1	847.82	Single overtopping point (backwater)
6	Red Deer River	Between XS 101 and XS 102, left bank	1	828.34	Single overtopping point (backwater) inundation for the Blindman River
7	Waskasoo Creek	Between XS 318 and XS 319, left bank	1	893.89	Single overtopping point (backwater)
8	Waskasoo Creek	Between XS 324 and XS 325, left bank	1	893.56	Single overtopping point (backwater)
9	Waskasoo Creek	Between XS 416 and XS 417, left bank	1	887.08	Single overtopping point (backwater)
10	Piper Creek	Between XS 156 and XS 157, right bank	1	892.85	Single overtopping point (backwater)
11	Piper Creek	Between XS 157 and XS 158, left bank	1	892.82	Single overtopping point (backwater)
12	Piper Creek	Between XS 245 and XS 255, right bank	1	873.61	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

75-Year Flood

A summary of manual edits applied to the inundation extent for the 75-year flood event is provided in Table 39.

Table 39: Special Areas for the 75-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 7 and XS 8, left bank	1	864.57	Single overtopping point (backwater)
2	Red Deer River	Downstream of XS 16, right bank	1	861.67	Single overtopping point (backwater)
3	Red Deer River	XS 21, left bank	1	860.94	Single overtopping point (backwater)
4	Red Deer River	Between XS 54 and XS 55, right bank	1	850.43	Single overtopping point (backwater)
5	Red Deer River	Downstream of XS 61, left bank	1	848.24	Single overtopping point (backwater)
6	Red Deer River	Between XS 61 and XS 62, left bank	1	848.15	Single overtopping point (backwater)
7	Red Deer River	Between XS 70 and XS 71, left bank	1	845.1	Single overtopping point (backwater)
8	Red Deer River	Between XS 101 and XS 102, left bank	1	828.77	Single overtopping point (backwater) inundation for the Blindman River
9	Waskasoo Creek	Between XS 537 and XS 538, left bank	1	857.68	Single overtopping point (backwater)
10	Piper Creek	Between XS 156 and XS 157, right bank	1	892.90	Single overtopping point (backwater)
11	Piper Creek	Between XS 245 and XS 255, right bank	1	873.71	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

100-Year Flood

A summary of manual edits applied to the inundation extent for the 100-year flood event is provided in Table 40.

Table 40: Special Areas for the 100-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 7 and XS 8, left bank	1	864.88	Single overtopping point (backwater)
2	Red Deer River	Between XS 15 and XS 16, left bank	1	862.10	Single overtopping point (backwater)
3	Red Deer River	Downstream of XS 16, right bank	1	862.03	Single overtopping point (backwater)
4	Red Deer River	XS 21, left bank	1	861.31	Single overtopping point (backwater)
5	Red Deer River	Between XS 54 and XS 55, right bank	1	850.61	Single overtopping point (backwater)
6	Red Deer River	Between XS 56 and XS 57, left bank	1	849.59	Single overtopping point (backwater)
7	Red Deer River	Between XS 60 and XS 61, left bank	1	848.24	Single overtopping point (backwater)
8	Red Deer River	Between XS 61 and XS 62, left bank	1	848.41	Single overtopping point (backwater)
9	Red Deer River	Between XS 70 and XS 71, left bank	1	845.33	Single overtopping point (backwater)
10	Red Deer River	Between XS 72 and XS 73, right bank	1	845.09	Single overtopping point (backwater). Same overtopping point as area 11.
11	Red Deer River	Between XS 72 and XS 76, right bank	3	845.09 upstream, 844.20 downstream	Single overtopping point causing overtopping downstream. Same overtopping point as area 10.
12	Red Deer River	Between XS 101 and XS 102, left bank	1	829.11	Single overtopping point (backwater) inundation for the Blindman River
13	Waskasoo Creek	Between XS 305 and XS 306, right bank	1	895.14	Single overtopping point (backwater)
14	Waskasoo Creek	Between XS 415 and XS 416, left bank	1	887.43	Single overtopping point (backwater)
15	Waskasoo Creek	Between XS 429 and XS 430, left bank	1	885.52	Single overtopping point (backwater)
16	Waskasoo Creek	Between XS 498 and XS 499, left bank	1	876.05	Single overtopping point (backwater)
17	Waskasoo Creek	Between XS 525 and XS 523, left bank	1	863.48	Single overtopping point (backwater)
18	Waskasoo Creek	XS 537, left bank	1	857.77	Single overtopping point (backwater)
19	Piper Creek	Between XS 245 and XS 255, right bank	1	873.80	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

200-Year Flood

A summary of manual edits applied to the inundation extent for the 200-year flood event is provided in Table 41.

Table 41: Special Areas for the 200-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 7 and XS 8, left bank	1	865.810	Single overtopping point (backwater)
2	Red Deer River	Between XS 15 and XS 16, left bank	1	863.13	Single overtopping point (backwater)
3	Red Deer River	Downstream of XS 16, right bank	1	863.03	Single overtopping point (backwater)
4	Red Deer River	XS 21, left bank	1	862.35	Single overtopping point (backwater)
5	Red Deer River	Between XS 56 and XS 57, left bank	1	850.09	Single overtopping point (backwater)
6	Red Deer River	Between XS 59 and XS 60, left bank	1	849.30	Single overtopping point (backwater)
7	Red Deer River	Between XS 61 and XS 62, left bank	1	849.19	Single overtopping point (backwater)
8	Red Deer River	Between XS 70 and XS 71, left bank	1	845.95	Single overtopping point (backwater)
9	Red Deer River	Between XS 71 and XS 72, right bank	1	845.80	Single overtopping point (backwater)
10	Red Deer River	Between XS 72 and XS 76, right bank	3	845.45 upstream, 844.20 downstream	Single overtopping point causing overtopping downstream.
11	Red Deer River	Between XS 101 and XS 102, left bank	1	830.0	Single overtopping point (backwater) inundation for the Blindman River
12	Waskasoo Creek	Between XS 427 and XS 428, left bank	1	885.99	Single overtopping point (backwater)
13	Waskasoo Creek	Between XS 535 and XS 536, left bank	1	858.05	Single overtopping point (backwater)
14	Waskasoo Creek	Between XS 546 and XS 547, left bank	1	856.88	Single overtopping point (backwater)
15	Piper Creek	Between XS 245 and XS 255, right bank	1	873.94	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

350-Year Flood

A summary of manual edits applied to the inundation extent for the 350-year flood event is provided in Table 42.

Table 42: Special Areas for the 350-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 15 and XS 16, left bank	1	864.03	Single overtopping point (backwater)
2	Red Deer River	Between XS 51 and XS 52, right bank	1	852.75	Single overtopping point (backwater)
3	Red Deer River	Between XS 60 and XS 61, left bank	1	849.73	Single overtopping point (backwater)
4	Red Deer River	Between XS 70 and XS 71, left bank	1	846.28	Single overtopping point (backwater)
5	Red Deer River	Between XS 72 and XS 76, right bank	3	845.80 upstream, 844.20 downstream	Single overtopping point causing overtopping downstream.
6	Red Deer River	Between XS 101 and XS 102, left bank	1	830.64	Single overtopping point (backwater) inundation for the Blindman River
7	Piper Creek	Between XS 245 and XS 255, right bank	1	874.09	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

500-Year Flood

A summary of manual edits applied to the inundation extent for the 500-year flood event is provided in Table 43.

Table 43: Special Areas for the 500-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 51 and XS 52, right bank	1	853.15	Single overtopping point (backwater)
2	Red Deer River	Between XS 63 and XS 64, left bank	1	849.71	Single overtopping point (backwater)
3	Red Deer River	Between XS 70 and XS 71, left bank	1	846.46	Single overtopping point (backwater)
4	Red Deer River	Between XS 101 and XS 102, left bank	1	830.98	Single overtopping point (backwater) inundation for the Blindman River
5	Waskasoo Creek	XS 325, left bank behind Waskasoo Avenue flood control structure	1	894.22	Single overtopping point (backwater). Potential flood control structure failure directly upstream of direct inundation.
6	Waskasoo Creek	Between XS 39 and XS 40, on the floodplain of the Red Deer River. Overtopping point between XS 539 and XS 541.	1	857.57	Water from Waskasoo Creek overtops the hydraulic divide between Waskasoo Creek and Red Deer River (approximately located along 50th Street) between 47th and 48th Avenue. Inundation on the Red Deer River right bank floodplain is delineated based on the Waskasoo Creek water levels at the overtopping point.
7	Piper Creek	Between XS 245 and XS 255, right bank	1	874.17	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

750-Year Flood

A summary of manual edits applied to the inundation extent for the 750-year flood event is provided in Table 44.

Table 44: Special Areas for the 750-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 51 and XS 52, right bank	1	853.58	Single overtopping point (backwater)
2	Red Deer River	Between XS 70 and XS 71, left bank	1	846.70	Single overtopping point (backwater)
3	Red Deer River	Between XS 101 and XS 102, left bank	1	831.46	Single overtopping point (backwater) inundation for the Blindman River
4	Waskasoo Creek	XS 384, right bank	1	891.00	Single overtopping point (backwater). Same overtopping point as area 5.
5	Waskasoo Creek	Between XS 384 and XS 392, right bank	3	891.00 upstream, 890.80 downstream	Single overtopping point causing overtopping downstream. Same overtopping point as area 4.
6	Waskasoo Creek	Between XS 39 and XS 40, on the floodplain of the Red Deer River. Overtopping point between XS 539 and XS 541.	1	857.68	Water from Waskasoo Creek overtops the hydraulic divide between Waskasoo Creek and Red Deer River (approximately located along 50th Street) between 47th and 48th Avenue. Inundation on the Red Deer River right bank floodplain is delineated based on the Waskasoo Creek water levels at the overtopping point.
7	Piper Creek	Between XS 245 and XS 255, right bank	1	874.25	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

1000-Year Flood

A summary of manual edits applied to the inundation extent for the 1000-year flood event is provided in Table 45.

Table 45: Special Areas for the 1000-Year Flood Event

No	River	Location	Scenario	Elevation	Comment
1	Red Deer River	Between XS 65 and XS 66, left bank	1	848.61	Single overtopping point (backwater)
2	Red Deer River	Between XS 70 and XS 71, left bank	1	846.87	Single overtopping point (backwater)
3	Red Deer River	Between XS 101 and XS 102, left bank	1	831.72	Single overtopping point (backwater) inundation for the Blindman River
4	Waskasoo Creek	XS 384, right bank	1	891.13	Single overtopping point (backwater). Same overtopping point as area 5.
5	Waskasoo Creek	Between XS 384 and XS 392, right bank	3	891.13 upstream, 890.80 downstream	Single overtopping point causing overtopping downstream. Same overtopping point as area 4.
6	Waskasoo Creek	Between XS 39 and XS 40, on the floodplain of the Red Deer River. Overtopping point between XS 539 and XS 541.	1	857.76	Water from Waskasoo Creek overtops the hydraulic divide between Waskasoo Creek and Red Deer River (approximately located along 50th Street) between 47th and 48th Avenue. Inundation on the Red Deer River right bank floodplain is delineated based on the Waskasoo Creek water levels at the overtopping point.
7	Piper Creek	Between XS 202 and 203, right bank	1	887.56	Single overtopping point (backwater)
8	Piper Creek	Between XS 245 and XS 255, right bank	1	874.33	Single overtopping point (backwater)

Note: Right bank is the bank on the right side when looking downstream, left bank is the bank on the left when looking downstream.

6.1.2 Potential Flood Control Structure Failure

Inundation due to potential flood control structure failure is mapped based on main channel water levels. Isolated areas behind flood control structures are only mapped as flood control structure failure if the flood water level in the main river channel is higher than the natural ground or the toe of the control structure as shown in Figure 33.

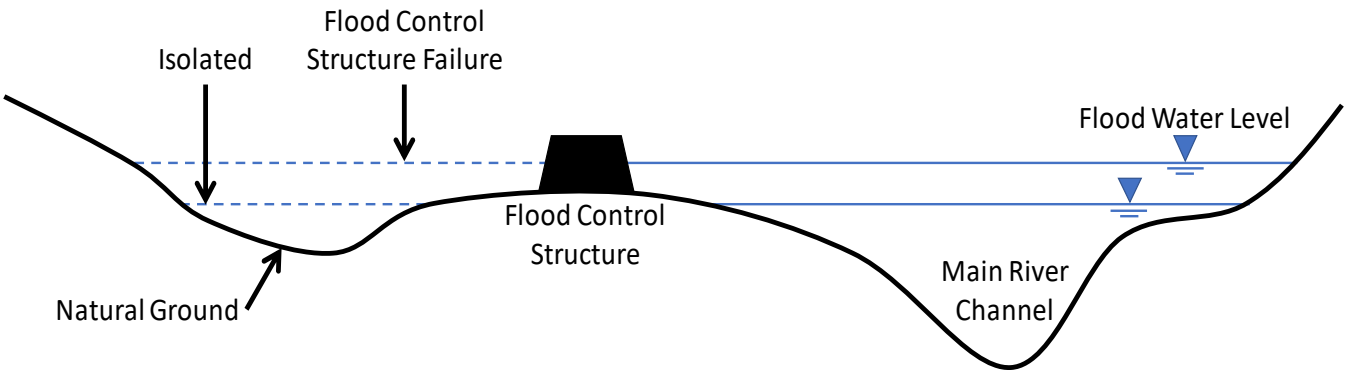

Figure 33: Illustration of Flood Control Structure Failure Inundation and Isolated Area Inundation

6.2 Flood Impacts

6.2.1 Residential Areas

Red Deer River

- Riverside Meadows east of 54th Avenue at the 1000 years return period.
- McKenzie Trail at return periods 35 years and higher.
- Asooahum Crossing at return periods 100 years and higher.

Waskasoo Creek

- Residential areas in Penhold between Lincoln and Lucine Street and east of Newton Drive at return periods 350 years and higher.
- Residential buildings south of Township Road 374 (NE 19-37-27 W4M and NW 20-37-27 W4M) at return periods 750 years and 1000 years.
- Residential buildings on Range Road 275 (NE 6-38-27 W4M and NW 5-38-27 W4M) at return periods 750 years and 1000 years.
- Capstone at Riverlands south of 43rd Street at return periods 100 years and higher and north of 43rd Street at return periods 350 years and higher.
- Downtown east of 47th Avenue and north of 55th Street at return periods 350 years and higher.
- Parkvale east of 46th Avenue at return periods 350 years and higher.
- Woodlea west of 44th Avenue at return periods of 200 years and higher and remaining areas of Woodlea at return periods 500 years and higher.
- Limited areas of Waskasoo west of 45th Avenue and south of Waskasoo Crescent at return periods 200 years and higher. Low lying areas along 42A Avenue at return periods 750 years and 1000 years.

Piper Creek

- No residential areas were affected by flooding along Piper Creek.

6.2.2 Commercial & Industrial Areas

Red Deer River

- Gravel pit on Township Road 382 (NW 12-38-28 W4M) at return periods of 200 years and higher and gravel pit on Range Road 280B (NW 13-38-28 W4M) at return periods of 35 years and higher.
- Railyards neighbourhood north of 52nd Street at return periods 350 years and higher.
- Campground in Riverside Light Industrial Park between Riverside Drive and the Red Deer River at return periods 35 years and higher. Other commercial buildings in the neighbourhood at return periods 200 years and higher.
- Riverside Heavy Industrial Park east of Riverside Drive at return periods 75 years and higher and west of Riverside Drive at return periods 500 years and higher. The Red Deer Waste Water treatment plant at return periods 350 years and higher.

Waskasoo Creek

- Capstone at Riverlands south of 43rd Street at return periods 100 years and higher and north of 43rd Street at return periods 350 years and higher.
- Downtown south of 45th Street at return periods 75 years and higher, between 45th Street and 50th Street at return periods 100 years and higher and north of 50th Street at return periods 500 years and higher.
- Parkvale east of 47th Avenue at return periods 350 years and higher.

Piper Creek

- No commercial and industrial areas were affected by flooding along Piper Creek.

6.2.3 Recreation Areas

Red Deer River

- Red Deer Golf and Country Club at return periods 35 years and higher.
- Bower Ponds Recreation area at return periods 35 years and higher.
- Great Chief Park at return periods 350 years and higher.
- Gaetz Lake Migratory Bird Sanctuary at return periods 350 years and higher.
- McKenzie Trail Recreation Area and Three Mile Bend Recreation Area at return periods 20 years and higher.
- River Bend Golf and Recreation Area at return periods 75 years and higher.

Waskasoo Creek

- Rotary Recreation Park at return periods 350 years and higher.

Piper Creek

- No recreational areas were affected by flooding along Piper Creek.

6.2.4 Hydraulic & Flood Control Structures

A bridge is considered to be affected by flooding when water reaches its low chord. A culvert crossing is considered to be affected by flooding when the upstream water level submerges the inlet of the highest culvert of the culvert group. A flood control structure is considered as affected by flooding when it is overtopped or bypassed.

The flood effects on bridges along the Red Deer River, Waskasoo Creek and Piper Creek are summarized respectively in Table 46, Table 47 and Table 48.

The flood effects on culvert crossings along Waskasoo Creek and Piper Creek are summarized respectively in Table 49 and Table 50. There are no culverts along the Red Deer River.

The flood effects on flood control structures within the study reaches are summarized in Table 51.

Table 46: Effects on Bridges Along the Red Deer River

Bridge Station (m)	Name	Minimum Low Chord Elevation (m)	Simulated Water Levels for Various Flood Events (m). Rounded to Nearest Decimeter.													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for the 100-year Flood Event (m)	Smallest Flood Event Causing Pressure Flow (Return Period)
			2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year			
45385.27	CP Rail Bridge	865.6	858.2	858.8	859.2	859.6	860.8	861.2	861.7	862.0	863.0	863.7	864.0	864.5	864.9	2.8	3.6	> 1000-year
45318.97	Red Deer Bypass (Queen Elizabeth II Highway) Northbound and Southbound Bridges	864.2	858.1	858.7	859.2	859.5	860.7	861.1	861.6	862.0	863.0	863.6	864.0	864.5	864.9	2.4	2.2	750-year
42454.70	Heritage Ranch Pedestrian Bridge	862.1	854.8	855.4	855.7	856.1	857.1	857.5	857.9	858.2	859.0	859.5	859.8	860.3	860.6	2.8	3.9	> 1000-year
40179.64	Taylor Drive Northbound and Southbound Bridges	861.1	851.7	852.3	852.7	853.0	854.1	854.5	855.0	855.3	856.2	856.9	857.2	857.7	858.1	2.8	5.8	> 1000-year
39395.52	CP Rail (58 Street) Pedestrian Bridge	856.5	850.8	851.4	851.8	852.2	853.3	853.7	854.1	854.5	855.4	856.0	856.2	856.7	857.2	3.3	2.0	750-year
39161.54	50 Avenue (Gaetz Avenue) Bridge	855.4	850.6	851.2	851.6	852.0	853.0	853.4	853.8	854.1	854.9	855.5	855.6	856.1	856.5	2.7	1.3	350-year
38992.80	49 Avenue Bridge	857.5	850.4	851.0	851.4	851.8	852.8	853.2	853.6	853.9	854.6	855.1	855.2	855.5	855.7	2.7	3.6	> 1000-year
37289.75	67 Street (David Thompson Highway) Bridge	856.4	848.6	849.1	849.5	849.7	850.5	850.8	851.1	851.2	851.8	852.1	852.3	852.7	852.9	3.0	5.2	> 1000-year
32422.86	Riverbend (Discovery Canyon) Pedestrian Bridge	848.2	842.9	843.5	843.9	844.3	845.3	845.6	845.9	846.0	846.5	846.9	847.1	847.3	847.4	3.1	2.2	> 1000-year

Table 47: Effects on Bridges Along Waskasoo Creek

Bridge Station (m)	Name	Minimum Low Chord Elevation (m)	Simulated Water Levels for Various Flood Events (m) . Rounded to Nearest Decimeter.												Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for the 100-year Flood Event (m)	Smallest Flood Event Causing Pressure Flow (Return Period)
			2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year			
33004.05	Township Road 364 Bridge	895.2	894.4	894.7	894.9	895.1	895.4	895.4	895.5	895.5	895.6	895.6	895.6	895.6	895.7	1.1	-0.3	35-year
31177.97	Range Road 280 Bridge	894.9	893.2	893.7	893.9	894.1	894.2	894.3	894.4	894.4	894.6	894.7	894.8	894.9	895.0	2.1	0.5	750-year
29248.34	Highway 42 Bridge	893.8	892.4	892.9	893.1	893.2	893.4	893.4	893.5	893.6	893.8	893.9	894.1	894.3	894.5	1.8	0.2	350-year
26835.45	Private Bridge	892.1	891.6	892.1	892.3	892.4	892.5	892.6	892.6	892.6	892.8	893.0	893.1	893.3	893.4	1.0	-0.5	10-year
25201.05	Township Road 372 Bridge	892.1	890.5	891.1	891.4	891.6	891.8	892.0	892.1	892.2	892.4	892.7	893.0	893.2	893.3	2.0	-0.1	75-year
25125.59	Private Bridge	891.2	890.5	891.0	891.3	891.5	891.7	891.9	892.0	892.0	892.0	892.2	892.2	892.3	892.3	2.0	-0.8	10-year
22192.14	Highway 2A Bridge	890.7	888.5	889.1	889.5	889.8	890.0	890.1	890.2	890.3	890.5	890.7	890.8	890.9	891.1	1.8	0.4	500-year
22128.42	CP Rail Bridge	891.2	888.4	889.0	889.3	889.6	889.8	889.9	889.9	890.0	890.2	890.3	890.3	890.4	890.5	2.1	1.2	> 1000-year
21338.10	Township Road 374 Bridge	890.0	887.9	888.4	888.8	889.0	889.2	889.3	889.4	889.5	889.6	889.9	890.0	890.4	890.5	2.0	0.5	500-year
20288.78	CP Rail Bridge	889.3	886.8	887.4	887.9	888.2	888.4	888.6	888.7	888.9	889.2	889.5	889.8	889.9	890.1	1.4	0.4	350-year
20254.69	Highway 2A Bridge	889.2	886.8	887.4	887.8	888.2	888.4	888.6	888.7	888.9	889.2	889.5	889.7	889.9	890.1	2.1	0.4	350-year
20000.10	Private Bridge	887.9	886.6	887.2	887.6	887.8	888.1	888.2	888.3	888.4	888.6	888.7	888.8	888.9	889.0	1.0	-0.5	35-year
19486.90	Private Bridge	887.8	886.2	886.8	887.2	887.4	887.6	887.7	887.8	887.8	888.1	888.3	888.4	888.5	888.6	2.3	0.0	100-year
18681.57	Lantern Street Bridge	887.3	885.5	886.1	886.4	886.7	886.9	887.0	887.1	887.2	887.5	887.7	887.8	887.9	888.1	1.6	0.1	200-year
17671.28	Township Road 375 Bridge	887.3	884.4	885.1	885.4	885.7	886.0	886.1	886.3	886.4	886.6	886.7	886.8	887.0	887.0	1.6	0.9	> 1000-year
15977.00	Highway 2A Bridge	885.7	882.8	883.4	883.8	884.1	884.4	884.6	884.8	884.9	885.3	885.7	885.8	886.0	886.1	2.6	0.8	500-year
15944.57	CP Rail Bridge	886.2	882.6	883.3	883.6	883.8	884.0	884.1	884.2	884.3	884.6	884.8	885.0	885.2	885.3	2.7	1.9	> 1000-year
15513.21	Range Road 275 Bridge	883.4	882.1	882.7	883.0	883.2	883.4	883.5	883.6	883.6	883.8	883.9	884.0	884.1	884.1	0.6	-0.2	50-year
12656.21	Township Road 380 Bridge	880.9	878.7	879.4	879.8	880.0	880.2	880.3	880.5	880.6	881.6	882.8	883.0	883.1	883.3	2.5	0.3	200-year
11473.08	Private Bridge	879.2	877.7	878.4	878.8	879.2	879.5	879.7	879.9	880.2	881.4	882.8	883.0	883.1	883.3	1.2	-0.9	20-year
9610.085	Range Road 275 Bridge	878.0	876.0	876.7	877.2	877.8	878.4	878.8	879.4	879.9	881.3	882.8	883.0	883.1	883.3	0.3	-1.9	35-year
9406.597	Highway 2 Bridge	877.4	875.7	876.4	877.0	877.4	877.9	878.1	878.5	878.9	880.0	881.0	881.4	881.6	881.6	3.6	-1.5	20-year
8725.840	Private Bridge	876.5	875.3	875.9	876.3	876.7	876.9	877.0	877.1	877.2	877.4	877.5	877.6	877.7	877.7	2.2	-0.7	20-year
5210.980	ACR Trail South Pedestrian Bridge	866.5	864.3	864.7	865.0	865.3	865.5	865.6	865.8	866.0	866.3	866.5	866.6	866.7	866.8	2.3	0.5	350-year
5005.230	ACR Trail North Pedestrian Bridge	864.8	863.2	863.6	863.9	864.1	864.3	864.3	864.3	864.4	864.7	865.0	865.1	865.3	865.4	2.6	0.4	350-year
3801.724	50 Avenue (Gaetz Avenue) Bridge[(1)]	857.4	856.0	856.6	856.9	857.3	857.5	857.7	857.8	857.9	858.0	858.1	858.1	858.1	858.1	1.6	-0.5	35-year
3611.609	49 Avenue Bridge	856.9	855.5	856.1	856.5	856.8	857.0	857.1	857.1	857.4	857.6	857.6	857.6	857.6	857.7	1.6	-0.5	35-year
2468.093	Barrett Park South Pedestrian Bridge	855.0	853.3	854.1	854.5	854.8	855.1	855.3	855.4	855.5	855.9	856.3	856.4	856.6	856.7	1.9	-0.5	35-year
2004.915	Barrett Park North Pedestrian Bridge	854.4	853.0	853.7	854.1	854.4	854.6	854.8	855.0	855.1	855.6	856.0	856.2	856.4	856.5	1.6	-0.7	35-year
1331.213	Ross Street Eastbound and Westbound Bridges	854.5	852.6	853.1	853.4	853.8	854.0	854.2	854.3	854.5	855.2	855.7	855.9	856.1	856.2	1.7	0.0	200-year

Table 47: Effects on Bridges Along Waskasoo Creek

Bridge Station (m)	Name	Minimum Low Chord Elevation (m)	Simulated Water Levels for Various Flood Events (m) . Rounded to Nearest Decimeter.													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for the 100-year Flood Event (m)	Smallest Flood Event Causing Pressure Flow (Return Period)
			2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year			
1253.214	Coronation Park South Pedestrian Bridge	854.5	852.3	852.7	853.1	853.5	853.8	853.9	854.1	854.2	854.9	855.3	855.4	855.7	855.9	1.6	0.3	200-year
982.1014	Coronation Park North Pedestrian Bridge	854.0	851.7	852.2	852.5	852.8	853.2	853.3	853.7	854.0	854.8	855.3	855.3	855.7	855.9	1.1	0.0	100-year
835.2544	53 Street Bridge	854.4	851.4	851.8	852.2	852.6	853.0	853.3	853.6	853.9	854.8	855.2	855.3	855.6	855.9	1.5	0.5	200-year
600.8005	55 Street Bridge	853.4	850.7	851.2	851.5	851.8	852.7	853.0	853.5	853.8	854.7	855.2	855.2	855.6	855.8	1.3	-0.4	75-year
153.1458	Gaetz Park Pedestrian Bridge	851.6	850.0	850.7	851.1	851.5	852.6	853.0	853.4	853.7	854.5	855.1	855.2	855.5	855.8	0.2	-2.1	35-year

(1) The 50 Avenue (Gaetz Avenue) Bridge on the Waskasoo Creek was surveyed and modelled as a bridge in the Study. It is acknowledged that the City of Red Deer recognizes this structure as a culvert.

Table 48: Effects on Bridges Along Piper Creek

Bridge Station (m)	Name	Minimum Low Chord Elevation (m)	Simulated Water Levels for Various Flood Events (m) . Rounded to Nearest Decimeter.													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for the 100-year Flood Event (m)	Smallest Flood Event Causing Pressure Flow (Return Period)
			2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year			
17514.25	Range Road 272 Bridge	892.8	891.7	892.0	892.2	892.3	892.5	892.5	892.6	892.6	892.7	892.8	892.9	893.0	893.1	1.3	0.2	350-year
6532.337	Bannerman Close Pedestrian Bridge	879.4	878.0	878.3	878.6	878.7	878.9	879.0	879.1	879.1	879.3	879.4	879.5	879.6	879.6	1.5	0.3	500-year
3764.790	Bower Woods East-West Pedestrian Bridge	874.6	872.5	872.8	873.1	873.3	873.5	873.6	873.6	873.7	873.9	874.0	874.1	874.2	874.2	1.6	0.9	> 1000-year
3178.546	Bower Woods North-South Pedestrian Bridge	873.3	870.6	870.9	871.2	871.4	871.5	871.6	871.7	871.8	872.0	872.1	872.2	872.3	872.4	1.9	1.5	> 1000-year
1825.649	Kin Canyon South Pedestrian Bridge	867.1	865.5	865.8	866.0	866.2	866.3	866.4	866.5	866.6	866.7	866.9	866.9	867.0	867.1	1.7	0.5	> 1000-year
1343.162	Kin Canyon North Pedestrian Bridge	864.5	863.3	863.5	863.7	863.9	864.1	864.1	864.3	864.3	864.5	864.7	864.9	865.0	865.2	2.2	0.2	200-year
635.7696	Rotary Picnic Park South Pedestrian Bridge	861.3	859.7	860.0	860.2	860.4	860.6	860.7	860.8	860.9	861.0	861.2	861.3	861.4	861.5	2.3	0.4	750-year
390.0081	Rotary Picnic Park North Pedestrian Bridge	860.0	858.1	858.4	858.6	858.8	859.0	859.1	859.2	859.2	859.4	859.5	859.6	859.7	859.7	2.3	0.8	> 1000-year

Table 49: Effects on Culverts Along the Waskasoo Creek

Culvert Station (m)	Name	Highest Top of Culvert Elevation (m)	Simulated Water Levels for Various Flood Events (m)													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for the 100-year Flood Event (m)	Smallest Flood Event Submerging the Inlet of the Highest Culvert of the Culvert Group
			2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year			
34225.38	Range Road 281 Culvert	895.0	895.5	895.6	895.6	895.7	895.7	895.7	895.8	895.8	895.8	895.9	895.9	895.9	895.9	1.2	-0.8	5-year
32212.93	Private Culvert	895.4	894.2	894.4	894.6	894.8	895.0	895.0	895.1	895.1	895.2	895.3	895.3	895.3	895.3	0.2	0.3	> 1000-year
31431.80	Private Culvert	893.2	893.7	893.9	894.0	894.2	894.3	894.3	894.4	894.5	894.7	894.8	894.9	895.0	895.0	0.1	-1.3	5-year
22894.80	Private Culvert	889.0	889.4	890.0	890.1	890.2	890.4	890.4	890.5	890.6	890.7	890.9	891.0	891.1	891.2	1.0	-1.6	5-year
14586.20	Private Culvert	881.8	880.9	881.8	882.2	882.4	882.4	882.5	882.5	882.5	882.6	882.9	883.1	883.2	883.4	1.7	-0.7	20-year
9482.278	CP Rail Culvert	877.6	875.8	876.6	877.2	877.8	878.3	878.7	879.3	879.9	881.3	882.8	883.0	883.1	883.3	2.6	-2.3	35-year
6805.485	Taylor Drive Culvert	873.4	871.5	872.2	872.6	873.1	873.4	873.9	874.9	875.1	875.3	875.5	875.6	875.7	875.8	3.3	-1.7	50-year
6308.135	32 Street Culvert	870.8	868.6	869.2	869.7	870.6	871.6	872.8	873.4	873.5	873.7	873.8	873.9	874.0	874.0	3.3	-2.7	50-year
5893.377	34 Street Culvert	869.5	867.4	868.1	868.7	869.3	870.0	870.7	871.4	871.7	872.0	872.2	872.3	873.0	873.2	3.6	-2.2	50-year
4500.285	43 Street Culvert	862.4	860.8	861.5	862.0	862.6	863.3	863.3	863.4	863.5	863.5	863.6	863.6	863.6	863.7	4.6	-1.1	35-year
4142.467	52 Avenue & 45 Street Loop Culvert	858.4	857.4	857.7	858.2	858.6	859.0	859.3	859.4	859.7	860.5	861.1	861.1	861.2	861.2	4.2	-1.3	35-year
3387.566	48 Avenue Culvert	856.7	854.7	855.0	855.7	856.1	856.4	856.6	856.7	856.8	857.1	857.3	857.4	857.6	857.7	1.4	-0.1	100-year

Table 50: Effects on Culverts Along the Piper Creek

Culvert Station (m)	Name	Highest Top of Culvert Elevation (m)	Simulated Water Levels for Various Flood Events (m)													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for the 100-year Flood Event (m)	Smallest Flood Event Submerging the Inlet of the Highest Culvert of the Culvert Group
			2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year			
18613.30	Private Culvert	892.8	892.4	892.5	892.5	892.7	892.8	892.8	892.9	892.9	893.0	893.1	893.2	893.2	893.3	0.03	-0.1	100-year
12376.40	40 Avenue Culvert	887.6	886.8	887.0	887.2	887.4	887.5	887.7	887.9	888.0	888.4	888.9	889.2	889.4	889.5	2.3	-0.4	75-year
12095.10	Private Culvert	886.9	886.8	887.0	887.1	887.2	887.2	887.3	887.3	887.3	887.4	887.5	887.5	887.5	887.5	0.5	-0.4	10-year
11554.53	Private Culvert	885.9	884.9	885.5	885.9	886.4	886.7	886.8	886.8	886.9	886.9	887.0	887.0	887.1	887.1	2.8	-1.0	35-year
7675.133	Delburne Road (19 Street) Culvert	883.9	881.7	882.2	882.5	882.8	883.1	883.3	883.5	883.6	884.1	884.5	885.0	885.4	885.8	3.8	0.3	350-year
2424.258	32 Street Culvert	872.9	867.8	868.1	868.2	868.4	868.5	868.6	868.8	869.0	869.0	869.0	869.1	869.9	870.0	2.6	3.9	> 1000-year
66.71176	43 Street Culvert	857.2	855.6	856.0	856.4	856.8	857.2	857.4	857.6	857.8	857.8	858.1	858.1	858.2	858.2	2.1	-0.6	75-year

Table 51: Effects on Flood Control Structures Along Study Reaches

Stream	Name	Flood Control Structure Status												Smallest Flood Event where the Flood Control Structure Fails
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year	
Red Deer River	McKenzie Trails Berm	None	None	None	Overtopped	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	20-Year
Red Deer River	Red Deer Wastewater Treatment Plant Dike	None	None	None	None	None	None	None	None	None	None	None	None	None	> 1000-Year
Waskasoo Creek	Penhold Dike #1	None	None	None	None	None	None	None	None	None	None	None	None	None	> 1000-Year
Waskasoo Creek	Penhold Dike #2	None	None	None	None	None	None	None	None	None	None	None	None	None	> 1000-Year
Waskasoo Creek	Safeway Dike	None	None	None	None	Overtopped	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	35-Year
Waskasoo Creek	Baymont Dike	None	None	None	None	None	None	Overtopped	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	Overtopped and Bypassed	75-Year

7.0 CONCLUSIONS

7.1 Model Setup

The HEC-RAS program (Version 5.0.6) was used as the software platform for developing the one-dimensional (1D) hydraulic model in the study area, and it was designed to perform 1D hydraulic calculations for a full network of natural and constructed channels.

All reaches in the study area are included into one integrated model setup. A conceptual two-dimensional hydraulic analysis was performed for the entire study area for the 100-year and 1000-year flood events, and the analysis was used to complement the professional judgement to inform selection of the cross section alignments.

Flood flow frequency estimates for the Red Deer River, Waskasoo Creek, and Piper Creek (Golder, 2021b) are used as the open boundaries and internal boundaries for the hydraulic model, and normal flow conditions is used at the downstream end of the Red Deer River study reach.

For this study, HEC-RAS is run in a steady state mode only.

7.2 Model Calibration

The HEC-RAS model was set up for the study reaches of the Red Deer River, Waskasoo Creek and the Piper Creek, and calibrated based on the available low flow, high flow, and rating curve data. The calibrated HEC-RAS model can be reliably used in this study for simulating various flood events with return periods ranging from 2 to 1,000 years.

River channel Manning's n roughness coefficient is the main model parameter used in calibrating the HEC-RAS model. The calibrated river channel Manning's n values for the low flow conditions on the Red Deer River, Waskasoo Creek and Piper Creek are generally higher than those for the high flow conditions.

The calibrated channel Manning's n values for the high flow conditions is 0.033 along the Piper Creek study reach and Waskasoo Creek study reach and range from 0.032 to 0.036 along the Red Deer River study reach. These Manning's n values are within the typical range of roughness values for similar rivers (Chow 1959).

7.3 Model Sensitivity

Model sensitivity was evaluated using the 100-year flood simulation results. The results of the sensitivity analysis show that variation of the river channel roughness values has a much higher influence on the simulated flood levels than variation of the floodplain roughness values, and that on average, the 100-year flood levels are estimated to be within a range of ±0.35 m of the simulated values along the Red Deer River, ±0.40 m along the Waskasoo Creek and ±0.10 m along the Piper Creek.

7.4 Flood Profiles

The calibrated HEC-RAS model provides 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. Computed water levels at a very small number of cross sections for some flood scenarios, were manually adjusted to the nearest lower or higher flood levels, or interpolated to avoid crossing of water level profiles.

7.5 Open Water Flood Inundation Map Production

The calibrated HEC-RAS model and the LiDAR DTM provided a good basis for simulating the flood levels and preparing the 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. The maps are presented separately in the Open Water Flood Inundation Map Library.

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APPENDIX A

Model Calibration Results

Table A.1: Comparison of Simulated and Surveyed Water Levels Along the Red Deer River During the 2017 Survey for Low Flow Calibration

No	River Station (m)	Surveyed Water Level (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Survey Date
1	48749	860.90	860.55	-0.35	20.76	24/09/2017
2	48323	859.84	859.90	0.06	20.76	24/09/2017
3	48001	859.52	859.56	0.04	20.76	24/09/2017
4	47653	859.37	859.36	-0.01	20.76	24/09/2017
5	47349	859.32	859.25	-0.07	20.76	24/09/2017
6	46982	859.29	858.63	-0.66	20.76	24/09/2017
7	46522	858.24	858.26	0.02	20.76	24/09/2017
8	46090	858.15	858.13	-0.02	20.76	24/09/2017
9	45605	857.17	857.05	-0.12	20.76	24/09/2017
10	45436	856.62	856.64	0.02	20.76	24/09/2017
11	45353	856.58	856.50	-0.08	20.76	24/09/2017
12	45246	856.50	856.39	-0.11	20.76	24/09/2017
13	45174	856.26	856.32	0.06	20.76	24/09/2017
14	44937	855.96	856.03	0.07	20.76	24/09/2017
15	44634	855.58	855.15	-0.43	20.76	24/09/2017
16	44163	855.02	854.86	-0.16	20.76	24/09/2017
17	39644	849.56	849.41	-0.15	21.37	27/09/2017
18	39180	849.03	849.01	-0.02	23.27	25/09/2017
19	39145	848.99	848.99	0.00	23.27	25/09/2017
20	39053	848.96	848.95	-0.01	23.27	25/09/2017
21	39011	848.94	848.89	-0.05	23.27	25/09/2017
22	38975	848.84	848.79	-0.05	23.27	25/09/2017
23	38770	848.60	848.29	-0.31	21.37	27/09/2017
24	38445	848.29	848.10	-0.19	21.37	27/09/2017
25	38032	848.30	847.97	-0.33	21.37	27/09/2017
26	37713	847.63	847.65	0.02	23.27	25/09/2017
27	37427	847.19	847.15	-0.04	23.27	25/09/2017
28	37323	847.09	847.10	0.01	23.27	25/09/2017
29	37225	847.06	847.06	0.00	23.27	25/09/2017
30	36832	846.66	846.50	-0.16	21.37	27/09/2017
31	36383	845.86	845.76	-0.10	21.37	27/09/2017
32	18535	822.51	822.46	-0.05	24.05	17/09/2017

Table A.1: Comparison of Simulated and Surveyed Water Levels Along the Red Deer River During the 2017 Survey for Low Flow Calibration

No	River Station (m)	Surveyed Water Level (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Survey Date
33	18130	822.33	822.10	-0.23	24.05	17/09/2017
34	17732	821.60	821.40	-0.20	24.05	17/09/2017
35	17338	821.14	821.15	0.01	24.05	17/09/2017
36	16933	821.08	821.00	-0.08	24.05	17/09/2017
37	16532	821.03	820.78	-0.25	24.05	17/09/2017
38	16131	820.37	820.01	-0.36	24.05	17/09/2017
39	15705	818.57	818.54	-0.03	24.05	17/09/2017
40	15318	818.20	818.22	0.02	24.05	17/09/2017
41	14918	817.58	817.57	-0.01	24.05	17/09/2017
42	14459	817.26	817.15	-0.11	24.05	17/09/2017
43	14026	816.99	816.50	-0.49	24.05	17/09/2017
44	13799	816.08	816.21	0.13	24.05	17/09/2017
45	13608	816.14	816.00	-0.14	24.32	18/09/2017
46	13388	815.76	815.80	0.04	24.32	18/09/2017
47	13167	815.56	815.55	-0.01	24.32	18/09/2017
48	12986	814.90	814.81	-0.09	24.32	18/09/2017
49	12768	814.37	814.35	-0.02	24.32	18/09/2017
50	12514	814.02	813.80	-0.22	24.32	18/09/2017
51	12096	813.62	813.54	-0.08	24.32	18/09/2017
52	11695	813.60	813.34	-0.26	24.32	18/09/2017
53	11295	812.69	812.69	0.00	21.87	19/09/2017
54	10896	812.02	812.04	0.02	21.87	19/09/2017
55	10494	811.73	811.55	-0.18	21.87	19/09/2017
56	10092	810.77	810.57	-0.20	21.87	19/09/2017
57	9661	810.43	810.39	-0.04	21.87	19/09/2017
58	9253	810.35	810.32	-0.03	21.87	19/09/2017
59	8854	810.26	810.09	-0.16	21.87	19/09/2017
60	8457	809.60	809.74	0.14	21.87	19/09/2017
61	4471	805.29	805.37	0.08	22.65	16/09/2017
62	4035	804.88	804.78	-0.10	22.65	16/09/2017
63	3639	804.38	804.29	-0.09	22.65	16/09/2017
64	3240	803.96	803.98	0.02	22.65	16/09/2017

Table A.1: Comparison of Simulated and Surveyed Water Levels Along the Red Deer River During the 2017 Survey for Low Flow Calibration

No	River Station (m)	Surveyed Water Level (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Survey Date
65	2838	803.87	803.70	-0.17	22.65	16/09/2017
66	2388	803.23	803.17	-0.06	22.65	16/09/2017
67	2040	802.75	802.81	0.06	22.65	16/09/2017
68	1636	802.28	802.18	-0.10	22.65	16/09/2017
69	1233	801.99	801.93	-0.06	22.65	16/09/2017
70	824	801.92	801.72	-0.20	22.65	16/09/2017
71	429	800.97	800.97	0.00	22.65	16/09/2017
72	183	800.79	800.77	-0.02	22.65	16/09/2017
73	58	800.74	800.69	-0.05	22.65	16/09/2017

Table A.2: Comparison of Simulated and Surveyed Water Levels Along Waskasoo Creek During the 2017 Survey for Low Flow Calibration

No	River Station (m)	Surveyed Water Level (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Survey Date
1	8570	874.19	874.08	-0.11	0.02	14/09/2017
2	8439	874.15	873.90	-0.25	0.02	14/09/2017
3	8263	874.16	873.80	-0.36	0.02	14/09/2017
4	8079	874.13	873.50	-0.63	0.02	14/09/2017
5	7820	874.18	873.36	-0.82	0.02	14/09/2017
6	7670	874.10	873.31	-0.79	0.02	14/09/2017
7	7548	873.80	872.80	-1.00	0.02	14/09/2017
8	7376	872.62	872.48	-0.13	0.02	14/09/2017
9	7249	872.69	872.41	-0.28	0.02	14/09/2017
10	7148	872.13	872.09	-0.04	0.02	14/09/2017
11	7021	872.05	871.95	-0.10	0.02	14/09/2017
12	6853	870.85	870.79	-0.06	0.02	14/09/2017
13	6764	870.20	870.07	-0.12	0.02	14/09/2017
14	6736	870.18	869.85	-0.33	0.02	14/09/2017
15	6605	869.41	869.30	-0.11	0.02	14/09/2017
16	6578	869.40	869.28	-0.12	0.02	14/09/2017
17	6497	868.52	868.43	-0.09	0.02	14/09/2017
18	6369	868.20	868.01	-0.19	0.02	14/09/2017
19	6251	867.27	866.70	-0.57	0.02	14/09/2017
20	6175	867.27	866.70	-0.57	0.02	14/09/2017
21	6071	867.28	866.70	-0.58	0.02	14/09/2017
22	5970	866.83	866.47	-0.36	0.02	14/09/2017
23	5812	866.17	865.96	-0.20	0.02	14/09/2017
24	5719	865.74	865.19	-0.55	0.02	14/09/2017
25	5571	865.74	864.91	-0.83	0.02	14/09/2017
26	5361	864.22	863.95	-0.27	0.02	14/09/2017
27	5284	864.06	863.69	-0.37	0.02	14/09/2017
28	5222	863.95	863.64	-0.31	0.02	14/09/2017
29	5200	863.92	863.26	-0.66	0.02	14/09/2017
30	5125	863.31	862.99	-0.32	0.02	14/09/2017
31	5013	862.88	862.66	-0.22	0.02	14/09/2017
32	4998	862.74	862.63	-0.11	0.02	14/09/2017

Table A.2: Comparison of Simulated and Surveyed Water Levels Along Waskasoo Creek During the 2017 Survey for Low Flow Calibration

No	River Station (m)	Surveyed Water Level (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Survey Date
33	4824	861.73	861.46	-0.27	0.02	14/09/2017
34	4707	861.14	861.10	-0.04	0.02	14/09/2017
35	4524	860.21	860.09	-0.12	0.02	14/09/2017
36	4472	859.80	859.50	-0.30	0.02	14/09/2017
37	4376	858.49	858.03	-0.46	0.02	14/09/2017
38	4306	857.80	857.56	-0.24	0.02	15/09/2017
39	4243	857.30	857.20	-0.10	0.02	15/09/2017
40	4209	857.18	856.91	-0.27	0.02	15/09/2017
41	4168	857.17	856.89	-0.28	0.02	15/09/2017
42	4120	856.53	856.48	-0.05	0.02	15/09/2017
43	4073	856.19	856.05	-0.14	0.02	15/09/2017
44	3936	855.74	855.40	-0.34	0.02	15/09/2017
45	3823	855.44	855.34	-0.10	0.02	15/09/2017
46	3783	855.35	855.24	-0.11	0.02	15/09/2017
47	3738	855.35	855.04	-0.31	0.02	15/09/2017
48	3635	854.97	854.72	-0.25	0.02	15/09/2017
49	3600	854.93	854.71	-0.22	0.02	15/09/2017
50	3582	854.78	854.66	-0.12	0.02	15/09/2017
51	3498	854.59	854.23	-0.36	0.02	15/09/2017
52	3444	854.33	854.19	-0.14	0.02	15/09/2017
53	3420	854.28	854.15	-0.13	0.02	15/09/2017
54	3360	854.25	854.07	-0.18	0.02	15/09/2017
55	3316	854.02	853.69	-0.33	0.02	15/09/2017
56	3176	853.78	853.39	-0.39	0.02	15/09/2017
57	3115	853.73	853.39	-0.34	0.02	15/09/2017
58	3074	853.67	853.28	-0.39	0.02	15/09/2017
59	2662	852.35	852.33	-0.02	0.038	16/09/2017
60	2558	852.34	852.29	-0.05	0.038	16/09/2017
61	2476	852.31	852.14	-0.17	0.038	16/09/2017
62	2460	852.28	852.08	-0.20	0.038	16/09/2017
63	2340	852.20	852.02	-0.18	0.038	16/09/2017
64	2209	852.19	852.00	-0.19	0.038	16/09/2017

Table A.2: Comparison of Simulated and Surveyed Water Levels Along Waskasoo Creek During the 2017 Survey for Low Flow Calibration

No	River Station (m)	Surveyed Water Level (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Survey Date
65	2095	852.17	851.96	-0.21	0.038	16/09/2017
66	2014	852.16	851.85	-0.31	0.038	16/09/2017
67	1996	852.13	851.84	-0.29	0.038	16/09/2017
68	1935	852.15	851.84	-0.31	0.038	16/09/2017
69	1825	852.40	852.43	0.03	1.37	13/09/2017
70	1700	852.35	852.39	0.04	1.37	13/09/2017
71	1605	852.35	852.36	0.01	1.37	13/09/2017
72	1490	852.33	852.31	-0.02	1.37	13/09/2017
73	1426	852.36	852.29	-0.07	1.37	13/09/2017
74	1380	852.36	852.27	-0.09	1.37	13/09/2017
75	1357	852.33	852.25	-0.08	1.37	13/09/2017
76	1245	851.84	851.72	-0.12	1.37	13/09/2017
77	1195	851.80	851.64	-0.16	1.37	13/09/2017
78	1094	851.78	851.59	-0.19	1.37	13/09/2017
79	699	850.72	850.56	-0.16	1.37	13/09/2017
80	380	849.35	849.30	-0.05	1.37	13/09/2017
81	301	848.91	848.99	0.08	1.37	13/09/2017
82	220	848.67	848.72	0.05	1.37	13/09/2017
83	165	848.47	848.45	-0.02	1.37	13/09/2017
84	143	848.45	848.20	-0.25	1.37	13/09/2017
85	63	848.33	848.16	-0.17	1.37	13/09/2017

Table A.3: Comparison of Simulated and Surveyed Water Levels Along Piper Creek During the 2017 Survey for Low Flow Calibration

No	River Station (m)	Surveyed Water Level (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Survey Date
1	6698	878.36	877.81	-0.55	0.11	20/09/2017
2	6542	878.38	877.70	-0.68	0.11	20/09/2017
3	6523	877.90	877.14	-0.76	0.11	20/09/2017
4	6341	877.22	876.85	-0.37	0.11	20/09/2017
5	6093	876.83	876.60	-0.23	0.11	20/09/2017
6	5913	876.63	876.49	-0.14	0.11	20/09/2017
7	5799	876.45	876.42	-0.03	0.11	20/09/2017
8	5670	876.43	875.92	-0.51	0.11	20/09/2017
9	5508	875.60	875.25	-0.35	0.11	20/09/2017
10	5357	875.58	875.21	-0.37	0.11	20/09/2017
11	5267	875.12	874.82	-0.30	0.11	20/09/2017
12	5149	874.86	874.53	-0.33	0.11	20/09/2017
13	4912	874.40	874.31	-0.09	0.11	20/09/2017
14	4744	873.86	873.89	0.03	0.11	20/09/2017
15	4559	873.61	873.38	-0.23	0.11	20/09/2017
16	4382	873.49	873.32	-0.17	0.11	20/09/2017
17	4271	873.37	873.29	-0.08	0.11	20/09/2017
18	2707	869.10	868.89	-0.21	0.27	21/09/2017
19	2572	868.44	868.51	0.07	0.27	21/09/2017
20	2456	867.71	867.62	-0.09	0.27	21/09/2017
21	2392	867.26	867.17	-0.09	0.27	21/09/2017
22	1445	863.67	863.39	-0.28	0.27	21/09/2017

Table A.4: Comparison of Simulated Water Levels and Surveyed Highwater Marks Along the Red Deer River for High Flow Calibration

No	River Station (m)	Surveyed Highwater Marks (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Year
1	46749	862.23	862.18	-0.05	1,290	2013
2	41342	855.48	855.50	0.02	1,290	2013
3	40196	854.19	854.27	0.09	1,290	2013
4	39702	854.16	853.75	-0.41	1,290	2013
5	39373	853.43	853.34	-0.09	1,290	2013
6	37299	850.46	850.56	0.10	1,292	2013
7	37248	850.75	850.45	-0.30	1,292	2013
8	35807	849.52	848.89	-0.63	1,292	2013
9	32429	845.65	845.38	-0.27	1,292	2013
10	29002	840.60	841.44	0.85	1,292	2013
11	45340	860.99	861.35	0.36	1,510	2005
12	45270	861.12	861.22	0.11	1,510	2005
13	41204	855.78	855.79	0.01	1,510	2005
14	40196	854.55	854.69	0.15	1,510	2005
15	40186	854.64	854.68	0.04	1,510	2005
16	40154	854.63	854.64	0.01	1,510	2005
17	40132	854.59	854.61	0.02	1,510	2005
18	39372	853.88	853.74	-0.15	1,510	2005
19	38971	853.15	853.22	0.07	1,510	2005
20	37298	851.10	850.81	-0.30	1,513	2005
21	37281	851.13	850.76	-0.37	1,513	2005
22	35845	850.06	849.16	-0.90	1,513	2005
23	35838	850.01	849.15	-0.86	1,513	2005
24	34346	847.52	847.81	0.30	1,513	2005
25	34346	847.49	847.81	0.32	1,513	2005
26	34345	847.56	847.81	0.25	1,513	2005
27	34345	847.37	847.81	0.44	1,513	2005
28	32401	846.11	845.63	-0.48	1,513	2005
29	29010	841.93	841.85	-0.08	1,513	2005
30	45352	859.51	860.02	0.51	908	1990
31	41370	854.27	854.74	0.48	908	1990
32	40177	852.97	853.44	0.47	908	1990

Table A.4: Comparison of Simulated Water Levels and Surveyed Highwater Marks Along the Red Deer River for High Flow Calibration

No	River Station (m)	Surveyed Highwater Marks (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Year
33	39358	852.18	852.56	0.38	908	1990
34	38973	851.74	852.13	0.39	908	1990
35	37266	849.65	849.99	0.34	915	1990
36	35868	848.27	848.51	0.25	915	1990
37	34351	846.32	846.85	0.53	915	1990
38	32424	844.29	844.69	0.41	915	1990
39	28999	840.49	840.66	0.18	915	1990

Table A.5: Comparison of Simulated Water Levels and Surveyed Highwater Marks Along Waskasoo Creek for High Flow Calibration

No	River Station (m)	Surveyed Highwater Marks (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Year
1	33009	894.96	895.18	0.23	19.2	2018
2	33008	894.96	895.17	0.22	19.2	2018
3	32997	894.97	895.12	0.16	19.2	2018
4	32988	894.73	895.09	0.36	19.2	2018
5	32983	894.73	895.06	0.34	19.2	2018
6	31197	894.16	894.12	-0.04	19.2	2018
7	31188	894.16	894.12	-0.03	19.2	2018
8	31181	894.09	894.10	0.01	19.2	2018
9	31171	894.07	894.06	-0.01	19.2	2018
10	31167	894.06	894.04	-0.01	19.2	2018
11	31143	894.02	894.01	0.00	19.2	2018
12	29305	893.26	893.31	0.05	19.2	2018
13	29271	893.31	893.29	-0.02	19.2	2018
14	29261	893.21	893.28	0.07	19.2	2018
15	29230	893.25	893.21	-0.04	19.2	2018
16	29221	893.16	893.21	0.05	19.2	2018
17	25209	891.35	891.71	0.36	22.1	2018
18	25195	891.51	891.67	0.15	22.1	2018
19	25178	891.42	891.64	0.23	22.1	2018
20	21378	888.96	889.11	0.15	22.1	2018
21	21354	889.07	889.09	0.02	22.1	2018
22	21331	889.04	889.04	-0.01	22.1	2018
23	21318	888.95	889.02	0.06	22.1	2018
24	21263	888.90	888.98	0.08	22.1	2018
25	15552	883.10	883.31	0.21	22.1	2018
26	15545	883.08	883.30	0.23	22.1	2018
27	15540	883.31	883.30	0.00	22.1	2018
28	15487	883.16	883.26	0.10	22.1	2018
29	15483	883.14	883.25	0.11	22.1	2018
30	9642	877.47	878.07	0.60	22.1	2018
31	9635	877.45	878.07	0.62	22.1	2018
32	9635	877.34	878.07	0.72	22.1	2018

Table A.5: Comparison of Simulated Water Levels and Surveyed Highwater Marks Along Waskasoo Creek for High Flow Calibration

No	River Station (m)	Surveyed Highwater Marks (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Year
33	9622	877.48	878.06	0.58	22.1	2018
34	9603	877.52	878.05	0.52	22.1	2018
35	9585	877.43	878.04	0.61	22.1	2018
36	3832	857.30	857.40	0.10	22.1	2018
37	3820	857.36	857.38	0.03	22.1	2018
38	3801	857.22	857.35	0.12	22.1	2018
39	3783	857.27	857.31	0.04	22.1	2018
40	3773	857.17	857.27	0.11	22.1	2018
41	3768	857.11	857.26	0.15	22.1	2018
42	3450	856.55	856.26	-0.29	32.0	2018
43	3440	856.52	856.23	-0.29	32.0	2018
44	3433	856.49	856.23	-0.26	32.0	2018
45	3416	856.55	856.24	-0.31	32.0	2018
46	3365	856.52	856.19	-0.33	32.0	2018
47	1279	853.85	853.63	-0.22	32.0	2018
48	1262	853.69	853.60	-0.09	32.0	2018
49	626	851.93	851.80	-0.13	32.0	2018
50	614	851.67	851.75	0.08	32.0	2018
51	583	851.56	851.55	-0.01	32.0	2018
52	574	851.55	851.52	-0.03	32.0	2018
53	34714	895.66	895.63	-0.03	15.0	2007
54	34700	895.35	895.63	0.28	15.0	2007
55	34656	895.55	895.63	0.08	15.0	2007
56	33013	894.87	895.02	0.15	15.0	2007
57	32979	894.55	894.92	0.37	15.0	2007
58	31186	894.11	893.97	-0.14	15.0	2007
59	31169	894.07	893.93	-0.14	15.0	2007
60	29259	893.18	893.14	-0.04	15.0	2007
61	29241	893.20	893.11	-0.09	15.0	2007
62	25210	892.20	891.49	-0.71	17.0	2007
63	25187	891.60	891.44	-0.16	17.0	2007
64	1294	853.20	853.39	0.19	24.0	2007

Table A.5: Comparison of Simulated Water Levels and Surveyed Highwater Marks Along Waskasoo Creek for High Flow Calibration

No	River Station (m)	Surveyed Highwater Marks (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Year
65	3821	856.61	857.10	0.49	17.0	1982
66	3777	856.61	857.02	0.41	17.0	1982
67	3771	856.47	857.00	0.53	17.0	1982
68	3632	855.69	856.62	0.93	17.0	1982
69	3534	855.55	856.34	0.79	17.0	1982
70	3451	856.09	855.94	-0.15	24.0	1982
71	3418	856.08	855.89	-0.19	24.0	1982
72	3352	855.56	855.84	0.28	24.0	1982
73	3226	855.56	855.60	0.04	24.0	1982
74	2731	854.94	854.93	-0.01	24.0	1982
75	2660	854.64	854.89	0.25	24.0	1982
76	1549	853.79	853.81	0.02	24.0	1982
77	1467	853.52	853.73	0.21	24.0	1982
78	1410	853.56	853.69	0.13	24.0	1982
79	1229	853.19	853.22	0.03	24.0	1982
80	1207	853.17	853.19	0.02	24.0	1982
81	1003	852.48	852.70	0.22	24.0	1982
82	921	851.93	852.56	0.63	24.0	1982
83	684	851.51	851.74	0.23	24.0	1982
84	575	851.00	851.31	0.31	24.0	1982
85	411	850.89	850.58	-0.31	24.0	1982

Table A.6: Comparison of Simulated Water Levels and Surveyed Highwater Marks Along Piper Creek for High Flow Calibration

No	River Station (m)	Surveyed Highwater Marks (m)	Simulated Water Level (Interpolated from Cross Sections) (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Year
1	6597	879.43	879.42	-0.01	25.0	2018
2	6544	879.52	879.31	-0.21	25.0	2018
3	6534	879.50	879.31	-0.19	25.0	2018
4	6528	879.48	879.31	-0.17	25.0	2018
5	6386	879.35	879.11	-0.23	25.0	2018
6	2520	869.38	869.48	0.10	25.0	2018
7	2495	869.26	869.25	0.00	25.0	2018
8	2462	869.05	868.96	-0.09	25.0	2018
9	2456	868.78	868.90	0.12	25.0	2018
10	2395	869.17	868.66	-0.51	25.0	2018
11	2395	869.17	868.66	-0.50	25.0	2018
12	2378	869.17	868.60	-0.57	25.0	2018
13	2366	868.86	868.55	-0.31	25.0	2018

APPENDIX B

Estimation of 2018 Flood Peak Discharge in Piper Creek

TECHNICAL MEMORANDUM

DATE 19 April 2021 **Reference No.** 21452576-TM-Rev0

TO Abdullah Mamun
Alberta Environment and Parks

CC Wolf Ploeger, Dejiang Long and Getu Biftu

FROM Gaven Tang **EMAIL gtang@golder.com**

RED DEER RIVER HAZARD STUDY – ESTIMATION OF 2018 FLOOD PEAK DISCHARGE IN PIPER CREEK

1.0 INTRODUCTION

On February 8, 2021, Alberta Environment and Parks (AEP) requested Golder Associates Ltd. (Golder) to confirm the 2018 flood peak discharge estimate for Piper Creek and the hydraulic model calibration for the Piper Creek study reach (Golder 2021b). This request is in response to a potential issue identified by the City of Red Deer that the estimated 2018 flood peak discharge of 25.0 m^3/s for Piper Creek (Golder 2021b) appeared questionable (City of Red Deer 2020). This question arose because Waskasoo Creek below Piper Creek had a measured discharge of 32.0 m^3/s, and Waskasoo Creek with a larger drainage area might have a discharge of 7.0 m^3/s (i.e., 32.0 m^3/s minus 25.0 m^3/s) that was much less than the estimated discharge for Piper Creek with a smaller drainage area.

This technical memorandum provides further explanation and justification to Golder's 2018 flood peak discharge estimate of 25.0 m^3/s for Piper Creek at its mouth. This memorandum should be read in conjunction with "Important Information and Limitations of this Report" which is included at the end of the report.

2.0 RELEVANT BACKGROUND INFORMATION

2.1 Hydrology Summary and Setting

The flood flow frequency estimates for the Red Deer River, Waskasoo Creek and Piper Creek are provided in the report by Golder (2021a). The naturalized flood flow frequency estimates at key locations in the study area are summarized in Table 1.

The effective drainage areas of Waskasoo Creek above Piper Creek and Piper Creek above Waskasoo Creek are 166 km^2 and 82 km^2, respectively. The effective drainage area of Piper Creek is approximately half of the effective drainage area of Waskasoo Creek.

The Piper Creek drainage area consists of a higher percentage of urbanized areas than the Waskasoo Creek drainage area that consists of a higher percentage of rural/agricultural areas (Figure 1). Urban areas typically result in peakier snowmelt flood events than the rural/agricultural areas.

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Table 1: Summary of Flood Flow Frequency Estimates

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Instantaneous Flood Peak Discharges for the Various Return Periods (m³/s)																							
				1000-year		750-year		500-year		350-year		200-year		100-year		75-year		50-year		35-year		20-year		10-year		5-year		2-year	
				Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower
RED DEER RIVER																											
Node 111	Red Deer River upstream of Red Deer	11,524	10,966	4,090	7,160 2,780	3,800	6,520 2,610	3,420	5,700 2,400	3,110	5,050 2,220	2,660	4,130 1,960	2,160	3,170 1,630	1,970	2,830 1,510	1,720	2,400 1,340	1,520	2,050 1,200	1,230	1,580 989	917	1,120 755	647	757 545	342	395 290
05CC002 / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11,609	11,052	4,240	7,140 2,810	3,940	6,520 2,650	3,550	5,710 2,440	3,230	5,090 2,260	2,760	4,190 1,990	2,250	3,230 1,670	2,050	2,880 1,560	1,790	2,440 1,390	1,580	2,090 1,250	1,280	1,620 1,030	959	1,160 788	677	790 572	359	416 308
Node 112	Red Deer River below Waskasoo Creek	12,096	11,302	4,250	7,170 2,810	3,950	6,560 2,660	3,560	5,760 2,440	3,230	5,110 2,260	2,760	4,200 2,000	2,240	3,240 1,680	2,050	2,880 1,560	1,790	2,440 1,390	1,580	2,090 1,250	1,280	1,620 1,030	953	1,150 785	672	782 568	356	413 305
Node 113	Red Deer River above Blindman River	12,096	11,302	4,250	7,170 2,810	3,950	6,560 2,660	3,560	5,760 2,440	3,230	5,110 2,260	2,760	4,200 2,000	2,240	3,240 1,680	2,050	2,880 1,560	1,790	2,440 1,390	1,580	2,090 1,250	1,280	1,620 1,030	953	1,150 785	672	782 568	356	413 305
Node 114	Red Deer River below Blindman River	14,010	13,336	4,640	7,790 2,890	4,310	7,100 2,740	3,880	6,190 2,540	3,520	5,490 2,360	3,000	4,500 2,080	2,430	3,450 1,770	2,220	3,070 1,640	1,940	2,590 1,480	1,710	2,230 1,340	1,380	1,720 1,120	1,030	1,220 855	722	834 613	382	450 323
Node 115	Red Deer River at Highway 11	14,128	13,454	4,600	7,980 2,880	4,270	7,280 2,720	3,830	6,350 2,510	3,480	5,590 2,320	2,960	4,560 2,060	2,400	3,480 1,740	2,180	3,100 1,620	1,900	2,620 1,460	1,680	2,220 1,320	1,350	1,700 1,100	1,000	1,200 839	706	815 601	374	441 316
RED DEER RIVER TRIBUTARIES																											
05CC011 / Node 307	Waskasoo Creek at Red Deer (WSC Station No. 05CC011)	487	250	107	264 39.9	99	231 38.5	88.7	192 36.7	80.2	161 35.1	67.7	122 31.9	53.9	87.3 27.9	48.7	75.3 26.4	41.8	61.7 24.2	36.3	51.5 21.7	28.3	38.9 17.6	19.8	27 12.4	12.7	18.3 7.91	5.16	8.05 3.14
Node 308	Waskasoo Creek above Piper Creek	326	166	72	175 26.5	67	154 25.6	60.2	128 24.4	54.6	107 23.3	46.3	81.1 21.2	37.1	58 18.5	33.5	50.1 17.5	28.9	41 16.1	25.1	34.2 14.4	19.6	25.9 11.7	13.7	17.9 8.24	8.71	12.2 5.26	3.47	5.35 2.09
Node 309	Waskasoo Creek below Highway 42	243	142	61.8	149 22.6	57.5	131 21.9	51.8	109 20.8	47	91.3 19.9	40	69.2 18.1	32.1	49.5 15.8	29	42.8 14.9	25	35 13.7	21.7	29.2 12.3	17	22.1 9.99	11.9	15.3 7.03	7.54	10.4 4.49	2.97	4.57 1.78
WASKASOO CREEK TRIBUTARIES																											
Node 310	Piper Creek above Waskasoo Creek	156	82	36.3	86.3 13	33.9	75.5 12.6	30.7	62.7 12	28	52.6 11.5	23.9	39.9 10.4	19.3	28.5 9.12	17.5	24.6 8.63	15.2	20.2 7.91	13.2	16.8 7.09	10.3	12.7 5.75	7.21	8.82 4.05	4.55	5.98 2.58	1.73	2.63 1.03
Node 311	Piper Creek below Highway 595	120	73	32.8	77.8 11.7	30.6	68 11.3	27.7	56.3 10.8	25.3	47.3 10.3	21.7	35.9 9.33	17.5	25.6 8.22	15.9	22.1 7.78	13.8	18.2 7.11	12	15.1 6.36	9.39	11.4 5.17	6.55	7.91 3.64	4.13	5.38 2.32	1.56	2.37 0.927
Node 312	Piper Creek below Township Road 374	81	59	26.4	62.3 9.37	24.7	54.2 9.03	22.4	45 8.65	20.5	37.8 8.22	17.6	28.7 7.46	14.3	20.5 6.56	13	17.7 6.23	11.2	14.5 5.7	9.79	12.1 5.09	7.68	9.13 4.14	5.36	6.32 2.91	3.37	4.3 1.85	1.26	1.9 0.742

Notes: (1) The flow change locations selected for the hydraulic modelling include: Red Deer River Nodes 202, 112 and 114; Red Deer Tributary Nodes 309, 308 and 307; and Waskasoo Creek Tributary Nodes 311 and 310.
(2) The flood peak discharges used in the hydraulic modelling are the values listed in the "Flood Est." column.
(3) The flood peak discharges used in the hydraulic modelling are for the naturalized flow conditions.

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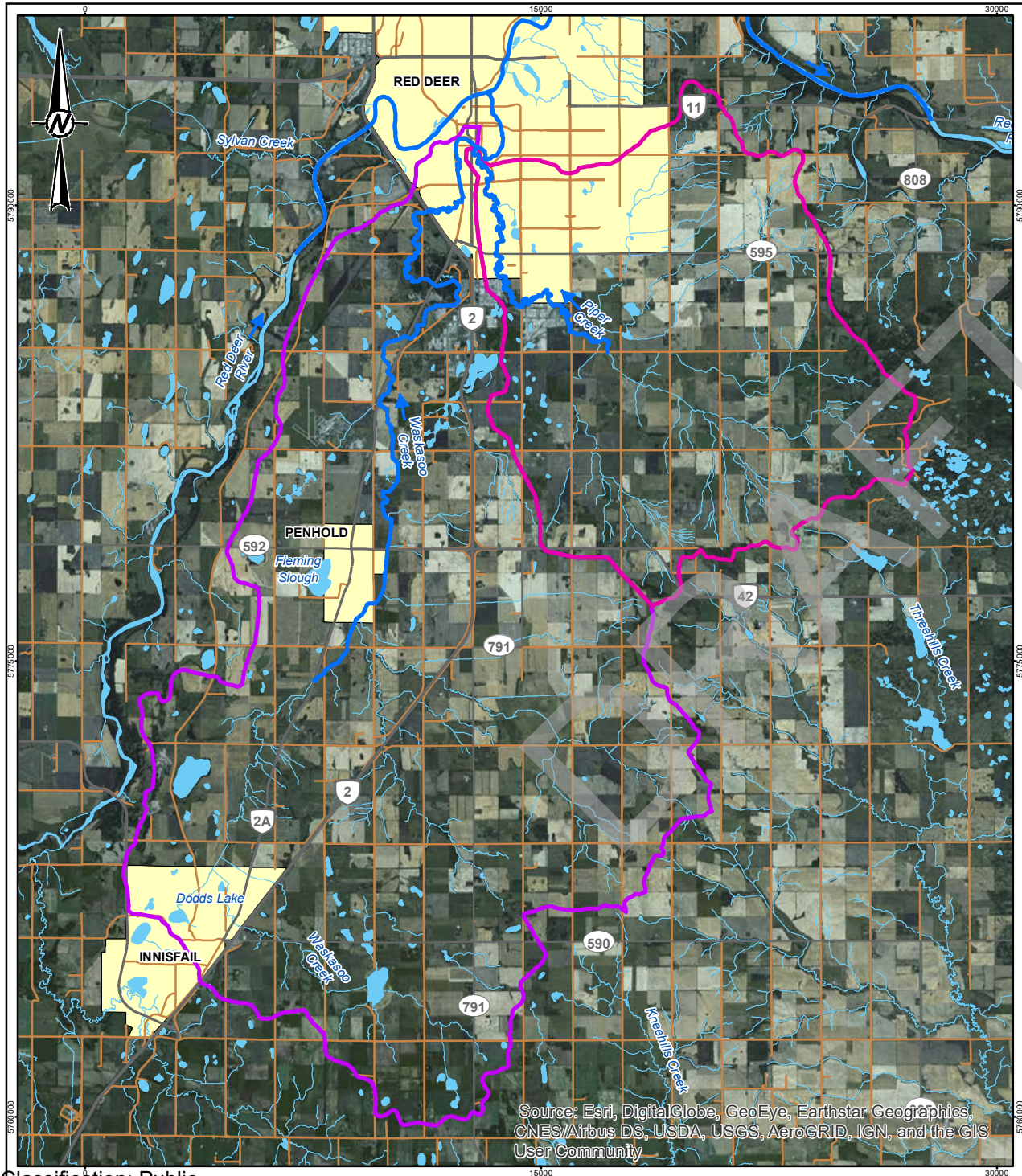

LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- FLOW DIRECTION
- WATERCOURSE
- WATERBODY
- POPULATED PLACE
- SURVEY REACH
- PIPER CREEK DRAINAGE AREA
- WASKASOO CREEK DRAINAGE AREA

0 5 10

1:200,000 KILOMETRES

REFERENCE(S)

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
WASKASOO CREEK AND PIPER CREEK DRAINAGE AREAS AT THE WASKASOO CREEK AND PIPER CREEK CONFLUENCE

CONSULTANT
GOLDER

YYYY-MM-DD	2021-04-15
DESIGNED	GT
PREPARED	PT
REVIEWED	GT
APPROVED	DL

PROJECT NO.	CONTROL	REV.	FIGURE
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2.2 Geomorphic Characteristics

The geomorphic characteristics of Waskasoo Creek and Piper Creek channels are relevant to the calibration and selection of the channel roughness coefficient values in the Red Deer River Hazard Study's hydraulic model. No direct discharge measurements were conducted for the available set of 2018 highwater marks on Piper Creek (AEP 2018). Whereas there are multiple years of highwater mark data and corresponding flood peak discharge measurements for Waskasoo Creek. The geomorphic characteristics of these two stream channels are similar. An overview of the geomorphic characteristics of Waskasoo Creek and Piper Creek is provided below, and a detailed description in the report by Golder (2021b).

Waskasoo Creek

Waskasoo Creek originates near Innisfail and flows mostly in a northeast direction until it joins with the Red Deer River. At the WSC Gauging Station No. 05CC011 (Waskasoo Creek at Red Deer), the total drainage area of Waskasoo Creek is 487 km^2. Within the study area, Waskasoo Creek flows from the Highway 2A bridge upstream of Penhold to its confluence with the Red Deer River.

Within the study reach of the Waskasoo Creek, the channel width ranges between 5.1 m and 27.8 m, and the bankfull depth which is approximated by the 2-year flood depth, ranges between 0.4 m and 3.3 m. The average channel slope of Waskasoo Creek ranges between 0.06% to 0.10% upstream of the Red Deer River valley, increases to 0.50% as it descends the Red Deer River valley, and decreases to 0.06% on the Red Deer River floodplain before its confluence with the Red Deer River.

The Waskasoo Creek floodplain is generally wide and flat within the study area. The floodplain areas are mostly farmlands along the upper reach and include urban development areas within the City of Red Deer. The floodplain width ranges from 5 times the channel width to 100 times the channel width, particularly for the large flood events. The floodplain is generally unconfined from the upstream boundary until Waskasoo Creek begins descending into the Red Deer River valley. In the area of the descent into the Red Deer River valley, the Waskasoo Creek floodplain is confined. The floodplain is relatively unconfined again after Waskasoo Creek reaches the bottom of the Red Deer River valley.

Piper Creek

Piper Creek originates at a location approximately 15 km southwest of the Waskasoo Creek and Red Deer River confluence. It flows in a northwest direction until it joins Waskasoo Creek in the City of Red Deer. At the Piper Creek and Waskasoo Creek confluence, the total drainage area of Piper Creek is 156 km^2. Within the study area, Piper Creek flows from Township Road 374 to its confluence with Waskasoo Creek.

Within the study reach of the Piper Creek, the channel width ranges between 5.9 m and 37.6 m, and the bankfull depth which is approximated by the 2-year flood depth, ranges between 0.3 m and 1.9 m. The average channel slope of Piper Creek is 0.10% upstream of the Red Deer River valley and increases to 0.45% before its confluence with Waskasoo Creek.

The Piper Creek floodplain is generally confined within the study area. The floodplain areas are mostly urban forested parklands with some farmlands near the upstream boundary. The floodplain width ranges from 2 times the channel width to 100 times the channel width, particularly for the large flood events. The floodplain is unconfined between the upstream boundary and the Range Road 272 Bridge. Downstream of this bridge, the floodplain is confined in a small valley until Piper Creek reaches its confluence with Waskasoo Creek.

Based on field observations, Piper Creek channel was estimated to have similar hydraulic and geomorphic characteristics as Waskasoo Creek.

3.0 ESTIMATION OF 2018 FLOOD PEAK DISCHARGE IN PIPER CREEK

3.1 Available Data

No hydrometric gauging exists on Piper Creek and no discharge measurement was taken along Piper Creek during the 2018 flood. However, there is a Water Survey of Canada (WSC) hydrometric gauge on Waskasoo Creek downstream of the Piper Creek mouth (WSC Station 05CC011 – Waskasoo Creek at Red Deer) that recorded a 2018 flood peak discharge of 32.0 m^3/s. Highwater marks were collected by AEP following the 2018 flood event (AEP 2018). Two methods were used for estimating the 2018 flood peak discharge along Piper Creek based on the available information and as described in the following sections.

3.2 Estimation based on the Highwater Marks

This method involved an assumption that the Piper Creek channel Manning's *n* value is the same as that of Waskasoo Creek because the two creeks have similar physical and geomorphic characteristics (described in Section 2.2). The calibrated channel Manning's *n* value for the high flow conditions in Waskasoo Creek is 0.033, which is within the typical range of roughness for similar creeks (Chow 1959).

The 2018 flood peak discharges in Piper Creek were estimated so that the highwater marks collected by AEP (2018) matched the simulated flood levels based on the selected Manning's n value of 0.033 for Piper Creek. Using this method, the flood peak discharges were estimated to be 22.8 m^3/s at Highway 595, and 25.0 m^3/s at the Waskasoo Creek Confluence. The ratio of the flood peak discharges along Piper Creek study reach was consistent with the hydrology assessment by Golder (2021a). Additional details and specific comparisons of simulated water levels against measured 2018 highwater marks are provided in Golder's report (2021b).

One of the effects of the Piper Creek effective drainage area being half of the Waskasoo Creek effective drainage area (described in Section 2.1) is that the flood peak of Piper Creek is expected to occur prior to that of Waskasoo Creek at the Red Deer gauge (WSC Station 05CC011). The flood peaks of both streams are not expected to be coincident at the gauge. When the Waskasoo Creek flood peak occurred at the gauge in 2018, the Piper Creek flood peak was expected to have already occurred. Therefore, the flood peak discharge of Waskasoo Creek above Piper Creek cannot be simply calculated by subtracting the estimated flood peak discharge of 25.0 m^3/s (Piper Creek above Waskasoo Creek) from the flood peak discharge of 32.0 m^3/s at the gauge.

Additionally, the Piper Creek drainage area consists of a higher percentage of urban areas than the Waskasoo Creek drainage area (described in Section 2.1). This factor is expected to have resulted in a peakier flood peak discharge per unit drainage area along Piper Creek than Waskasoo Creek. Therefore, it is expected that Piper Creek had a higher flood peak discharge per unit drainage area than Waskasoo Creek.

As discussed above, the differences in drainage area size and land use composition between Piper Creek and Waskasoo Creek explain why the Piper Creek 2018 flood peak discharge estimate of 25.0 m^3/s at the mouth is reasonable and justifiable.

3.3 Estimation Based on Effective Drainage Area Ratio Alone

An alternative method of estimating the 2018 flood peak discharge was only based on the ratio of effective drainage areas (Figure 1) between Waskasoo Creek and Piper Creek, without accounting for the other factors influencing the flood peak discharges as discussed in Section 3.2. Using this alternative method, the flood peak discharges were estimated to be 9.6 m^3/s at Highway 595, and 10.5 m^3/s at the Waskasoo Creek Confluence. The corresponding channel Manning's *n* value for the Piper Creek reach of the hydraulic model was 0.08 if these flood peak discharge estimates were used. Based on our professional judgement and published roughness values in Chow (1959), the Manning's *n* value of 0.08 is considered unreasonably high for the Piper Creek study reach.

Sensitivity analyses were conducted to evaluate the effects of changing model parameters on the simulated 100-year flood water levels (Golder 2021b). The model parameters included in the sensitivity analyses are the downstream boundary condition and Manning's *n* values for channels and floodplains. The results of the sensitivity analyses were used to quantify the level of uncertainty associated with the simulated 100-year flood levels. The sensitivity analysis results are summarized in Table 2.

The results of the sensitivity analyses show that flood level simulation along Piper Creek is much less sensitive than Waskasoo Creek and the Red Deer River to adjustments of the Channel Manning's *n* roughness value. Adjustments of +10% and -10% to the channel roughness resulted in a 4 cm and 5 cm average change to water levels, respectively.

The low sensitivity of the simulated Piper Creek flood levels to the channel roughness values and the unreasonably high roughness value that would need to be selected for Piper Creek (*n* = 0.08) show that the estimated 2018 Piper Creek flood peak discharges based on the effective drainage area ratio alone are unreasonably low.

Table 2: Summary of Sensitivity Analysis Results

Water Body	Parameter	Absolute Water Level Difference due to Various Percent Changes from the Base Values (m)							
		Channel Manning's *n*		Floodplain Manning's *n*		Channel and Floodplain Manning's *n*		Downstream Boundary Energy Slope	
		+10%	-10%	+10%	-10%	+10%	-10%	+20%	-20%
Red Deer River	Maximum	0.34	0.34	0.08	0.09	0.36	0.37	0.30	0.39
	Minimum	0.06	0.06	0.00	0.01	0.13	0.11	0.00	0.00
	Average	0.22	0.24	0.04	0.05	0.26	0.28	0.01	0.01
Waskasoo Creek	Maximum	0.39	0.38	0.05	0.05	0.40	0.39	0.00	0.00
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.07	0.07	0.02	0.02	0.09	0.08	0.00	0.00
Piper Creek	Maximum	0.09	0.10	0.02	0.02	0.09	0.10	0.00	0.00
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.04	0.05	0.01	0.01	0.05	0.05	0.00	0.00

4.0 CONCLUSIONS

The above comparison of the two methods used for estimating 2018 flood peak discharge in the Piper Creek show that the method based on the selected Manning's n value for Waskasoo Creek and available highwater marks collected by AEP (2018) is more reliable than the alternative method based on the effective drainage area ratio alone. Therefore, the estimated 25.0 m^3/s flood peak discharge for Piper Creek mouth is reasonable and justifiable. In addition, the hydraulic model developed for Piper Creek (Golder 2021b) remains valid and reliable.

5.0 CLOSURE

This technical memorandum was prepared and reviewed by the undersigned.

Golder Associates Ltd.

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Reviewed by:

ORIGINAL SIGNED BY

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GT/WP/DL/rd

6.0 REFERENCES

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7.0 IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

APPENDIX C

Flood Profiles

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 1	Red Deer River	Upper Reach	50825.77	861.59	863.93	864.50	864.84	865.17	866.17	866.51	866.91	867.21	868.03	868.54	868.82	869.23	869.64	
XS 2	Red Deer River	Upper Reach	50612.84	861.4	863.74	864.30	864.64	864.96	865.94	866.27	866.67	866.96	867.75	868.26	868.55	868.96	869.24	
XS 3	Red Deer River	Upper Reach	50269.23	861.46	863.41	863.95	864.29	864.61	865.60	865.94	866.34	866.64	867.45	867.95	868.23	868.65	868.94	
XS 4	Red Deer River	Upper Reach	49938.22	861.13	862.95	863.55	863.91	864.26	865.31	865.66	866.07	866.38	867.21	867.72	868.01	868.41	868.70	
XS 5	Red Deer River	Upper Reach	49655.82	860.12	862.62	863.23	863.60	863.94	864.98	865.33	865.75	866.05	866.89	867.36	867.63	868.02	868.28	
XS 6	Red Deer River	Upper Reach	49055.81	859.3	862.12	862.66	862.99	863.30	864.24	864.57	864.96	865.24	866.05	866.65	867.01	867.46	867.77	
XS 7	Red Deer River	Upper Reach	48749.21	859.59	861.84	862.37	862.71	863.02	864.00	864.34	864.75	865.05	865.88	866.45	866.78	867.20	867.48	
XS 8	Red Deer River	Upper Reach	48322.90	858.58	861.37	861.98	862.35	862.69	863.72	864.08	864.51	864.82	865.69	866.28	866.62	867.06	867.34	
XS 9	Red Deer River	Upper Reach	48001.02	858.96	861.06	861.68	862.05	862.38	863.37	863.71	864.12	864.43	865.31	865.91	866.26	866.69	866.97	
XS 10	Red Deer River	Upper Reach	47652.55	857.72	860.77	861.35	861.70	862.01	862.95	863.28	863.67	863.96	864.78	865.33	865.64	866.20	866.63	
XS 11	Red Deer River	Upper Reach	47349.09	858.16	860.50	861.06	861.39	861.70	862.63	862.96	863.36	863.66	864.50	865.07	865.38	865.80	866.16	
XS 12	Red Deer River	Upper Reach	46981.79	858.16	860.04	860.61	860.95	861.26	862.22	862.57	862.99	863.32	864.19	864.77	865.09	865.55	865.91	
XS 13	Red Deer River	Upper Reach	46521.84	856.39	859.58	860.11	860.45	860.77	861.80	862.18	862.63	862.98	863.94	864.56	864.93	865.44	865.84	
XS 14	Red Deer River	Upper Reach	46090.06	857.54	859.08	859.59	859.94	860.28	861.36	861.75	862.22	862.57	863.58	864.25	864.64	865.19	865.64	
XS 15	Red Deer River	Upper Reach	45605.37	856.65	858.33	858.98	859.38	859.76	860.94	861.36	861.88	862.27	863.35	864.05	864.46	865.02	865.48	
XS 16	Red Deer River	Upper Reach	45435.72	855.6	858.15	858.82	859.24	859.62	860.78	861.19	861.68	862.04	863.04	863.66	864.01	864.50	864.91	UPSTREAM OF CP RAIL BRIDGE
XS 17	Red Deer River	Upper Reach	45353.49	855.36	858.05	858.73	859.15	859.53	860.70	861.11	861.61	861.97	862.98	863.60	863.96	864.45	864.87	UPSTREAM OF RED DEER BYPASS (QE II HIGHWAY) NORTHBOUND AND SOUTHBOUND BRIDGES; DOWNSTREAM OF CP RAIL BRIDGE
XS 18	Red Deer River	Upper Reach	45245.89	854.23	857.94	858.62	859.03	859.40	860.54	860.94	861.42	861.77	862.74	863.33	863.66	864.12	864.48	DOWNSTREAM OF RED DEER BYPASS (QE II HIGHWAY) NORTHBOUND AND SOUTHBOUND BRIDGES
XS 19	Red Deer River	Upper Reach	45174.46	855.66	857.84	858.51	858.92	859.30	860.49	860.89	861.38	861.74	862.73	863.34	863.69	864.16	864.54	
XS 20	Red Deer River	Upper Reach	44936.59	854.85	857.53	858.24	858.67	859.07	860.31	860.73	861.24	861.62	862.65	863.27	863.63	864.12	864.51	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 21	Red Deer River	Upper Reach	44633.82	854.6	857.20	857.94	858.38	858.79	860.02	860.44	860.94	861.31	862.35	862.98	863.37	863.89	864.31	
XS 22	Red Deer River	Upper Reach	44163.05	852.77	856.72	857.39	857.79	858.15	859.23	859.59	860.02	860.34	861.20	861.59	861.78	862.21	862.47	
XS 23	Red Deer River	Upper Reach	43861.84	853.19	856.45	857.07	857.44	857.78	858.77	859.10	859.49	859.77	860.49	861.07	861.19	861.61	861.92	
XS 24	Red Deer River	Upper Reach	43519.64	852.99	856.10	856.68	857.04	857.36	858.34	858.67	859.06	859.34	860.06	860.53	860.99	861.35	861.62	
XS 25	Red Deer River	Upper Reach	43236.64	852.72	855.81	856.37	856.72	857.04	858.01	858.33	858.71	859.00	859.68	860.17	860.44	860.86	861.16	
XS 26	Red Deer River	Upper Reach	42903.22	853.55	855.40	855.98	856.33	856.66	857.64	857.96	858.35	858.64	859.44	859.96	860.25	860.70	861.02	
XS 27	Red Deer River	Upper Reach	42464.36	852.77	854.75	855.37	855.74	856.09	857.11	857.45	857.86	858.16	858.98	859.50	859.79	860.28	860.62	UPSTREAM OF HERITAGE RANCH PEDESTRIAN BRIDGE
XS 28	Red Deer River	Upper Reach	42446.18	852.5	854.71	855.32	855.69	856.03	857.05	857.38	857.78	858.08	858.86	859.37	859.65	860.15	860.49	DOWNSTREAM OF HERITAGE RANCH PEDESTRIAN BRIDGE
XS 29	Red Deer River	Upper Reach	42160.41	851.77	854.19	854.76	855.12	855.46	856.48	856.82	857.22	857.50	858.29	858.88	859.21	859.69	860.11	
XS 30	Red Deer River	Upper Reach	41789.26	851.18	853.56	854.18	854.56	854.91	855.98	856.33	856.73	857.03	857.85	858.46	858.77	859.27	859.67	
XS 31	Red Deer River	Upper Reach	41460.10	850.07	853.12	853.73	854.08	854.41	855.44	855.81	856.24	856.55	857.39	857.99	858.30	858.76	859.12	
XS 32	Red Deer River	Upper Reach	41212.28	849.76	852.88	853.48	853.83	854.16	855.20	855.58	856.01	856.33	857.18	857.82	858.13	858.62	858.94	
XS 33	Red Deer River	Upper Reach	40939.34	850.43	852.43	853.02	853.41	853.78	854.91	855.30	855.75	856.08	856.94	857.58	857.88	858.39	858.79	
XS 34	Red Deer River	Upper Reach	40682.44	849.51	852.13	852.75	853.14	853.51	854.66	855.06	855.51	855.84	856.69	857.34	857.65	858.20	858.61	
XS 35	Red Deer River	Upper Reach	40402.18	848.97	851.92	852.49	852.86	853.21	854.28	854.64	855.09	855.43	856.43	857.16	857.49	858.05	858.46	
XS 36	Red Deer River	Upper Reach	40214.98	849.84	851.73	852.30	852.68	853.03	854.13	854.51	854.96	855.30	856.24	856.89	857.17	857.67	858.05	UPSTREAM OF TAYLOR DRIVE NORTHBOUND AND SOUTHBOUND BRIDGES
XS 37	Red Deer River	Upper Reach	40125.10	849.52	851.58	852.16	852.54	852.90	854.01	854.39	854.84	855.18	856.12	856.77	857.04	857.54	857.92	DOWNSTREAM OF TAYLOR DRIVE NORTHBOUND AND SOUTHBOUND BRIDGES
XS 38	Red Deer River	Upper Reach	39934.84	849.13	851.26	851.91	852.31	852.69	853.84	854.24	854.72	855.08	856.06	856.74	857.03	857.55	857.94	
XS 39	Red Deer River	Upper Reach	39644.34	847.93	850.97	851.63	852.03	852.40	853.52	853.90	854.34	854.67	855.57	856.19	856.41	856.91	857.37	
XS 40	Red Deer River	Upper Reach	39413.17	848.07	850.78	851.43	851.83	852.20	853.31	853.69	854.13	854.46	855.38	856.02	856.23	856.73	857.18	UPSTREAM OF CP RAIL (58 STREET) PEDESTRIAN BRIDGE
XS 41	Red Deer River	Upper Reach	39380.99	847.91	850.73	851.37	851.77	852.13	853.21	853.57	853.99	854.30	855.12	855.68	855.81	856.28	856.71	DOWNSTREAM OF CP RAIL (58 STREET) PEDESTRIAN BRIDGE

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 42	Red Deer River	Upper Reach	39316.98	848.28	850.68	851.32	851.71	852.07	853.13	853.49	853.90	854.21	855.03	855.60	855.73	856.21	856.65	
XS 43	Red Deer River	Upper Reach	39179.93	847.38	850.59	851.22	851.61	851.96	853.03	853.39	853.80	854.10	854.93	855.49	855.60	856.11	856.53	UPSTREAM OF 50 AVENUE (GAETZ AVENUE) BRIDGE
XS 44	Red Deer River	Upper Reach	39145.07	847.65	850.55	851.18	851.56	851.91	852.96	853.32	853.73	854.03	854.84	855.40	855.49	855.87	856.16	DOWNSTREAM OF 50 AVENUE (GAETZ AVENUE) BRIDGE
XS 45	Red Deer River	Upper Reach	39053.47	847.74	850.49	851.10	851.48	851.82	852.88	853.24	853.66	853.97	854.81	855.38	855.47	855.89	856.20	
XS 46	Red Deer River	Upper Reach	39010.69	847.7	850.43	851.04	851.42	851.77	852.81	853.16	853.55	853.85	854.62	855.14	855.18	855.48	855.68	UPSTREAM OF 49 AVENUE BRIDGE
XS 47	Red Deer River	Upper Reach	38975.33	847.71	850.35	850.97	851.35	851.69	852.74	853.08	853.47	853.76	854.53	855.05	855.05	855.37	855.62	DOWNSTREAM OF 49 AVENUE BRIDGE
XS 48	Red Deer River	Upper Reach	38769.98	847.3	850.12	850.76	851.14	851.48	852.54	852.89	853.30	853.60	854.41	854.95	854.95	855.27	855.53	
XS 49	Red Deer River	Lower Reach	38445.43	846.67	849.89	850.49	850.85	851.16	852.09	852.38	852.70	852.95	853.52	853.87	854.18	854.47	854.70	
XS 50	Red Deer River	Lower Reach	38032.04	846.3	849.55	850.07	850.38	850.66	851.52	851.79	852.10	852.31	852.89	853.25	853.46	853.75	854.00	
XS 51	Red Deer River	Lower Reach	37712.52	846.94	849.08	849.65	849.97	850.26	851.10	851.37	851.67	851.89	852.50	852.95	853.23	853.62	853.92	
XS 52	Red Deer River	Lower Reach	37426.76	846.19	848.62	849.20	849.53	849.82	850.66	850.93	851.27	851.51	852.21	852.71	853.01	853.42	853.75	
XS 53	Red Deer River	Lower Reach	37322.76	845.06	848.56	849.14	849.46	849.74	850.53	850.77	851.05	851.23	851.75	852.12	852.34	852.66	852.92	UPSTREAM OF 67 STREET (DAVID THOMPSON HIGHWAY) BRIDGE
XS 54	Red Deer River	Lower Reach	37225.10	845.65	848.47	849.04	849.34	849.61	850.33	850.54	850.77	850.92	851.32	851.57	851.71	851.91	852.06	DOWNSTREAM OF 67 STREET (DAVID THOMPSON HIGHWAY) BRIDGE
XS 55	Red Deer River	Lower Reach	36831.75	845.61	847.95	848.57	848.93	849.21	849.95	850.15	850.38	850.53	850.95	851.23	851.39	851.64	851.83	
XS 56	Red Deer River	Lower Reach	36383.15	845.04	847.46	848.09	848.41	848.65	849.26	849.44	849.64	849.78	850.23	850.56	850.77	851.08	851.29	
XS 57	Red Deer River	Lower Reach	35880.01	844.08	847.03	847.65	847.98	848.23	848.92	849.12	849.35	849.52	850.01	850.37	850.59	850.94	851.16	
XS 58	Red Deer River	Lower Reach	35601.52	843.46	846.74	847.34	847.67	847.90	848.56	848.77	849.00	849.18	849.70	850.09	850.33	850.71	850.94	
XS 59	Red Deer River	Lower Reach	35330.31	844.33	846.42	847.07	847.42	847.65	848.23	848.43	848.67	848.87	849.46	849.90	850.16	850.57	850.81	
XS 60	Red Deer River	Lower Reach	34972.09	841.95	846.06	846.65	846.93	847.15	847.85	848.09	848.39	848.63	849.29	849.76	850.05	850.48	850.74	
XS 61	Red Deer River	Lower Reach	34626.84	843.55	845.65	846.21	846.55	846.85	847.68	847.94	848.25	848.49	849.20	849.69	849.98	850.42	850.68	
XS 62	Red Deer River	Lower Reach	34291.70	842.1	845.21	845.77	846.10	846.39	847.31	847.64	848.01	848.29	849.05	849.57	849.88	850.34	850.61	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 63	Red Deer River	Lower Reach	33836.30	842.38	844.50	845.18	845.60	845.97	847.09	847.45	847.85	848.15	848.95	849.49	849.80	850.27	850.55	
XS 64	Red Deer River	Lower Reach	33469.21	840.93	844.00	844.76	845.16	845.53	846.66	847.01	847.43	847.74	848.56	849.13	849.47	849.98	850.27	
XS 65	Red Deer River	Lower Reach	33149.52	840.48	843.71	844.43	844.81	845.14	846.15	846.44	846.77	846.99	847.61	848.03	848.28	848.77	848.92	
XS 66	Red Deer River	Lower Reach	32699.42	840.55	843.18	843.88	844.29	844.66	845.73	846.02	846.36	846.59	847.22	847.64	847.91	848.11	848.36	RED DEER WASTEWATER TREAMENT PLANT DIKE
XS 67	Red Deer River	Lower Reach	32432.03	839.11	842.87	843.53	843.91	844.26	845.31	845.56	845.85	846.04	846.54	846.86	847.09	847.26	847.35	UPSTREAM OF RIVERBEND (DISCOVERY CANYON) PEDESTRIAN BRIDGE; RED DEER WASTEWATER TREAMENT PLANT DIKE
XS 68	Red Deer River	Lower Reach	32414.68	839.82	842.82	843.47	843.86	844.21	845.28	845.53	845.82	846.01	846.52	846.84	847.02	847.26	847.44	DOWNSTREAM OF RIVERBEND (DISCOVERY CANYON) PEDESTRIAN BRIDGE; RED DEER WASTEWATER TREAMENT PLANT DIKE
XS 69	Red Deer River	Lower Reach	32149.29	840.13	842.49	843.14	843.54	843.91	845.03	845.27	845.54	845.72	846.21	846.50	846.65	846.86	847.01	RED DEER WASTEWATER TREAMENT PLANT DIKE
XS 70	Red Deer River	Lower Reach	31855.04	839.65	842.17	842.85	843.26	843.63	844.72	845.00	845.32	845.52	846.07	846.39	846.56	846.79	846.95	RED DEER WASTEWATER TREAMENT PLANT DIKE
XS 71	Red Deer River	Lower Reach	31477.41	838.57	841.62	842.31	842.73	843.10	844.27	844.58	844.93	845.19	845.83	846.16	846.35	846.61	846.78	
XS 72	Red Deer River	Lower Reach	31193.10	837.67	841.23	841.95	842.37	842.76	843.93	844.29	844.70	844.99	845.62	845.97	846.16	846.44	846.62	
XS 73	Red Deer River	Lower Reach	30821.19	838.11	840.85	841.58	842.01	842.40	843.56	843.89	844.26	844.52	845.24	845.60	845.83	846.16	846.34	
XS 74	Red Deer River	Lower Reach	30352.26	837.84	840.46	841.16	841.57	841.95	843.11	843.50	843.93	844.24	845.04	845.42	845.66	846.01	846.18	
XS 75	Red Deer River	Lower Reach	29823.91	836.45	839.84	840.47	840.85	841.20	842.27	842.62	843.06	843.36	844.15	844.65	845.01	845.48	845.72	
XS 76	Red Deer River	Lower Reach	29182.45	836.47	839.03	839.70	840.10	840.44	841.50	841.87	842.34	842.64	843.39	843.80	844.08	844.41	844.58	
XS 77	Red Deer River	Lower Reach	28618.83	835.45	838.21	838.91	839.33	839.71	840.93	841.33	841.79	842.08	842.90	843.41	843.68	844.16	844.37	
XS 78	Red Deer River	Lower Reach	28183.51	834.18	837.75	838.42	838.82	839.19	840.31	840.69	841.10	841.37	842.24	842.84	843.14	843.52	843.74	
XS 79	Red Deer River	Lower Reach	27721.33	834.09	837.22	837.85	838.23	838.57	839.64	840.00	840.41	840.71	841.64	842.13	842.51	842.90	843.21	
XS 80	Red Deer River	Lower Reach	27308.17	834.01	836.68	837.27	837.64	837.98	839.02	839.37	839.77	840.06	840.89	841.43	841.74	842.18	842.53	
XS 81	Red Deer River	Lower Reach	26905.58	833.55	836.26	836.82	837.16	837.49	838.51	838.86	839.27	839.56	840.41	840.96	841.29	841.72	842.04	
XS 82	Red Deer River	Lower Reach	26510.09	834.06	835.74	836.30	836.64	836.97	838.01	838.37	838.78	839.08	839.93	840.45	840.75	841.13	841.41	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 83	Red Deer River	Lower Reach	26125.69	832.65	835.03	835.68	836.08	836.47	837.66	838.06	838.51	838.83	839.75	840.32	840.63	841.05	841.35	
XS 84	Red Deer River	Lower Reach	25724.84	831.44	834.61	835.21	835.56	835.90	836.95	837.30	837.70	837.99	838.78	839.31	839.60	839.99	840.28	
XS 85	Red Deer River	Lower Reach	25331.72	831.82	834.29	834.82	835.14	835.46	836.48	836.82	837.22	837.51	838.31	838.83	839.12	839.51	839.78	
XS 86	Red Deer River	Lower Reach	24923.78	831.99	833.65	834.22	834.58	834.92	836.01	836.37	836.78	837.07	837.88	838.40	838.69	839.08	839.35	
XS 87	Red Deer River	Lower Reach	24538.72	830.53	832.95	833.59	833.97	834.33	835.43	835.79	836.20	836.49	837.32	837.87	838.17	838.57	838.85	
XS 88	Red Deer River	Lower Reach	24141.29	829.58	832.44	833.07	833.46	833.82	834.93	835.30	835.71	836.00	836.83	837.37	837.67	838.06	838.31	
XS 89	Red Deer River	Lower Reach	23740.57	829.54	831.96	832.55	832.91	833.25	834.34	834.70	835.12	835.41	836.24	836.76	837.04	837.41	837.67	
XS 90	Red Deer River	Lower Reach	23340.39	828.97	831.52	832.07	832.42	832.75	833.85	834.23	834.64	834.92	835.74	836.24	836.51	836.89	837.18	
XS 91	Red Deer River	Lower Reach	22938.25	828.89	830.82	831.45	831.84	832.21	833.41	833.81	834.24	834.53	835.38	835.89	836.19	836.61	836.92	
XS 92	Red Deer River	Lower Reach	22538.81	827.22	830.08	830.76	831.17	831.54	832.71	833.05	833.42	833.65	834.32	834.77	835.05	835.46	835.75	
XS 93	Red Deer River	Lower Reach	22137.36	825.73	829.37	830.00	830.38	830.72	831.77	832.11	832.53	832.84	833.74	834.41	834.78	835.28	835.62	
XS 94	Red Deer River	Lower Reach	21732.48	825.69	828.76	829.37	829.74	830.08	831.18	831.55	831.99	832.30	833.18	833.78	834.14	834.65	834.97	
XS 95	Red Deer River	Lower Reach	21331.67	825.22	828.21	828.79	829.16	829.51	830.66	831.05	831.50	831.82	832.69	833.28	833.61	834.04	834.35	
XS 96	Red Deer River	Lower Reach	20931.63	825.79	827.65	828.26	828.65	829.01	830.21	830.61	831.06	831.38	832.25	832.85	833.18	833.63	833.94	
XS 97	Red Deer River	Lower Reach	20531.20	824.79	827.17	827.80	828.19	828.55	829.82	830.22	830.68	831.01	831.88	832.49	832.82	833.29	833.60	
XS 98	Red Deer River	Lower Reach	20130.07	824.34	826.79	827.39	827.77	828.12	829.43	829.83	830.29	830.63	831.50	832.12	832.46	832.92	833.21	
XS 99	Red Deer River	Lower Reach	19733.30	824.56	826.26	826.89	827.30	827.68	829.09	829.51	829.96	830.30	831.17	831.79	832.13	832.60	832.88	
XS 100	Red Deer River	Lower Reach	19336.36	823.48	825.61	826.35	826.79	827.19	828.72	829.14	829.59	829.93	830.84	831.49	831.84	832.32	832.58	
XS 101	Red Deer River	Lower Reach	18933.84	822.56	825.17	825.96	826.41	826.81	828.44	828.87	829.31	829.65	830.54	831.16	831.50	831.97	832.22	
XS 102	Red Deer River	Lower Reach	18534.81	820.76	824.67	825.42	825.85	826.23	827.75	828.15	828.58	828.91	829.80	830.46	830.81	831.29	831.55	
XS 103	Red Deer River	Lower Reach	18130.02	820.38	823.98	824.71	825.12	825.48	826.80	827.13	827.48	827.72	828.45	828.96	829.27	829.76	830.03	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 104	Red Deer River	Lower Reach	17731.79	820.41	823.33	824.03	824.42	824.76	826.14	826.50	826.87	827.14	827.93	828.49	828.83	829.30	829.58	
XS 105	Red Deer River	Lower Reach	17337.65	819.61	822.94	823.57	823.94	824.26	825.56	825.91	826.27	826.54	827.33	827.91	828.26	828.74	829.02	
XS 106	Red Deer River	Lower Reach	16932.79	819.61	822.58	823.16	823.49	823.79	825.04	825.38	825.75	826.02	826.84	827.43	827.78	828.26	828.53	
XS 107	Red Deer River	Lower Reach	16531.58	819.41	822.14	822.63	822.93	823.20	824.44	824.79	825.16	825.43	826.24	826.81	827.14	827.61	827.88	
XS 108	Red Deer River	Lower Reach	16130.57	819.4	821.18	821.81	822.15	822.46	823.81	824.17	824.55	824.83	825.68	826.29	826.63	827.13	827.40	
XS 109	Red Deer River	Lower Reach	15705.00	817.34	820.27	820.97	821.33	821.66	823.04	823.39	823.76	824.03	824.80	825.38	825.72	826.21	826.50	
XS 110	Red Deer River	Lower Reach	15317.64	817.5	819.77	820.43	820.80	821.13	822.54	822.90	823.29	823.57	824.41	825.06	825.41	825.94	826.23	
XS 111	Red Deer River	Lower Reach	14918.03	816.7	819.28	819.92	820.29	820.62	821.99	822.35	822.73	823.01	823.81	824.38	824.74	825.28	825.61	
XS 112	Red Deer River	Lower Reach	14458.86	815.7	818.78	819.34	819.67	819.96	821.19	821.52	821.88	822.14	822.91	823.48	823.83	824.35	824.66	
XS 113	Red Deer River	Lower Reach	14026.46	815.56	818.07	818.67	819.01	819.33	820.68	821.04	821.42	821.70	822.54	823.15	823.52	824.07	824.39	
XS 114	Red Deer River	Lower Reach	13799.14	814.87	817.76	818.35	818.71	819.03	820.41	820.78	821.17	821.46	822.32	822.94	823.32	823.88	824.20	
XS 115	Red Deer River	Lower Reach	13607.58	815.36	817.51	818.11	818.47	818.80	820.19	820.56	820.95	821.25	822.13	822.76	823.14	823.71	824.04	
XS 116	Red Deer River	Lower Reach	13387.72	814.63	817.22	817.79	818.14	818.47	819.89	820.28	820.70	821.01	821.93	822.58	822.98	823.54	823.88	
XS 117	Red Deer River	Lower Reach	13167.22	814.8	816.84	817.48	817.88	818.23	819.73	820.14	820.57	820.89	821.83	822.49	822.88	823.46	823.80	
XS 118	Red Deer River	Lower Reach	12985.87	814.05	816.50	817.23	817.65	818.01	819.51	819.91	820.33	820.64	821.55	822.20	822.60	823.18	823.53	
XS 119	Red Deer River	Lower Reach	12767.85	812.72	816.15	816.87	817.26	817.60	819.04	819.42	819.83	820.13	821.01	821.61	821.99	822.54	822.86	
XS 120	Red Deer River	Lower Reach	12514.23	812.95	815.79	816.49	816.89	817.24	818.73	819.12	819.54	819.85	820.74	821.35	821.73	822.28	822.61	
XS 121	Red Deer River	Lower Reach	12095.69	811.72	815.44	816.09	816.48	816.82	818.23	818.59	818.99	819.27	820.10	820.71	821.08	821.64	821.98	
XS 122	Red Deer River	Lower Reach	11694.75	811.78	815.03	815.63	815.99	816.33	817.71	818.08	818.48	818.78	819.64	820.27	820.65	821.23	821.57	
XS 123	Red Deer River	Lower Reach	11295.14	811.75	814.43	815.08	815.46	815.83	817.31	817.70	818.14	818.45	819.39	820.07	820.48	821.10	821.47	
XS 124	Red Deer River	Lower Reach	10896.45	811.25	813.86	814.55	814.97	815.36	816.85	817.23	817.66	817.96	818.86	819.52	819.91	820.50	820.85	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 125	Red Deer River	Lower Reach	10494.05	810.3	813.35	814.08	814.51	814.90	816.27	816.61	816.99	817.28	818.14	818.77	819.15	819.73	820.07	
XS 126	Red Deer River	Lower Reach	10091.86	810.04	812.82	813.61	814.08	814.50	815.94	816.29	816.69	817.00	817.90	818.56	818.96	819.56	819.91	
XS 127	Red Deer River	Lower Reach	9660.78	808.08	812.38	813.08	813.48	813.84	815.42	815.87	816.35	816.69	817.69	818.39	818.82	819.45	819.83	
XS 128	Red Deer River	Lower Reach	9252.76	808.74	812.12	812.78	813.17	813.52	815.03	815.44	815.86	816.17	817.07	817.72	818.11	818.69	819.02	
XS 129	Red Deer River	Lower Reach	8853.51	809.57	811.74	812.39	812.79	813.14	814.66	815.07	815.50	815.80	816.71	817.36	817.74	818.32	818.67	
XS 130	Red Deer River	Lower Reach	8456.51	808.41	811.33	811.96	812.35	812.69	814.16	814.55	814.96	815.26	816.14	816.78	817.16	817.71	818.04	
XS 131	Red Deer River	Lower Reach	8050.92	808.88	810.88	811.53	811.92	812.27	813.76	814.15	814.56	814.86	815.74	816.37	816.74	817.31	817.65	
XS 132	Red Deer River	Lower Reach	7651.76	807.99	810.33	811.02	811.42	811.77	813.25	813.64	814.06	814.36	815.26	815.90	816.29	816.86	817.19	
XS 133	Red Deer River	Lower Reach	7232.59	806.83	809.85	810.57	810.97	811.33	812.80	813.19	813.60	813.90	814.76	815.40	815.78	816.34	816.67	
XS 134	Red Deer River	Lower Reach	6844.65	806.35	809.51	810.21	810.61	810.96	812.37	812.74	813.14	813.42	814.25	814.85	815.21	815.74	816.06	
XS 135	Red Deer River	Lower Reach	6441.97	806.13	809.14	809.81	810.20	810.54	811.96	812.34	812.74	813.03	813.87	814.48	814.86	815.41	815.74	
XS 136	Red Deer River	Lower Reach	6039.55	805.61	808.87	809.52	809.89	810.22	811.61	811.99	812.38	812.66	813.51	814.13	814.51	815.08	815.41	
XS 137	Red Deer River	Lower Reach	5989.13	805.8	808.83	809.47	809.84	810.17	811.55	811.93	812.32	812.61	813.45	814.07	814.45	815.01	815.34	
XS 138	Red Deer River	Lower Reach	5640.52	805.62	808.52	809.13	809.49	809.82	811.19	811.57	811.97	812.26	813.11	813.73	814.10	814.66	814.99	
XS 139	Red Deer River	Lower Reach	5241.27	806.05	808.08	808.71	809.07	809.40	810.78	811.16	811.56	811.85	812.68	813.29	813.66	814.21	814.53	
XS 140	Red Deer River	Lower Reach	4844.88	805.15	807.59	808.23	808.60	808.92	810.32	810.71	811.11	811.40	812.27	812.89	813.27	813.83	814.16	
XS 141	Red Deer River	Lower Reach	4471.10	804.16	807.11	807.77	808.16	808.49	809.93	810.33	810.74	811.04	811.90	812.53	812.91	813.48	813.81	
XS 142	Red Deer River	Lower Reach	4034.64	803.82	806.56	807.24	807.64	807.99	809.51	809.91	810.34	810.66	811.57	812.23	812.63	813.22	813.57	
XS 143	Red Deer River	Lower Reach	3638.59	803.39	806.11	806.81	807.21	807.58	809.11	809.51	809.93	810.24	811.13	811.77	812.15	812.73	813.06	
XS 144	Red Deer River	Lower Reach	3239.65	802.76	805.73	806.41	806.80	807.16	808.60	808.98	809.36	809.64	810.46	811.04	811.38	811.90	812.21	
XS 145	Red Deer River	Lower Reach	2838.25	802.8	805.36	806.04	806.43	806.78	808.21	808.58	808.97	809.25	810.07	810.66	811.03	811.57	811.90	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 146	Red Deer River	Lower Reach	2387.76	801.86	804.82	805.48	805.86	806.19	807.59	807.96	808.35	808.63	809.47	810.08	810.45	811.02	811.35	
XS 147	Red Deer River	Lower Reach	2040.44	801.9	804.43	805.09	805.47	805.81	807.23	807.61	808.01	808.31	809.19	809.83	810.21	810.79	811.13	
XS 148	Red Deer River	Lower Reach	1635.67	801.6	804.01	804.67	805.04	805.38	806.80	807.19	807.61	807.92	808.81	809.46	809.85	810.43	810.78	
XS 149	Red Deer River	Lower Reach	1232.97	800.35	803.61	804.22	804.57	804.88	806.24	806.62	807.02	807.31	808.16	808.77	809.13	809.69	810.01	
XS 150	Red Deer River	Lower Reach	824.42	800.63	803.24	803.82	804.15	804.45	805.80	806.18	806.59	806.88	807.73	808.34	808.72	809.30	809.64	
XS 151	Red Deer River	Lower Reach	429.08	799.95	802.64	803.27	803.62	803.95	805.36	805.76	806.18	806.49	807.37	808.01	808.40	809.01	809.37	
XS 152	Red Deer River	Lower Reach	182.53	799.48	802.29	802.92	803.28	803.61	805.03	805.43	805.85	806.16	807.06	807.72	808.13	808.76	809.12	
XS 153	Red Deer River	Lower Reach	58.17	800	802.17	802.79	803.15	803.48	804.89	805.28	805.69	806.00	806.87	807.50	807.88	808.47	808.81	
XS 154	Piper Creek	Piper Creek	19702.34	891.94	892.72	892.86	892.93	892.99	893.03	893.05	893.08	893.09	893.14	893.18	893.22	893.27	893.33	
XS 155	Piper Creek	Piper Creek	19555.82	892.09	892.70	892.80	892.84	892.88	892.91	892.93	892.95	892.98	893.06	893.13	893.18	893.24	893.31	
XS 156	Piper Creek	Piper Creek	19410.43	892.04	892.65	892.72	892.76	892.80	892.83	892.86	892.91	892.94	893.04	893.12	893.17	893.23	893.31	
XS 157	Piper Creek	Piper Creek	19205.33	892.04	892.58	892.64	892.68	892.72	892.78	892.83	892.88	892.93	893.03	893.11	893.16	893.23	893.30	
XS 158	Piper Creek	Piper Creek	19041.00	891.98	892.50	892.58	892.62	892.69	892.76	892.81	892.87	892.92	893.02	893.11	893.16	893.23	893.30	
XS 159	Piper Creek	Piper Creek	18773.24	891.85	892.45	892.52	892.57	892.66	892.75	892.81	892.87	892.91	893.02	893.10	893.16	893.22	893.30	
XS 160	Piper Creek	Piper Creek	18620.05	891.71	892.44	892.50	892.54	892.65	892.75	892.80	892.87	892.91	893.02	893.10	893.15	893.22	893.30	UPSTREAM OF PRIVATE CULVERT
XS 161	Piper Creek	Piper Creek	18606.56	891.74	892.22	892.41	892.52	892.65	892.74	892.80	892.86	892.91	893.02	893.10	893.15	893.22	893.30	DOWNSTREAM OF PRIVATE CULVERT
XS 162	Piper Creek	Piper Creek	18361.84	891.61	892.11	892.33	892.49	892.63	892.74	892.80	892.86	892.91	893.02	893.10	893.15	893.22	893.30	
XS 163	Piper Creek	Piper Creek	18208.29	891.58	892.03	892.28	892.45	892.61	892.72	892.78	892.85	892.90	893.01	893.10	893.15	893.22	893.30	
XS 164	Piper Creek	Piper Creek	18069.89	891.45	891.93	892.22	892.42	892.58	892.69	892.75	892.82	892.87	892.99	893.08	893.14	893.21	893.29	
XS 165	Piper Creek	Piper Creek	17842.90	891.21	891.85	892.14	892.34	892.49	892.61	892.67	892.75	892.80	892.93	893.03	893.10	893.18	893.27	
XS 166	Piper Creek	Piper Creek	17816.40	891.37	891.83	892.11	892.31	892.47	892.59	892.65	892.72	892.78	892.90	893.00	893.07	893.16	893.25	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 167	Piper Creek	Piper Creek	17627.43	891.19	891.75	892.03	892.22	892.39	892.51	892.58	892.65	892.71	892.84	892.94	893.00	893.10	893.20	
XS 168	Piper Creek	Piper Creek	17535.17	891.05	891.71	891.98	892.17	892.33	892.45	892.50	892.57	892.62	892.73	892.82	892.88	892.96	893.07	UPSTREAM OF RANGE ROAD 272 BRIDGE
XS 169	Piper Creek	Piper Creek	17495.33	891.18	891.66	891.94	892.13	892.28	892.38	892.44	892.50	892.54	892.64	892.71	892.76	892.80	892.84	DOWNSTREAM OF RANGE ROAD 272 BRIDGE
XS 170	Piper Creek	Piper Creek	17331.70	890.96	891.50	891.83	892.03	892.20	892.31	892.37	892.44	892.48	892.59	892.67	892.72	892.77	892.80	
XS 171	Piper Creek	Piper Creek	17166.06	890.55	891.26	891.66	891.86	892.05	892.17	892.24	892.31	892.36	892.47	892.56	892.60	892.65	892.69	
XS 172	Piper Creek	Piper Creek	16989.32	890.3	891.03	891.50	891.74	891.94	892.06	892.13	892.20	892.25	892.35	892.43	892.47	892.52	892.55	
XS 173	Piper Creek	Piper Creek	16831.83	889.76	890.97	891.40	891.65	891.84	891.95	892.02	892.08	892.13	892.22	892.30	892.34	892.37	892.40	
XS 174	Piper Creek	Piper Creek	16648.46	889.89	890.92	891.30	891.52	891.69	891.78	891.84	891.90	891.94	892.03	892.10	892.13	892.17	892.19	
XS 175	Piper Creek	Piper Creek	16435.54	890.04	890.84	891.18	891.39	891.54	891.62	891.67	891.73	891.76	891.86	891.94	891.97	892.02	892.05	
XS 176	Piper Creek	Piper Creek	16354.76	890.09	890.65	891.06	891.27	891.43	891.54	891.61	891.68	891.72	891.83	891.91	891.95	892.00	892.03	
XS 177	Piper Creek	Piper Creek	16159.29	889.47	890.35	890.80	891.02	891.20	891.33	891.41	891.49	891.55	891.67	891.78	891.83	891.89	891.92	
XS 178	Piper Creek	Piper Creek	15939.21	889.33	890.16	890.55	890.74	890.91	891.05	891.13	891.21	891.27	891.41	891.52	891.58	891.64	891.69	
XS 179	Piper Creek	Piper Creek	15770.67	889.13	889.92	890.35	890.57	890.77	890.91	891.00	891.09	891.15	891.30	891.41	891.47	891.54	891.58	
XS 180	Piper Creek	Piper Creek	15577.42	888.94	889.76	890.21	890.42	890.61	890.74	890.82	890.91	890.96	891.09	891.18	891.23	891.28	891.32	
XS 181	Piper Creek	Piper Creek	15447.78	888.74	889.71	890.13	890.31	890.46	890.58	890.65	890.72	890.78	890.90	891.00	891.04	891.10	891.14	
XS 182	Piper Creek	Piper Creek	15314.99	888.49	889.70	890.10	890.27	890.41	890.52	890.59	890.66	890.72	890.85	890.95	891.00	891.05	891.09	
XS 183	Piper Creek	Piper Creek	15153.35	888.54	889.68	890.07	890.23	890.36	890.45	890.52	890.59	890.64	890.77	890.86	890.90	890.95	890.99	
XS 184	Piper Creek	Piper Creek	15119.05	888.67	889.46	889.86	890.02	890.18	890.30	890.38	890.46	890.51	890.64	890.73	890.79	890.85	890.90	
XS 185	Piper Creek	Piper Creek	14919.67	887.84	888.91	889.31	889.56	889.77	889.92	890.00	890.10	890.16	890.31	890.41	890.47	890.53	890.58	
XS 186	Piper Creek	Piper Creek	14816.36	888.01	888.82	889.19	889.42	889.60	889.73	889.80	889.88	889.93	890.05	890.13	890.17	890.21	890.24	
XS 187	Piper Creek	Piper Creek	14613.51	887.82	888.45	888.85	889.08	889.28	889.43	889.51	889.59	889.64	889.76	889.86	889.92	889.99	890.04	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 188	Piper Creek	Piper Creek	14380.35	887.32	888.25	888.58	888.81	889.01	889.15	889.23	889.32	889.37	889.50	889.61	889.69	889.78	889.83	
XS 189	Piper Creek	Piper Creek	14231.95	887.21	888.11	888.33	888.54	888.73	888.87	888.95	889.05	889.11	889.27	889.42	889.53	889.67	889.73	
XS 190	Piper Creek	Piper Creek	14035.75	886.83	887.21	887.68	887.97	888.22	888.37	888.46	888.56	888.64	888.83	889.07	889.31	889.52	889.59	
XS 191	Piper Creek	Piper Creek	13897.14	886.25	887.13	887.59	887.87	888.11	888.27	888.36	888.47	888.55	888.76	889.02	889.28	889.50	889.56	
XS 192	Piper Creek	Piper Creek	13709.09	886.13	887.03	887.45	887.71	887.93	888.08	888.17	888.27	888.36	888.64	888.98	889.28	889.50	889.56	
XS 193	Piper Creek	Piper Creek	13535.83	886	886.95	887.32	887.55	887.76	887.91	888.01	888.13	888.24	888.58	888.96	889.26	889.49	889.55	
XS 194	Piper Creek	Piper Creek	13340.10	885.71	886.93	887.26	887.47	887.66	887.80	887.91	888.04	888.16	888.54	888.94	889.25	889.48	889.54	
XS 195	Piper Creek	Piper Creek	13182.27	886	886.91	887.21	887.40	887.58	887.72	887.84	887.98	888.11	888.51	888.93	889.25	889.47	889.54	
XS 196	Piper Creek	Piper Creek	13105.06	885.42	886.89	887.18	887.37	887.55	887.70	887.82	887.97	888.10	888.51	888.93	889.25	889.47	889.54	
XS 197	Piper Creek	Piper Creek	12970.57	885.13	886.87	887.15	887.34	887.51	887.66	887.79	887.95	888.08	888.51	888.93	889.25	889.47	889.54	
XS 198	Piper Creek	Piper Creek	12772.82	885.52	886.86	887.11	887.28	887.47	887.63	887.77	887.93	888.08	888.51	888.93	889.24	889.47	889.53	
XS 199	Piper Creek	Piper Creek	12602.11	885.4	886.85	887.07	887.25	887.44	887.62	887.75	887.93	888.07	888.50	888.93	889.24	889.47	889.53	
XS 200	Piper Creek	Piper Creek	12397.44	885.48	886.83	887.04	887.19	887.36	887.53	887.67	887.85	887.99	888.42	888.85	889.17	889.44	889.51	UPSTREAM OF 40 AVENUE CULVERT
XS 201	Piper Creek	Piper Creek	12355.73	884.93	886.83	887.00	887.10	887.20	887.26	887.30	887.34	887.38	887.45	887.50	887.53	887.57	887.59	DOWNSTREAM OF 40 AVENUE CULVERT
XS 202	Piper Creek	Piper Creek	12253.96	885	886.83	887.00	887.10	887.19	887.25	887.29	887.33	887.36	887.43	887.48	887.52	887.55	887.58	
XS 203	Piper Creek	Piper Creek	12118.36	885.11	886.83	886.99	887.09	887.18	887.24	887.27	887.31	887.34	887.40	887.45	887.48	887.52	887.54	UPSTREAM OF PRIVATE CULVERT
XS 204	Piper Creek	Piper Creek	12071.83	884.79	885.62	886.07	886.26	886.54	886.77	886.84	886.91	886.96	887.06	887.14	887.19	887.24	887.27	DOWNSTREAM OF PRIVATE CULVERT
XS 205	Piper Creek	Piper Creek	11902.07	884.7	885.43	885.79	886.06	886.47	886.73	886.80	886.87	886.91	887.00	887.08	887.12	887.17	887.21	
XS 206	Piper Creek	Piper Creek	11729.91	884.38	884.92	885.49	885.93	886.41	886.69	886.76	886.82	886.87	886.95	887.02	887.06	887.10	887.12	
XS 207	Piper Creek	Piper Creek	11565.41	883.63	884.93	885.47	885.90	886.40	886.68	886.75	886.81	886.85	886.93	887.00	887.04	887.08	887.11	UPSTREAM OF PRIVATE CULVERT
XS 208	Piper Creek	Piper Creek	11544.17	883.77	884.85	885.24	885.50	885.73	885.88	885.97	886.05	886.11	886.24	886.33	886.39	886.45	886.50	DOWNSTREAM OF PRIVATE CULVERT

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 209	Piper Creek	Piper Creek	11355.69	883.33	884.83	885.19	885.43	885.65	885.79	885.87	885.94	885.99	886.10	886.18	886.23	886.28	886.33	
XS 210	Piper Creek	Piper Creek	11135.95	883.9	884.82	885.16	885.40	885.60	885.74	885.81	885.88	885.93	886.03	886.10	886.14	886.19	886.23	
XS 211	Piper Creek	Piper Creek	10899.91	883.64	884.77	885.09	885.32	885.52	885.64	885.70	885.76	885.80	885.87	885.92	885.95	885.98	886.06	
XS 212	Piper Creek	Piper Creek	10738.50	883.51	884.59	884.98	885.21	885.42	885.54	885.61	885.67	885.71	885.79	885.84	885.87	885.91	886.02	
XS 213	Piper Creek	Piper Creek	10586.45	883.22	884.40	884.82	885.06	885.25	885.36	885.41	885.46	885.50	885.59	885.66	885.70	885.78	885.97	
XS 214	Piper Creek	Piper Creek	10412.42	883.14	884.20	884.59	884.85	885.07	885.22	885.29	885.37	885.41	885.52	885.59	885.63	885.73	885.95	
XS 215	Piper Creek	Piper Creek	10255.17	883.04	883.86	884.41	884.69	884.92	885.07	885.15	885.23	885.28	885.39	885.46	885.50	885.65	885.91	
XS 216	Piper Creek	Piper Creek	10053.58	882.49	883.74	884.27	884.56	884.77	884.91	884.99	885.06	885.11	885.22	885.29	885.36	885.59	885.90	
XS 217	Piper Creek	Piper Creek	9860.26	882.62	883.64	884.15	884.44	884.64	884.77	884.84	884.91	884.96	885.07	885.16	885.26	885.55	885.88	
XS 218	Piper Creek	Piper Creek	9578.67	882.32	883.25	883.83	884.15	884.35	884.49	884.57	884.66	884.72	884.87	884.98	885.16	885.52	885.87	
XS 219	Piper Creek	Piper Creek	9392.44	882.07	883.10	883.67	883.98	884.18	884.32	884.40	884.49	884.54	884.68	884.79	885.06	885.48	885.85	
XS 220	Piper Creek	Piper Creek	9214.14	882.08	882.96	883.48	883.80	884.01	884.16	884.24	884.33	884.39	884.53	884.71	885.05	885.48	885.85	
XS 221	Piper Creek	Piper Creek	8942.85	881.99	882.70	883.24	883.57	883.79	883.93	884.02	884.11	884.17	884.36	884.63	885.03	885.48	885.85	
XS 222	Piper Creek	Piper Creek	8704.02	881.72	882.44	883.06	883.38	883.59	883.74	883.83	883.93	884.00	884.25	884.60	885.02	885.47	885.85	
XS 223	Piper Creek	Piper Creek	8539.04	881.4	882.28	882.92	883.21	883.43	883.58	883.67	883.78	883.88	884.22	884.59	885.02	885.47	885.85	
XS 224	Piper Creek	Piper Creek	8277.62	881.31	882.09	882.72	882.98	883.21	883.37	883.48	883.63	883.76	884.18	884.58	885.01	885.47	885.84	
XS 225	Piper Creek	Piper Creek	8211.09	881.03	882.01	882.60	882.88	883.12	883.30	883.43	883.59	883.74	884.17	884.57	885.01	885.47	885.84	
XS 226	Piper Creek	Piper Creek	8086.90	880.98	881.90	882.41	882.70	882.97	883.21	883.37	883.57	883.72	884.17	884.57	885.01	885.47	885.84	
XS 227	Piper Creek	Piper Creek	7859.48	880.96	881.79	882.26	882.56	882.89	883.16	883.33	883.54	883.69	884.15	884.56	885.00	885.46	885.84	
XS 228	Piper Creek	Piper Creek	7703.33	880.88	881.69	882.17	882.47	882.81	883.08	883.26	883.46	883.62	884.09	884.50	884.95	885.41	885.79	UPSTREAM OF DELBURNE ROAD (19 STREET) CULVERT
XS 229	Piper Creek	Piper Creek	7642.63	880.31	880.77	881.08	881.26	881.47	881.61	881.69	881.78	881.84	881.98	882.09	882.15	882.21	882.25	DOWNSTREAM OF DELBURNE ROAD (19 STREET) CULVERT

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 230	Piper Creek	Piper Creek	7570.02	879.72	880.39	880.78	881.04	881.28	881.43	881.51	881.60	881.66	881.80	881.91	881.97	882.03	882.08	
XS 231	Piper Creek	Piper Creek	7434.67	879.42	879.95	880.37	880.69	880.93	881.07	881.15	881.23	881.29	881.43	881.54	881.61	881.68	881.74	
XS 232	Piper Creek	Piper Creek	7257.54	878.82	879.66	880.08	880.40	880.65	880.77	880.85	880.93	880.99	881.13	881.24	881.30	881.37	881.42	
XS 233	Piper Creek	Piper Creek	7083.34	878.7	879.13	879.48	879.71	880.03	880.20	880.30	880.40	880.48	880.64	880.75	880.81	880.87	880.92	
XS 234	Piper Creek	Piper Creek	6869.48	877.7	878.41	878.85	879.11	879.32	879.49	879.60	879.70	879.79	879.97	880.10	880.18	880.27	880.34	
XS 235	Piper Creek	Piper Creek	6697.88	877.58	878.27	878.64	878.86	879.04	879.18	879.27	879.36	879.43	879.58	879.71	879.79	879.87	879.94	
XS 236	Piper Creek	Piper Creek	6542.12	877.56	878.00	878.30	878.55	878.72	878.87	878.96	879.05	879.12	879.27	879.39	879.47	879.55	879.61	UPSTREAM OF BANNERMAN CLOSE PEDESTRIAN BRIDGE
XS 237	Piper Creek	Piper Creek	6522.56	876.96	877.66	878.24	878.51	878.71	878.86	878.95	879.05	879.12	879.28	879.40	879.48	879.56	879.62	DOWNSTREAM OF BANNERMAN CLOSE PEDESTRIAN BRIDGE
XS 238	Piper Creek	Piper Creek	6341.15	876.61	877.45	878.06	878.32	878.50	878.65	878.73	878.83	878.89	879.02	879.11	879.17	879.23	879.27	
XS 239	Piper Creek	Piper Creek	6092.66	876.3	877.19	877.76	878.03	878.21	878.36	878.45	878.54	878.61	878.76	878.88	878.95	879.03	879.09	
XS 240	Piper Creek	Piper Creek	5913.17	876.19	876.95	877.31	877.55	877.74	877.88	877.96	878.05	878.11	878.26	878.38	878.44	878.52	878.57	
XS 241	Piper Creek	Piper Creek	5799.00	876.2	876.79	877.12	877.34	877.53	877.67	877.75	877.85	877.91	878.08	878.20	878.27	878.35	878.40	
XS 242	Piper Creek	Piper Creek	5669.59	875.74	876.20	876.45	876.85	877.05	877.18	877.27	877.36	877.42	877.58	877.70	877.76	877.84	877.89	
XS 243	Piper Creek	Piper Creek	5508.28	874.73	875.75	876.23	876.54	876.76	876.92	877.01	877.11	877.18	877.34	877.46	877.53	877.61	877.67	
XS 244	Piper Creek	Piper Creek	5356.91	874.93	875.58	876.04	876.30	876.49	876.63	876.72	876.81	876.87	877.01	877.12	877.18	877.25	877.30	
XS 245	Piper Creek	Piper Creek	5266.67	874.72	875.33	875.83	876.07	876.27	876.42	876.51	876.60	876.65	876.78	876.88	876.94	877.00	877.05	
XS 246	Piper Creek	Piper Creek	5149.40	874.04	875.22	875.67	875.89	876.09	876.23	876.32	876.41	876.48	876.62	876.72	876.78	876.86	876.91	
XS 247	Piper Creek	Piper Creek	4912.15	874.2	874.92	875.28	875.51	875.69	875.84	875.92	876.01	876.07	876.22	876.30	876.36	876.43	876.48	
XS 248	Piper Creek	Piper Creek	4743.60	873.49	874.41	874.88	875.17	875.37	875.53	875.62	875.71	875.77	875.91	875.91	875.97	876.03	876.08	
XS 249	Piper Creek	Piper Creek	4558.57	873.24	873.92	874.37	874.68	874.91	875.13	875.24	875.35	875.42	875.56	875.68	875.75	875.83	875.88	
XS 250	Piper Creek	Piper Creek	4382.37	872.93	873.80	874.19	874.47	874.69	874.90	875.00	875.10	875.16	875.31	875.42	875.49	875.56	875.61	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 251	Piper Creek	Piper Creek	4270.93	873.01	873.68	874.01	874.28	874.46	874.66	874.73	874.81	874.87	875.00	875.12	875.18	875.25	875.30	
XS 252	Piper Creek	Piper Creek	4142.42	872.77	873.21	873.54	873.75	873.93	874.08	874.18	874.28	874.35	874.52	874.67	874.75	874.85	874.91	
XS 253	Piper Creek	Piper Creek	4021.16	872.11	872.90	873.34	873.59	873.82	873.98	874.08	874.19	874.27	874.44	874.59	874.68	874.77	874.84	
XS 254	Piper Creek	Piper Creek	3922.19	871.99	872.72	873.17	873.43	873.67	873.83	873.92	874.02	874.10	874.27	874.42	874.50	874.60	874.66	
XS 255	Piper Creek	Piper Creek	3769.29	871.81	872.48	872.84	873.07	873.31	873.45	873.55	873.64	873.71	873.87	874.01	874.09	874.17	874.23	UPSTREAM OF BOWER WOODS EAST-WEST PEDESTRIAN BRIDGE
XS 256	Piper Creek	Piper Creek	3759.76	871.9	872.38	872.78	873.03	873.27	873.42	873.51	873.60	873.67	873.84	873.97	874.05	874.14	874.20	DOWNSTREAM OF BOWER WOODS EAST-WEST PEDESTRIAN BRIDGE
XS 257	Piper Creek	Piper Creek	3576.29	871.11	871.85	872.26	872.53	872.78	872.93	873.01	873.10	873.17	873.33	873.46	873.54	873.62	873.68	
XS 258	Piper Creek	Piper Creek	3463.69	871.03	871.60	871.99	872.25	872.45	872.57	872.63	872.69	872.73	872.82	872.90	872.95	873.01	873.05	
XS 259	Piper Creek	Piper Creek	3185.60	870.04	870.63	870.91	871.19	871.35	871.50	871.61	871.72	871.80	871.99	872.14	872.23	872.33	872.41	UPSTREAM OF BOWER WOODS NORTH-SOUTH PEDESTRIAN BRIDGE
XS 260	Piper Creek	Piper Creek	3170.90	870.16	870.53	870.78	870.98	871.19	871.39	871.47	871.55	871.61	871.75	871.86	871.93	872.00	872.05	DOWNSTREAM OF BOWER WOODS NORTH-SOUTH PEDESTRIAN BRIDGE
XS 261	Piper Creek	Piper Creek	3071.72	869.22	869.87	870.30	870.58	870.87	871.05	871.12	871.20	871.26	871.39	871.50	871.56	871.63	871.68	
XS 262	Piper Creek	Piper Creek	2869.18	868.63	869.45	869.84	870.11	870.35	870.47	870.54	870.61	870.66	870.79	870.89	870.96	871.03	871.09	
XS 263	Piper Creek	Piper Creek	2706.72	868.58	869.15	869.46	869.67	869.82	869.95	870.03	870.11	870.17	870.31	870.43	870.51	870.60	870.67	
XS 264	Piper Creek	Piper Creek	2571.96	868.27	868.74	869.00	869.18	869.35	869.49	869.57	869.62	869.67	869.90	870.04	870.13	870.23	870.33	
XS 265	Piper Creek	Piper Creek	2455.59	867.36	867.84	868.06	868.21	868.36	868.49	868.57	868.78	868.95	868.95	868.98	869.06	869.90	870.01	UPSTREAM OF 32 STREET CULVERT
XS 266	Piper Creek	Piper Creek	2391.91	866.88	867.34	867.65	867.87	868.06	868.21	868.30	868.39	868.45	868.61	868.74	868.82	868.91	868.97	DOWNSTREAM OF 32 STREET CULVERT
XS 267	Piper Creek	Piper Creek	2039.17	865.18	865.87	866.27	866.55	866.71	866.84	866.93	867.02	867.08	867.24	867.36	867.43	867.52	867.58	
XS 268	Piper Creek	Piper Creek	1829.27	864.84	865.48	865.78	865.97	866.16	866.32	866.42	866.51	866.58	866.72	866.85	866.92	867.01	867.08	UPSTREAM OF KIN CANYON SOUTH PEDESTRIAN BRIDGE
XS 269	Piper Creek	Piper Creek	1821.47	864.81	865.47	865.76	865.93	866.10	866.25	866.35	866.44	866.51	866.65	866.77	866.84	866.92	866.99	DOWNSTREAM OF KIN CANYON SOUTH PEDESTRIAN BRIDGE
XS 270	Piper Creek	Piper Creek	1651.14	864.4	864.78	865.04	865.25	865.44	865.59	865.67	865.75	865.81	865.96	866.08	866.15	866.21	866.26	
XS 271	Piper Creek	Piper Creek	1444.90	863.06	863.68	864.02	864.25	864.46	864.62	864.72	864.81	864.87	865.02	865.12	865.20	865.31	865.38	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 272	Piper Creek	Piper Creek	1346.25	862.82	863.27	863.52	863.70	863.89	864.05	864.14	864.25	864.32	864.51	864.71	864.87	865.04	865.15	UPSTREAM OF KIN CANYON NORTH BRIDGE
XS 273	Piper Creek	Piper Creek	1340.07	862.57	863.16	863.50	863.70	863.90	864.05	864.15	864.25	864.33	864.51	864.66	864.74	864.83	864.88	DOWNSTREAM OF KIN CANYON NORTH BRIDGE
XS 274	Piper Creek	Piper Creek	1189.56	861.95	862.30	862.52	862.70	862.86	862.99	863.06	863.14	863.20	863.34	863.46	863.53	863.61	863.67	
XS 275	Piper Creek	Piper Creek	1061.64	861.18	861.69	861.98	862.14	862.32	862.47	862.57	862.67	862.74	862.90	863.02	863.09	863.18	863.24	
XS 276	Piper Creek	Piper Creek	864.73	860.32	860.66	860.93	861.20	861.39	861.56	861.67	861.79	861.87	862.05	862.19	862.27	862.37	862.44	
XS 277	Piper Creek	Piper Creek	704.01	859.22	859.92	860.23	860.44	860.61	860.75	860.83	860.92	860.99	861.16	861.29	861.36	861.43	861.48	
XS 278	Piper Creek	Piper Creek	648.79	859.31	859.75	860.04	860.25	860.44	860.59	860.69	860.79	860.87	861.06	861.21	861.30	861.39	861.45	
XS 279	Piper Creek	Piper Creek	638.85	859.31	859.69	859.98	860.20	860.41	860.56	860.66	860.77	860.85	861.04	861.20	861.29	861.39	861.45	UPSTREAM OF ROTARY PICNIC PARK SOUTH PEDESTRIAN BRIDGE
XS 280	Piper Creek	Piper Creek	632.69	859.14	859.54	859.80	860.00	860.19	860.35	860.44	860.53	860.60	860.77	860.90	860.95	860.99	861.00	DOWNSTREAM OF ROTARY PICNIC PARK SOUTH PEDESTRIAN BRIDGE
XS 281	Piper Creek	Piper Creek	540.04	858.27	858.82	859.10	859.30	859.50	859.68	859.78	859.89	859.96	860.16	860.30	860.38	860.48	860.55	
XS 282	Piper Creek	Piper Creek	392.07	857.73	858.10	858.42	858.64	858.83	858.98	859.07	859.16	859.22	859.37	859.49	859.57	859.66	859.72	UPSTREAM OF ROTARY PICNIC PARK NORTH PEDESTRIAN BRIDGE
XS 283	Piper Creek	Piper Creek	387.94	857.62	858.08	858.38	858.59	858.78	858.91	858.99	859.08	859.14	859.27	859.36	859.42	859.48	859.51	DOWNSTREAM OF ROTARY PICNIC PARK NORTH PEDESTRIAN BRIDGE
XS 284	Piper Creek	Piper Creek	334.22	857.26	857.56	857.79	857.96	858.16	858.29	858.37	858.45	858.51	858.65	858.76	858.82	858.90	858.95	
XS 285	Piper Creek	Piper Creek	168.42	855.41	856.04	856.31	856.57	856.91	857.24	857.46	857.72	857.86	857.86	858.13	858.18	858.23	858.26	
XS 286	Piper Creek	Piper Creek	84.99	855.22	855.62	856.04	856.43	856.82	857.15	857.38	857.64	857.78	857.78	858.07	858.14	858.20	858.24	UPSTREAM OF 43 STREET CULVERT
XS 287	Piper Creek	Piper Creek	48.71	854.69	855.35	855.96	856.34	856.70	856.97	857.13	857.29	857.33	857.34	857.40	857.47	857.59	857.67	DOWNSTREAM OF 43 STREET CULVERT
XS 288	Waskasoo Creek	Upper Reach	34635.60	894.17	895.49	895.55	895.61	895.66	895.70	895.72	895.75	895.78	895.83	895.87	895.90	895.93	895.95	
XS 289	Waskasoo Creek	Upper Reach	34486.16	894.19	895.49	895.55	895.60	895.66	895.70	895.72	895.75	895.77	895.82	895.87	895.89	895.92	895.95	
XS 290	Waskasoo Creek	Upper Reach	34337.95	894.25	895.49	895.55	895.60	895.66	895.70	895.72	895.75	895.77	895.82	895.86	895.89	895.92	895.94	
XS 291	Waskasoo Creek	Upper Reach	34246.47	894.15	895.49	895.55	895.60	895.65	895.70	895.72	895.75	895.77	895.81	895.85	895.88	895.91	895.93	UPSTREAM OF RANGE ROAD 281 CULVERT
XS 292	Waskasoo Creek	Upper Reach	34116.75	894.2	895.18	895.37	895.39	895.39	895.39	895.46	895.53	895.55	895.59	895.63	895.65	895.69	895.71	DOWNSTREAM OF RANGE ROAD 281 CULVERT

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 293	Waskasoo Creek	Upper Reach	34034.44	894.04	894.49	894.75	894.99	895.22	895.39	895.46	895.53	895.55	895.58	895.62	895.65	895.68	895.70	
XS 294	Waskasoo Creek	Upper Reach	33883.05	893.88	894.45	894.75	894.99	895.22	895.39	895.46	895.53	895.54	895.58	895.62	895.64	895.67	895.69	
XS 295	Waskasoo Creek	Upper Reach	33733.72	893.88	894.42	894.74	894.99	895.22	895.39	895.46	895.53	895.54	895.57	895.61	895.64	895.67	895.69	
XS 296	Waskasoo Creek	Upper Reach	33584.00	893.74	894.39	894.74	894.99	895.22	895.39	895.46	895.52	895.54	895.57	895.61	895.63	895.66	895.68	
XS 297	Waskasoo Creek	Upper Reach	33435.24	893.57	894.38	894.73	894.99	895.22	895.39	895.46	895.52	895.54	895.57	895.61	895.63	895.66	895.68	
XS 298	Waskasoo Creek	Upper Reach	33283.83	893.45	894.38	894.73	894.99	895.21	895.39	895.46	895.52	895.54	895.57	895.61	895.63	895.66	895.68	
XS 299	Waskasoo Creek	Upper Reach	33135.89	893.35	894.38	894.73	894.98	895.21	895.39	895.45	895.52	895.54	895.57	895.60	895.63	895.66	895.68	
XS 300	Waskasoo Creek	Upper Reach	33017.50	893.3	894.36	894.70	894.93	895.14	895.35	895.44	895.51	895.52	895.55	895.59	895.61	895.64	895.66	UPSTREAM OF TOWNSHIP ROAD 264 BRIDGE
XS 301	Waskasoo Creek	Upper Reach	32982.53	893.25	894.33	894.64	894.84	895.01	895.12	895.17	895.24	895.27	895.36	895.42	895.45	895.49	895.51	DOWNSTREAM OF TOWNSHIP ROAD 264 BRIDGE
XS 302	Waskasoo Creek	Upper Reach	32835.01	893.17	894.27	894.55	894.73	894.93	895.06	895.12	895.18	895.22	895.31	895.37	895.39	895.43	895.46	
XS 303	Waskasoo Creek	Upper Reach	32682.84	893.01	894.25	894.50	894.65	894.85	894.99	895.06	895.13	895.17	895.26	895.32	895.35	895.38	895.41	
XS 304	Waskasoo Creek	Upper Reach	32534.92	892.87	894.24	894.48	894.62	894.82	894.97	895.04	895.11	895.15	895.24	895.29	895.31	895.34	895.37	
XS 305	Waskasoo Creek	Upper Reach	32384.64	892.86	894.23	894.46	894.61	894.80	894.96	895.03	895.10	895.14	895.23	895.28	895.30	895.33	895.35	
XS 306	Waskasoo Creek	Upper Reach	32223.84	892.87	894.21	894.43	894.58	894.79	894.95	895.02	895.09	895.13	895.21	895.26	895.28	895.31	895.33	UPSTREAM OF PRIVATE CULVERT
XS 307	Waskasoo Creek	Upper Reach	32203.38	892.41	893.85	894.33	894.57	894.79	894.94	895.02	895.08	895.12	895.21	895.26	895.27	895.30	895.33	DOWNSTREAM OF PRIVATE CULVERT
XS 308	Waskasoo Creek	Upper Reach	32082.43	892.86	893.81	894.28	894.51	894.71	894.86	894.94	895.00	895.05	895.13	895.18	895.19	895.21	895.23	
XS 309	Waskasoo Creek	Upper Reach	31935.31	892.59	893.77	894.21	894.40	894.56	894.68	894.74	894.78	894.80	894.83	894.89	894.97	895.06	895.10	
XS 310	Waskasoo Creek	Upper Reach	31785.15	892.43	893.73	894.14	894.29	894.38	894.45	894.50	894.56	894.60	894.72	894.84	894.93	895.02	895.06	
XS 311	Waskasoo Creek	Upper Reach	31635.61	892.48	893.69	894.06	894.20	894.28	894.36	894.41	894.48	894.54	894.68	894.81	894.91	895.00	895.05	
XS 312	Waskasoo Creek	Upper Reach	31485.84	892.3	893.65	893.96	894.04	894.17	894.28	894.35	894.44	894.50	894.65	894.79	894.89	894.99	895.03	
XS 313	Waskasoo Creek	Upper Reach	31442.97	892.17	893.65	893.94	894.02	894.15	894.26	894.34	894.43	894.49	894.65	894.79	894.89	894.99	895.03	UPSTREAM OF PRIVATE CULVERT

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 314	Waskasoo Creek	Upper Reach	31420.60	892.09	893.33	893.81	893.99	894.14	894.26	894.33	894.42	894.49	894.64	894.78	894.89	894.98	895.03	DOWNSTREAM OF PRIVATE CULVERT
XS 315	Waskasoo Creek	Upper Reach	31337.08	892	893.29	893.74	893.94	894.11	894.24	894.32	894.41	894.48	894.64	894.78	894.88	894.98	895.02	
XS 316	Waskasoo Creek	Upper Reach	31187.78	892.38	893.19	893.66	893.87	894.05	894.19	894.27	894.37	894.43	894.60	894.74	894.84	894.92	894.96	UPSTREAM OF RANGE ROAD 280 BRIDGE
XS 317	Waskasoo Creek	Upper Reach	31166.55	892.09	893.17	893.64	893.83	893.99	894.10	894.17	894.24	894.29	894.39	894.46	894.51	894.61	894.70	DOWNSTREAM OF RANGE ROAD 280 BRIDGE
XS 318	Waskasoo Creek	Upper Reach	31030.69	892.15	893.11	893.56	893.72	893.84	893.91	893.95	893.99	894.03	894.11	894.22	894.31	894.48	894.61	
XS 319	Waskasoo Creek	Upper Reach	30871.62	892.09	893.04	893.51	893.65	893.75	893.81	893.85	893.89	893.93	894.04	894.18	894.28	894.47	894.59	PENHOLD DIKE #1
XS 320	Waskasoo Creek	Upper Reach	30844.99	892.11	893.03	893.49	893.62	893.72	893.79	893.83	893.87	893.91	894.03	894.17	894.28	894.47	894.59	PENHOLD DIKE #1
XS 321	Waskasoo Creek	Upper Reach	30733.96	891.81	892.95	893.41	893.56	893.67	893.74	893.78	893.82	893.86	893.99	894.15	894.26	894.46	894.58	PENHOLD DIKE #1
XS 322	Waskasoo Creek	Upper Reach	30582.52	891.87	892.87	893.30	893.41	893.50	893.57	893.63	893.71	893.77	893.94	894.12	894.24	894.45	894.58	PENHOLD DIKE #1
XS 323	Waskasoo Creek	Upper Reach	30425.94	891.13	892.80	893.21	893.31	893.41	893.51	893.58	893.67	893.74	893.92	894.11	894.23	894.44	894.57	PENHOLD DIKE #1
XS 324	Waskasoo Creek	Upper Reach	30286.63	891.65	892.74	893.13	893.25	893.37	893.48	893.56	893.65	893.73	893.91	894.10	894.23	894.44	894.57	PENHOLD DIKE #1
XS 325	Waskasoo Creek	Upper Reach	30139.86	891.62	892.68	893.07	893.22	893.35	893.47	893.55	893.64	893.72	893.91	894.10	894.22	894.44	894.57	PENHOLD DIKE #1
XS 326	Waskasoo Creek	Upper Reach	29985.25	891.71	892.62	892.99	893.14	893.30	893.44	893.53	893.63	893.70	893.90	894.09	894.22	894.43	894.57	PENHOLD DIKE #2
XS 327	Waskasoo Creek	Upper Reach	29834.00	891.47	892.55	892.94	893.11	893.28	893.43	893.52	893.62	893.70	893.89	894.09	894.22	894.43	894.56	PENHOLD DIKE #2
XS 328	Waskasoo Creek	Upper Reach	29684.77	891.2	892.50	892.90	893.09	893.28	893.42	893.51	893.62	893.70	893.89	894.09	894.21	894.43	894.56	PENHOLD DIKE #2
XS 329	Waskasoo Creek	Upper Reach	29528.95	891.43	892.45	892.88	893.09	893.27	893.42	893.51	893.62	893.69	893.89	894.09	894.21	894.43	894.56	PENHOLD DIKE #2
XS 330	Waskasoo Creek	Upper Reach	29384.32	891.19	892.42	892.88	893.08	893.27	893.42	893.51	893.61	893.69	893.89	894.09	894.21	894.43	894.56	PENHOLD DIKE #2
XS 331	Waskasoo Creek	Upper Reach	29265.61	890.97	892.41	892.86	893.05	893.23	893.36	893.44	893.53	893.60	893.76	893.94	894.05	894.26	894.53	UPSTREAM OF HIGHWAY 42 BRIDGE
XS 332	Waskasoo Creek	Upper Reach	29232.09	891.12	892.39	892.83	893.01	893.16	893.26	893.32	893.39	893.43	893.53	893.63	893.69	893.77	893.83	DOWNSTREAM OF HIGHWAY 42 BRIDGE
XS 333	Waskasoo Creek	Upper Reach	29080.61	890.9	892.33	892.80	892.99	893.14	893.25	893.31	893.37	893.42	893.52	893.61	893.67	893.76	893.81	
XS 334	Waskasoo Creek	Upper Reach	28926.22	890.77	892.27	892.77	892.97	893.13	893.24	893.30	893.36	893.41	893.51	893.60	893.66	893.75	893.81	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 335	Waskasoo Creek	Upper Reach	28774.62	890.97	892.21	892.70	892.89	893.02	893.12	893.18	893.25	893.31	893.44	893.55	893.62	893.72	893.78	
XS 336	Waskasoo Creek	Upper Reach	28624.56	890.98	892.15	892.69	892.89	893.04	893.15	893.20	893.27	893.32	893.44	893.55	893.62	893.71	893.77	
XS 337	Waskasoo Creek	Upper Reach	28474.39	890.84	892.09	892.65	892.86	893.02	893.12	893.18	893.25	893.30	893.42	893.53	893.60	893.70	893.76	
XS 338	Waskasoo Creek	Upper Reach	28324.14	890.85	892.03	892.60	892.80	892.96	893.07	893.14	893.21	893.26	893.39	893.50	893.57	893.67	893.74	
XS 339	Waskasoo Creek	Upper Reach	28175.69	890.63	891.99	892.55	892.76	892.92	893.04	893.10	893.18	893.24	893.37	893.48	893.56	893.66	893.72	
XS 340	Waskasoo Creek	Upper Reach	28022.16	890.62	891.95	892.50	892.73	892.89	893.01	893.08	893.16	893.22	893.35	893.47	893.54	893.64	893.71	
XS 341	Waskasoo Creek	Upper Reach	27876.51	890.6	891.91	892.44	892.67	892.83	892.95	893.02	893.10	893.15	893.28	893.40	893.48	893.59	893.66	
XS 342	Waskasoo Creek	Upper Reach	27726.40	890.55	891.86	892.38	892.61	892.76	892.87	892.93	893.00	893.06	893.18	893.30	893.38	893.49	893.57	
XS 343	Waskasoo Creek	Upper Reach	27577.64	890.27	891.83	892.33	892.57	892.72	892.83	892.89	892.96	893.01	893.14	893.25	893.34	893.46	893.53	
XS 344	Waskasoo Creek	Upper Reach	27428.42	890.65	891.79	892.28	892.51	892.66	892.76	892.82	892.88	892.93	893.06	893.18	893.27	893.40	893.48	
XS 345	Waskasoo Creek	Upper Reach	27276.15	890.65	891.74	892.21	892.42	892.57	892.67	892.72	892.79	892.83	892.96	893.11	893.21	893.36	893.44	
XS 346	Waskasoo Creek	Upper Reach	27124.37	890.6	891.67	892.15	892.36	892.49	892.57	892.62	892.67	892.71	892.83	893.00	893.11	893.27	893.36	
XS 347	Waskasoo Creek	Upper Reach	26980.19	890.67	891.62	892.11	892.34	892.47	892.56	892.60	892.66	892.70	892.82	892.99	893.11	893.27	893.36	
XS 348	Waskasoo Creek	Upper Reach	26844.80	890.65	891.58	892.08	892.30	892.43	892.51	892.55	892.60	892.64	892.77	892.96	893.08	893.26	893.35	UPSTREAM OF PRIVATE BRIDGE
XS 349	Waskasoo Creek	Upper Reach	26827.29	890.62	891.57	892.05	892.24	892.36	892.44	892.49	892.54	892.59	892.74	892.95	893.08	893.25	893.35	DOWNSTREAM OF PRIVATE BRIDGE
XS 350	Waskasoo Creek	Upper Reach	26666.51	890.61	891.52	891.99	892.16	892.26	892.32	892.37	892.44	892.52	892.70	892.94	893.07	893.25	893.34	
XS 351	Waskasoo Creek	Upper Reach	26516.18	890.46	891.46	891.92	892.08	892.20	892.26	892.31	892.40	892.49	892.69	892.93	893.06	893.24	893.34	
XS 352	Waskasoo Creek	Upper Reach	26366.78	890.31	891.36	891.82	891.98	892.12	892.19	892.25	892.36	892.47	892.68	892.92	893.06	893.24	893.34	
XS 353	Waskasoo Creek	Upper Reach	26218.49	890.11	891.27	891.71	891.79	891.88	892.05	892.20	892.33	892.46	892.67	892.92	893.05	893.24	893.33	
XS 354	Waskasoo Creek	Upper Reach	26071.50	889.76	891.18	891.66	891.77	891.91	892.07	892.20	892.33	892.45	892.67	892.92	893.05	893.24	893.33	
XS 355	Waskasoo Creek	Upper Reach	25920.17	889.58	891.08	891.61	891.75	891.90	892.06	892.19	892.33	892.45	892.67	892.92	893.05	893.24	893.33	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 356	Waskasoo Creek	Upper Reach	25769.27	889.63	890.95	891.52	891.71	891.88	892.05	892.19	892.33	892.45	892.67	892.92	893.05	893.24	893.33	
XS 357	Waskasoo Creek	Upper Reach	25619.54	889.35	890.82	891.37	891.61	891.83	892.03	892.18	892.32	892.44	892.66	892.91	893.05	893.23	893.33	
XS 358	Waskasoo Creek	Upper Reach	25464.89	889.01	890.71	891.25	891.54	891.79	892.01	892.16	892.31	892.44	892.66	892.91	893.05	893.23	893.33	
XS 359	Waskasoo Creek	Upper Reach	25312.70	888.92	890.57	891.12	891.43	891.72	891.97	892.14	892.29	892.42	892.64	892.90	893.04	893.23	893.32	
XS 360	Waskasoo Creek	Upper Reach	25212.60	889.33	890.51	891.07	891.35	891.61	891.83	891.98	892.11	892.23	892.40	892.65	892.98	893.21	893.31	UPSTREAM OF TOWNSHIP ROAD 372 BRIDGE
XS 361	Waskasoo Creek	Upper Reach	25188.74	889.44	890.49	891.05	891.32	891.55	891.76	891.89	892.00	892.08	892.11	892.17	892.18	892.24	892.29	DOWNSTREAM OF TOWNSHIP ROAD 372 BRIDGE
XS 362	Waskasoo Creek	Upper Reach	25132.22	889.23	890.47	891.02	891.28	891.51	891.71	891.85	891.95	892.03	892.03	892.17	892.18	892.25	892.31	UPSTREAM OF PRIVATE BRIDGE
XS 363	Waskasoo Creek	Upper Reach	25118.96	889.15	890.46	891.01	891.27	891.48	891.64	891.73	891.80	891.87	892.02	892.14	892.14	892.22	892.27	DOWNSTREAM OF PRIVATE BRIDGE
XS 364	Waskasoo Creek	Upper Reach	25005.97	889.11	890.40	890.93	891.19	891.39	891.53	891.62	891.68	891.74	891.88	892.00	892.06	892.14	892.19	
XS 365	Waskasoo Creek	Upper Reach	24854.74	889.16	890.30	890.84	891.11	891.30	891.44	891.52	891.61	891.67	891.81	891.92	891.99	892.06	892.11	
XS 366	Waskasoo Creek	Upper Reach	24705.39	889.1	890.21	890.75	891.00	891.18	891.32	891.40	891.49	891.55	891.69	891.80	891.86	891.92	891.97	
XS 367	Waskasoo Creek	Upper Reach	24553.98	888.94	890.11	890.66	890.91	891.11	891.27	891.36	891.45	891.52	891.66	891.76	891.82	891.89	891.94	
XS 368	Waskasoo Creek	Upper Reach	24401.69	889.02	890.02	890.58	890.83	891.02	891.18	891.26	891.35	891.41	891.55	891.66	891.72	891.79	891.84	
XS 369	Waskasoo Creek	Upper Reach	24248.07	888.83	889.90	890.50	890.76	890.97	891.13	891.22	891.32	891.39	891.53	891.63	891.69	891.76	891.81	
XS 370	Waskasoo Creek	Upper Reach	24229.99	888.47	889.88	890.49	890.75	890.96	891.12	891.22	891.31	891.38	891.52	891.62	891.68	891.75	891.80	
XS 371	Waskasoo Creek	Upper Reach	24091.53	888.34	889.81	890.43	890.70	890.91	891.08	891.17	891.27	891.33	891.48	891.58	891.64	891.71	891.76	
XS 372	Waskasoo Creek	Upper Reach	23940.87	888.29	889.77	890.37	890.63	890.84	891.01	891.10	891.19	891.26	891.39	891.49	891.55	891.62	891.67	
XS 373	Waskasoo Creek	Upper Reach	23787.93	888.15	889.69	890.28	890.51	890.66	890.80	890.87	890.96	891.01	891.14	891.25	891.32	891.41	891.48	
XS 374	Waskasoo Creek	Upper Reach	23639.51	887.82	889.61	890.23	890.46	890.62	890.77	890.85	890.94	890.99	891.14	891.25	891.33	891.41	891.48	
XS 375	Waskasoo Creek	Upper Reach	23487.15	887.71	889.56	890.18	890.42	890.58	890.73	890.81	890.90	890.96	891.11	891.23	891.30	891.39	891.46	
XS 376	Waskasoo Creek	Upper Reach	23329.02	887.55	889.51	890.13	890.36	890.55	890.70	890.79	890.88	890.93	891.08	891.20	891.27	891.36	891.43	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 377	Waskasoo Creek	Upper Reach	23179.08	887.73	889.47	890.08	890.28	890.45	890.59	890.67	890.74	890.80	890.94	891.04	891.11	891.20	891.29	
XS 378	Waskasoo Creek	Upper Reach	23027.88	887.7	889.42	890.01	890.17	890.31	890.44	890.53	890.61	890.67	890.84	890.97	891.05	891.15	891.25	
XS 379	Waskasoo Creek	Upper Reach	22908.11	887.5	889.38	889.97	890.12	890.24	890.36	890.44	890.52	890.57	890.73	890.86	890.95	891.09	891.20	UPSTREAM OF PRIVATE CULVERT
XS 380	Waskasoo Creek	Upper Reach	22881.55	887.26	889.03	889.64	889.90	890.11	890.27	890.37	890.46	890.51	890.69	890.83	890.93	891.07	891.19	DOWNSTREAM OF PRIVATE CULVERT
XS 381	Waskasoo Creek	Upper Reach	22728.35	887.54	888.94	889.54	889.83	890.06	890.23	890.33	890.42	890.47	890.66	890.81	890.91	891.05	891.18	
XS 382	Waskasoo Creek	Upper Reach	22575.17	887.23	888.81	889.41	889.74	889.99	890.18	890.28	890.38	890.44	890.63	890.79	890.89	891.04	891.17	
XS 383	Waskasoo Creek	Upper Reach	22424.48	887.35	888.68	889.27	889.61	889.89	890.10	890.22	890.33	890.39	890.60	890.76	890.87	891.02	891.16	
XS 384	Waskasoo Creek	Upper Reach	22273.60	886.98	888.55	889.14	889.47	889.75	889.95	890.08	890.20	890.33	890.56	890.73	890.84	891.00	891.13	
XS 385	Waskasoo Creek	Upper Reach	22219.55	887.41	888.51	889.11	889.46	889.75	889.96	890.08	890.19	890.29	890.52	890.67	890.78	890.93	891.06	UPSTREAM OF HIGHWAY 2A BRIDGE
XS 386	Waskasoo Creek	Upper Reach	22174.71	887.49	888.47	889.07	889.42	889.69	889.88	889.99	890.09	890.18	890.38	890.50	890.58	890.71	890.80	DOWNSTREAM OF HIGHWAY 2A BRIDGE
XS 387	Waskasoo Creek	Upper Reach	22140.90	887.37	888.38	888.98	889.32	889.58	889.75	889.86	889.94	890.02	890.18	890.25	890.30	890.41	890.50	UPSTREAM OF CP RAIL BRIDGE
XS 388	Waskasoo Creek	Upper Reach	22116.00	887.18	888.38	888.99	889.34	889.60	889.78	889.89	889.98	890.07	890.24	890.31	890.37	890.48	890.56	DOWNSTREAM OF CP RAIL BRIDGE
XS 389	Waskasoo Creek	Upper Reach	21970.96	887.09	888.29	888.89	889.22	889.46	889.61	889.70	889.77	889.84	889.99	890.20	890.34	890.52	890.63	
XS 390	Waskasoo Creek	Upper Reach	21840.30	887.18	888.17	888.79	889.12	889.32	889.45	889.52	889.63	889.71	889.89	890.10	890.26	890.45	890.57	
XS 391	Waskasoo Creek	Upper Reach	21668.35	886.63	888.03	888.66	888.99	889.21	889.37	889.47	889.59	889.68	889.87	890.09	890.25	890.45	890.56	
XS 392	Waskasoo Creek	Upper Reach	21517.58	886.55	887.93	888.53	888.88	889.13	889.30	889.41	889.54	889.63	889.82	890.05	890.23	890.43	890.55	
XS 393	Waskasoo Creek	Upper Reach	21352.32	886.5	887.86	888.44	888.78	889.01	889.16	889.26	889.38	889.47	889.63	889.85	890.04	890.35	890.51	UPSTREAM OF TOWNSHIP ROAD 374 BRIDGE
XS 394	Waskasoo Creek	Upper Reach	21324.33	886.58	887.83	888.40	888.73	888.95	889.08	889.16	889.26	889.33	889.44	889.66	889.85	890.03	890.12	DOWNSTREAM OF TOWNSHIP ROAD 374 BRIDGE
XS 395	Waskasoo Creek	Upper Reach	21211.71	886.21	887.69	888.28	888.61	888.86	889.01	889.11	889.23	889.32	889.45	889.70	889.91	890.10	890.19	
XS 396	Waskasoo Creek	Upper Reach	21061.19	885.99	887.52	888.15	888.45	888.68	888.81	888.92	889.06	889.18	889.33	889.65	889.88	890.08	890.18	
XS 397	Waskasoo Creek	Upper Reach	20911.11	885.62	887.41	888.06	888.35	888.53	888.60	888.71	888.84	888.95	889.32	889.65	889.88	890.08	890.18	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 398	Waskasoo Creek	Upper Reach	20758.45	885.27	887.30	887.94	888.24	888.45	888.61	888.74	888.89	889.01	889.32	889.65	889.88	890.08	890.18	
XS 399	Waskasoo Creek	Upper Reach	20608.70	885.6	887.14	887.75	888.12	888.39	888.59	888.72	888.87	889.00	889.32	889.65	889.88	890.08	890.17	
XS 400	Waskasoo Creek	Upper Reach	20455.98	885.45	886.96	887.58	887.99	888.32	888.55	888.69	888.86	888.99	889.31	889.64	889.88	890.08	890.17	
XS 401	Waskasoo Creek	Upper Reach	20303.40	885.49	886.82	887.43	887.85	888.17	888.42	888.56	888.74	888.87	889.20	889.53	889.76	889.92	890.14	UPSTREAM OF CP RAIL BRIDGE
XS 402	Waskasoo Creek	Upper Reach	20274.66	885.63	886.80	887.42	887.84	888.17	888.41	888.56	888.73	888.85	889.18	889.49	889.71	889.89	890.11	UPSTREAM OF HIGHWAY 2A BRIDGE; DOWNSTREAM OF CP RAIL BRIDGE
XS 403	Waskasoo Creek	Upper Reach	20238.11	885.51	886.78	887.38	887.77	888.04	888.23	888.33	888.43	888.50	888.65	888.78	888.86	888.92	888.97	DOWNSTREAM OF HIGHWAY 2A BRIDGE
XS 404	Waskasoo Creek	Upper Reach	20157.10	885.03	886.71	887.30	887.68	887.96	888.19	888.30	888.41	888.48	888.66	888.80	888.88	888.97	889.03	
XS 405	Waskasoo Creek	Upper Reach	20007.14	884.94	886.60	887.19	887.57	887.83	888.05	888.18	888.31	888.39	888.57	888.73	888.82	888.91	888.97	UPSTREAM OF PRIVATE BRIDGE
XS 406	Waskasoo Creek	Upper Reach	19993.07	885.11	886.59	887.18	887.56	887.83	888.05	888.17	888.30	888.38	888.56	888.72	888.81	888.90	888.96	DOWNSTREAM OF PRIVATE BRIDGE
XS 407	Waskasoo Creek	Upper Reach	19853.68	884.82	886.49	887.08	887.47	887.71	887.91	888.02	888.16	888.24	888.44	888.62	888.71	888.81	888.87	
XS 408	Waskasoo Creek	Upper Reach	19727.86	884.47	886.39	886.97	887.35	887.63	887.85	887.97	888.10	888.18	888.40	888.59	888.69	888.79	888.85	
XS 409	Waskasoo Creek	Upper Reach	19611.32	884.67	886.30	886.88	887.25	887.52	887.72	887.84	887.97	888.06	888.29	888.51	888.60	888.71	888.77	
XS 410	Waskasoo Creek	Upper Reach	19495.41	884.67	886.23	886.80	887.16	887.39	887.55	887.66	887.76	887.84	888.08	888.33	888.43	888.54	888.61	UPSTREAM OF PRIVATE BRIDGE
XS 411	Waskasoo Creek	Upper Reach	19478.36	884.98	886.20	886.77	887.12	887.34	887.49	887.58	887.66	887.72	887.89	888.05	888.14	888.25	888.30	DOWNSTREAM OF PRIVATE BRIDGE
XS 412	Waskasoo Creek	Upper Reach	19395.64	884.54	886.13	886.70	887.05	887.27	887.42	887.53	887.63	887.70	887.90	888.08	888.19	888.31	888.37	
XS 413	Waskasoo Creek	Upper Reach	19238.61	884.59	886.01	886.55	886.88	887.13	887.32	887.43	887.54	887.62	887.83	888.02	888.15	888.27	888.33	
XS 414	Waskasoo Creek	Upper Reach	19090.29	884.43	885.84	886.39	886.70	886.97	887.18	887.29	887.41	887.49	887.73	887.93	888.07	888.20	888.26	
XS 415	Waskasoo Creek	Upper Reach	18930.50	884.43	885.72	886.27	886.61	886.90	887.11	887.23	887.36	887.45	887.70	887.92	888.06	888.19	888.25	
XS 416	Waskasoo Creek	Upper Reach	18781.57	884.26	885.60	886.14	886.48	886.80	887.02	887.15	887.28	887.37	887.64	887.86	888.01	888.15	888.20	
XS 417	Waskasoo Creek	Upper Reach	18700.24	884.05	885.54	886.06	886.40	886.69	886.90	887.01	887.13	887.20	887.46	887.66	887.80	887.93	888.07	UPSTREAM OF LANTERN STREET BRIDGE
XS 418	Waskasoo Creek	Upper Reach	18667.47	884.12	885.52	886.04	886.37	886.67	886.87	886.99	887.09	887.17	887.32	887.44	887.51	887.60	887.65	DOWNSTREAM OF LANTERN STREET BRIDGE

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 419	Waskasoo Creek	Upper Reach	18479.48	883.95	885.33	885.86	886.19	886.50	886.70	886.82	886.92	886.99	887.12	887.22	887.29	887.36	887.41	
XS 420	Waskasoo Creek	Upper Reach	18328.47	883.64	885.17	885.78	886.13	886.44	886.65	886.77	886.87	886.94	887.08	887.19	887.26	887.34	887.40	
XS 421	Waskasoo Creek	Upper Reach	18179.03	883.57	885.01	885.66	886.01	886.31	886.51	886.62	886.73	886.80	886.97	887.10	887.18	887.26	887.32	
XS 422	Waskasoo Creek	Upper Reach	18025.47	883.67	884.80	885.48	885.82	886.12	886.32	886.44	886.56	886.65	886.85	887.00	887.09	887.19	887.26	
XS 423	Waskasoo Creek	Upper Reach	17865.71	883.16	884.62	885.26	885.60	885.93	886.16	886.30	886.44	886.54	886.76	886.92	887.02	887.13	887.20	
XS 424	Waskasoo Creek	Upper Reach	17682.69	883.42	884.41	885.05	885.41	885.74	885.98	886.11	886.25	886.35	886.57	886.74	886.84	886.95	887.02	UPSTREAM OF TOWNSHIP ROAD 375 BRIDGE
XS 425	Waskasoo Creek	Upper Reach	17661.39	883.42	884.35	885.00	885.37	885.70	885.93	886.05	886.17	886.25	886.44	886.59	886.68	886.78	886.85	DOWNSTREAM OF TOWNSHIP ROAD 375 BRIDGE
XS 426	Waskasoo Creek	Upper Reach	17500.88	882.93	884.20	884.85	885.21	885.54	885.76	885.87	885.98	886.06	886.23	886.38	886.47	886.56	886.63	
XS 427	Waskasoo Creek	Upper Reach	17382.71	882.76	884.13	884.78	885.14	885.46	885.67	885.77	885.87	885.94	886.11	886.26	886.34	886.43	886.49	
XS 428	Waskasoo Creek	Upper Reach	17242.98	882.95	884.01	884.67	885.02	885.34	885.53	885.62	885.70	885.75	885.91	886.09	886.18	886.28	886.34	
XS 429	Waskasoo Creek	Upper Reach	17085.58	882.91	883.89	884.55	884.91	885.22	885.40	885.48	885.55	885.60	885.77	885.99	886.10	886.20	886.27	
XS 430	Waskasoo Creek	Upper Reach	16963.94	882.63	883.83	884.48	884.83	885.14	885.30	885.39	885.45	885.49	885.68	885.93	886.04	886.15	886.22	
XS 431	Waskasoo Creek	Upper Reach	16775.86	882.8	883.68	884.31	884.64	884.95	885.16	885.26	885.31	885.34	885.59	885.89	886.01	886.13	886.20	
XS 432	Waskasoo Creek	Upper Reach	16631.70	882.6	883.53	884.18	884.52	884.81	885.05	885.16	885.19	885.20	885.54	885.87	885.99	886.11	886.19	
XS 433	Waskasoo Creek	Upper Reach	16481.07	882.24	883.36	884.03	884.38	884.66	884.88	884.98	885.11	885.11	885.50	885.85	885.97	886.09	886.17	
XS 434	Waskasoo Creek	Upper Reach	16326.56	882.11	883.04	883.72	884.10	884.39	884.62	884.70	884.89	885.07	885.48	885.84	885.97	886.09	886.16	
XS 435	Waskasoo Creek	Upper Reach	16176.75	881.66	882.79	883.45	883.82	884.17	884.46	884.66	884.88	885.04	885.47	885.83	885.95	886.07	886.15	
XS 436	Waskasoo Creek	Upper Reach	15994.03	881.04	882.78	883.43	883.78	884.11	884.38	884.55	884.76	884.92	885.33	885.69	885.83	885.96	886.05	UPSTREAM OF HIGHWAY 2A BRIDGE
XS 437	Waskasoo Creek	Upper Reach	15959.25	881.73	882.63	883.29	883.59	883.83	884.01	884.11	884.23	884.32	884.56	884.79	884.97	885.17	885.30	UPSTREAM OF CP RAIL BRIDGE; DOWNSTREAM OF HIGHWAY 2A BRIDGE
XS 438	Waskasoo Creek	Upper Reach	15931.12	881.56	882.54	883.22	883.50	883.71	883.86	883.93	884.00	884.05	884.13	884.17	884.18	884.27	884.36	DOWNSTREAM OF CP RAIL BRIDGE
XS 439	Waskasoo Creek	Upper Reach	15863.30	881.3	882.42	883.05	883.30	883.48	883.59	883.66	883.74	883.81	883.95	884.06	884.13	884.22	884.28	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 440	Waskasoo Creek	Upper Reach	15712.60	880.97	882.27	882.89	883.16	883.35	883.48	883.56	883.65	883.71	883.85	883.96	884.03	884.12	884.18	
XS 441	Waskasoo Creek	Upper Reach	15523.43	880.93	882.11	882.73	883.02	883.23	883.37	883.46	883.56	883.62	883.77	883.89	883.97	884.05	884.13	UPSTREAM OF RANGE ROAD 275 BRIDGE
XS 442	Waskasoo Creek	Upper Reach	15503.48	880.92	882.06	882.69	883.00	883.20	883.35	883.44	883.54	883.61	883.76	883.88	883.95	884.04	884.11	DOWNSTREAM OF RANGE ROAD 275 BRIDGE
XS 443	Waskasoo Creek	Upper Reach	15412.03	880.83	881.94	882.58	882.91	883.13	883.28	883.37	883.47	883.54	883.70	883.82	883.90	883.99	884.06	
XS 444	Waskasoo Creek	Upper Reach	15264.07	880.69	881.83	882.48	882.81	883.04	883.19	883.29	883.39	883.46	883.61	883.72	883.80	883.89	883.96	
XS 445	Waskasoo Creek	Upper Reach	15046.85	880.41	881.65	882.31	882.63	882.82	882.94	883.01	883.09	883.15	883.25	883.33	883.38	883.45	883.56	
XS 446	Waskasoo Creek	Upper Reach	14987.57	880.35	881.51	882.19	882.51	882.70	882.83	882.91	883.00	883.07	883.19	883.28	883.34	883.42	883.55	
XS 447	Waskasoo Creek	Upper Reach	14873.61	880.28	881.16	881.93	882.33	882.50	882.59	882.66	882.72	882.77	882.88	882.99	883.14	883.24	883.43	
XS 448	Waskasoo Creek	Upper Reach	14701.16	879.54	880.99	881.80	882.24	882.41	882.49	882.53	882.58	882.61	882.68	882.91	883.10	883.21	883.41	
XS 449	Waskasoo Creek	Upper Reach	14592.40	879.57	880.91	881.75	882.21	882.37	882.44	882.48	882.53	882.54	882.60	882.88	883.08	883.20	883.40	UPSTREAM OF PRIVATE CULVERT
XS 450	Waskasoo Creek	Upper Reach	14579.99	879.04	880.77	881.49	881.79	882.01	882.13	882.19	882.25	882.28	882.35	882.87	883.08	883.20	883.40	DOWNSTREAM OF PRIVATE CULVERT
XS 451	Waskasoo Creek	Upper Reach	14510.07	879.37	880.71	881.41	881.69	881.87	881.96	882.01	882.06	882.10	882.18	882.87	883.08	883.19	883.40	
XS 452	Waskasoo Creek	Upper Reach	14342.99	879.22	880.45	881.19	881.43	881.61	881.71	881.77	881.83	881.87	882.06	882.86	883.07	883.19	883.40	
XS 453	Waskasoo Creek	Upper Reach	14193.57	878.64	880.23	880.93	881.21	881.45	881.60	881.68	881.74	881.79	882.03	882.86	883.07	883.19	883.39	
XS 454	Waskasoo Creek	Upper Reach	14004.32	878.47	880.04	880.68	880.96	881.21	881.39	881.51	881.57	881.63	881.96	882.85	883.06	883.18	883.39	
XS 455	Waskasoo Creek	Upper Reach	13802.78	878.27	879.82	880.41	880.71	880.96	881.13	881.21	881.32	881.40	881.90	882.84	883.05	883.17	883.38	
XS 456	Waskasoo Creek	Upper Reach	13649.30	878.26	879.69	880.28	880.57	880.81	880.97	881.08	881.22	881.33	881.88	882.83	883.05	883.17	883.38	
XS 457	Waskasoo Creek	Upper Reach	13465.48	878.1	879.55	880.12	880.41	880.69	880.90	881.03	881.19	881.30	881.87	882.83	883.05	883.16	883.38	
XS 458	Waskasoo Creek	Upper Reach	13302.59	878.19	879.35	879.93	880.26	880.57	880.80	880.95	881.12	881.24	881.85	882.82	883.04	883.16	883.37	
XS 459	Waskasoo Creek	Upper Reach	13076.77	877.83	879.15	879.79	880.15	880.46	880.70	880.85	881.02	881.15	881.82	882.82	883.04	883.15	883.36	
XS 460	Waskasoo Creek	Upper Reach	12913.65	877.78	879.01	879.66	880.01	880.32	880.55	880.70	880.87	881.01	881.76	882.80	883.02	883.13	883.34	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 461	Waskasoo Creek	Upper Reach	12667.91	877.59	878.73	879.38	879.75	880.03	880.22	880.34	880.50	880.63	881.61	882.79	883.01	883.13	883.34	UPSTREAM OF TOWNSHIP ROAD 380 BRIDGE
XS 462	Waskasoo Creek	Upper Reach	12641.14	877.28	878.73	879.38	879.73	879.98	880.15	880.25	880.37	880.49	881.36	882.78	883.00	883.12	883.33	DOWNSTREAM OF TOWNSHIP ROAD 380 BRIDGE
XS 463	Waskasoo Creek	Upper Reach	12395.86	877.37	878.62	879.25	879.58	879.83	880.00	880.11	880.26	880.40	881.40	882.78	883.01	883.12	883.34	
XS 464	Waskasoo Creek	Upper Reach	12220.91	876.99	878.45	879.10	879.44	879.70	879.88	880.00	880.16	880.32	881.40	882.78	883.00	883.12	883.34	
XS 465	Waskasoo Creek	Upper Reach	12067.92	876.86	878.35	879.00	879.34	879.59	879.76	879.88	880.05	880.25	881.39	882.78	883.00	883.12	883.33	
XS 466	Waskasoo Creek	Upper Reach	11940.70	877.03	878.23	878.88	879.20	879.47	879.68	879.82	880.02	880.23	881.39	882.78	883.00	883.12	883.33	
XS 467	Waskasoo Creek	Upper Reach	11667.22	876.75	877.91	878.60	878.96	879.30	879.57	879.74	879.96	880.20	881.39	882.78	883.00	883.12	883.33	
XS 468	Waskasoo Creek	Upper Reach	11485.96	876.57	877.65	878.43	878.84	879.21	879.49	879.66	879.89	880.15	881.38	882.78	883.00	883.11	883.33	UPSTREAM OF PRIVATE BRIDGE
XS 469	Waskasoo Creek	Upper Reach	11460.21	876.39	877.64	878.40	878.80	879.16	879.42	879.58	879.82	880.11	881.38	882.78	883.00	883.11	883.33	DOWNSTREAM OF PRIVATE BRIDGE
XS 470	Waskasoo Creek	Upper Reach	11251.34	875.86	877.50	878.22	878.59	878.94	879.19	879.37	879.69	880.06	881.37	882.78	883.00	883.11	883.33	
XS 471	Waskasoo Creek	Upper Reach	11082.43	876.06	877.43	878.14	878.50	878.85	879.12	879.32	879.65	880.04	881.37	882.77	883.00	883.11	883.33	
XS 472	Waskasoo Creek	Upper Reach	10922.10	875.77	877.34	878.02	878.38	878.72	878.99	879.18	879.55	879.96	881.35	882.76	882.99	883.10	883.32	
XS 473	Waskasoo Creek	Upper Reach	10770.32	875.99	877.21	877.90	878.27	878.63	878.92	879.13	879.52	879.97	881.35	882.77	882.99	883.10	883.32	
XS 474	Waskasoo Creek	Upper Reach	10618.72	875.54	877.04	877.74	878.13	878.51	878.83	879.07	879.50	879.96	881.35	882.77	882.99	883.10	883.32	
XS 475	Waskasoo Creek	Upper Reach	10547.19	875.89	876.93	877.63	878.03	878.43	878.74	879.05	879.49	879.95	881.35	882.77	882.99	883.10	883.32	
XS 476	Waskasoo Creek	Upper Reach	10395.28	875.46	876.81	877.52	877.93	878.34	878.67	878.99	879.45	879.93	881.34	882.76	882.98	883.09	883.31	
XS 477	Waskasoo Creek	Upper Reach	10250.98	875.36	876.70	877.38	877.79	878.21	878.55	878.93	879.43	879.92	881.34	882.76	882.98	883.10	883.31	
XS 478	Waskasoo Creek	Upper Reach	10107.98	875.36	876.52	877.19	877.61	878.09	878.56	878.94	879.43	879.92	881.34	882.76	882.98	883.10	883.31	
XS 479	Waskasoo Creek	Upper Reach	9937.59	874.9	876.29	877.00	877.44	877.94	878.46	878.87	879.40	879.90	881.34	882.76	882.98	883.09	883.31	
XS 480	Waskasoo Creek	Upper Reach	9779.72	874.89	876.09	876.83	877.32	877.87	878.42	878.84	879.38	879.89	881.33	882.76	882.98	883.09	883.31	
XS 481	Waskasoo Creek	Upper Reach	9616.96	874.65	875.98	876.71	877.24	877.81	878.37	878.80	879.37	879.89	881.33	882.76	882.98	883.09	883.31	UPSTREAM OF RANGE ROAD 275 BRIDGE

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 482	Waskasoo Creek	Upper Reach	9597.33	874.97	875.94	876.67	877.22	877.79	878.35	878.76	879.34	879.89	881.33	882.76	882.98	883.09	883.31	DOWNSTREAM OF RANGE ROAD 275 BRIDGE
XS 483	Waskasoo Creek	Upper Reach	9504.05	874.77	875.81	876.58	877.16	877.76	878.33	878.74	879.30	879.85	881.30	882.75	882.98	883.09	883.31	UPSTREAM OF CP RAIL CULVERT
XS 484	Waskasoo Creek	Upper Reach	9462.94	874.51	875.79	876.53	877.07	877.57	878.02	878.31	878.71	879.11	880.12	881.12	881.41	881.55	881.62	DOWNSTREAM OF CP RAIL CULVERT
XS 485	Waskasoo Creek	Upper Reach	9429.14	875.09	875.70	876.44	876.96	877.44	877.86	878.14	878.53	878.94	879.95	880.96	881.41	881.57	881.64	UPSTREAM OF HIGHWAY 2 BRIDGE
XS 486	Waskasoo Creek	Upper Reach	9346.23	874.1	875.57	876.28	876.71	877.03	877.26	877.38	877.49	877.57	877.75	877.85	877.91	877.96	878.00	DOWNSTREAM OF HIGHWAY 2 BRIDGE
XS 487	Waskasoo Creek	Upper Reach	9147.63	873.56	875.54	876.22	876.63	876.95	877.19	877.31	877.43	877.52	877.73	877.86	877.94	878.03	878.10	
XS 488	Waskasoo Creek	Upper Reach	9018.24	874.34	875.49	876.16	876.56	876.88	877.12	877.25	877.36	877.45	877.67	877.80	877.89	877.98	878.04	
XS 489	Waskasoo Creek	Upper Reach	8846.00	874.26	875.35	875.99	876.39	876.71	876.96	877.08	877.18	877.26	877.45	877.56	877.64	877.73	877.79	
XS 490	Waskasoo Creek	Upper Reach	8736.87	874.21	875.27	875.93	876.33	876.65	876.90	877.02	877.12	877.20	877.40	877.50	877.58	877.66	877.71	UPSTREAM OF PRIVATE BRIDGE
XS 491	Waskasoo Creek	Upper Reach	8714.81	873.95	875.26	875.91	876.30	876.62	876.84	876.94	877.00	877.06	877.22	877.30	877.38	877.45	877.50	DOWNSTREAM OF PRIVATE BRIDGE
XS 492	Waskasoo Creek	Upper Reach	8570.08	873.98	875.16	875.80	876.20	876.51	876.73	876.81	876.89	876.94	877.10	877.16	877.22	877.30	877.35	
XS 493	Waskasoo Creek	Upper Reach	8438.82	873.67	875.02	875.63	876.01	876.31	876.52	876.65	876.80	876.84	877.03	877.07	877.14	877.22	877.27	
XS 494	Waskasoo Creek	Upper Reach	8263.11	873.69	874.86	875.43	875.80	876.10	876.32	876.46	876.60	876.71	876.92	876.92	876.98	877.06	877.12	
XS 495	Waskasoo Creek	Upper Reach	8078.89	873.44	874.69	875.23	875.59	875.89	876.10	876.23	876.37	876.47	876.68	876.76	876.85	876.93	876.99	
XS 496	Waskasoo Creek	Upper Reach	7820.01	873.17	874.45	874.95	875.29	875.58	875.78	875.91	876.06	876.16	876.38	876.50	876.59	876.68	876.75	
XS 497	Waskasoo Creek	Upper Reach	7669.98	873.16	874.19	874.68	875.01	875.29	875.49	875.62	875.78	875.88	876.09	876.15	876.21	876.28	876.32	
XS 498	Waskasoo Creek	Upper Reach	7547.78	872.75	873.63	874.16	874.52	874.80	875.01	875.13	875.36	875.47	875.67	875.86	875.96	876.09	876.16	
XS 499	Waskasoo Creek	Upper Reach	7375.95	872.24	873.37	873.85	874.17	874.45	874.67	874.83	875.18	875.31	875.56	875.73	875.83	875.95	876.03	
XS 500	Waskasoo Creek	Upper Reach	7248.84	872.34	873.09	873.52	873.78	874.01	874.21	874.41	875.03	875.20	875.48	875.66	875.77	875.89	875.97	
XS 501	Waskasoo Creek	Upper Reach	7148.16	871.92	872.89	873.31	873.55	873.78	874.01	874.27	875.00	875.17	875.44	875.63	875.73	875.86	875.93	
XS 502	Waskasoo Creek	Upper Reach	7021.19	871.87	872.30	872.60	872.88	873.31	873.67	874.09	874.96	875.14	875.42	875.60	875.71	875.83	875.91	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 503	Waskasoo Creek	Upper Reach	6853.29	870.75	871.54	872.16	872.61	873.06	873.44	873.92	874.86	875.06	875.34	875.52	875.62	875.74	875.82	UPSTREAM OF TAYLOR DRIVE CULVERT
XS 504	Waskasoo Creek	Upper Reach	6764.34	869.99	870.61	870.98	871.22	871.43	871.91	872.88	873.43	873.54	873.70	873.79	873.84	873.93	873.96	DOWNSTREAM OF TAYLOR DRIVE CULVERT
XS 505	Waskasoo Creek	Upper Reach	6736.27	869.78	870.42	870.91	871.20	871.47	871.99	872.94	873.49	873.60	873.80	873.92	874.00	874.12	874.18	
XS 506	Waskasoo Creek	Upper Reach	6604.86	868.97	870.09	870.56	870.76	871.01	871.83	872.91	873.48	873.59	873.78	873.90	873.98	874.10	874.16	
XS 507	Waskasoo Creek	Upper Reach	6578.44	869.24	869.80	870.26	870.45	870.94	871.82	872.90	873.46	873.57	873.76	873.88	873.95	874.07	874.13	
XS 508	Waskasoo Creek	Upper Reach	6496.52	868.33	869.28	869.80	870.21	870.89	871.79	872.90	873.46	873.57	873.76	873.88	873.96	874.08	874.13	
XS 509	Waskasoo Creek	Upper Reach	6369.44	867.92	868.59	869.19	869.73	870.59	871.59	872.75	873.36	873.48	873.67	873.78	873.85	873.97	874.02	UPSTREAM OF 32 STREET CULVERT
XS 510	Waskasoo Creek	Upper Reach	6250.98	866.49	867.74	868.42	868.94	869.55	870.20	870.81	871.51	871.75	872.08	872.23	872.32	872.96	873.14	DOWNSTREAM OF 32 STREET CULVERT
XS 511	Waskasoo Creek	Upper Reach	6174.52	866.43	867.68	868.38	868.93	869.56	870.23	870.85	871.55	871.81	872.16	872.33	872.44	873.09	873.26	
XS 512	Waskasoo Creek	Upper Reach	6071.06	866.55	867.58	868.32	868.89	869.53	870.20	870.83	871.54	871.79	872.13	872.30	872.40	873.07	873.24	
XS 513	Waskasoo Creek	Upper Reach	5969.64	866.42	867.41	868.12	868.66	869.28	869.95	870.67	871.43	871.68	872.00	872.18	872.29	873.04	873.22	UPSTREAM OF 34 STREET CULVERT
XS 514	Waskasoo Creek	Upper Reach	5812.23	865.92	866.60	867.04	867.35	867.66	867.92	868.09	868.29	868.44	868.80	869.10	869.30	869.52	870.34	DOWNSTREAM OF 34 STREET CULVERT
XS 515	Waskasoo Creek	Upper Reach	5718.90	865.08	865.94	866.40	866.71	866.97	867.16	867.28	867.41	867.50	867.72	867.91	868.00	868.13	868.23	
XS 516	Waskasoo Creek	Upper Reach	5570.90	864.77	865.56	866.00	866.35	866.62	866.82	866.95	867.08	867.17	867.38	867.58	867.64	867.76	867.84	
XS 517	Waskasoo Creek	Upper Reach	5360.57	863.88	864.72	865.19	865.49	865.78	866.00	866.15	866.31	866.45	866.79	867.06	867.26	867.43	867.56	
XS 518	Waskasoo Creek	Upper Reach	5284.36	863.52	864.52	864.97	865.27	865.55	865.77	865.90	866.04	866.15	866.40	866.62	866.69	866.77	866.86	
XS 519	Waskasoo Creek	Upper Reach	5221.91	863.49	864.33	864.72	865.03	865.30	865.50	865.64	865.82	865.97	866.26	866.53	866.60	866.68	866.78	UPSTREAM OF ACR TRAIL SOUTH PEDESTRIAN BRIDGE
XS 520	Waskasoo Creek	Upper Reach	5200.05	863.15	864.10	864.63	864.98	865.26	865.47	865.60	865.76	865.89	866.12	866.32	866.42	866.57	866.63	DOWNSTREAM OF ACR TRAIL SOUTH PEDESTRIAN BRIDGE
XS 521	Waskasoo Creek	Upper Reach	5124.74	862.91	863.78	864.22	864.54	864.82	865.02	865.16	865.34	865.48	865.65	865.65	865.75	865.80	865.89	
XS 522	Waskasoo Creek	Upper Reach	5012.50	862.39	863.23	863.62	863.89	864.11	864.26	864.32	864.34	864.35	864.69	865.02	865.07	865.33	865.39	UPSTREAM OF ACR TRAIL NORTH PEDESTRIAN BRIDGE
XS 523	Waskasoo Creek	Upper Reach	4997.96	862.56	863.09	863.49	863.77	863.99	864.12	864.24	864.37	864.47	864.70	864.88	864.97	865.09	865.15	DOWNSTREAM OF ACR TRAIL NORTH PEDESTRIAN BRIDGE

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 524	Waskasoo Creek	Upper Reach	4824.15	861.39	862.17	862.59	862.86	863.14	863.54	863.63	863.77	863.85	864.02	864.16	864.26	864.38	864.48	
XS 525	Waskasoo Creek	Upper Reach	4707.23	860.96	861.69	862.06	862.39	862.80	863.37	863.43	863.56	863.63	863.73	863.80	863.85	863.89	863.92	
XS 526	Waskasoo Creek	Upper Reach	4524.34	860.02	860.79	861.47	862.00	862.55	863.25	863.28	863.41	863.47	863.52	863.59	863.59	863.62	863.65	UPSTREAM OF 43 STREET CULVERT
XS 527	Waskasoo Creek	Upper Reach	4472.18	859.44	860.00	860.40	860.67	860.87	861.03	861.13	861.25	861.33	861.52	861.70	861.79	861.91	861.98	DOWNSTREAM OF 43 STREET CULVERT
XS 528	Waskasoo Creek	Upper Reach	4376.01	857.84	858.69	859.12	859.44	859.76	860.02	860.16	860.32	860.42	860.76	861.15	861.17	861.19	861.55	
XS 529	Waskasoo Creek	Upper Reach	4305.61	857.48	858.23	858.66	858.87	859.02	859.16	859.29	859.44	859.58	860.37	861.12	861.17	861.22	861.24	
XS 530	Waskasoo Creek	Upper Reach	4243.46	857.09	857.70	858.04	858.42	858.72	859.07	859.35	859.45	859.74	860.49	861.11	861.14	861.17	861.17	
XS 531	Waskasoo Creek	Upper Reach	4209.08	856.84	857.53	857.92	858.32	858.67	859.04	859.34	859.43	859.73	860.49	861.11	861.14	861.17	861.17	
XS 532	Waskasoo Creek	Upper Reach	4168.37	856.74	857.39	857.68	858.19	858.59	859.00	859.31	859.40	859.71	860.48	861.10	861.14	861.17	861.17	UPSTREAM OF 52 AVENUE & 45 STREET LOOP CULVERT
XS 533	Waskasoo Creek	Upper Reach	4120.06	856.35	857.06	857.51	857.82	858.09	858.30	858.42	858.55	858.64	858.84	859.01	859.12	859.24	859.33	DOWNSTREAM OF 52 AVENUE & 45 STREET LOOP CULVERT
XS 534	Waskasoo Creek	Upper Reach	4072.56	855.99	856.64	857.12	857.49	857.78	858.00	858.12	858.24	858.31	858.44	858.55	858.62	858.71	858.77	
XS 535	Waskasoo Creek	Upper Reach	3935.85	855.13	856.18	856.75	857.10	857.41	857.67	857.81	857.93	857.99	858.08	858.11	858.14	858.16	858.18	
XS 536	Waskasoo Creek	Upper Reach	3822.85	855.27	855.96	856.55	856.93	857.26	857.54	857.71	857.84	857.91	858.03	858.05	858.09	858.12	858.14	UPSTREAM OF 50 AVENUE (GAETZ AVENUE) BRIDGE[4]
XS 537	Waskasoo Creek	Upper Reach	3782.86	855.09	855.91	856.53	856.89	857.20	857.45	857.61	857.70	857.77	857.93	857.93	857.95	857.99	858.02	DOWNSTREAM OF 50 AVENUE (GAETZ AVENUE) BRIDGE[4]
XS 538	Waskasoo Creek	Upper Reach	3737.66	855	855.78	856.39	856.75	857.04	857.28	857.42	857.55	857.63	857.75	857.75	857.78	857.82	857.84	SAFEWAY DIKE
XS 539	Waskasoo Creek	Upper Reach	3635.27	854.58	855.53	856.11	856.47	856.76	857.00	857.11	857.14	857.41	857.55	857.55	857.57	857.60	857.74	UPSTREAM OF 49 AVENUE BRIDGE; SAFEWAY DIKE
XS 540	Waskasoo Creek	Upper Reach	3599.87	854.61	855.44	856.03	856.41	856.71	856.98	857.13	857.28	857.33	857.40	857.48	857.56	857.67	857.76	DOWNSTREAM OF 49 AVENUE BRIDGE
XS 541	Waskasoo Creek	Upper Reach	3582.46	854.57	855.36	855.95	856.34	856.68	856.96	857.12	857.28	857.33	857.40	857.48	857.56	857.68	857.76	
XS 542	Waskasoo Creek	Lower Reach	3498.19	854.16	855.18	855.71	856.05	856.37	856.63	856.77	856.93	857.02	857.18	857.34	857.45	857.61	857.72	
XS 543	Waskasoo Creek	Lower Reach	3443.94	854.06	854.96	855.37	855.72	856.08	856.41	856.65	856.87	856.98	857.14	857.31	857.43	857.59	857.71	BAYMONT DIKE
XS 544	Waskasoo Creek	Lower Reach	3420.28	854.1	854.67	855.04	855.67	856.09	856.40	856.59	856.74	856.84	857.09	857.29	857.42	857.59	857.71	UPSTREAM OF 48 AVENUE CULVERT; BAYMONT DIKE

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 545	Waskasoo Creek	Lower Reach	3359.85	853.99	854.65	855.24	855.68	856.04	856.32	856.47	856.66	856.78	856.98	857.23	857.39	857.57	857.70	DOWNSTREAM OF 48 AVENUE CULVERT
XS 546	Waskasoo Creek	Lower Reach	3316.46	853.66	854.44	855.06	855.49	855.86	856.13	856.28	856.43	856.54	856.89	857.19	857.36	857.55	857.69	
XS 547	Waskasoo Creek	Lower Reach	3176.45	852.87	854.35	854.94	855.36	855.72	855.99	856.14	856.30	856.42	856.75	857.06	857.23	857.44	857.60	
XS 548	Waskasoo Creek	Lower Reach	3115.07	853.3	854.26	854.78	855.19	855.52	855.76	855.88	855.97	856.03	856.25	856.48	856.58	856.70	856.77	
XS 549	Waskasoo Creek	Lower Reach	3074.01	853.22	854.14	854.64	855.06	855.35	855.58	855.72	855.91	856.04	856.41	856.73	856.88	857.06	857.19	
XS 550	Waskasoo Creek	Lower Reach	2990.35	852.96	853.59	854.35	854.82	855.19	855.46	855.62	855.82	855.96	856.35	856.68	856.83	857.01	857.14	
XS 551	Waskasoo Creek	Lower Reach	2834.76	852.23	853.57	854.35	854.82	855.19	855.47	855.64	855.83	855.96	856.34	856.67	856.82	857.00	857.13	
XS 552	Waskasoo Creek	Lower Reach	2754.18	852.04	853.53	854.30	854.75	855.11	855.38	855.55	855.75	855.88	856.28	856.60	856.76	856.94	857.06	
XS 553	Waskasoo Creek	Lower Reach	2662.06	852.07	853.48	854.25	854.70	855.06	855.32	855.47	855.65	855.77	856.14	856.45	856.59	856.76	856.87	
XS 554	Waskasoo Creek	Lower Reach	2558.02	852.15	853.39	854.15	854.59	854.95	855.22	855.39	855.57	855.70	856.08	856.41	856.55	856.72	856.85	
XS 555	Waskasoo Creek	Lower Reach	2475.85	851.97	853.30	854.05	854.47	854.82	855.08	855.25	855.42	855.54	855.94	856.28	856.42	856.60	856.73	UPSTREAM OF BARETT PARK SOUTH PEDESTRIAN BRIDGE
XS 556	Waskasoo Creek	Lower Reach	2460.33	851.88	853.30	854.06	854.48	854.83	855.09	855.25	855.41	855.52	855.89	856.23	856.37	856.56	856.70	DOWNSTREAM OF BARETT PARK SOUTH PEDESTRIAN BRIDGE
XS 557	Waskasoo Creek	Lower Reach	2340.35	851.85	853.21	853.96	854.37	854.71	854.95	855.11	855.27	855.39	855.82	856.19	856.34	856.53	856.67	
XS 558	Waskasoo Creek	Lower Reach	2208.95	851.8	853.13	853.85	854.27	854.59	854.83	854.99	855.15	855.27	855.73	856.14	856.29	856.49	856.63	
XS 559	Waskasoo Creek	Lower Reach	2095.24	851.79	853.03	853.73	854.15	854.47	854.71	854.86	855.02	855.13	855.60	856.00	856.14	856.35	856.49	
XS 560	Waskasoo Creek	Lower Reach	2014.00	851.59	852.98	853.67	854.08	854.40	854.63	854.79	854.95	855.07	855.59	856.02	856.17	856.37	856.52	UPSTREAM OF BARRETT PARK NORTH PEDESTRIAN BRIDGE
XS 561	Waskasoo Creek	Lower Reach	1995.83	851.61	852.97	853.65	854.06	854.38	854.61	854.75	854.91	855.03	855.55	855.99	856.14	856.35	856.49	DOWNSTREAM OF BARRETT PARK NORTH PEDESTRIAN BRIDGE
XS 562	Waskasoo Creek	Lower Reach	1935.17	851.48	852.92	853.59	853.99	854.31	854.56	854.71	854.87	854.99	855.53	855.98	856.12	856.34	856.48	
XS 563	Waskasoo Creek	Lower Reach	1825.12	851.62	852.85	853.50	853.88	854.20	854.47	854.64	854.81	854.93	855.50	855.96	856.10	856.32	856.46	
XS 564	Waskasoo Creek	Lower Reach	1700.06	851.33	852.79	853.41	853.78	854.12	854.40	854.58	854.75	854.88	855.47	855.94	856.08	856.29	856.44	
XS 565	Waskasoo Creek	Lower Reach	1604.85	851.32	852.74	853.33	853.69	854.02	854.28	854.44	854.63	854.77	855.43	855.91	856.06	856.27	856.42	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 566	Waskasoo Creek	Lower Reach	1490.25	851.39	852.67	853.21	853.58	853.91	854.19	854.35	854.53	854.69	855.40	855.89	856.04	856.26	856.40	
XS 567	Waskasoo Creek	Lower Reach	1425.81	851.45	852.63	853.16	853.53	853.86	854.13	854.29	854.47	854.61	855.37	855.88	856.02	856.24	856.39	
XS 568	Waskasoo Creek	Lower Reach	1380.23	851.68	852.61	853.13	853.50	853.83	854.10	854.28	854.46	854.62	855.37	855.87	856.02	856.24	856.39	
XS 569	Waskasoo Creek	Lower Reach	1357.45	851.71	852.57	853.07	853.44	853.76	854.03	854.18	854.34	854.48	855.24	855.73	855.86	856.08	856.23	UPSTREAM OF ROSS STREET EASTBOUND AND WESTBOUND BRIDGES
XS 570	Waskasoo Creek	Lower Reach	1303.84	851.64	852.46	852.91	853.26	853.56	853.82	853.97	854.12	854.27	854.89	855.29	855.36	855.64	855.89	DOWNSTREAM OF ROSS STREET EASTBOUND AND WESTBOUND BRIDGES
XS 571	Waskasoo Creek	Lower Reach	1261.65	851.51	852.25	852.68	853.10	853.46	853.76	853.91	854.07	854.23	854.93	855.34	855.41	855.70	855.94	UPSTREAM OF CORONATION PARK SOUTH PEDESTRIAN BRIDGE
XS 572	Waskasoo Creek	Lower Reach	1244.78	851.27	852.07	852.66	853.06	853.41	853.69	853.87	854.09	854.30	854.96	855.35	855.42	855.70	855.94	DOWNSTREAM OF CORONATION PARK SOUTH PEDESTRIAN BRIDGE
XS 573	Waskasoo Creek	Lower Reach	1195.01	850.96	852.01	852.59	852.98	853.33	853.61	853.80	854.01	854.23	854.94	855.34	855.41	855.70	855.93	
XS 574	Waskasoo Creek	Lower Reach	1093.95	850.66	851.93	852.48	852.86	853.21	853.49	853.68	853.90	854.13	854.89	855.32	855.38	855.67	855.92	
XS 575	Waskasoo Creek	Lower Reach	994.89	850.86	851.73	852.15	852.50	852.84	853.19	853.34	853.73	854.03	854.83	855.28	855.34	855.65	855.90	UPSTREAM OF CORONATION PARK NORTH PEDESTRIAN BRIDGE
XS 576	Waskasoo Creek	Lower Reach	969.31	850.98	851.49	852.06	852.45	852.81	853.20	853.44	853.77	854.04	854.81	855.26	855.33	855.63	855.89	DOWNSTREAM OF CORONATION PARK NORTH PEDESTRIAN BRIDGE
XS 577	Waskasoo Creek	Lower Reach	910.68	850.28	851.47	851.99	852.37	852.72	853.12	853.37	853.71	853.99	854.78	855.24	855.30	855.61	855.87	
XS 578	Waskasoo Creek	Lower Reach	843.79	850.48	851.36	851.84	852.20	852.55	853.00	853.27	853.62	853.91	854.75	855.23	855.29	855.61	855.87	UPSTREAM OF 53 STREET BRIDGE
XS 579	Waskasoo Creek	Lower Reach	827.50	850.61	851.31	851.78	852.13	852.47	852.94	853.22	853.58	853.88	854.70	855.19	855.24	855.58	855.85	DOWNSTREAM OF 53 STREET BRIDGE
XS 580	Waskasoo Creek	Lower Reach	698.94	849.96	850.87	851.33	851.67	852.00	852.72	853.06	853.48	853.81	854.66	855.16	855.21	855.56	855.84	
XS 581	Waskasoo Creek	Lower Reach	616.05	849.74	850.74	851.15	851.48	851.79	852.65	853.01	853.45	853.79	854.66	855.16	855.21	855.56	855.83	UPSTREAM OF 55 STREET BRIDGE
XS 582	Waskasoo Creek	Lower Reach	588.67	849.73	850.47	850.97	851.36	851.69	852.63	852.99	853.41	853.72	854.54	855.11	855.16	855.54	855.82	DOWNSTREAM OF 55 STREET BRIDGE
XS 583	Waskasoo Creek	Lower Reach	557.76	849.62	850.39	850.91	851.31	851.65	852.64	853.00	853.41	853.72	854.55	855.12	855.16	855.54	855.82	
XS 584	Waskasoo Creek	Lower Reach	498.82	849.54	850.18	850.80	851.20	851.57	852.62	852.98	853.40	853.71	854.54	855.11	855.16	855.54	855.82	
XS 585	Waskasoo Creek	Lower Reach	380.04	848.8	850.07	850.75	851.16	851.54	852.62	852.98	853.41	853.72	854.55	855.11	855.16	855.54	855.82	
XS 586	Waskasoo Creek	Lower Reach	300.88	848.15	850.06	850.73	851.15	851.52	852.61	852.98	853.40	853.72	854.55	855.11	855.16	855.53	855.81	

Table C.1: Simulated Flood Profiles

Cross Section	River	Reach	River Station	Minimum Channel Elevation	2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1000-year	Notes
XS 587	Waskasoo Creek	Lower Reach	220.41	848.29	850.05	850.72	851.12	851.49	852.59	852.96	853.39	853.70	854.53	855.09	855.13	855.51	855.79	
XS 588	Waskasoo Creek	Lower Reach	164.65	847.98	850.04	850.71	851.11	851.49	852.60	852.97	853.39	853.71	854.54	855.10	855.15	855.52	855.81	UPSTREAM OF GAETZ PARK PEDESTRIAN BRIDGE
XS 589	Waskasoo Creek	Lower Reach	143.29	847.03	850.04	850.71	851.11	851.47	852.59	852.96	853.39	853.70	854.53	855.10	855.14	855.52	855.80	DOWNSTREAM OF GAETZ PARK PEDESTRIAN BRIDGE
XS 590	Waskasoo Creek	Lower Reach	63.24	847.13	850.04	850.71	851.11	851.48	852.59	852.97	853.39	853.70	854.53	855.10	855.15	855.52	855.81	

Notes: 1) Simulated water level replaced with higher water level from lower flow profile to avoid profile crossing.
2) Simulated water level replaced with lower water level from higher flow profile to avoid profile crossing.
3) Simulated water level interpolated between upstream and downstream cross-sections.
4) The 50 Avenue (Gaetz Avenue) Bridge on the Waskasoo Creek was surveyed and modelled as a bridge in the Study. It is acknowledged that the City of Red Deer recognizes this structure as a culvert.

APPENDIX D

Model Sensitivity Analysis

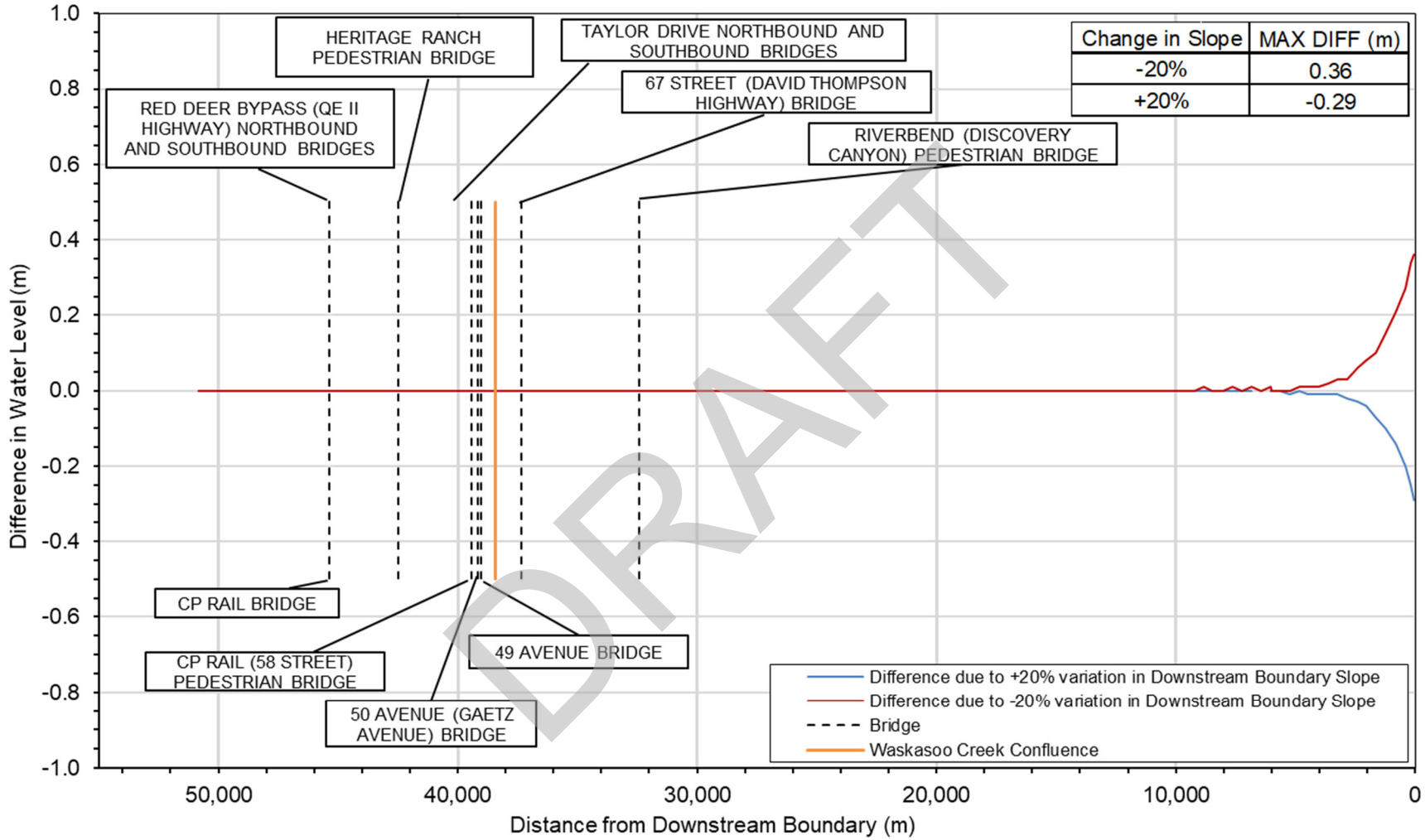

Figure D.1: Downstream Boundary Condition Sensitivity Analysis for Red Deer River

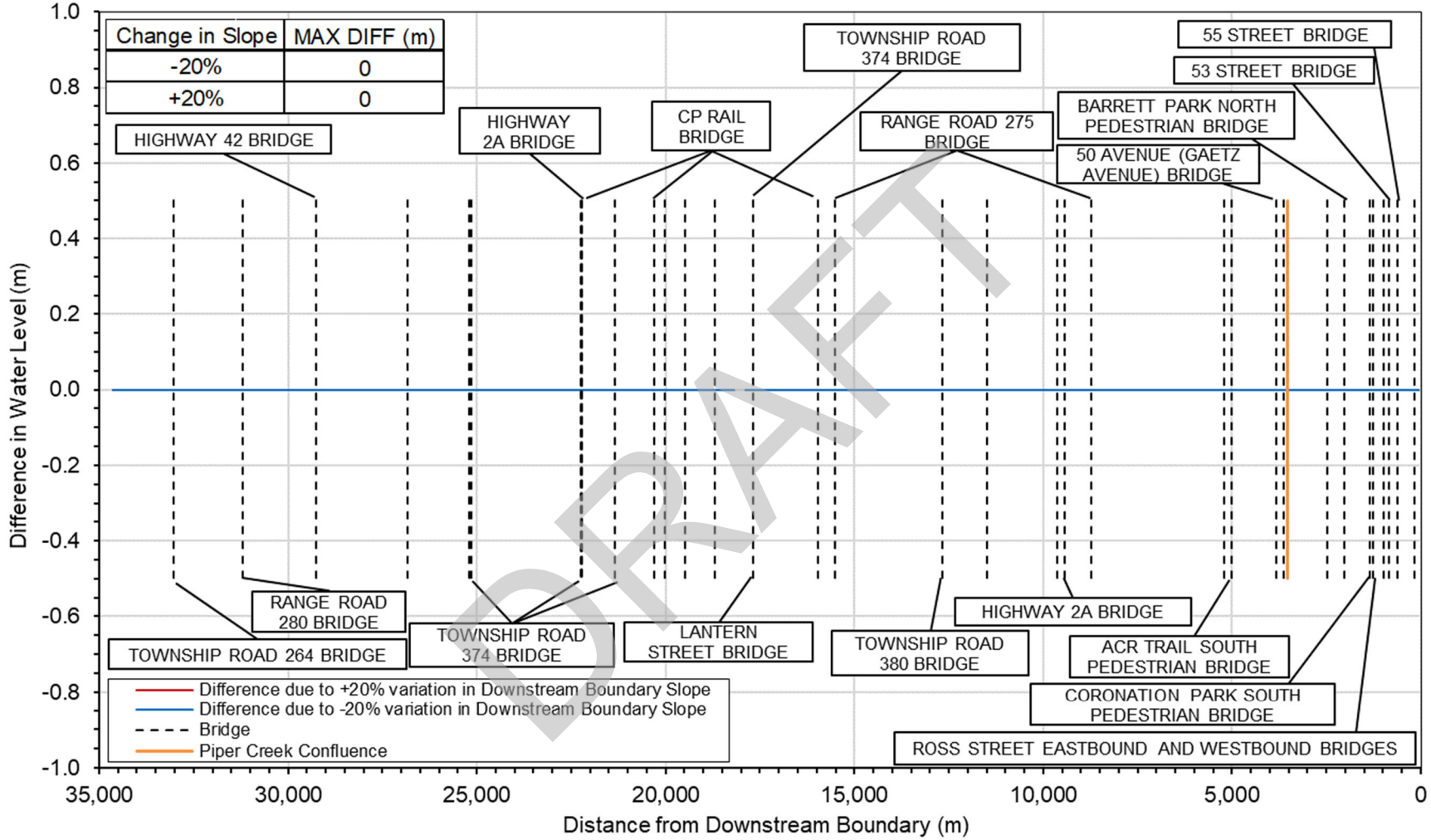

Figure D.2: Downstream Boundary Condition Sensitivity Analysis for Waskasoo Creek

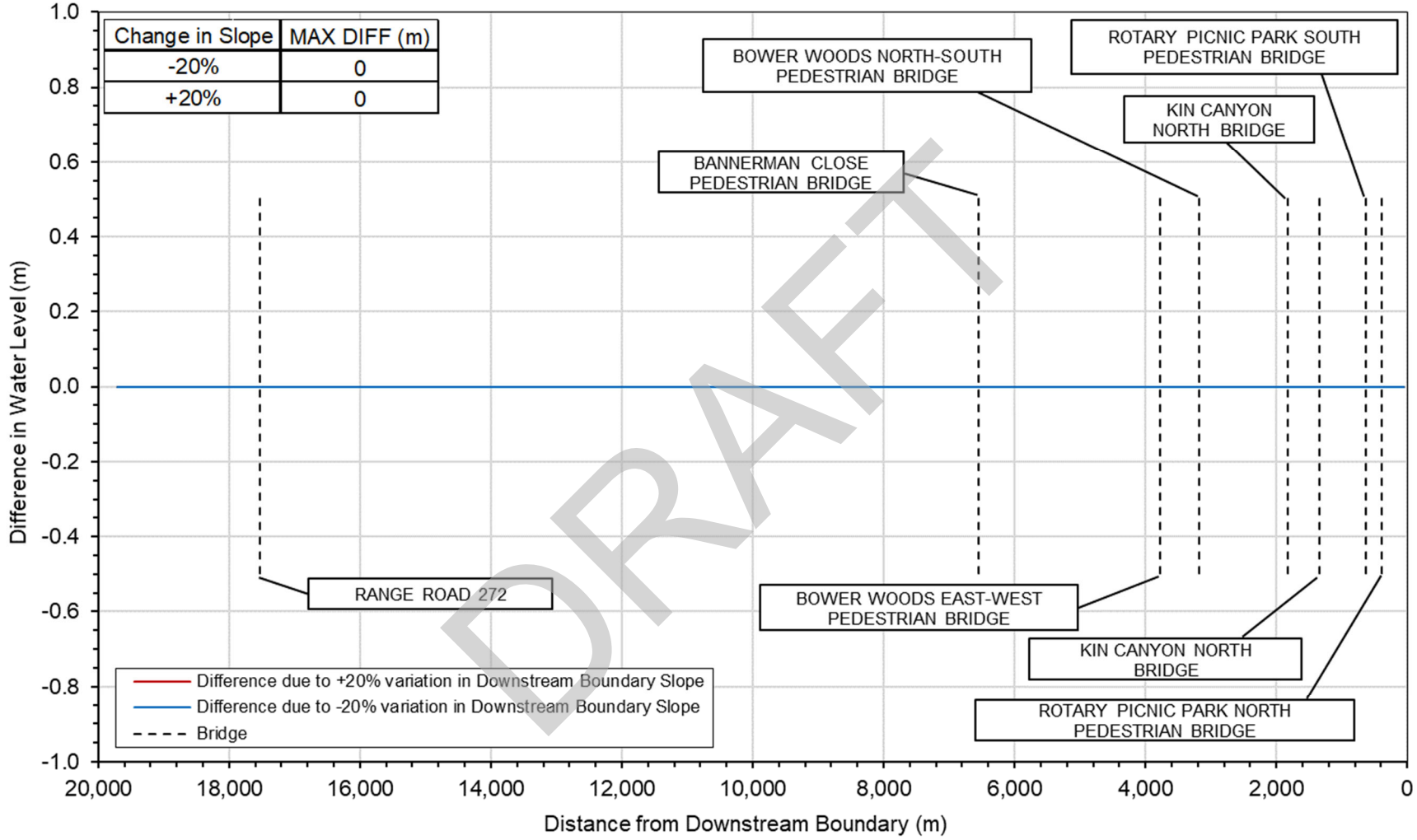

Figure D.3: Downstream Boundary Condition Sensitivity Analysis for Piper Creek

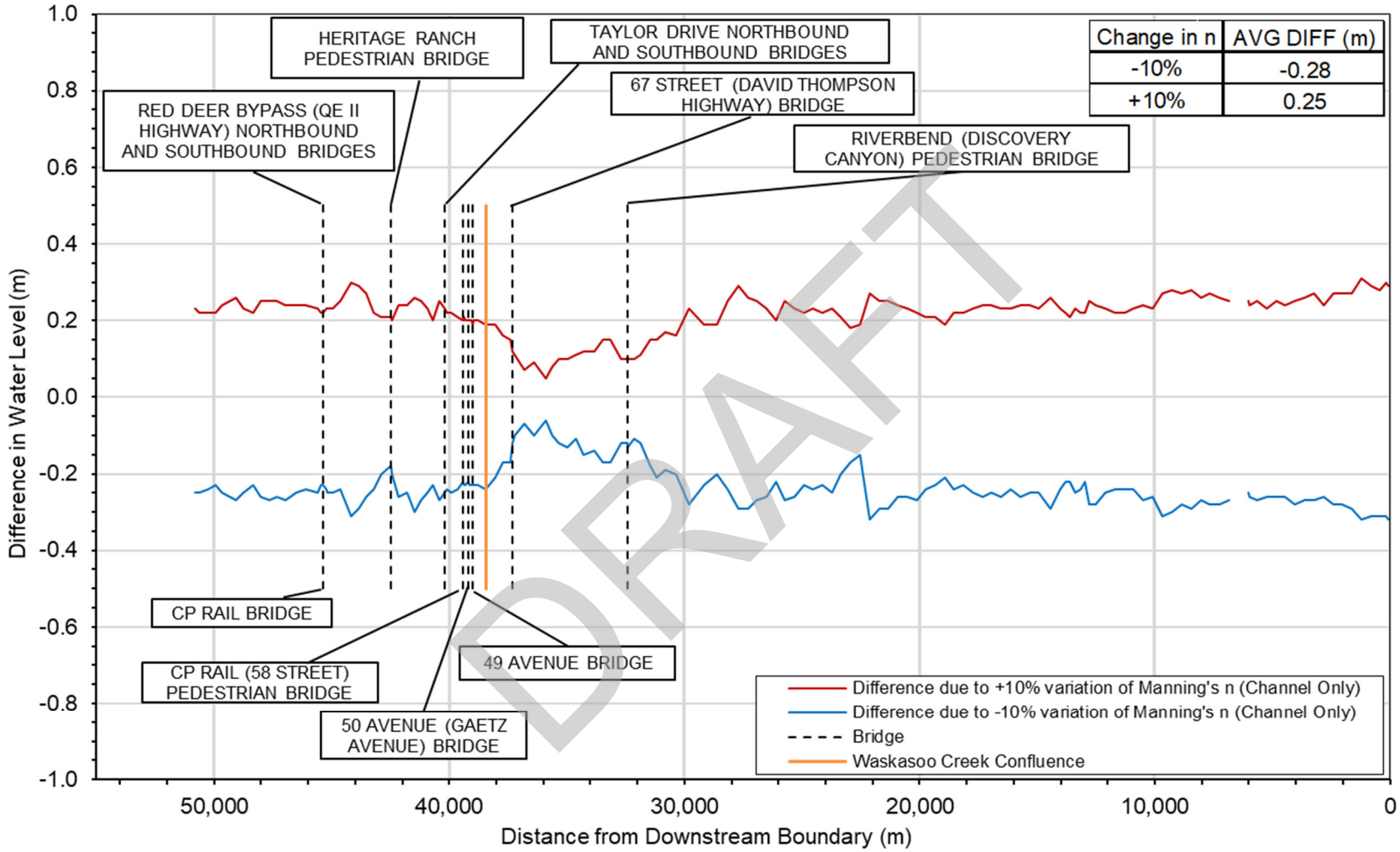

Figure D.4: Channel Roughness Sensitivity Analysis for Red Deer River

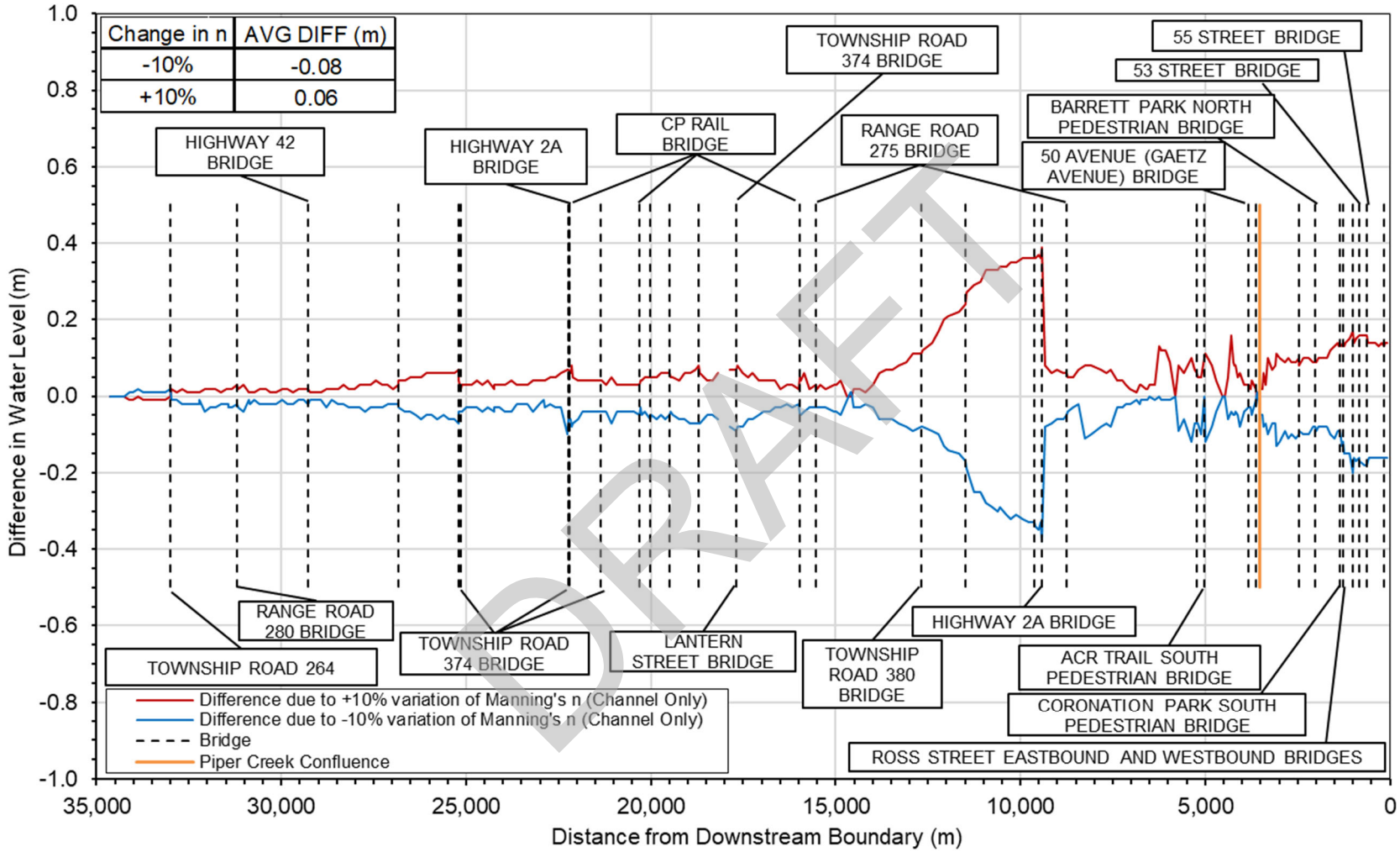

Figure D.5: Channel Roughness Sensitivity Analysis for Waskasoo Creek

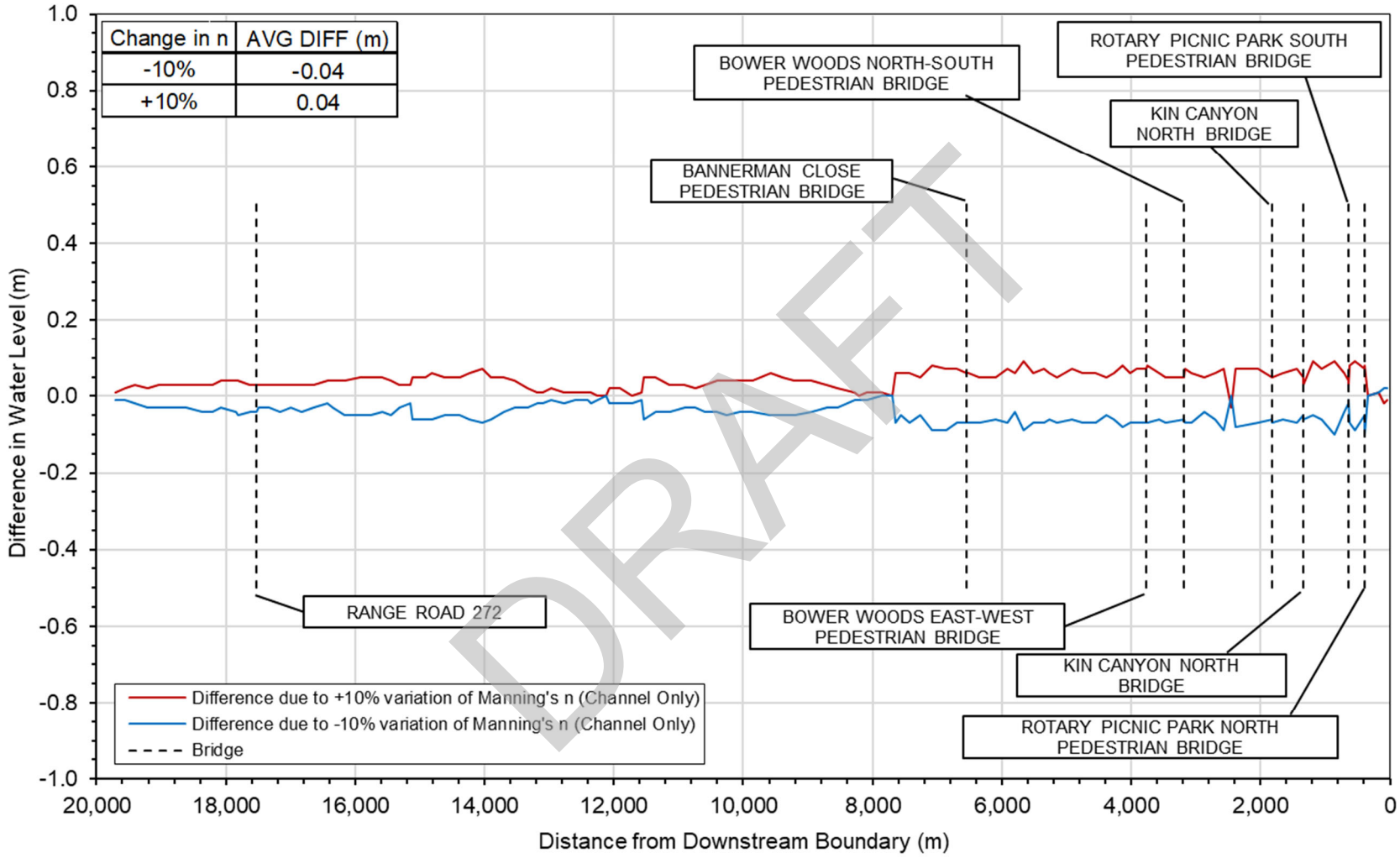

Figure D.6: Channel Roughness Sensitivity Analysis for Piper Creek

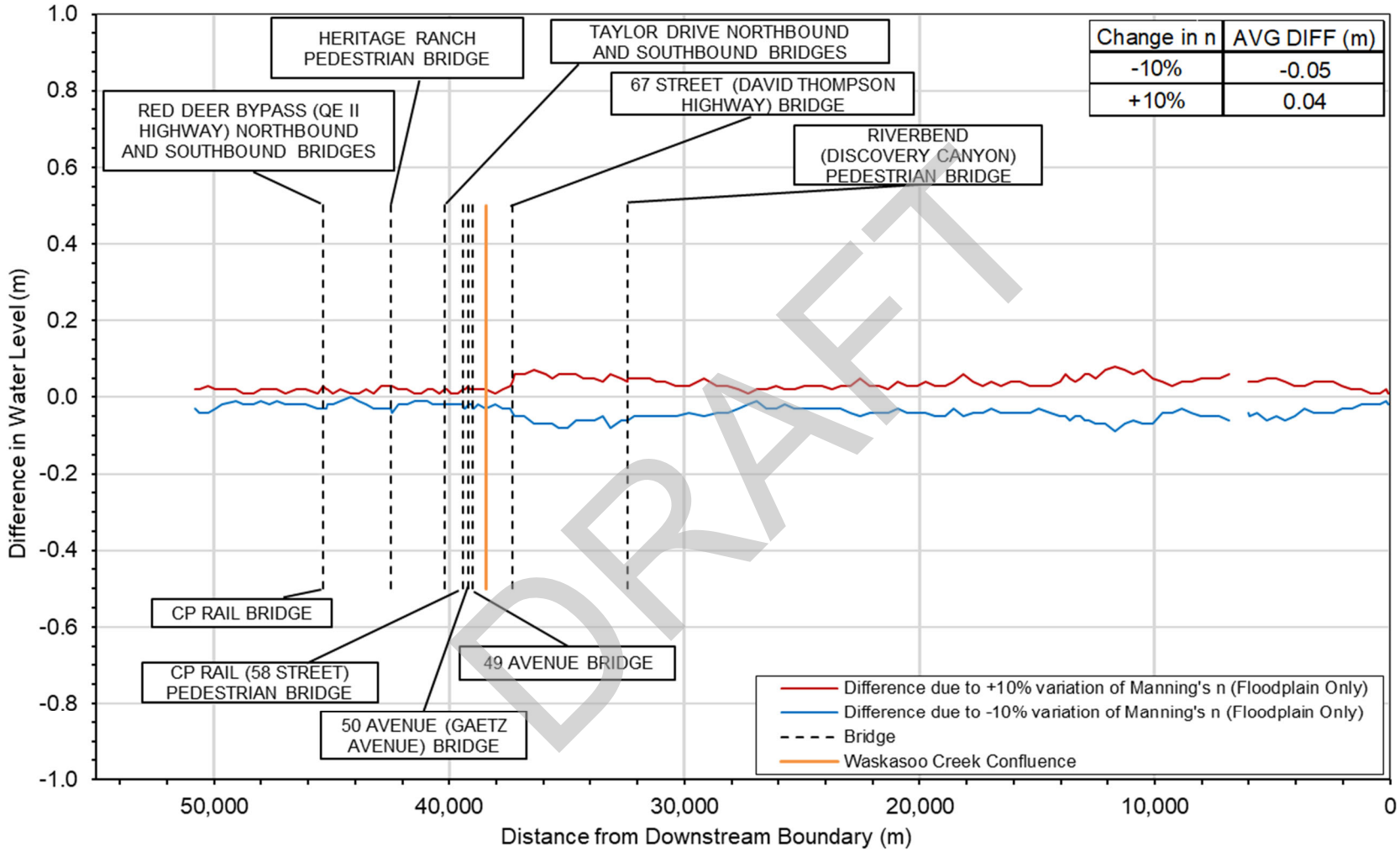

Figure D.7: Floodplain Roughness Sensitivity Analysis for Red Deer River

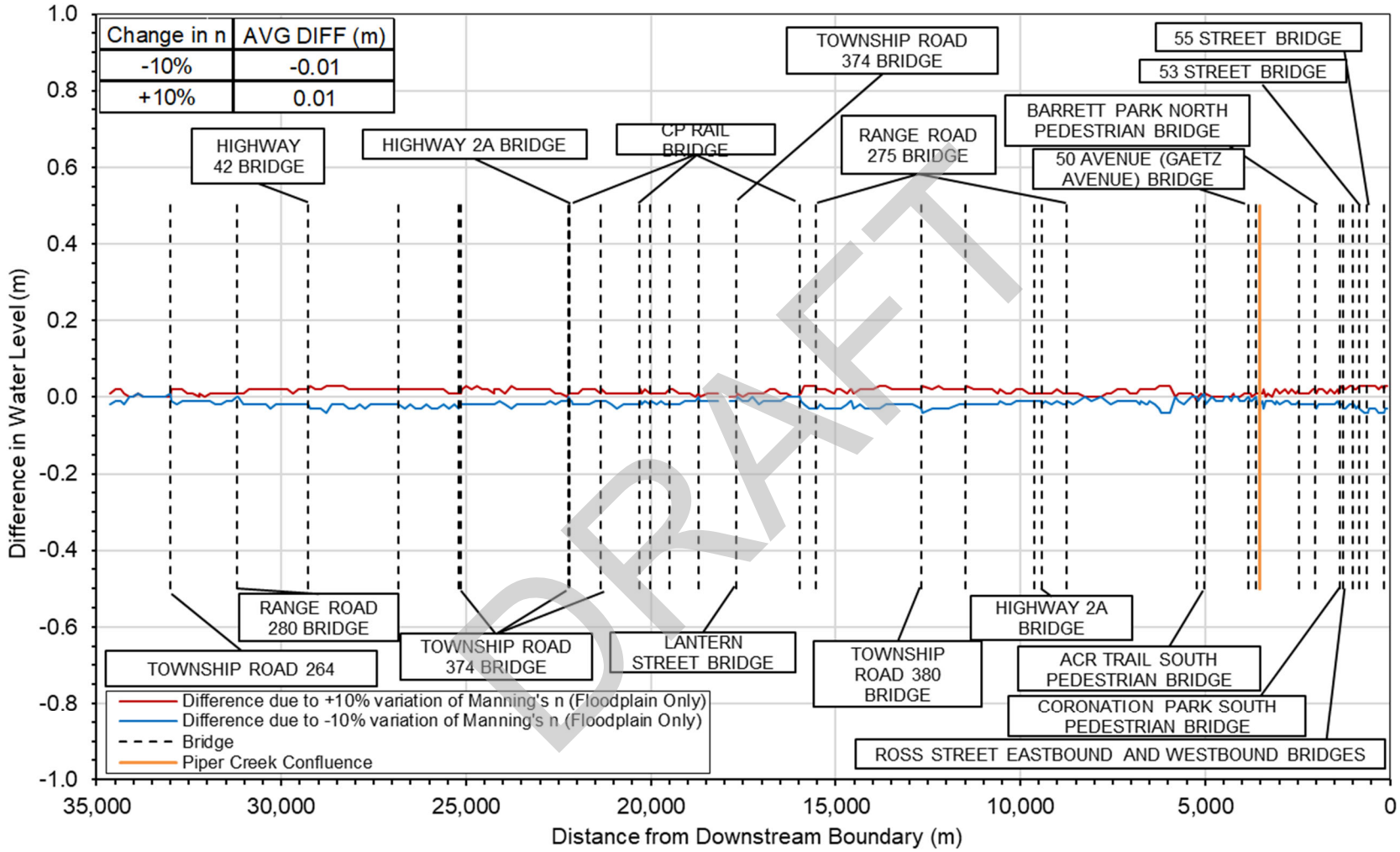

Figure D.8: Floodplain Roughness Sensitivity Analysis for Waskasoo Creek

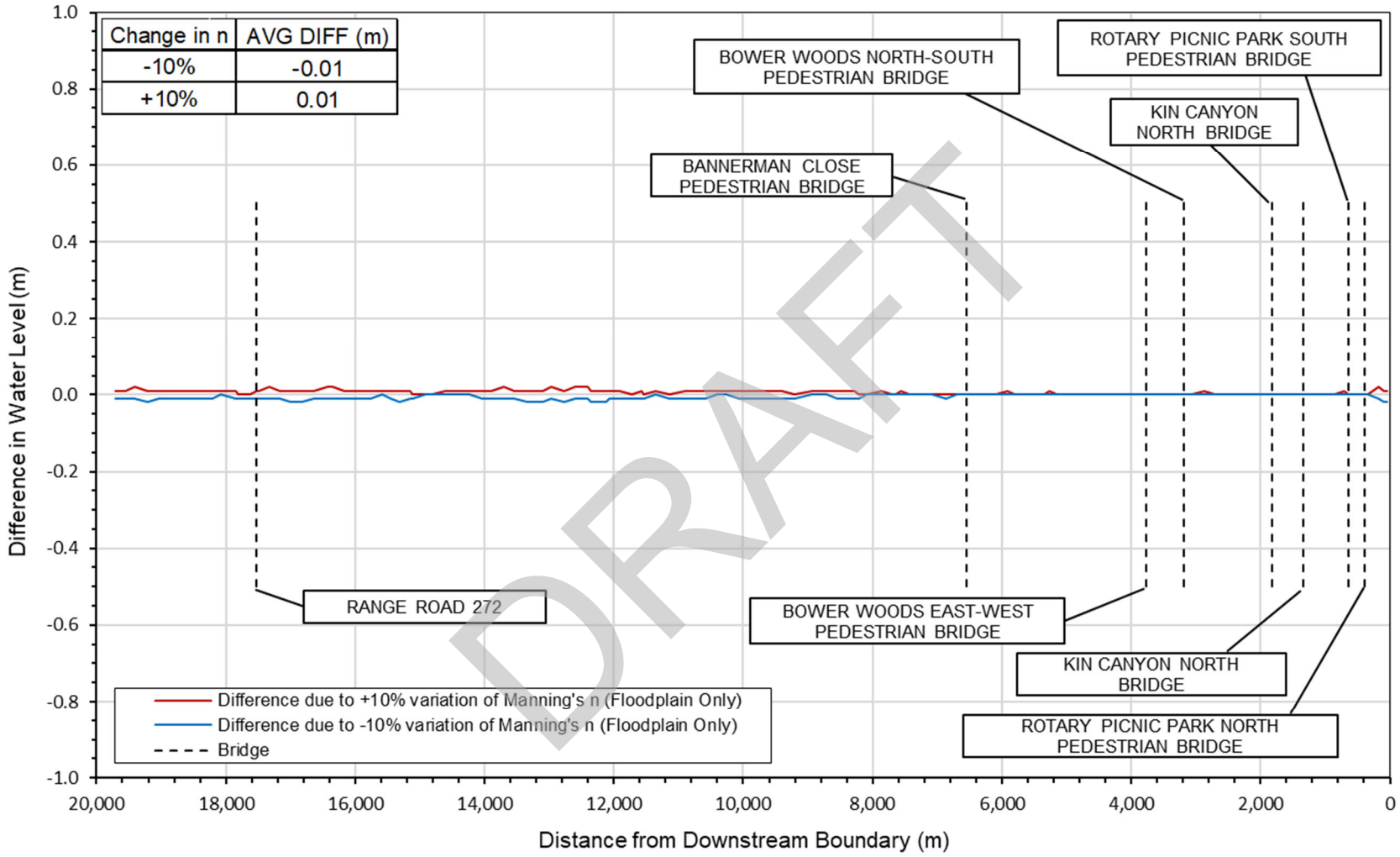

Figure D.9: Floodplain Roughness Sensitivity Analysis for Piper Creek

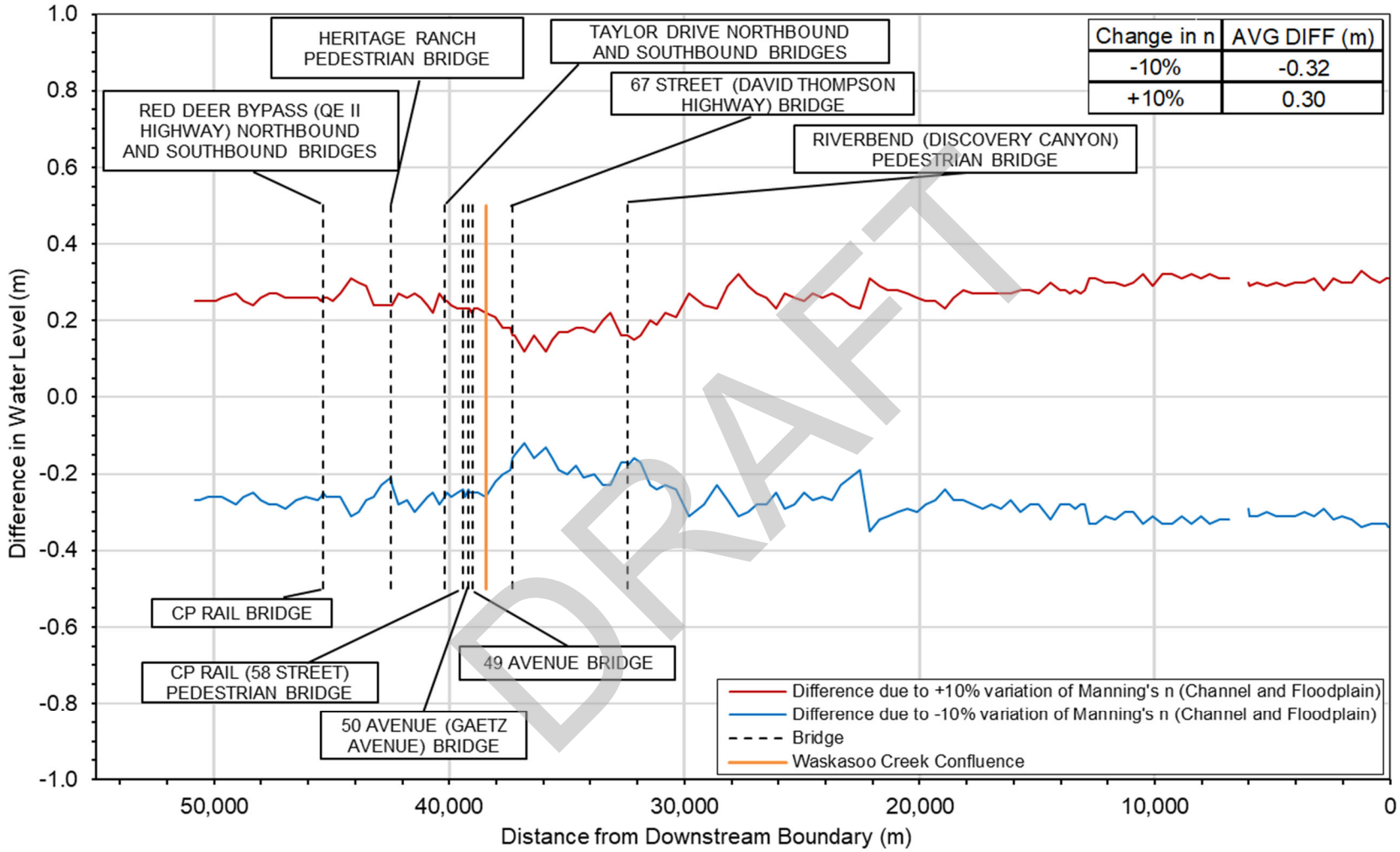

Figure D.10: Channel and Floodplain Roughness Sensitivity Analysis for Red Deer River

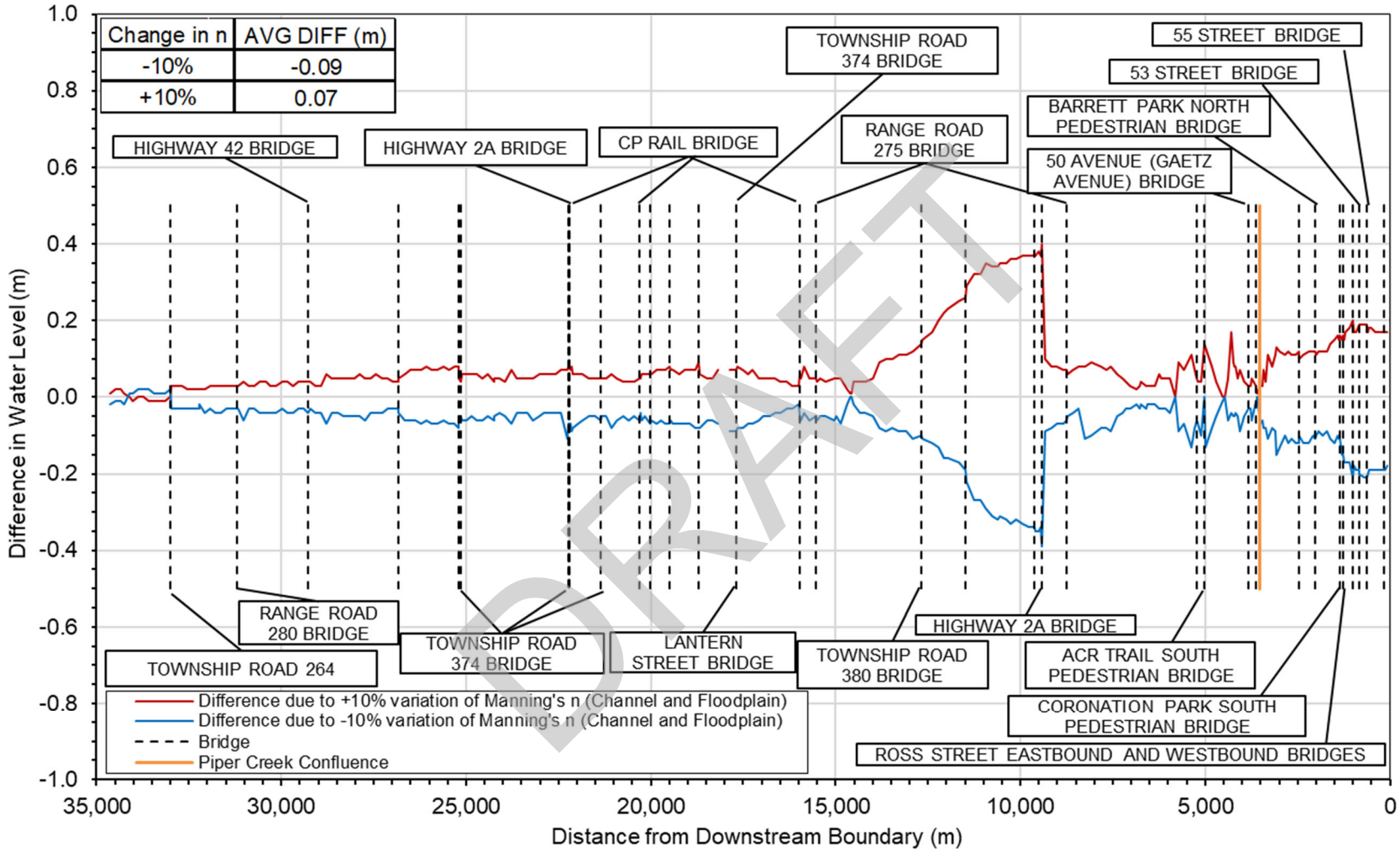

Figure D.11: Channel and Floodplain Roughness Sensitivity Analysis for Waskasoo Creek

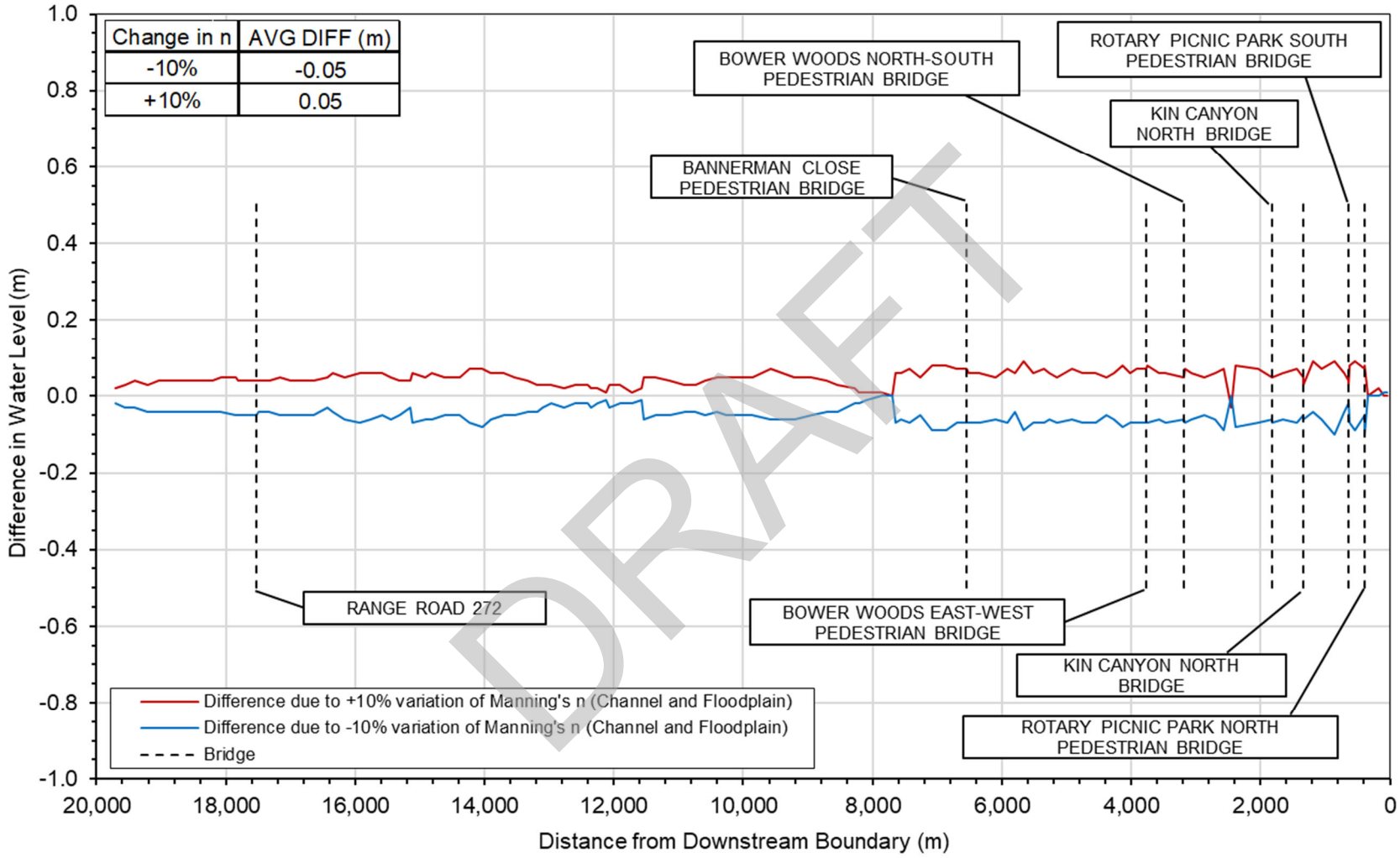

Figure D.12: Channel and Floodplain Roughness Sensitivity Analysis for Piper Creek

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