REPORT

Channel Stability Investigation Report

Red Deer River Hazard Study

Submitted to:

Alberta Environment and Parks
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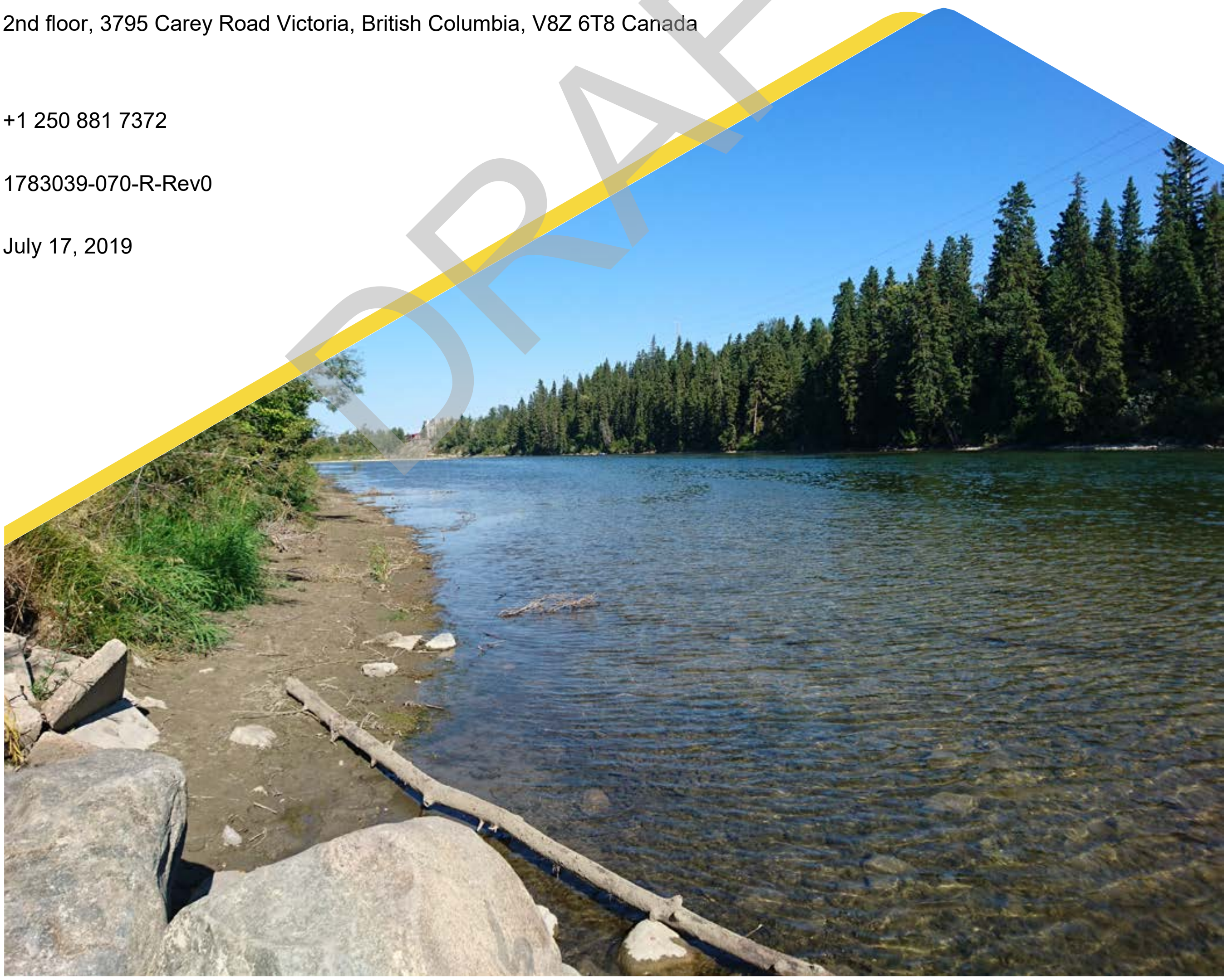

Executive Summary

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in September 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, the Counties of Lacombe and Red Deer, and the public.

The Red Deer River Hazard Study includes multiple components and deliverables. This report documents the methodology and results of the channel stability investigation component, which provides qualitative and limited quantitative information about general channel stability along the study reaches.

The study area was divided into nine stream reaches for the purpose of the channel stability investigation (see Table i).

Table i: Study Area Reaches

River	Reach No.	Reach Description	Length (km)
Red Deer River	1	Highway 11 to Blindman River	19
	2	Blindman River to Waskasoo Creek	20
	3	Waskasoo Creek to Station 50+200	12
Waskasoo Creek	4	Outlet at Red Deer River to Piper Creek	3.5
	5	Piper Creek to Station 7+000	3.8
	6	Station 7+000 to Range Road 275	8.2
	7	Range Road 275 to Station 34+600	19
Piper Creek	8	Outlet at Waskasoo Creek to 19th Street	12
	9	19th Street to McKenzie Road	7.6

The channel stability investigation involved channel bank delineation and comparison, cross section comparison, thalweg comparison, and rating curve comparison.

The channel bank delineation and comparison was conducted by outlining the banks and mapping river features in historical and recent imagery datasets. The cross section and thalweg comparisons were conducted by assessing changes between historical and recent cross sections and thalweg data through qualitative and quantitative analyses. For the rating curve comparison, historical and current rating curves for two Water Survey of Canada (WSC) gauges within the study area were compared relative to observed changes in the river thalweg and features of the nearest river cross sections. The data collected from the comparison of river geometry and from channel bank delineation were used to inform the interpretations of changes observed in the rating curves.

The results of the investigation were used to develop criteria for channel stability based on the movement of the rivers over time and the ability of the active river channels to convey flood flows. The results for each reach are summarized below:

Reach 1

Reach 1 of the Red Deer River is typically characterized by a low gradient (approximately 0.11%), straight to meandering, single-threaded channel corridor. The bank alignment is similar in 1962 and in 2017, although limited channel corridor widening was observed in localized areas. Channel narrowing may have resulted in a reduced flood conveyance capacity for the reach, although the flow modeling (Golder 2019b) suggests that the river is underfit for the river valley and that the channel is typically capable of conveying flows greater than the 5 year flood event.

Reach 1 is considered typically stable due to the lack of significant channel corridor movement.

Reach 2

Reach 2 of the Red Deer River is typically characterized by a low gradient (approximately 0.13%), meandering to torturously meandering, single-threaded channel corridor. The bank alignment is similar in 1962 and 2017 for more than half of the reach, but bank erosion and migration has occurred near the apex of a few meander bends. The reach is primarily experiencing minor degradation, although localized sections of aggradation and degradation up to approximately 1 m occur where the river flows through a dense concentration of bridges in the City of Red Deer.

The flow modeling (Golder, 2019b) suggests that the river is underfit for the river valley and that the channel is typically capable of conveying flows greater than the 5 year flood event.

Reach 2 is considered typically stable due to the lack of significant channel corridor movement or widespread aggradation. However, localized channel zones near the apexes of some meander bends have been classified as unstable due to evidence of bank erosion and meander migration.

Reach 3

Reach 3 of the Red Deer River is typically characterized by a low gradient (approximately 0.12%), straight to meandering, single-threaded channel corridor. Analysis of historical and modern imagery suggests that the bank alignment is similar in 1962 and in 2017. The reach is primarily experiencing minor degradation, although localized sections of aggradation and degradation exceeding 1 m occur where the river flows through a dense concentration of bridges in the city of Red Deer.

The flow modeling (Golder, 2019b) suggests that the river is underfit for the river valley and that the channel is typically capable of conveying flows greater than the 5 year flood event. Reach 3 is considered typically stable due to the lack of significant channel corridor movement or widespread aggradation.

Reach 4

Reach 4 of Waskasoo Creek is characterized by a straight to gently meandering, single-threaded channel corridor. Slope in this reach is moderate at approximately 0.20%. The channel corridor has migrated over the few hundred metres immediately upstream of the stream mouth. Bank mapping and cross sectional analyses suggest that the channel has not shifted position by more than a couple metres over the rest of the reach. Bed elevation has remained approximately stable over most of the reach, but degradation exceeding 1.5 m occurred at the downstream end of the reach where Waskasoo Creek enters Red Deer River. It appears as though anthropogenic reworking of the channel may have decreased the flood conveyance capacity for the reach.

Reach 4 is considered typically stable over most of its length due to the lack of significant channel corridor movement or widespread aggradation. Approximately 500 m at the downstream end of the reach is classified as unstable due to significant observed channel migration.

Reach 5

Reach 5 of Waskasoo Creek is characterized by a straight to torturously meandering, single-threaded channel corridor. The slope (approximately 0.50%) is steeper than adjacent reaches because the reach is situated at the downstream end of a knickpoint. The downstream third of the channel appears to have been straightened prior to 1962, and the upstream third was straightened during the observed period.

The meandering sub-reach between the straight sections does not appear to have shifted position over the observed period. However, the thalweg data suggests that this sub-reach has aggraded by almost 2 m over the observed period. The cause of the sediment accumulation is unclear, but it may be linked to channel straightening just upstream. Severe aggradation in the middle of the reach would likely reduce the conveyance capacity locally.

Reach 5 is considered typically stable on its upstream and downstream ends due to lack of natural channel corridor movement or widespread aggradation. The meandering section near the middle of the reach is classified as unstable due to evidence of severe aggradation.

Reach 6

Reach 6 of Waskasoo Creek is characterized by a gentle (approximately 0.11%), torturously meandering, single-threaded channel corridor. The bank alignment is similar in 1962 and 2017 except for in a couple locations where meander bend cutoffs have occurred. Historical cross section and thalweg data are not available for this reach, so it is unclear whether the conveyance capacity of the channel has changed over time.

Reach 6 is considered typically stable due to limited channel movement. Meander bend cutoffs are possible but are unlikely to result in a widening of the meander belt.

Reach 7

Reach 7 of Waskasoo Creek is characterized by a very gentle (approximately 0.069%), straight, single-threaded channel corridor. The channel corridor was torturously meandering in the historical period but was straightened over the observed period. The cross section analysis suggests that the channel corridor may have migrated by up to a few meters over the observed period, but there are otherwise no significant changes to cross sectional geometry. Sections of the channel where historical thalweg data is available have been primarily degradational. The absence of significant changes to cross sectional geometry suggests that the conveyance capacity of the channel has not changed extensively.

Reach 6 is considered typically stable due to limited evidence of channel movement or widespread aggradation.

Reach 8

Reach 8 of Piper Creek is characterized by a moderately to torturously meandering, single-threaded channel corridor. The slope (approximately 0.34%) is steeper than adjacent reaches because the reach is situated at the downstream end of a knickpoint. The bank alignment is similar in 1962 and 2017 except for in a couple locations where meander bend cutoffs have occurred or where the channel has been straightened. Historical cross section and thalweg data are not available for this reach, so it is unclear whether the conveyance capacity of the channel has changed over time.

Reach 8 is considered typically stable due to limited channel movement. Meander bend cutoffs are possible but are unlikely to result in a widening of the meander belt.

Reach 9

Reach 9 of Piper Creek is characterized by a very gentle (approximately 0.096%) moderately to torturously meandering, single-threaded channel corridor. The bank alignment is similar in 1962 and 2017 except for in a couple locations where meander bend cutoffs have occurred or where the channel has been straightened. Historical cross section and thalweg data are not available for this reach, so it is unclear whether the conveyance capacity of the channel has changed over time.

Reach 8 is considered typically stable due to limited channel movement. Meander bend cutoffs are possible but are unlikely to result in a widening of the meander belt.

Acknowledgements

This component of the Red Deer River Hazard Study was led by Mr. Rowland Atkins. Overall project management was provided by Mr. Gaven Tang and Dr. Dejiang Long. The channel stability investigation team included Ms. Morgan Tidd, Mr. Gaven Tang, and Dr. Kathryn De Rego with GIS support provided by Mr. Peter Thiede, Mr. Sean Kurash and Mr. Scott Gordon.

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1.0 INTRODUCTION

1.1 Study Objectives

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in September 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 three streams in the vicinity of Red Deer, Alberta (i.e., Red Deer River from Highway 11 to a location approximately 5 km upstream of Highway 2, Waskasoo Creek from its mouth to its crossing with Highway 2A approximately 1 km south of Range Road 280, and Piper Creek from its mouth to McKenzie Road).

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.

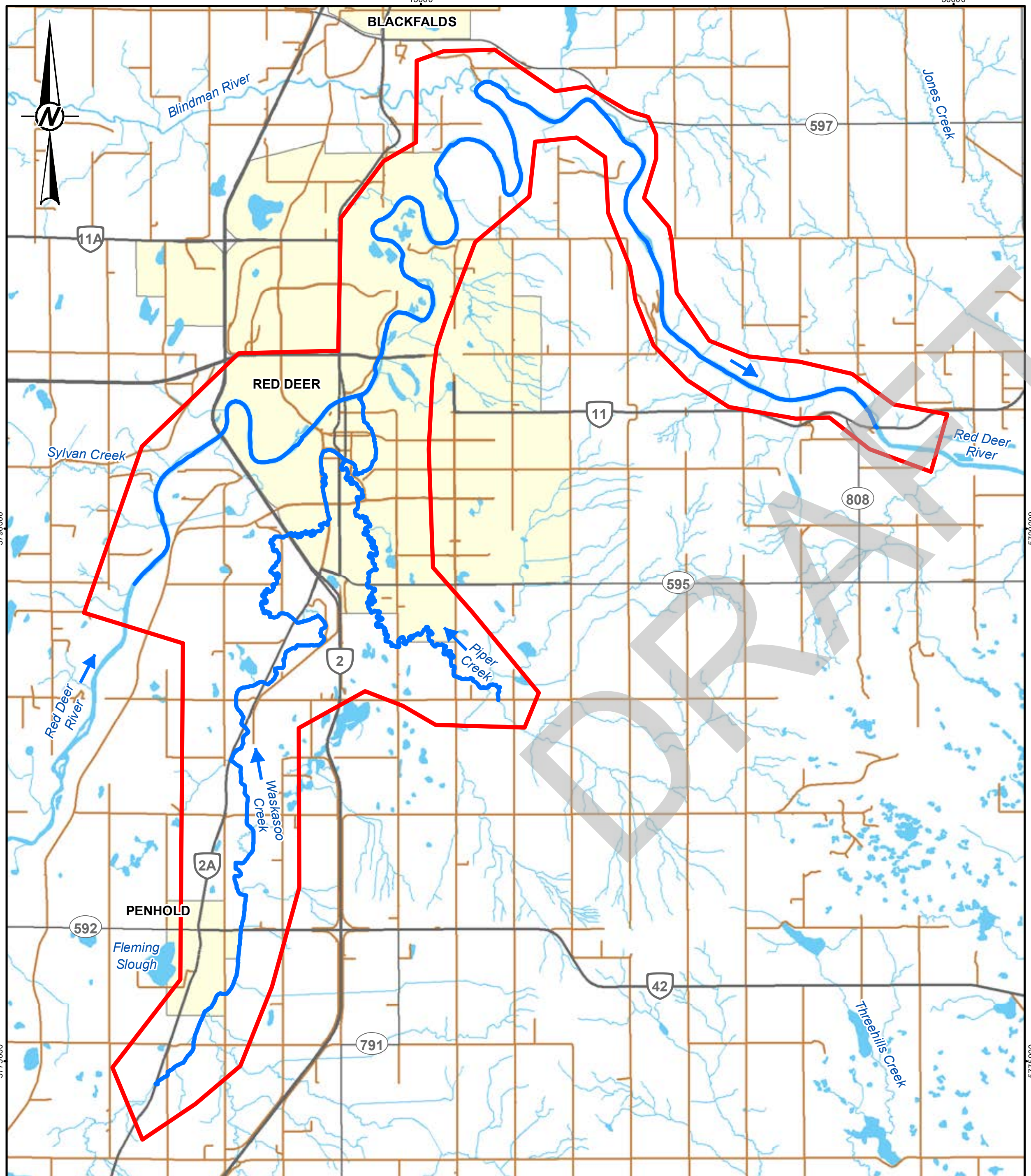
The study includes multiple components and deliverables. This report documents the methodology and results of the channel stability investigation component, which provides qualitative and limited quantitative information regarding general channel stability along the study reaches.

1.2 Study Area and Reaches

The study area includes approximately 51 km of Red Deer River, 35 km of Waskasoo Creek, and 20 km of Piper Creek. Streams within the study area have been divided into 9 reaches appropriate for the channel stability investigation, including three along Red Deer River, four along Waskasoo Creek, and two along Piper Creek. The reaches are listed in Table 1 and presented in Figure 2.

Table 1: Channel Stability Investigation Reaches

River	Reach No.	Reach Description	Length (km)
Red Deer River	1	Highway 11 to Blindman River	19
	2	Blindman River to Waskasoo Creek	20
	3	Waskasoo Creek to STN 50+200	12
Waskasoo Creek	4	Outlet at Red Deer River to Piper Creek	3.5
	5	Piper Creek to STN 7+000	3.8
	6	STN 7+000 to Range Road 275	8.2
	7	Range Road 275 to STN 34+600	19
Piper Creek	8	Outlet at Waskasoo Creek to 19th Street	12
	9	19th Street to McKenzie Road	7.6



LEGEND

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

0 5 10

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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	2019-07-17
DESIGNED	G.TANG
PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
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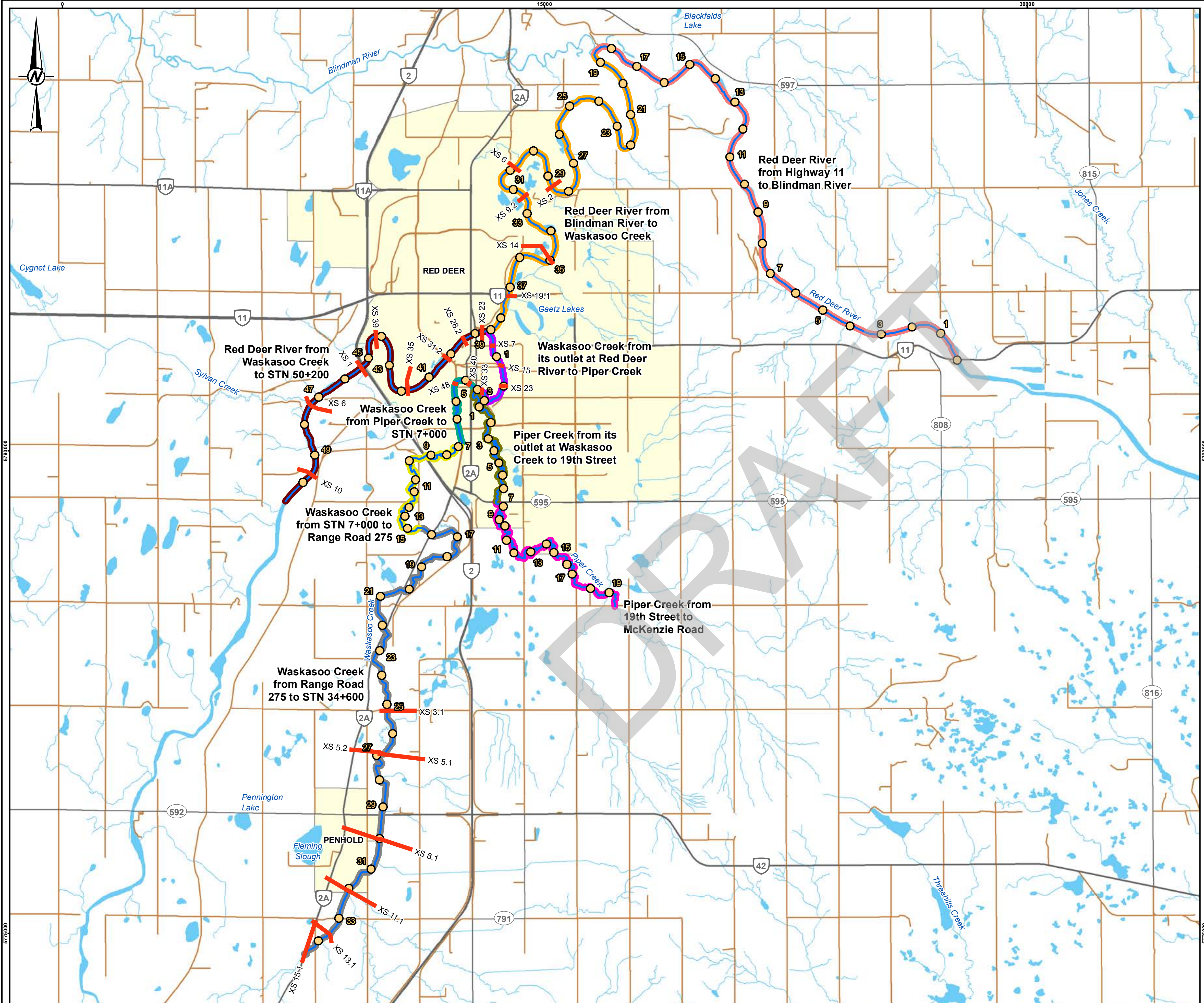
Classification: Public



LEGEND

- RIVER STATION POST (km)
- COMPARISON CROSS SECTION
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERCOURSE
- WATERBODY
- POPULATED PLACE

RIVER REACHES

- RED DEER RIVER FROM HIGHWAY 11 TO BLINDMAN RIVER
- RED DEER RIVER FROM BLINDMAN RIVER TO WASKASOO CREEK
- RED DEER RIVER FROM WASKASOO CREEK TO STN 50+200
- WASKASOO CREEK FROM ITS OUTLET AT RED DEER RIVER TO PIPER CREEK
- WASKASOO CREEK FROM PIPER CREEK TO STN 7+000
- WASKASOO CREEK FROM STN 7+000 TO RANGE ROAD 275
- WASKASOO CREEK FROM RANGE ROAD 275 TO STN 34+600
- PIPER CREEK FROM ITS OUTLET AT WASKASOO CREEK TO 19TH STREET
- PIPER CREEK FROM 19TH STREET TO MCKENZIE ROAD

0 3 6
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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
RIVER REACHES

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-17
DESIGNED	S.KURASH
PREPARED	P.TAN
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
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Classification: Public

1.3 Scope of Work

The scope of the channel stability investigation component of the study includes the following activities:

- Historical aerial photography preparation;
- Channel bank delineation and comparison: identification and comparison of recent and historical channel banks to establish representative illustrative bank stability and instability conditions in the study area;
- Cross section comparison: comparison of available historical and current main channel cross sections along the study reaches;
- Thalweg profile comparison: comparison of recent and any available historical thalweg profiles to identify any changes;
- Gauge rating curve comparison: comparison of stream gauge rating curves and evaluation of rating curve changes; and
- Classification of channel stability: division of the study area into geomorphically-unique reaches and evaluation of channel stability for each reach.

2.0 AVAILABLE DATA

2.1 Aerial Imagery

Aerial imagery obtained for this study included recent imagery collected in 2018 as well as historical imagery consisting of photos collected in 1962. Both imagery sets provide full coverage of the study area. A summary of imagery specifications is presented in Table 2. Details on image preparation for the historical imagery are presented in Appendix B.

Table 2: Summary of Aerial Imagery

Era	Date(s) of Collection	Scale	Resolution (m)	Source	Accuracy (m)
Recent	July 2018	-	0.30	Provided by AEP	0.9 m (adjustment accuracy)
Historical	06/30/1962, 07/03/1962, 07/09/1962, 07/18/1962, 08/01/1962	1:31,680	0.64	Provided by AEP	6 m

2.2 Cross Section and Thalweg Data

Cross section data was obtained from historical flood risk mapping studies and from river survey data collected in autumn 2017 (Golder, 2019a). The historical cross sections were collected between 1989 and 2007 and provide complete coverage of Reaches 3, 4 and 5, as well as approximately one half of Reach 2, one third of Reach 6, and one third of Reach 7. Modern cross section data is available for the entire study area. Thalweg data was extracted from the historical and modern cross sections.

A summary of the topographic data is presented in Table 3.

Table 3: Summary of Cross Section and Thalweg Data

Dataset	Reach or Sub-reach	Date(s) of Collection	Resolution (m)	Source	Accuracy (m)
1991 Red Deer survey data	Partial coverage of Reaches 2 and 3	circa 1991	Variable	Alberta Environment, reported in W-E-R Engineering (1991)	Unknown, but data reported to centimetre scale
2000 Red Deer survey data	Partial coverage of Reach 3	2000	Variable	Maltais Geomatics (2000), reported in AMEC (2007)	Unknown, but data reported to centimetre scale
1995 Waskasoo survey data	Complete coverage of Reaches 4 and 5 and partial coverage of Reach 6	1989-1995	Variable	B.K. Hydrology Service (1995)	Unknown, but data reported to centimetre scale
2001 Waskasoo survey data	Partial coverage of Reach 7	2001, with additions in 2007	Variable	UMA Engineering (2008)	Unknown, but data reported to millimetre scale
2017 survey data	Complete coverage of 1-9	August-October 2017	Variable	Golder (2019a)	+/- 0.05 (RTK survey)

2.3 Rating Curve Data

Current and historic rating curves were obtained from the Water Survey of Canada (WSC) for two gauges [i.e., Red Deer River at Red Deer (05CC002) and Waskasoo Creek at Red Deer (05CC011)]. The Red Deer River at Red Deer gauge was established in 1911 at the Highway 2 crossing in Reach 3. It was moved approximately 1 km upstream to the Gaetz Street bridge in 1947. In 1966, it was moved downstream approximately 160 m to the 49th Avenue bridge, then was moved approximately 600 m downstream to the railway bridge in 1979. Rating curve data are available from 1950 to the present.

The Waskasoo Creek at Red Deer gauge was established in 1984 at the 50th Street crossing in Reach 4 and has remained in the same location to the present. Rating curve data are available from 1985 to the present.

3.0 METHODS

3.1 Channel Bank Delineation and Comparison

The channel bank delineation and comparison were conducted using orthorectified and georeferenced (triangulated) historical air photos viewed using ArcMap™ software. Historical air photos were reviewed using stereoscopic image display software. For the modern period, the 2018 orthophoto data were viewed in conjunction with contour data derived from 2017 LiDAR imagery provided by AEP and from the 2017 survey (Golder 2019a). Coverage, resolution and scale of the imagery are described in Section 2.1.

Channel features were delineated directly onscreen from historical and recent aerial imagery at a scale of 1:2,000. Mapped features include the following:

- Active channel (polygon format). Surfaces within the active channel lack established vegetation (e.g., bushes and trees over approximately 0.5 m in height) and are expected to typically convey flow during a 2-year flood event. The active channel may be composed of one dominant channel that carries the majority of flow along with one or more sub-dominant channels, or multiple sub-dominant channels.

- Banks (line format). The left and right banks are defined as the left-most and right-most margins of the active channel, respectively.
- Vegetated islands (polygon format). Vegetated islands are defined as patches of established vegetation that are situated between the left and right banks.
- Bank protection (polygon format). Bank protection includes man-made features designed to stabilize channel banks, such as riprap.

Once mapped, the digital channel margins were exported into an ArcGIS 10.3 (ArcMap) database with geospatial attributes.

Visual comparisons of the historically-imaged and most recently-imaged channels were undertaken on the most recent photo base provided by AEP. The comparisons were focused on identifying characteristics of channel instability, including the following:

- Presence of channel morphologies typically characterized by instability (e.g., braided and wandering morphologies);
- Expansion, contraction, and/or migration of the channel corridor. The channel corridor consists of terrain (including both active channel and vegetated islands) that is situated between the left and right banks; and
- Reorganization within the channel corridor, including migration or avulsion of dominant and sub-dominant channels, formation or loss of islands, or changes in channel morphology.

Floodplain reactivation, which is defined as the percentage of active channel mapped for the modern period that was not active channel during the historical period, was not assessed because the channels within the study area typically experienced little widespread visible channel change more commonly associated with braided or multiple thread channels. The channels reviewed were typically single thread channels.

Movement of the meander belt was qualitatively reviewed where necessary to aid interpretations of stream evolution. The meander belt is defined as the portion of floodplain across which the channel can be expected to shift on decadal or longer timescales. The meander belt is typically as wide or wider than the active channel corridor.

A select set of figures were developed to highlight typical reach characteristics. These figures are accompanied by a technical summary of the general nature of general lateral stability in the study area (e.g., observations that lateral instability is highest on the downstream, outside portion of the major meanders).

3.2 Cross Section Comparison

For the cross section comparison, a preliminary analysis was carried out to identify an appropriate number of representative cross sections for comparison to provide adequate coverage and detail of the study area. For the analysis, a subsample of 25 representative cross sections in Reaches 2 to 5 and Reach 7 were selected for review in detail (see Figure 1 for cross section locations). The selected representative cross sections were compared with estimates of meander spacing to validate coverage of major river features. Cross section comparisons were not completed for Reaches 1, 6, 8 and 9 because adequate historical cross section data was not available.

Qualitative and quantitative analyses were conducted on the representative cross sections. The qualitative analysis included review and documentation of cross section features such as single thread or multiple thread channels, left-handedness or right-handedness (i.e., the deepest part being located on the left[1] or right side of the river channel), skewness (i.e., cross sections with a uniform geometry or leaning to left or right), and evidence of aggradation or degradation.

The quantitative analysis of channel geometry consisted of the estimation of bankfull cross sectional area, maximum bankfull depth, bankfull width, and average bankfull depth for each cross section. A HEC-RAS model evaluating the flood levels associated with the 2-year flood (Golder 2019b) was used as an aid for delineating the bankfull channel.

The parameters mentioned above were used to determine channel type and changes in hydraulic capacity using simple hydraulic relationships. A high level statistical analysis was conducted on the river geometry for reaches and sub-reaches with at least four adequate cross sections to determine the significance of recorded changes.

3.3 Thalweg Profile Comparison

The thalweg is the line that passes through the deepest part of the river in the downstream direction. It links the deepest areas of the river together and is a representative feature of the longitudinal profile of a channel.

Historical and current thalweg profiles were reviewed as part of this analysis. Where both historical and current coverage was available, increases or decreases in thalweg elevation and slope were evaluated and documented in context with reviewed cross sections and major river features. Areas of scour or degradation (bed elevation decrease) and sedimentation or aggradation (bed elevation increase) were identified, and reach-averaged net bed volume changes were calculated.

Due to the limited coverage of historical data, a plan view comparison of the thalweg to evaluate lateral migration was not created. Migration of the river channel that was documented in the channel bank and cross section comparisons, was deemed sufficient to address lateral migration.

3.4 Rating Curve Comparison

Rating curves at hydrometric gauges can be altered due to changes in channel geometry or riverbed elevation. The passage of sediments through the river and the mobile nature of many riverbeds can cause bed levels to increase and decrease in response to natural river changes and flood events.

Available rating curve data for the gauges on Red Deer River and Waskasoo Creek were provided by WSC as described in Section 2.3. The historical and current rating curves were compared, in context with observed changes in the river and features of nearby cross sections. Information collected from the comparison of channel banks, cross sections, and thalweg profiles, was used to inform the interpretation of changes observed in the rating curves.

[1] When describing cross section stationing or properties, left and right are defined relative to an observer facing downstream.

3.5 Classification of Reach Stability

Results of the channel delineation, cross section, thalweg, and rating curve comparisons were used to develop criteria for channel instability and to designate each reach as unstable or stable. For the purposes of this study, unstable channels are those for which:

- high levels of channel migration (see Section 4.1 for its definition) occur over the scale of decades; and
- trends in bed elevation change or cross sectional area suggest that the ability of the active channel to convey flood flows may be decreasing.

The criteria are not designed to be universal and are applicable to this study only. The designation of stable or unstable reaches is not specifically related to whether the reach is in equilibrium. For example, a degrading channel may be classified as stable for this analysis if the above criteria are met, even though it is not in equilibrium.

4.0 RESULTS

4.1 Criteria for Channel Stability

Characteristics of unstable and stable channel sub-reaches based on observations from the channel bank delineation and comparison, cross section comparison, thalweg comparison, and rating curve comparison are presented in Table 4.

Table 4: Criteria for Channel Stability and Instability

Geomorphic Metric	Sign of Stability	Sign of Instability
Channel corridor position change	Left and right banks remain in approximately the same position or the channel narrows	Change in the position of the left or right banks is over 10% of the modern channel corridor width (except in cases of narrowing) and the meander bend is apparently migrating downstream
Change in position of vegetated islands	Vegetated islands grow or remain in the same position	Vegetated islands shift upstream or downstream
Change in cross sectional area	Cross sectional area has remained stable or has increased	Cross sectional area has decreased due to significant channel deposition

The stream reaches in this study were primarily single-threaded with few vegetated islands, so the floodplain reactivation percentage was not considered an appropriate metric of channel stability. Instead, sub-reaches where meander bends are migrating downstream are classified as unstable. In these locations, the left or right banks typically changed position by more than approximately 10% of the modern active channel width and the position of vegetated islands changed. Channels are also considered unstable if there are signs that the cross sectional area of the active channel has decreased due to aggradation or significant bar growth.

Indicators of lateral channel stability are described for each reach in Section 4.2. Changes to cross section area are described in Sections 4.3 to 4.5.

4.2 Channel Delineation and Comparison

4.2.1 Summary

Observations from the channel mapping and comparison analysis for each sub-reach are listed in Table 5 and presented in Figure 3 to Figure 11. The summary of channel stability for all reaches is presented in Figure 12. Summaries for individual reaches are presented in the following sections.

Table 5: Channel Bank Delineation and Comparison

Reach	Representative Sub-reach (km)	Description
1 - Red Deer River from Highway 11 to Blindman River	12-15	■ Meandering, primary single-threaded planform with occasional vegetated islands ■ Confined by terraces on portions of both banks ■ Point bar with low vegetation present in historical period; vegetation becomes more mature by modern period ■ Vegetated islands remain approximately stable over the observed period ■ Left bank erodes up to approximately 15 m along the downstream portion of a meander bend ■ Channel corridor narrows on the right bank approximately 45 m due to point bar stabilization ■ Sub-reach is considered laterally stable
2 - Red Deer River from Blindman River to Waskasoo Creek	20-23	■ Single-threaded, torturous meandering planform ■ Confined by a terrace on the right bank ■ Narrow point bar present in historical period; becomes vegetated by modern period ■ No apparent bank erosion ■ Channel corridor narrows on right bank by approximately 20 m due to point bar stabilization ■ Sub-reach is considered laterally stable
	33-36	■ Meandering, primarily single-threaded planform with occasional vegetated islands ■ Confined by a terrace on the right bank ■ Side bars and point bars present ■ Vegetated island has increased in size and shifted to the right ■ Outer edge of meander bend on right bank has shifted downstream approximately 200 m, resulting in approximately 40 m of bank erosion ■ Channel corridor has widened up to approximately 30 m on a small portion of the left bank ■ Channel corridor has narrowed up to approximately 30 m due to stabilization of some point and side bars ■ Sub-reach is considered laterally unstable
3 - Red Deer River from Waskasoo Creek to STN 50+200	46-48	■ Meandering to straight, primarily single-threaded planform with a vegetated island located close to the left bank ■ Confined by a terrace on the upstream half of the left bank ■ One small side bar observed in historical period; becomes vegetated by modern period ■ Vegetated island has grown slightly ■ No apparent bank erosion ■ Slight channel corridor narrowing due to stabilization of a small side bar ■ Sub-reach is considered laterally stable

Table 5: Channel Bank Delineation and Comparison

Reach	Representative Sub-reach (km)	Description
4 - Waskasoo Creek from its outlet at Red Deer River to Piper Creek	0-0.7	■ Straight to meandering, single-threaded planform. Becomes more meandering over the observed period ■ Confined by terraces on both banks in the upstream portion of the sub-reach ■ No apparent bars or islands, however visibility is limited due to forest cover ■ Channel corridor migrates up to 20 m (greater than the channel width) at the apex of meander bends ■ Mouth of channel corridor shifted approximately 30 m downstream ■ Channel corridor width change cannot be determined due to low channel visibility ■ Sub-reach is considered laterally unstable
	1.6-2.2	■ Straight to meandering, single-threaded planform ■ Confined by terrace on right bank ■ No apparent bars or islands, however visibility is limited due to forest cover ■ Migration of channel corridor appears to be minor; visibility is limited in historical period ■ Channel corridor width change cannot be determined due to low channel visibility ■ Sub-reach is considered laterally stable
5 - Waskasoo Creek from Piper Creek to STN 7+000	5.9-6.0	■ Single-threaded, torturous meandering planform. Some reaches appear to have been straightened in the modern period ■ Confined by Taylor Drive on the left bank and a terrace on the right bank ■ No apparent bars or islands, however visibility is limited due to forest cover ■ Meander cut-off and some movement of the channel is noted, however it appears to be caused by anthropogenic channel straightening rather than by natural processes. Meander bends that have not been altered do not appear to have migrated ■ Channel corridor width change cannot be determined due to low channel visibility ■ Sub-reach is considered laterally stable
6 - Waskasoo Creek from STN 7+000 to Range Road 275	7.7-9.1	■ Single-threaded, torturous meandering planform ■ Confined by terraces on portions of both banks ■ No apparent bars or islands, however visibility is limited due to forest cover ■ Meander cut-off has occurred along one bend, but other bends have not apparently migrated ■ Channel corridor width change cannot be determined due to low channel visibility ■ Sub-reach is considered laterally stable
	9.1-9.9	■ Single-threaded, straight to meandering planform ■ Confined on portions of both banks by terraces and by road crossing ■ No apparent bars or islands, however visibility is limited due to forest cover ■ Meander bends do not appear to have migrated ■ Channel corridor width change cannot be determined due to low channel visibility ■ Sub-reach is considered laterally stable
7 - Waskasoo Creek from Range Road 275 to STN 34+600	22.9-23.4	■ Primarily single-threaded, torturous meandering planform with occasional vegetated islands in historical period; channel is straightened over the observed period ■ Unconfined channel ■ No apparent bars ■ Channel corridor position change appears to be due to anthropogenic straightening ■ Channel corridor width change cannot be determined due to the small size of the stream ■ Sub-reach is considered laterally stable

Table 5: Channel Bank Delineation and Comparison

Reach	Representative Sub-reach (km)	Description
8 - Piper Creek from its outlet at Waskasoo Creek to 19th Street	4.2-5.8	■ Single-threaded, torturous meandering planform ■ Confined on portions of both banks by terraces ■ No apparent bars or islands, however visibility is limited due to forest cover ■ Meander bends do not appear to have migrated, although former channels were observed ■ Channel corridor width change cannot be determined due to low channel visibility and the small size of the stream ■ Sub-reach is considered laterally stable
9 - Piper Creek from 19th Street to McKenzie Road	8.2-9.9	■ Single-threaded, torturous meandering planform ■ Confined on portions of both banks by terraces ■ No apparent bars or islands, however visibility is limited due to forest cover ■ Meander cut-off has occurred along one bend, and one bend has apparently been straightened. Most other bends have not apparently migrated ■ Channel corridor width change cannot be determined due to low channel visibility ■ Sub-reach is considered laterally stable

4.2.2 Reach 1

Reach 1, which extends from Highway 11 to Blindman River, is typically straight to gently meandering. The valley is narrow due to confining terraces on both sides, and the modern floodplain is sporadic. The channel corridor is primarily single-threaded, with occasional vegetated islands, point bars, and side bars. The channel corridor width typically narrowed over the observed period due to stabilization of side bars. Otherwise, the position of the banks remained approximately stable.

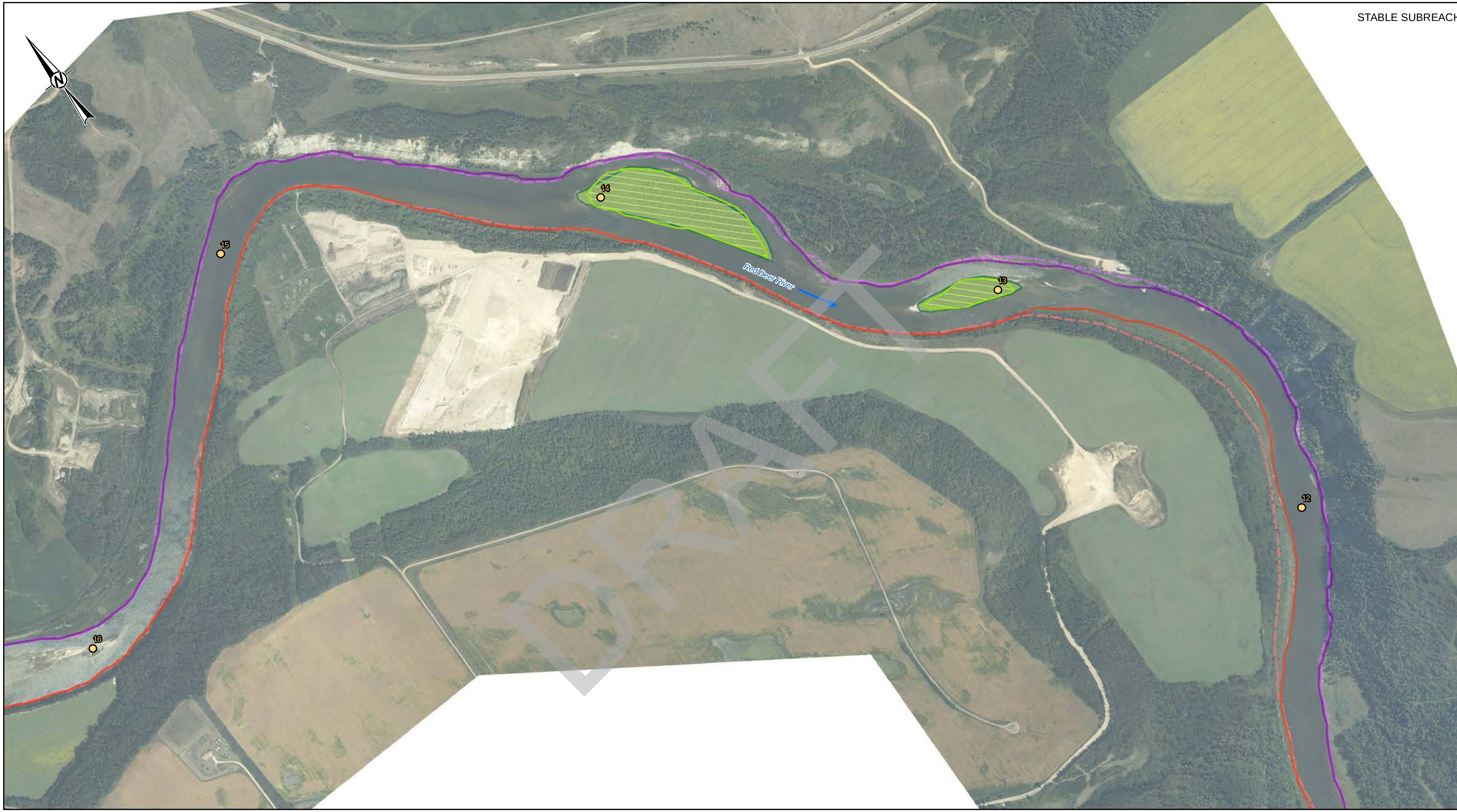
A subset of this reach is presented in Figure 3. The channel corridor has migrated slightly at the downstream end of a meander bend, but otherwise the banks and vegetated islands have remained stable.

Reach 1 is considered typically laterally stable due to the lack of channel corridor migration or change in island position.

4.2.3 Reach 2

Reach 2, which extends from Blindman River to Waskasoo Creek, is torturously meandering. The channel corridor is primarily single-threaded, with occasional vegetated islands, point bars, and side bars. The meander belt is confined by terraces on both sides, and bank erosion has occurred along the outer bends of some meanders either immediately upstream or downstream of the terrace bluffs. Channel width typically narrowed over the observed period due to stabilization of side bars.

A subset of Reach 2 showing a typically stable meander is presented in Figure 4. The terrace has confined the meander, leading to a highly sinuous planform. No bars or vegetated islands are apparent, and the banks have remained approximately stable over the observed period.



LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

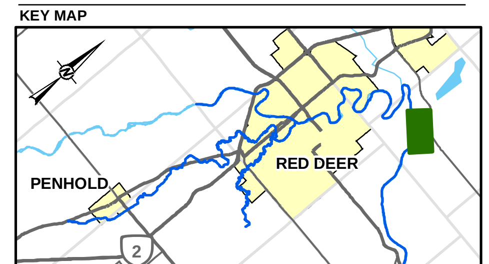
LEGEND KEY MAP

- STABLE SUBREACH

0 400 800

1:8,500 METRES

KEY MAP



PROJECT

RED DEER RIVER HAZARD STUDY

TITLE

CHANNEL BANK COMPARISON OF REACH 1 - RED DEER RIVER FROM HIGHWAY 11 TO BLINDMAN RIVER - REPRESENTATIVE SUBREACH

REFERENCE(S)

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CLIENT

ALBERTA ENVIRONMENT AND PARKS

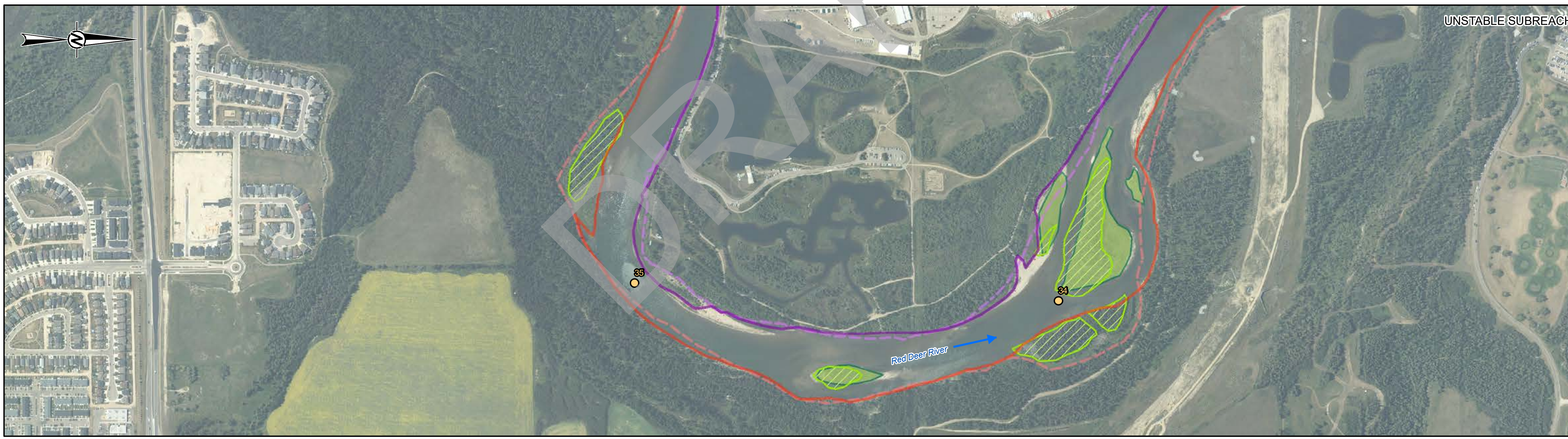
Alberta Government

CONSULTANT

GOLDER

YYYY-MM-DD	2019-07-17
DESIGNED	M.TIDD
PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	3



LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

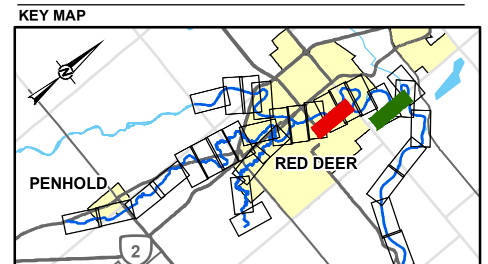
LEGEND KEY MAP

- STABLE SUBREACH
- UNSTABLE SUBREACH

0 400 800

1:8,500 METRES

KEY MAP



PROJECT

RED DEER RIVER HAZARD STUDY

TITLE

CHANNEL BANK COMPARISON OF REACH 2 - RED DEER RIVER FROM BLINDMAN RIVER TO WASKASOO CREEK - REPRESENTATIVE SUBREACHES

REFERENCE(S)

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PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	4

LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

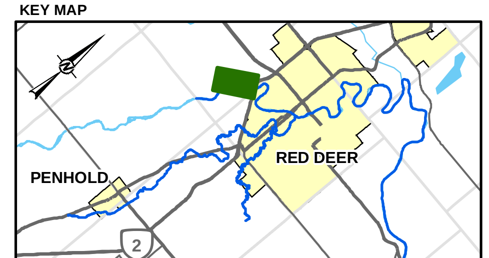
LEGEND KEY MAP

- STABLE SUBREACH

0 400 800

1:8,500 METRES

KEY MAP



PROJECT

RED DEER RIVER HAZARD STUDY

TITLE

CHANNEL BANK COMPARISON OF REACH 3 - RED DEER RIVER FROM WASKASOO CREEK TO STN 50+200 - REPRESENTATIVE SUBREACH

REFERENCE(S)

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PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	5

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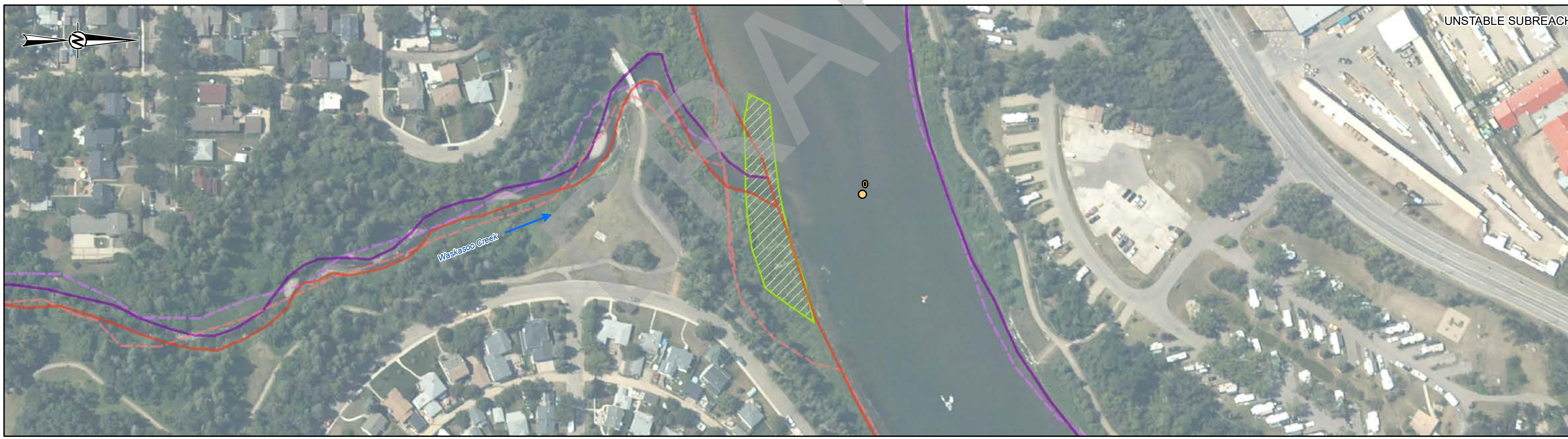


LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

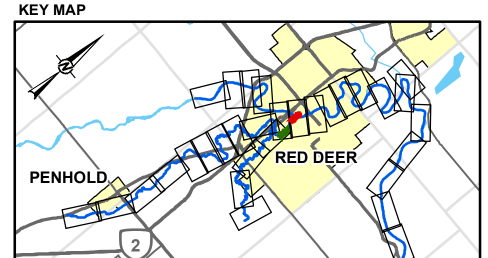
LEGEND KEY MAP

- STABLE SUBREACH
- UNSTABLE SUBREACH

0 80 160

1:2,000 METRES

KEY MAP



PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 4 - WASKASOO CREEK FROM ITS OUTLET AT RED DEER RIVER TO PIPER CREEK - REPRESENTATIVE SUBREACHES

REFERENCE(S)
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PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	6

LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

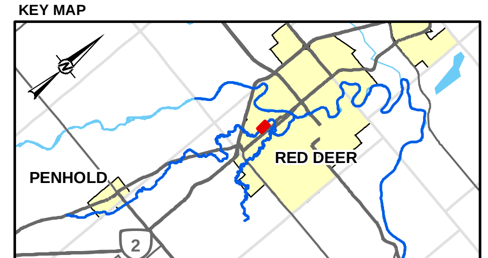
LEGEND KEY MAP

- UNSTABLE SUBREACH

0 80 160

1:2,000 METRES

KEY MAP



PROJECT

RED DEER RIVER HAZARD STUDY

TITLE

CHANNEL BANK COMPARISON OF REACH 5 - WASKASOO CREEK FROM PIPER CREEK TO STN 7+000 - REPRESENTATIVE SUBREACH

REFERENCE(S)

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PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	7

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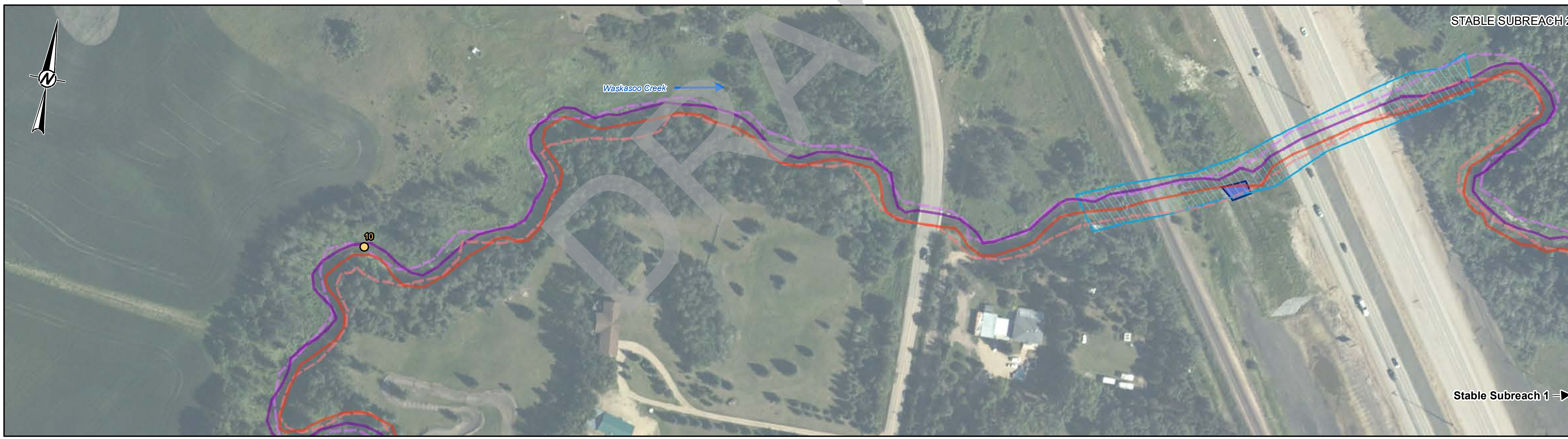
25mm



LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

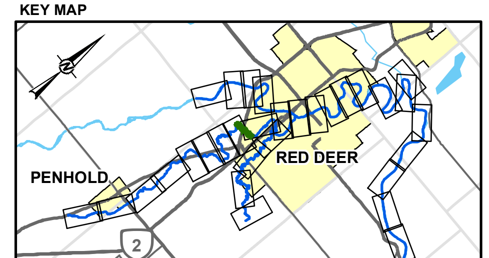
LEGEND KEY MAP

- STABLE SUBREACH

0 80 160

1:2,000 METRES

KEY MAP



PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 6 - WASKASOO CREEK FROM STN 7+000 TO RANGE ROAD 275 - REPRESENTATIVE SUBREACHES

REFERENCE(S)

CLIENT
ALBERTA ENVIRONMENT AND PARKS

Alberta Government

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-17
DESIGNED	M.TIDD
PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	**8**

LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

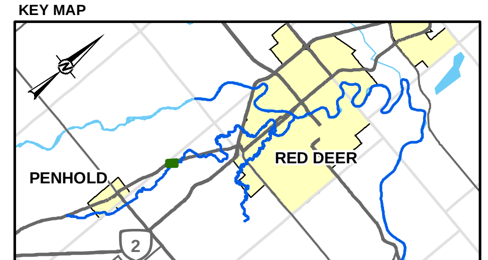
LEGEND KEY MAP

- STABLE SUBREACH

0 80 160

1:2,000 METRES

KEY MAP



PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 7 - WASKASOO CREEK FROM RANGE ROAD 275 TO STN 34+600 - REPRESENTATIVE SUBREACH

REFERENCE(S)
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PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	9

25mm
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Classification: Public

LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

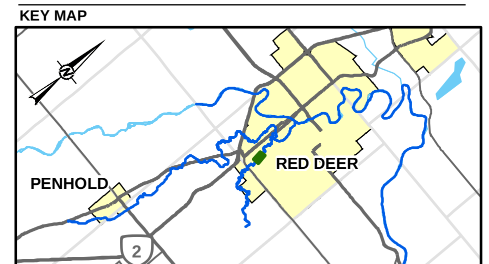
LEGEND KEY MAP

- STABLE SUBREACH

0 80 160

1:2,000 METRES

KEY MAP



PROJECT

RED DEER RIVER HAZARD STUDY

TITLE

CHANNEL BANK COMPARISON OF REACH 8 - PIPER CREEK FROM ITS OUTLET AT WASKASOO CREEK TO 19TH STREET - REPRESENTATIVE SUBREACH

REFERENCE(S)

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DESIGNED	M.TIDD
PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	**10**

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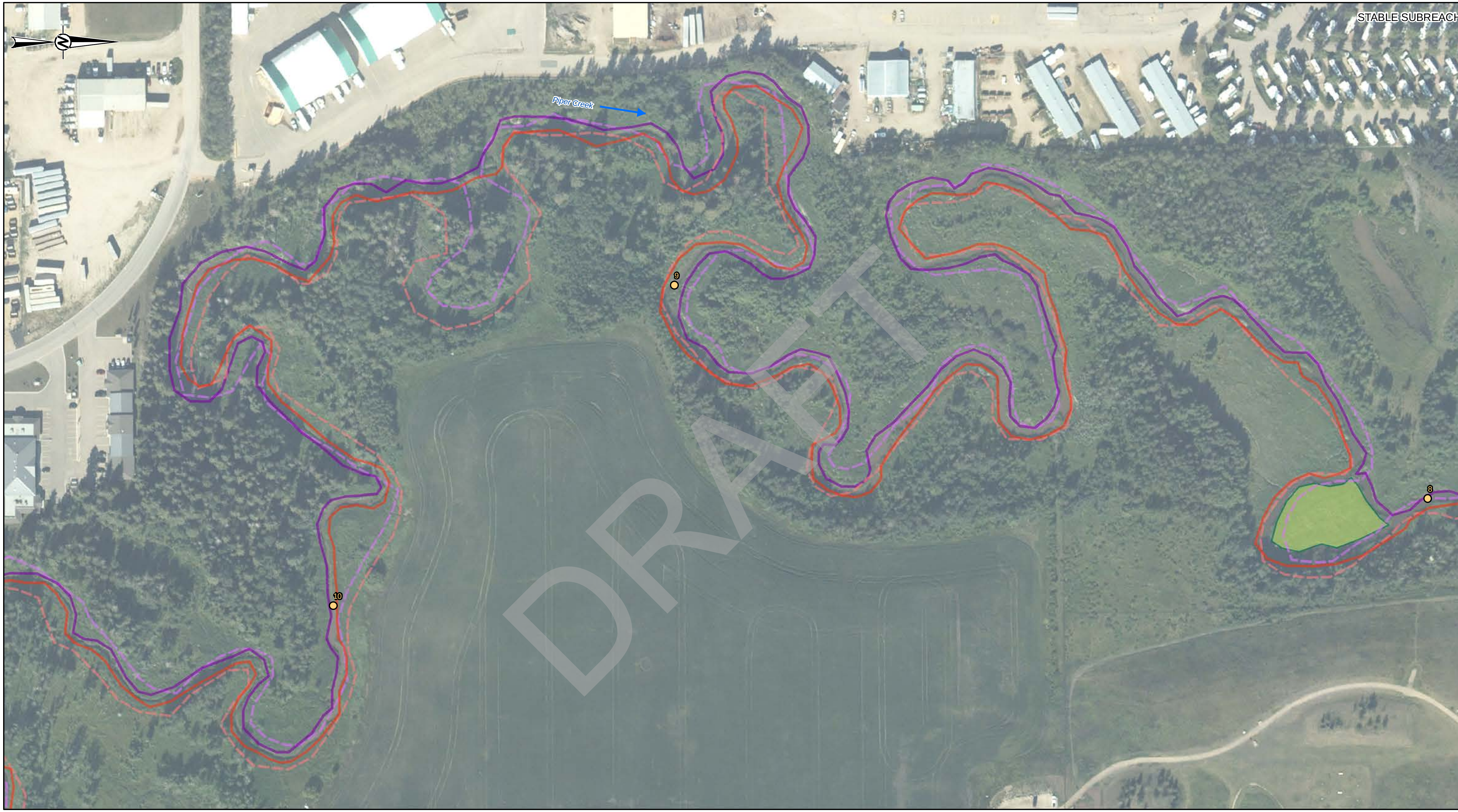
Classification: Public



LEGEND

- RIVER STATION POST (km)
- FLOW DIRECTION
- RIGHT BANK (2018)
- RIGHT BANK HISTORICAL (1962)
- LEFT BANK (2018)
- LEFT BANK HISTORICAL (1962)
- PROTECTED BANK (2018)
- PROTECTED BANK (1962)
- VEGETATED ISLAND (2018)
- VEGETATED ISLAND HISTORICAL (1962)

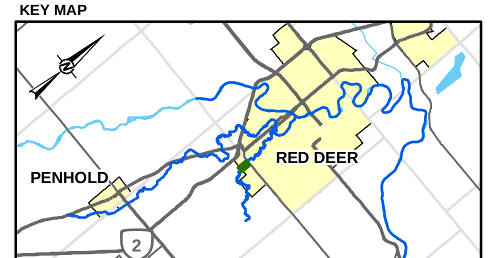
LEGEND KEY MAP

- STABLE SUBREACH

0 80 160

1:2,000 METRES

KEY MAP



PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 9 - PIPER CREEK FROM 19TH STREET TO MCKENZIE ROAD - REPRESENTATIVE SUBREACH

REFERENCE(S)
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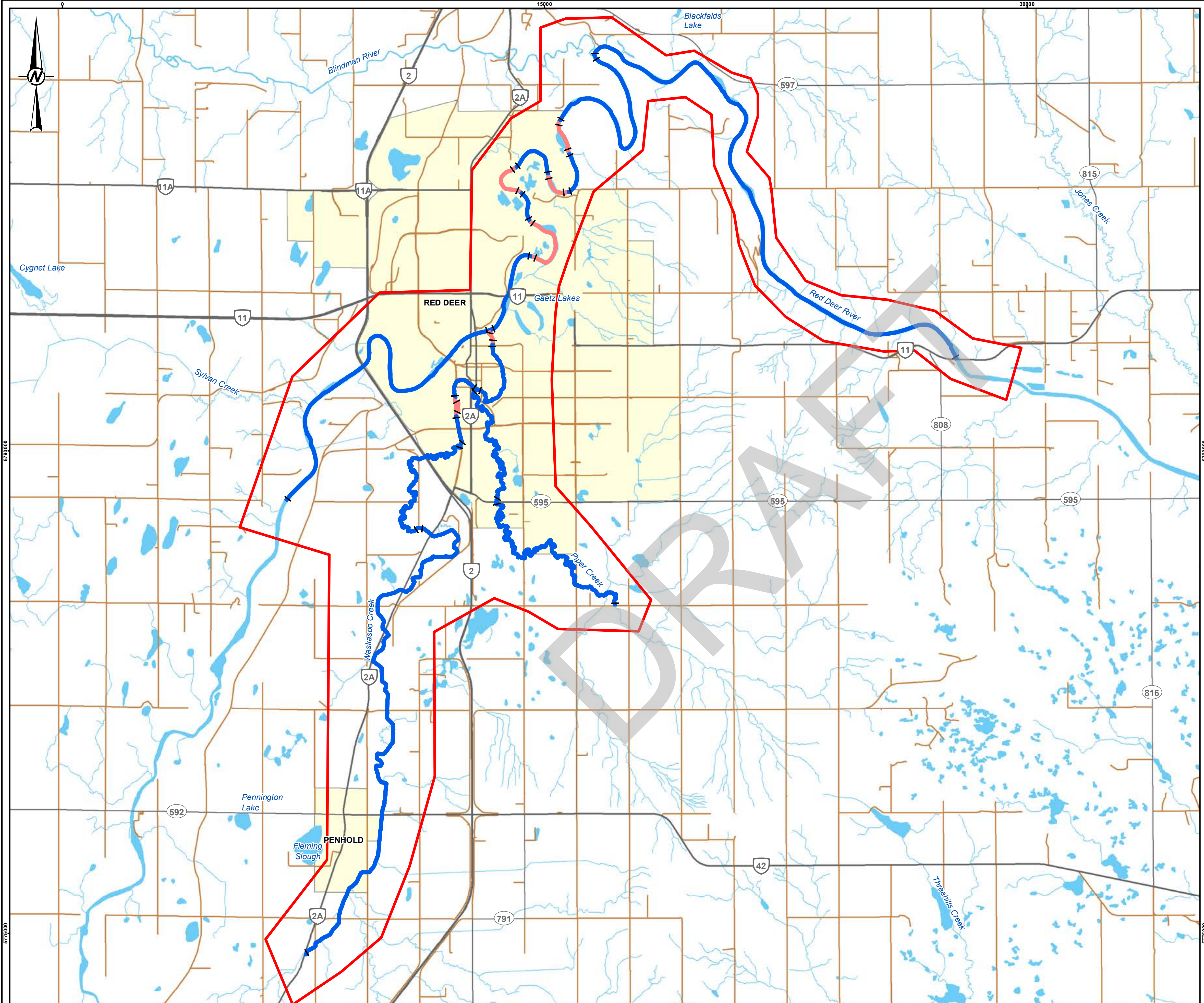
DESIGNED	M.TIDD
PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	11



LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERCOURSE
- WATERBODY
- POPULATED PLACE
- RIVER HAZARD STUDY AREA

RIVER REACH

- STABLE
- UNSTABLE

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
CHANNEL STABILITY OVERVIEW MAP

CONSULTANT

GOLDER

YYYY-MM-DD	2019-07-17
DESIGNED	P.THIEDE
PREPARED	S.KURASH
REVIEWED	R.ATKINS
APPROVED	D.LONG

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	12

Classification: Public

A second subset of Reach 2 showing a typically unstable meander is presented in Figure 4. In this sub-reach, the meander bend is partially confined by the terrace, but the channel corridor becomes more active just downstream of it. In this location, the channel corridor is locally wider due to the presence of vegetated islands and a point bar. The corridor migrated approximately 200 m downstream, resulting in bank erosion.

Reach 2 is considered laterally stable over more than half of its length due to the lack of channel corridor migration. However, locally unstable sub-reaches occur near the apexes of a few migrating meander bends.

4.2.4 Reach 3

Reach 3, which extends from Waskasoo Creek to Station 50+200, is typically straight to meandering. The upstream third of the valley is narrow due to confining terraces on both sides, but the valley bottom becomes wider downstream. The channel corridor is primarily single-threaded, and bars and vegetated islands are rare. Channel corridor width typically narrowed over the observed period due to stabilization of side bars. Otherwise, the position of the banks remained approximately stable.

A subset of this reach is presented in Figure 5. A vegetated island located close to the left bank grew on its upstream end over the observed period. The position of the banks remained approximately stable.

Reach 1 is considered typically laterally stable due to the lack of channel corridor migration or substantial change in island position.

4.2.5 Reach 4

Reach 4, which extends along Waskasoo Creek from its mouth at Red Deer River to Piper Creek, is typically straight to gently meandering, with a localized sub-reach that is torturously meandering. The reach is situated on the modern Red Deer floodplain and flows adjacent to a Red Deer River terrace over approximately half of the right bank. The stream become incised approximately 800 m upstream of the Red Deer confluence. The channel corridor appears to be primarily single-threaded.

Mid-channel bars and point bars were observed along the few hundred metres immediately upstream of the stream mouth. No bars were apparent over the rest of the reach, although visibility of the channel corridor was limited due to dense forest cover and the small size of the stream. The channel corridor appears to have been straightened. In general, the left and right banks have not moved over the observed period except near the stream mouth.

A second subset of Reach 4 showing stable conditions typical over the rest of the reach is presented in Figure 6. The channel corridor appears to have remained in approximately the same position, although visibility of the active channel was low due to tree cover. Limited bank erosion may have occurred at the apexes of the meander bends.

A subset of Reach 4 showing the typically unstable conditions near the stream mouth is also presented in Figure 6. The channel appears to have been artificially straightened prior to 1962. Over the observed period, the channel transitioned to a more meandering planform. Meander bend apexes migrated up to approximately 20 m, and the stream mouth migrated downstream approximately 30 m in response to a leftward shift of the right bank of Red Deer River.

Reach 4 is considered laterally stable due to the lack of channel corridor migration except for the downstream-most few hundred metres of channel near the Waskasoo Creek mouth. Here, the channel is considered laterally unstable due to more extensive channel corridor migration and downstream progression of the stream mouth.

4.2.6 Reach 5

Over the length of Reach 5, which extends from Piper Creek to Station 7+000, the channel corridor transitions from having a torturous meandering planform confined by terraces to flowing straight and unconfined over the modern Red Deer floodplain. The channel corridor is typically single-threaded, and sediment bars appear to be rare, although visibility of the channel corridor was limited due to dense forest cover and the small size of the stream. The left and right banks appear to have remained approximately stable over the observed period except for a few sub-reaches where anthropogenic channel corridor straightening appears to have taken place.

A subset of Reach 5 is presented in Figure 7. The position of the channel corridor has changed substantially over the observed period, but this appears to be a result of anthropogenic channel straightening rather than migration. Meander bends where straightening has not taken place, have remained approximately stable. However, the sub-reach is accumulating sediment and is therefore considered unstable (see Section 4.4.3).

The straight portions of Reach 5 are similar to those presented in the straight sub-reach of Reach 4 in Figure 6.

Reach 5 is considered typically laterally stable due to the lack of channel corridor migration. However, parts of the reach are classified as unstable due to aggradation (see Section 4.4.3).

4.2.7 Reach 6

Reach 6, which extends from Station 7+000 to Range Road 275, is typically single threaded and torturously meandering with a few locations that have been straightened. The meander belt is confined by terraces on both sides. In the historical period, some vegetated islands were present at locations where meander cutoffs appear to have been occurring.

No sediment bars were observed, although visibility of the channel corridor was limited due to dense forest cover and the small size of the stream. The left and right banks appear to have remained approximately stable over the observed period except for a few sub-reaches where channel cutoffs or apparent anthropogenic channel corridor straightening has taken place.

A subset of Reach 6 showing the typically stable torturously meandering channel corridor is presented in Figure 8. One meander cut-off has occurred, abandoning approximately 130 m of channel. The channel corridor is highly sinuous over the rest of the sub-reach, and a few potential cut-off locations are present where bends are less than approximately 20 m apart. However, except for the cut-off, channel corridor migration has been minimal.

A second subset of Reach 6 showing typically stable, straight to gently meandering conditions is also presented in Figure 8. In this location, the channel corridor appears to have a naturally low sinuosity. The channel was apparently straightened prior to the historical period in the vicinity of the Highway 2 crossing. The channel banks do not appear to have moved significantly over the observed period.

Reach 6 is considered typically stable due to the lack of channel corridor migration, although occasional meander bend cutoffs are possible.

4.2.8 Reach 7

Reach 7, which extends from Range Road 275 to Station 34+600, is typically single-threaded and straight. In the historical period, the channel was primarily single-threaded and torturously meandering with occasional vegetated islands in locations where channel corridor cutoffs were occurring. However, the left and right banks appear to have been anthropogenically straightened over the observed period. The meander belt is not typically confined in this reach. Sediment bars appear to be rare, although visibility of the active channel was limited due to the small size of the stream.

A subset of Reach 7 showing typically straightened channel corridor conditions is presented in Figure 9. In this location, the historical channel was torturously meandering, and two meander bend cutoffs appear to have been in progress, resulting in short multi-threaded channel sections containing vegetated islands. By the modern period, the channel had been apparently anthropogenically straightened.

Reach 7 is considered typically stable due to the lack of evidence of significant natural channel movement. However, left unmaintained, the channel may begin to transition back to a meandering planform.

4.2.9 Reach 8

Reach 8, which extends along Piper Creek from its outlet at Waskasoo Creek to 19th Street, is typically single-threaded, with moderately sinuous to tortuous meanders. The meander belt is confined by terraces on both banks. In the upstream half of the reach, the valley bottom is approximately 80 to 120 m wide, and it broadens to approximately 150 to 350 m over the downstream half of the reach.

Sediment bars appear to be rare, although visibility of the active channel was limited due to forest cover and the small size of the stream. In general, the left and right banks appear to have remained approximately stable, although the channel corridor has moved in a few locations as a result of apparently anthropogenic channel straightening and meander bend cutoff.

A subset of Reach 8 showing typically stable conditions is presented in Figure 10. The channel corridor is typically torturously meandering, and potential meander bend cutoff locations are present in sections where bends are less than approximately 15 m apart. The channel corridor has remained in approximately the same position over the observed period, and no meander bend cutoffs occurred.

Reach 8 is considered typically stable due to the lack of channel corridor migration, although occasional meander bend cutoffs are possible.

4.2.10 Reach 9

Reach 9, which extends from 19th Street to McKenzie Road, is typically single-threaded and torturously meandering with rare vegetated islands. In the upstream quarter of the reach, the meander belt is unconfined, and the channel corridor is poorly defined in some locations. Downstream, the channel becomes incised, and terraces confine the meander belt along both banks.

Sediment bars appear to be rare, although visibility of the active channel was limited due to forest cover and the small size of the stream. In general, the left and right banks appear to have remained approximately stable, although the channel corridor has moved in a few locations as a result of apparently anthropogenic channel straightening and meander bend cutoff.

A subset of Reach 9 showing typically stable conditions is presented in Figure 11. The channel corridor is typically torturously meandering, and a meander bend cutoff occurred over the observed period. The rest of the channel corridor has typically remained in approximately the same position.

Reach 9 is considered typically stable due to the lack of channel corridor migration, although occasional meander bend cutoffs are possible.

4.3 Cross Section Comparison

Detailed qualitative and quantitative descriptions and figures for the cross section comparisons are presented in Appendix A. Comparisons are available for the upstream half of Reach 2, Reaches 3 and 4, the downstream third of Reach 5, and the upstream third of Reach 7. Table 6 provides a summary of representative cross section geometry.

Table 6: Summary of Representative Cross Section Geometry

Reach or Representative Sub-reach	Maximum Bankfull Depth (m)		Average Bankfull Depth (m)		Bankfull Width (m)		Cross sectional Area (m^2)	
	Historical	Recent	Historical	Recent	Historical	Recent	Historical	Recent
Reach 2—Red Deer River (kms 29-32)	6.7	5.6	4.9	3.8	156	157	607	568
Reach 2—Red Deer River (kms 35-37)	5.8	5.9	4.0	3.3	167	424	658	1062
Reach 3—Red Deer River (kms 39-50) (2)	4.4	4.2	3.2	2.9	132	127	446	375
Reach 4—Waskasoo Creek (kms 0.6-3.4)	2.5	2.3	1.7	1.4	14	11	28	22
Reach 5—Waskasoo Creek (kms 3.8-4.4)	2.7	2.4	1.5	1.4	13	13	20	19
Reach 7—Waskasoo Creek (kms 25.1-32.1)	1.6	1.8	1.0	1.0	15	37	14	37
Reach 7—Waskasoo Creek (kms 33.6-34.6)	0.4	0.5	0.2	0.2	11	11	2.7	2.2

Notes: (1) Historical geometry derived from 1991, 1995, 2007, or 2008 models, and recent geometry derived from 2017 surveys. (2) Representative cross sections were collected over more than one time period.

Two types of behaviour were identified in the sections of Reach 2 where cross section comparison was possible. The cross sectional area of the sub-reach between river km 29 and 32 decreased from, on average, approximately 607 m^2 to approximately 568 m^2. The decrease appears to be related to variances in the height of the bank as surveyed. A review of available imagery and profile locations suggests that these variances are most likely explained as resulting from inconsistencies in the relative surveyed locations between the historical and modern cross section surveys. The channel width remained approximately the same, and no signs of aggradation or degradation were observed. Statistical analysis of geometric change was not possible due to a small sample size of adequate cross sections.

Farther upstream, over river km 35-37, the cross sectional area increased from, on average, approximately 658 m^2 to approximately 1062 m^2. The depth did not change considerably, and the larger recent cross sectional area appears to be caused primarily by an increase in bankfull width of over 200 m due to the construction of a feature resembling a wetland. Statistical analysis of geometric change was not possible due to a small sample size of adequate cross sections.

In Reach 3, the cross sectional area decreased slightly from approximately 446 m^2 to approximately 375 m^2. In most locations, bankfull depth did not change. At some cross sections, width increased, and it decreased slightly at others. At a few cross sections, the channel migrated by a couple metres. None of the changes to the geometric parameters were significant at the 96% confidence level.

In Reaches 1, 2 and 3, a review of the HEC-RAS model for Red Deer River indicates that flows exceeding the 5-year flood event are typically contained within the channel banks. The current river is underfit for its current valley and channel corridor. The current valley is a relict feature that was likely carved by glacial meltwater during the last ice age. Red Deer River currently occupies that larger relict channel.

The construction of the Gleneffer Dam has likely affected the frequency of peak flows such that regulated flows can be expected to be less peaky than an unregulated hydrologic regime. The construction of the dam will have likely resulted in the trapping of sediment load in the reservoir and bed degradation downstream of the dam as the river discharge re-establishes its sediment load. The reduced flood peaks resulting from flow regulation at Gleneffer Dam as well as degradation of the bed due to sediment recruitment downstream of the dam may also reduce the likelihood of flows overtopping the channel banks.

In Reach 4, the cross sectional area decreased from approximately 28 to approximately 22 m^2. In most locations, the channel narrowed. At some cross sections, aggradation and migration of a couple metres occurred. None of the changes to the geometric parameters were significant at the 96% confidence level.

The portions of Reach 5 for which cross sectional data is available experienced minimal change. Statistical analysis of geometric change was not possible due to a small sample size of adequate cross sections.

Two types of behaviour were identified in the sections of Reach 7 where cross section comparison was possible. The cross sectional area of the sub-reach between river km 25.1 and 32.1 increased by more than a factor of two, primarily due to channel widening from, on average, approximately 15 to approximately 37 m. Much of the widening can be attributed to the construction of a new channel apparent on one cross section. Migration of up to approximately 10 m was observed, although the channel only migrated a couple metres on most cross sections. None of the changes to the geometric parameters were significant at the 96% confidence level.

From river km 33.6-34.6, the channel is small and poorly defined. Cross sectional geometry experienced minimal change. Statistical analysis of geometric change was not possible due to a small sample size of adequate cross sections.

4.4 Thalweg Profile Comparison

4.4.1 Summary

Observations on channel longitudinal profile and thalweg elevation change over time were made on Red Deer River and Waskasoo Creek using the historical and modern surveys (Figure 13 and Figure 14). Elevation difference plots were created to highlight the measured changes and are presented in Figure 16 and Figure 17. Positive numbers are indicative of accretion (or aggradation) and negative numbers are indicative of scour (or degradation). Table 7 summarizes the reach-averaged channel slopes and net fluxes of sediment through the reaches. Historical thalweg data is not available for Reaches 1, 6, 8 and 9. Only partial coverage of Reaches 2, 3, 5, and 7 is available.

Longitudinal profiles exhibiting a concave shape are typical of a stream reach in equilibrium (Ritter et al. 1995). The longitudinal profile for the Red Deer River (Figure 13) is approximately linear. This may indicate that the stream is out of equilibrium, but it is more likely that the study area is too small to detect large-scale longitudinal patterns. The longitudinal profiles for Waskasoo Creek (Figure 14) and Piper Creek (Figure 15) are both convex, which suggests that both streams are also generally out of equilibrium. More details on each stream are provided in the following sections.

Table 7: Summary of Net Volume Bed Change

River	Reach and Description	Assessed River Stations (km)	Average Reach Slope (m/m)	Net Bed Volume Change per unit channel width per year (m^3/m/yr)
Red Deer River	Reach 2—Blindman River to Waskasoo Creek	28-39	0.0013	-128
	Reach 3—Waskasoo Creek to STN 50+200	39-51	0.0012	-86
Total net bed volume change per year for Red Deer River				*-214*
Waskasoo Creek	Reach 4—Red Deer River to Piper Creek	0-3.5	0.0020	-0.76
	Reach 5—Piper Creek to STN 7+000	3.5-5.8	0.0050	87
	Reach 7—Range Road 275 to STN 34+600	25.2-34.7	0.00069	-204
Total net bed volume change per year for Waskasoo Creek				*-118*

4.4.2 Red Deer River

The Red Deer River flows through gentle terrain typical of the Prairies. The modern floodplain has incised approximately 30 to 150 m below the general prairie surface, likely driven by excess discharge of glacial meltwater during deglaciation resulting in the initial carving of the Red Deer River valley. Red Deer River presently occupies this valley, and the construction of dams along the river upstream of the study reach have likely contributed to a general reduction in available sediment supply compared with pre-regulation conditions. Pre-regulation sediment supply was likely significantly less than the sediment supply during the immediate postglacial period due to the waning with time of periglacial conditions (e.g., limited vegetative cover, loose soils). Dickson Dam was constructed in 1983 at a location approximately 45 km upstream of Reach 3. Alterations to the hydrologic and sediment supply regimes on Red Deer River due to dam construction and operation may have resulted in changes to the longitudinal profile and channel geometry.

The channel gradient of Red Deer River is approximately 0.1% throughout the study area (Figure 13). The study area comprises a relatively small portion of the river, so large-scale longitudinal patterns such as a concave profile may not be apparent in the thalweg data. It is also possible that the longitudinal profile is imposed by underlying bedrock or glacial sediments and is not a result of fluvial processes characteristic of the modern Red Deer River.

In Reaches 2 and 3, the thalweg has generally lowered by up to approximately 1 m since the historical period, although in a few locations, the channel aggraded by a few centimetres (Figure 16). Between 1991 and 2017, local aggradation and degradation were both highest in the vicinity of bridges within the City of Red Deer, near the boundary of Reaches 2 and 3 and near Station 46+000. For example, the channel locally degraded approximately 1.5 m at a location approximately 1 km upstream of the Highway 2 bridge and aggraded by approximately 1.3 m under the bridge. In surveyed sub-reaches not near bridges, the channel typically degraded by up to approximately 0.5 m. Thalweg data is available for both 1991 and 2007 at locations just upstream of the Highway 2 bridge. Degradation between 2007 and 2017 was less than 0.25 m, suggesting that the bed in that location may be becoming relatively stable.

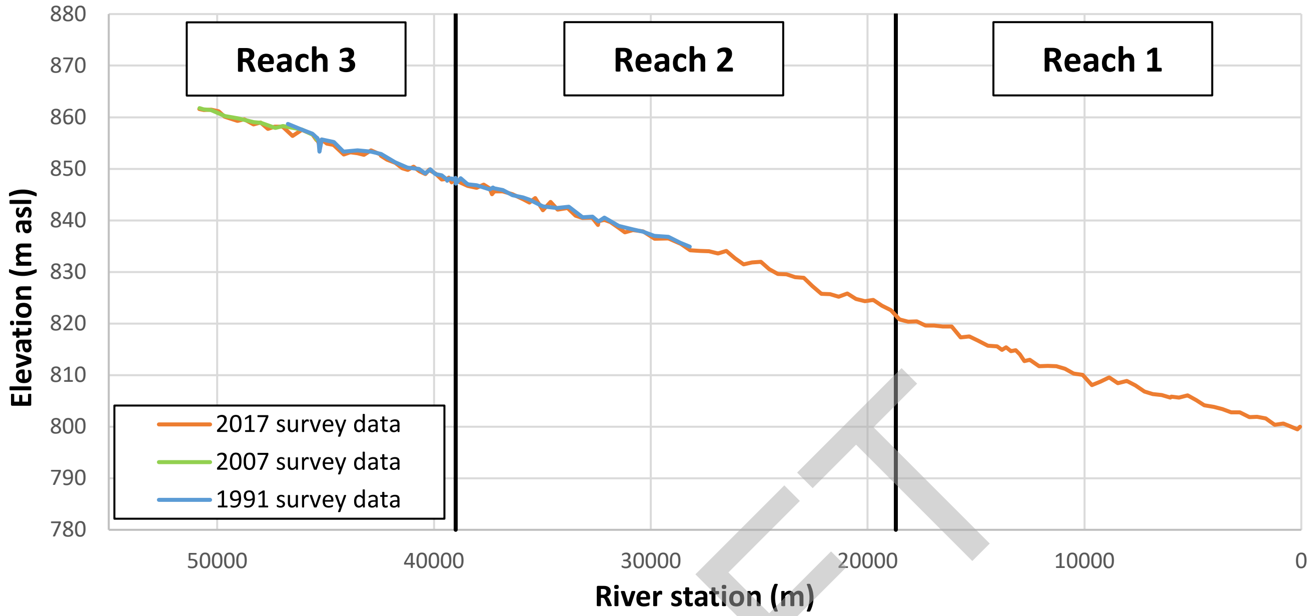

Figure 13: Longitudinal Profile for Red Deer River

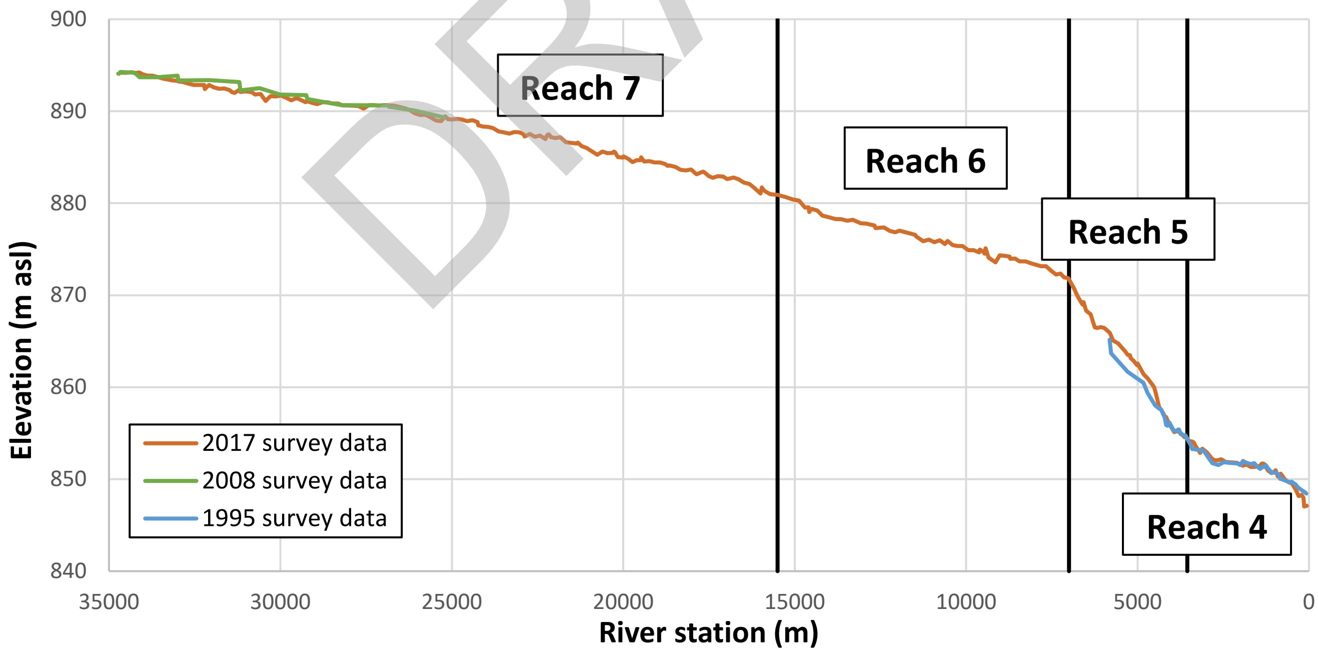

Figure 14: Longitudinal Profile for Waskasoo Creek

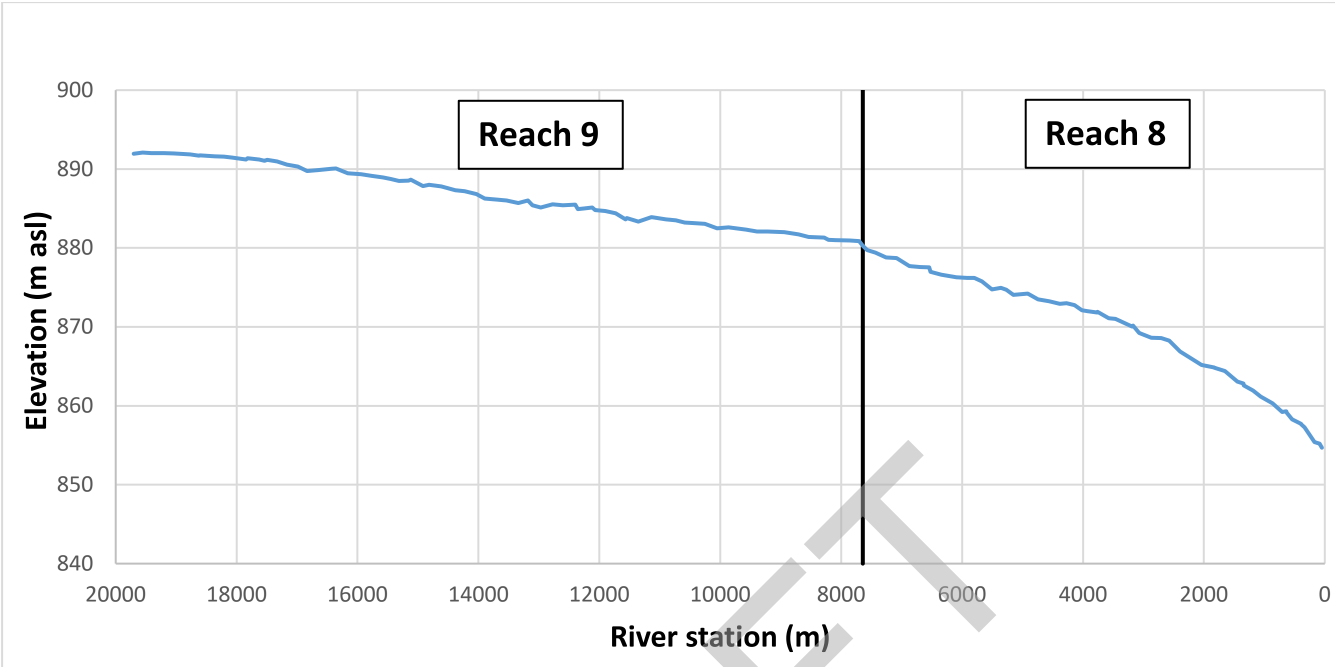

Figure 15: Longitudinal Profile for Piper Creek

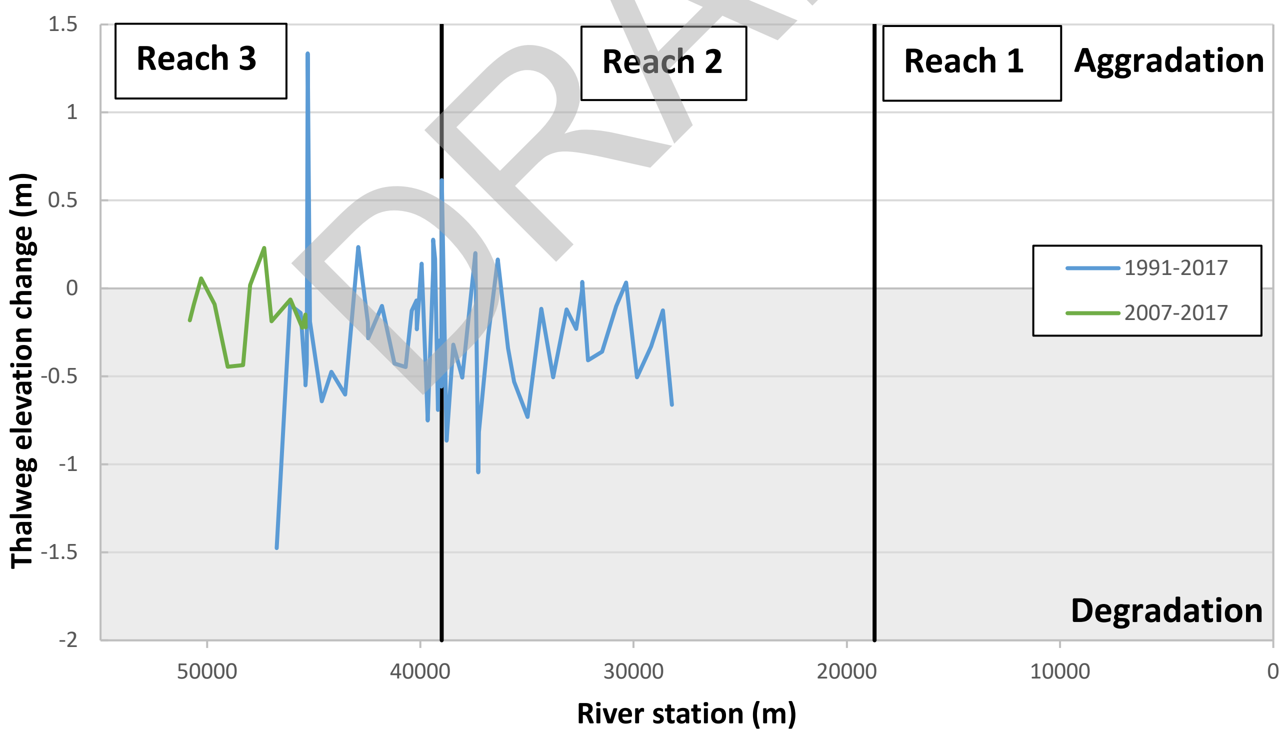

Figure 16: Red Deer River Thalweg Elevation Difference

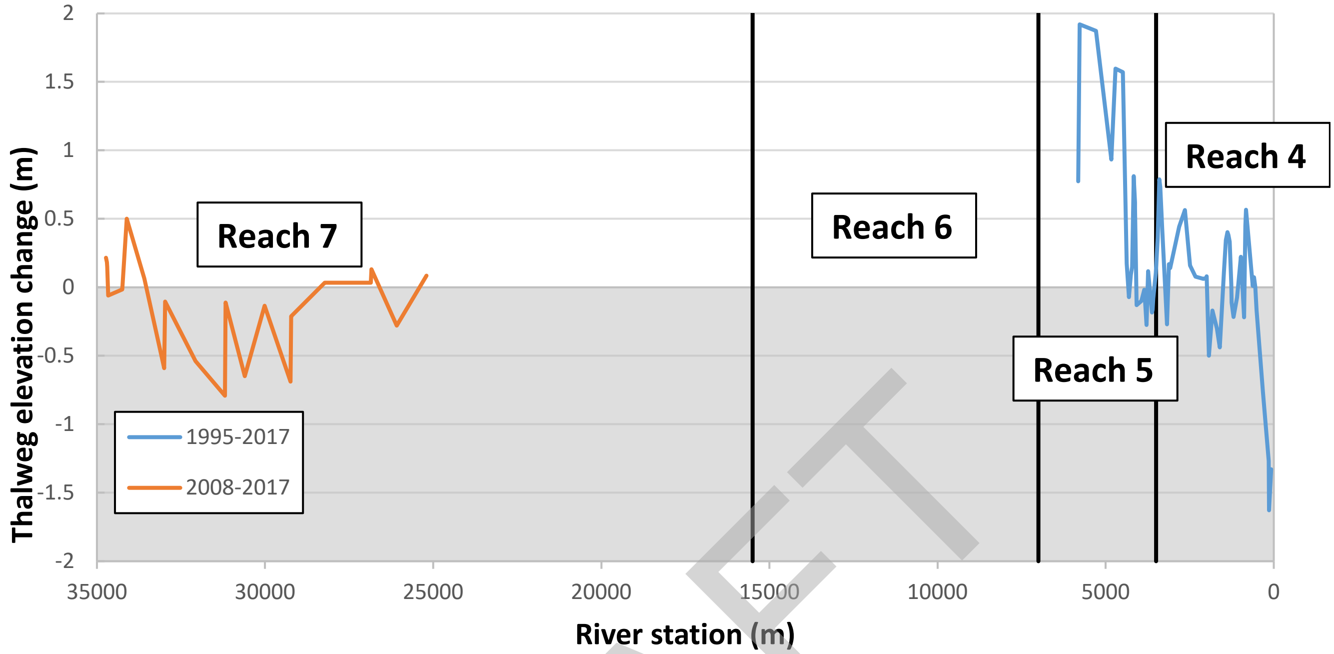

Figure 17: Waskasoo Creek Thalweg Elevation Difference

The sections of Reaches 2 and 3 where thalweg data is available are experiencing net losses of approximately 128 and 86 m^3 of sediment per unit channel width per year, respectively (Table 7). Theses changes are consistent with anticipated patterns of river evolution for this region. Over the long term (thousands of years), the Red Deer River valley has been experiencing a net reduction of sediment as the river has cut into relict glacial and deglacial surfaces. Degradation over the past several decades may be a result of a loss of sediment supply caused by trapping on the upstream side of Dickson Dam.

4.4.3 Waskasoo Creek

Waskasoo Creek flows through typically gentle terrain on the Prairies. Over the long term (thousands of years), the stream appears to be responding to base level lowering at its mouth caused by degradation on Red Deer River. Slope is gentle (approximately 0.07%) along Reach 7 (Figure 14). The channel begins to become incised within the general prairie surface along Reach 6, where the slope increases to approximately 0.1%. The slope increases abruptly to approximately 0.5% at a knickpoint located near the boundary between Reaches 5 and 6. It becomes gentler (approximately 0.2%) in Reach 4 where the stream flows across a terrace of Red Deer River, before steepening just upstream of the mouth.

The thalweg elevation has remained approximately stable over most of Reach 4. Local aggradation and degradation between 1995 and 2017 is typically under 0.75 m. The net annual erosion of the bed per unit channel width is less than 1 m^3/m/yr (Table 7); however, Waskasoo Creek degraded by more than 1.5 m over the few hundred metres upstream of its mouth.

Waskasoo Creek has been aggrading over the surveyed sections of Reach 5, particularly between Station 4+500 and Station 5+800. The cause of the increase is not clear, but the slope near the zone of aggradation is slightly lower than the upstream portion of the reach, where channel straightening has occurred. It is possible that the sub-reach between Station 4+500 and Station 5+800 is accumulating sediment sourced from the straightened section, where the ability of the stream to transport sediment will have increased with increasing slope. The net bed volume increase per unit channel width for surveyed sections of Reach 5 is approximately 87 m^3/m/yr.

In Reach 7, Waskasoo Creek is typically degradational, although local degradation has remained below 1 m between 2008 and 2017. The cause of degradation is unclear, although channel straightening may have led to an increase in bed slope, which typically increases sediment transport capacity. The net bed volume decrease rate per unit channel width for surveyed sections of Reach 7 is approximately 204 m^3/m/yr.

4.4.4 Piper Creek

Piper Creek flows through typically gentle terrain on the Prairies. Over the long term (thousands of years), the stream appears to be responding to base level lowering at its mouth caused by degradation on Waskasoo Creek. Slope is gentle (approximately 0.1%) along Reach 9 (Figure 15). It begins to increase gradually over Reach 8 (where the average slope is approximately 0.3%) until the stream mouth at Waskasoo Creek. The channel is typically incised within the general prairie surface except at the upstream end of Reach 9.

No historical survey data is available for Piper Creek.

4.5 Rating Curve Comparison

4.5.1 Data Availability

Rating curves are available for Red Deer River and Waskasoo Creek. No curves are available for Piper Creek. The results of rating comparisons based on the available data are described in the following sections.

4.5.2 Red Deer River

The gauge for Red Deer River is located at the downstream end of Reach 3, just upstream of Waskasoo Creek. Rating curves are presented in Figure 18. The gauge was established in 1911, and rating curves are available between 1950 and 2016. From 1950-1966, the gauge was located on the Highway 2 bridge, approximately 6 km upstream of its present location. In 1966, it was moved to the 49th Avenue bridge, approximately 400 m downstream of its present location. In 1978, it was moved to its present location at the railway bridge upstream of Gaetz Avenue. The curves for the periods 1950-1965, 1971-1975, and 1981-2016 must be compared separately because of the gauge location changes.

The rating curves for the period 1950-1960 changed little. There was a slight downward shift in the curve between 1960 and 1965 which could represent channel widening or degradation. Evidence of small amounts of channel widening and degradation were observed in the cross section and thalweg analyses. Therefore, it is not possible to determine the cause of the shift.

No changes were observed on the rating curves for the period 1971-1975.

There was an upward shift in the upper tail of the rating curves between 2003 and 2005. Possible causes of the shift include channel narrowing or aggradation. The shift is only noticeable for flows above approximately 350 m^3/s, so it is likely that the shift is due to channel narrowing, as aggradation would conceivably affect stages at lower discharges. Channel narrowing was observed over many parts of the reach.

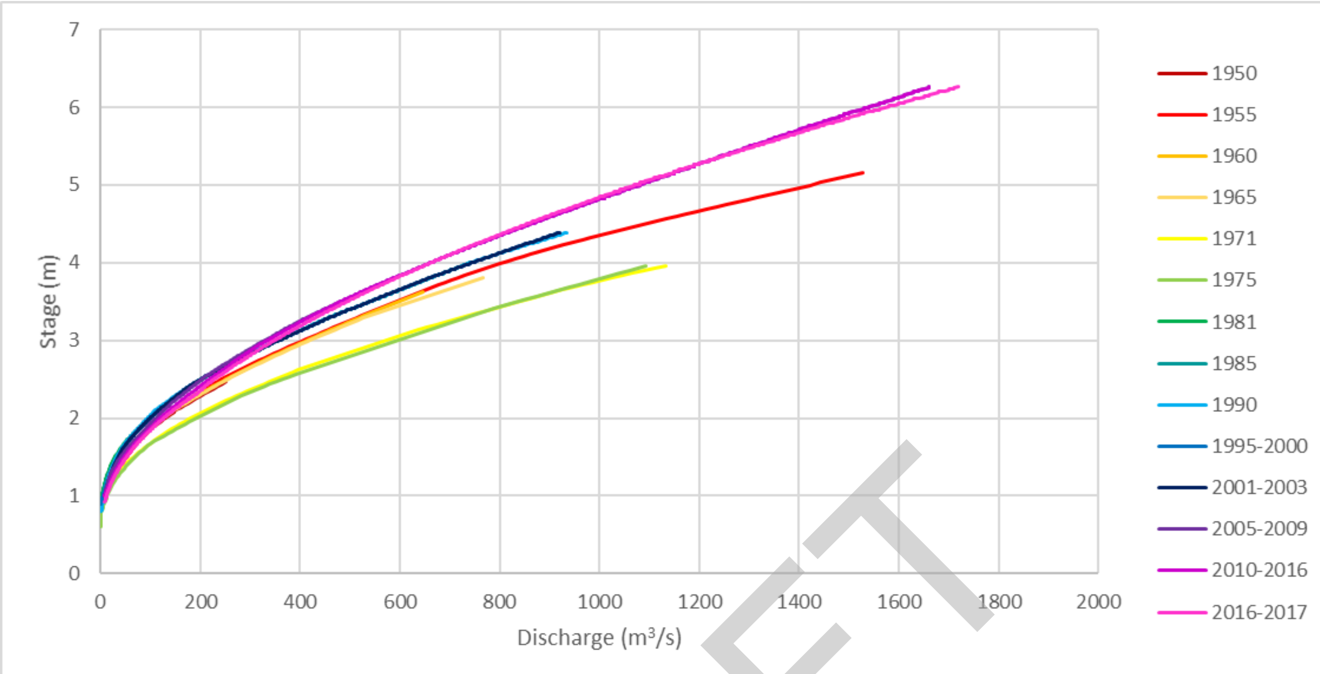

Figure 18: Rating Curves for Red Deer River at Red Deer

4.5.3 Waskasoo Creek

The gauge for Waskasoo Creek is located in Reach 4, at a location approximately 1.2 km upstream of the stream mouth. The gauge was established in 1984. Rating curves are available between 1985 and 2017. Rating curves are presented in Figure 19. An assessment of available records suggests that the gauge has not been moved over its lifetime.

The rating curve shifted incrementally upward for lower flows and downward for high flows above approximately 10 m^3/s between 1985 and 2003. Possible causes of the upward shift for low flows include channel narrowing near the channel bed or aggradation. The downward shift for high flows may be accounted for by channel widening.

Cross sections in the vicinity of the gauge (Appendix A) show that the elevation of the channel bed has increased slightly and that the channel has become wider near the top of the channel and narrower near the bottom. The changes to channel shape appear to have resulted from anthropogenic reworking of the channel rather than from fluvial processes. It is possible that some aggradation occurred naturally, although the thalweg data suggests that the elevation over most of Reach 4 has remained relatively stable (see Section 4.4.3).

Between 2003 and 2017, there was a downward shift in the rating curve which could represent channel widening or degradation. As the elevation for most of reach has remained relatively stable, channel widening is the most likely cause. Widening may have been a result of anthropogenic reworking of the channel rather than bank erosion.

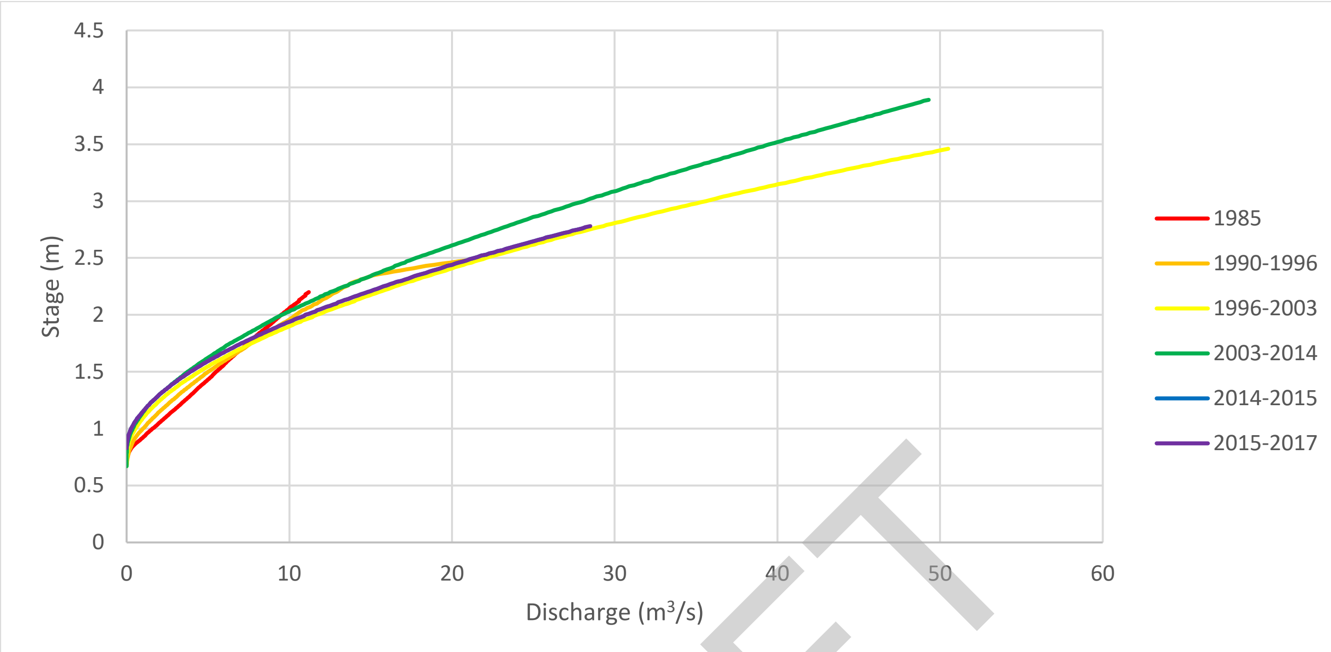

Figure 19: Rating Curves for Waskasoo Creek at Red Deer

5.0 CONCLUSIONS

The results from the channel delineation, cross section, thalweg profile, and rating curve comparisons are summarized below for each reach. Key characteristics are summarized in Table 8. The channel stability of the reaches is mapped in Figure 12.

Table 8: Summary of Reach Characteristics

Reach and Description	Current Width to Depth Ratio (m/m)	Reach Slope (m/m)	Sinuosity (Thalweg Length/Straight Valley Length) (m/m)	Summary of Observations
1 - Highway 11 to Blindman River	-	0.0011	1.1	■ Straight to meandering planform ■ Meander belt confined by bluffs ■ Channel narrowing and limited localized widening ■ Limited number of bars suggests low to moderate sediment supply
2 - Blindman River to Waskasoo Creek	41-128	0.0013	2.2	■ Meandering to torturously meandering planform ■ Meander belt partially confined by bluffs ■ Bank erosion and channel migration near the apex of some meander bends ■ Channel narrowing ■ Primarily degrading ■ Net bed volume change in measured sub-reach: -128 $m^3/m/yr$ ■ Limited number of bars and degradation suggests low to moderate sediment supply

Table 8: Summary of Reach Characteristics

Reach and Description	Current Width to Depth Ratio (m/m)	Reach Slope (m/m)	Sinuosity (Thalweg Length/Straight Valley Length) (m/m)	Summary of Observations
3 - Waskasoo Creek to Station 50+200	44	0.0012	1.2	■ Straight to meandering planform ■ Meander belt partially confined by bluffs ■ Limited to no migration ■ Channel narrowing ■ Primarily degrading with localized aggradation ■ Net bed volume change in measured sub-reach: -86 m^3/m/yr ■ Very limited number of bars and degradation suggests low sediment supply
4 - Outlet at Red Deer River to Piper Creek	8	0.0020	1.2	■ Typically straight to gently meandering planform ■ Meander belt partially confined by bluffs ■ Channel migration near stream mouth ■ Degradation near stream mouth ■ Net bed volume change: -0.76 m^3/m/yr ■ Presence of mid-channel and point bars suggests moderate sediment supply
5 - Piper Creek to Station 7+000	9	0.0050	1.7	■ Torturously meandering and straight planforms ■ Meander belt confined by bluffs in upstream sections ■ Channel straightening ■ Aggradation in middle section of reach ■ Net bed volume change in measured sub-reach: 87 m^3/m/yr ■ Evidence of aggradation suggests sediment supply is high
6 - Station 7+000 to Range Road 275	-	0.0011	1.6	■ Typically torturously meandering planform ■ Meander belt confined by terraces ■ Limited meander cutoffs observed ■ Limited number of bars suggests low to moderate sediment supply
7 - Range Road 275 to Station 34+600	37-55	0.00069	1.2	■ Typically straight planform that was historically torturously meandering ■ Meander belt is unconfined ■ Channel straightening ■ Limited meander cutoffs observed in historical period ■ Primarily degrading ■ Net bed volume change in measured sub-reach: -204 m^3/m/yr ■ Limited number of bars suggests low to moderate sediment supply
8 - Outlet at Waskasoo Creek to 19th Street	-	0.0034	2.9	■ Typically moderate to torturously meandering planform ■ Meander belt confined by terraces ■ Limited channel straightening ■ Limited meander cutoffs observed ■ Limited number of bars suggests low to moderate sediment supply

Table 8: Summary of Reach Characteristics

Reach and Description	Current Width to Depth Ratio (m/m)	Reach Slope (m/m)	Sinuosity (Thalweg Length/Straight Valley Length) (m/m)	Summary of Observations
9 - 19th Street to McKenzie Road	-	0.00096	1.2	▪ Typically torturously meandering planform ▪ Mender belt confined by terraces in downstream sections ▪ Limited channel straightening ▪ Limited meander cutoffs observed ▪ Limited number of bars suggests low to moderate sediment supply

Reach 1

Reach 1 of the Red Deer River is typically characterized by a low gradient (approximately 0.11%), straight to meandering, single-threaded channel corridor that has incised into the general prairie surface. The channel has typically narrowed due to vegetation encroachment onto point bars. The bank alignment is similar in 1962 and in 2017, although limited channel corridor widening was observed in localized areas. Channel narrowing may have resulted in a reduced flood conveyance capacity for the reach, although the flow modeling (Golder, 2019b) suggests that the channel is typically overfit for the modern flow regime.

Reach 1 is considered typically stable due to the lack of significant channel corridor movement.

Reach 2

Reach 2 of the Red Deer River is typically characterized by a low gradient (approximately 0.13%), meandering to torturously meandering, single-threaded channel corridor incised into a broad, flat feature resembling a glacial outwash plain. The bank alignment is similar in 1962 and 2017 for more than half of the reach, but bank erosion and migration has occurred near the apex of a few meander bends. In these locations, the channel corridor is locally multi-threaded and wider than adjacent sub-reaches.

The reach is primarily experiencing minor degradation, although localized sections of aggradation and degradation up to approximately 1 m occur where the river flows through a dense concentration of bridges in the city of Red Deer. Some channel corridor narrowing has occurred due to vegetation encroachment onto point bars.

The cross sectional area apparently decreased over much of the reach based on analysis of the surveyed bank tops; however, the observed variances in the surveys appears to be related to inconsistencies between the historical and modern surveys rather than an actual change in bank top elevation, because these variances are observed where abutments have been constructed for bridges over the river.

Near the centre of the reach, the construction of a feature resembling a wetland has increased channel capacity. Bank lowering and channel narrowing will have resulted in a reduced conveyance capacity for the reach, although the flow modeling (Golder 2019b) suggests that the channel is typically overfit for the modern flow regime.

Reach 2 is considered typically stable due to the lack of significant channel corridor movement or widespread aggradation. However, localized channel zones near the apexes of some meander bends have been classified as unstable due to evidence of bank erosion and meander migration.

Reach 3

Reach 3 of the Red Deer River is typically characterized by a low gradient (approximately 0.12%), straight to meandering, single-threaded channel corridor incised into a broad, flat feature resembling a glacial outwash plain. The channel has typically narrowed due to vegetation encroachment onto point bars, although limited channel widening was noted on some of the cross sectional data.

Analysis of historical and modern imagery suggests that the bank alignment is similar in 1962 and in 2017. The reach is primarily experiencing minor degradation, although localized sections of aggradation and degradation exceeding 1 m occur where the river flows through a dense concentration of bridges in the city of Red Deer.

The reach-average cross sectional area of the channel has apparently decreased over much of the reach based on analysis of the surveyed bank tops; however, the observed variances in the surveys appears to be related to inconsistencies between the historical and modern surveys rather than an actual change in bank top elevation, because these variances are observed where abutments have been constructed for bridges over the river. The channel narrowing may have contributed to a reduced flood conveyance capacity for the reach, but the flow modeling (Golder, 2019b) suggests that the channel is typically overfit for the modern flow regime.

Reach 3 is considered typically stable due to the lack of significant channel corridor movement or widespread aggradation.

Reach 4

Reach 4 of Waskasoo Creek is characterized by a straight to gently meandering, single-threaded channel corridor that is partially incised into the modern Red Deer River floodplain. Slope in this reach is moderate at approximately 0.20%. The channel corridor has migrated over the few hundred metres immediately upstream of the stream mouth.

Bank mapping and cross sectional analyses suggest that the channel has not shifted position by more than a couple metres over the rest of the reach. Bed elevation has remained approximately stable over most of the reach, but degradation exceeding 1.5 m occurred at the downstream end of the reach where Waskasoo Creek enters Red Deer River. The cross sectional data suggest that channel area has decreased slightly. It appears as though the channel may have been anthropogenically reworked. This may have decreased the flood conveyance capacity for the reach.

Reach 4 is considered typically stable over most of its length due to the lack of significant channel corridor movement or widespread aggradation. Approximately 500 m at the downstream end of the reach is classified as unstable due to significant observed channel migration.

Reach 5

Reach 5 of Waskasoo Creek is characterized by a straight to torturously meandering, single-threaded channel corridor that is incised into a broad, flat feature resembling a glacial outwash plain. The slope (approximately 0.50%) is steeper than adjacent reaches because the reach is situated at the downstream end of a knickpoint, which likely developed due to base level lowering following long-term degradation of Red Deer River.

The downstream third of the channel appears to have been straightened prior to 1962, and the upstream third was straightened during the observed period. The meandering sub-reach between the straight sections does not appear to have shifted position over the observed period. However, the thalweg data suggests that this sub-reach has aggraded by almost 2 m over the observed period. The cause of the sediment accumulation is unclear, but it may be linked to channel straightening just upstream.

The cross sections selected for analysis only cover the downstream third of the reach and suggest that channel area has not changed significantly over the observed period. However, possible significant aggradation in the middle of the reach would likely locally reduce the conveyance capacity.

Reach 5 is considered typically stable on its upstream and downstream ends due to lack of natural channel corridor movement or widespread aggradation. The meandering section near the middle of the reach is classified as unstable due to evidence of severe aggradation.

Reach 6

Reach 6 of Waskasoo Creek is characterized by a gentle (approximately 0.11%), torturously meandering, single-threaded channel corridor that is incised into a broad, flat feature resembling a glacial outwash plain. The bank alignment is similar in 1962 and 2017 except for in a couple locations where meander bend cutoffs have occurred. Historical cross section and thalweg data is not available for this reach, so it is unclear whether the conveyance capacity of the channel has changed over time.

Reach 6 is considered typically stable due to limited channel movement. Meander bend cutoffs are possible but are unlikely to result in a widening of the meander belt.

Reach 7

Reach 7 of Waskasoo Creek is characterized by a very gentle (approximately 0.069%), straight, single-threaded channel corridor. The channel corridor was torturously meandering in the historical period but was straightened over the observed period. A few meander bend cutoffs in progress were observed on the historical imagery.

The cross section analysis suggests that the channel corridor may have migrated by a up to a few meters over the observed period, but there are otherwise no significant changes to cross sectional geometry. Sections of the channel where historical thalweg data is available have been primarily degradational. The absence of significant changes to cross sectional geometry suggests that the conveyance capacity of the channel has not changed extensively.

Reach 6 is considered typically stable due to limited evidence of channel movement or widespread aggradation.

Reach 8

Reach 8 of Piper Creek is characterized by a moderately to torturously meandering, single-threaded channel corridor that is incised into a broad, flat feature resembling a glacial outwash plain. The slope (approximately 0.34%) is steeper than adjacent reaches, because the reach is situated at the downstream end of a knickpoint, which likely developed due to base level lowering following long-term degradation of Red Deer River.

The bank alignment is similar in 1962 and 2017 except for in a couple locations where meander bend cutoffs have occurred or where the channel has been straightened. Historical cross section and thalweg data is not available for this reach, so it is unclear whether the conveyance capacity of the channel has changed over time.

Reach 8 is considered typically stable due to limited channel movement. Meander bend cutoffs are possible but are unlikely to result in a widening of the meander belt.

Reach 9

Reach 9 of Piper Creek is characterized by a very gentle (approximately 0.096%) moderately to torturously meandering, single-threaded channel corridor. The downstream portion of the reach is incised into a broad, flat feature resembling a glacial outwash plain. The bank alignment is similar in 1962 and 2017 except for in a couple locations where meander bend cutoffs have occurred or where the channel has been straightened. Historical cross section and thalweg data is not available for this reach, so it is unclear whether the conveyance capacity of the channel has changed over time.

Reach 8 is considered typically stable due to limited channel movement. Meander bend cutoffs are possible but are unlikely to result in a widening of the meander belt.

Signature Page

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https://golderassociates.sharepoint.com/sites/17336g/technical work/08_channel stability investigation/03_reporting/rev0/1783039-070-r-rev0_red deer channel stability report.docx

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APPENDIX A

Cross Section Comparison

Table 1: Cross Section Geometry for the historical and modern periods

Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 2—Red Deer River from Blindman River to Waskasoo Creek	1991	2	29	-	769	212	222	-	6.1	-	3.5	■ Channel cross-sectional area, maximum, and average depth were not calculated for the 1991 data due to apparently inaccurate data ■ Cross-section is located just upstream of bend apex ■ Multi-threaded channel with 1 dominant and 1 sub-dominant channel ■ Dominant channel is lightly left-handed and not skewed ■ Channel widened approximately 10 metres on the right bank ■ Inaccurate data prevents assessment of aggradation or degradation Vegetated island on middle-left side of channel
	1991	6	31	556	502	149	151	5.0	5.1	3.7	3.3	■ Located in straight channel section ■ Single-threaded channel ■ Left-handed and not skewed ■ No significant changes to width. Average depth decreases slightly ■ No apparent migration ■ No apparent aggradation or degradation
	1991	9.2	32	659	435	107	97	8.3	5.9	6.2	4.5	■ Located near apex of bend ■ Single-threaded channel ■ Left-handed and not skewed ■ No significant width change. Depth decreases due to an apparent lowering of the left bank ■ No apparent migration ■ No apparent aggradation or degradation

Table 1: Cross Section Geometry for the historical and modern periods

Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 2—Red Deer River from Blindman River to Waskasoo Creek	1991	14	35	631	1389	179	687	6.3	5.8	3.5	2.0	■ Cross-section is located along bend in channel ■ Single-threaded channel becomes multi-threaded with a dominant channel and approximately 4 sub-dominant channels. A wetland appears to have been constructed at the cross-section. ■ Left-handed and left skewed in 1991; skew is not apparent in 2017. ■ Channel widening of several hundred metres and a reduction in average depth by over a meter ■ No apparent channel migration ■ Degradation of up to approximately a meter ■ The channel corridor now contains several vegetated islands as a result of the transition to a multi-threaded planform
	1991	19.1	37	685	734	155	162	5.3	6.0	4.4	4.5	■ Cross-section is located in a straight section of channel at bridge crossing ■ Single-threaded channel ■ Slightly left-handed and not skewed ■ Channel widens by a few metres and deepens slightly ■ No apparent migration ■ Degradation of approximately 0.6 metres ■ Mid-channel bar developed
Reach 3—Red Deer River from Waskasoo Creek to STN 50+200	1991	23	39	480	403	172	161	4.1	4.5	2.8	2.5	■ Cross-section is located approximately halfway along a shallow meander bend ■ Single-threaded channel ■ Changes from uniform and not skewed to left-handed and slightly left skewed ■ Channel narrowing of approximately 10 metres and a slight reduction of average depth ■ Channel migrated a few metres to the left ■ Degradation of approximately 0.5 metres

Table 1: Cross Section Geometry for the historical and modern periods

Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 3—Red Deer River from Waskasoo Creek to STN 50+200	1991	28.2	39	994	544	161	140	8.6	5.6	6.2	5.6	■ Cross-section is located in a straight section just downstream of a slight bend ■ Single-threaded channel. Historical channel may have contained a sub-dominant channel. ■ Left-handed and not skewed ■ Channel narrowing and loss of approximately 3 metres of the right bank, potentially due to development ■ Channel migrated a few metres to the left ■ No apparent aggradation or degradation
	1991	31.2	31	777	636	167	150	5.9	5.1	4.7	4.2	■ Located at a bridge crossing in a straight section of channel ■ Single-threaded channel, likely influenced by bank stabilization works ■ Slightly left-handed and not skewed ■ Decrease in channel width. Likely due to slight difference in sampling location. No significant change to channel depth. ■ No apparent migration ■ No apparent aggradation or degradation
	1991	35	42	264	269	110	113	3.1	3.4	2.4	2.4	■ Located near apex of meander bend ■ Single-threaded channel ■ Right-handed with no skew in the historical period. Very slight right skew develops. Floodplain is right-skewed. ■ Very slight channel widening and deepening. ■ Right bank has moved a couple metres to right. Possible bluff failure. ■ Slight degradation
	1991	39	44	500	540	117	123	7.0	7.4	4.3	4.4	■ Cross-section is located near the apex of a meander bend ■ Single-threaded channel ■ Left-handed and left-skewed ■ Channel widens on right bank by approximately 40 metres ■ No change in depth ■ No migration ■ No aggradation or degradation

Table 1: Cross Section Geometry for the historical and modern periods

Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 3—Red Deer River from Waskasoo Creek to STN 50+200	2007	1	45	152	162	103	107	2.0	2.3	1.5	1.5	Located on a straight section of channel at a bridge Single-threaded channel Very slightly right-handed and not skewed So significant change to width or depth Possible migration to the left a couple metres No apparent aggradation or degradation
	2007	6	47	273	263	127	123	3.1	2.8	2.1	2.1	Located slightly downstream of bend apex Single-threaded channel Left-handed and not skewed No major width or depth change No apparent migration No apparent aggradation or degradation
	2007	10	50	130	182	98	97	1.8	2.4	1.3	1.9	Located just upstream of bend apex Single-threaded channel Left-handedness and not skewed. Floodplain has a right skew No significant change to channel width. Slight increase in the elevation of the left bank leads to an increase in average depth of approximately 0.6 metres No apparent migration Slight degradation of up to approximately half a metre
Reach 4—Waskasoo Creek from its outlet at Red Deer River to Piper Creek	1995	7.1	0.59	60	50	20	23	4.7	4.1	2.9	2.2	Located in straight channel section at bridge crossing Changes from uniform and not skewed to slightly right-handed and not skewed Channel narrows by a couple metres and becomes shallower by approximately 0.8 m Channel migrates slightly (<1 metre) to the left No major aggradation or degradation Mid-channel bar develops

Table 1: Cross Section Geometry for the historical and modern periods

Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 4—Waskasoo Creek from its outlet at Red Deer River to Piper Creek	1995	15.1	1.3	26	13	16	12	2.1	1.8	1.7	1.1	■ Located in straight channel section at bridge crossing. Historical cross-section does not appear to be perpendicular to the stream; geometry may be skewed. ■ Single-threaded channel ■ Changes from slightly left-handed and not skewed to slightly right-handed and not skewed ■ Channel apparently narrows and shallows, but historic cross-section dimensions may be exaggerated due to the section potentially being sub-parallel to flow ■ No apparent channel migration ■ Channel aggrades approximately 0.4 metres
	1995	23.1	2.0	18	14	12	11	2.1	2.0	1.5	1.3	■ Location downstream of the apex of a low-sinuosity meander ■ Single-threaded channel ■ Right-handed channel. Develops a slight right skew. ■ Channel narrows slightly ■ No apparent channel migration ■ Channel aggrades by approximately 0.1-0.2 metres on the left side, but the thalweg elevation does not change substantially
	1995	33.1	3.4	8	11	9	14	1.4	1.3	0.9	0.8	■ Located on a straight channel section at a bridge crossing ■ Single-threaded channel ■ Changes from right-handed and right skewed to slightly left-handed and not skewed ■ Apparent increase in channel width. Change to depth is minor. ■ Migration of a couple metres to the left ■ Aggradation of approximately 0.6 metres ■ Right floodplain surface has been lowered. Cross-section is in a developed area; possible disturbance

Table 1: Cross Section Geometry for the historical and modern periods

Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 5—Waskasoo Creek from Piper Creek to STN 7+000	1995	40	3.8	15	8	13	8	2.1	1.1	1.2	0.9	■ Straight channel section ■ Single-threaded channel ■ Changes from uniform and not skewed to very slightly left-handed and not skewed ■ Channel has narrowed and shallowed. Possible dredging. ■ Channel migrated a few metres to the right ■ No apparent aggradation or degradation ■ In 2017, channel appears to be benched, with the upper bench higher than the 1995 channel
	1995	48	4.4	23	30	14	17	3.3	3.6	1.7	1.8	■ Straight channel section ■ Single-threaded channel ■ Uniform and not skewed ■ Slight increase in channel width and depth ■ Migration of approximately 1 metre to the right ■ Slight degradation of approximately 0.1 m
Reach 7—Waskasoo Creek from Range Road 275 to STN 34+600	2008	3.1	25.1	16	21	12	18	2.2	2.2	1.3	1.2	■ Located at a straight channel section at a bridge crossing ■ Single-threaded channel ■ Slightly right-handed and not skewed ■ Channel widened approximately 6 metres ■ Channel migrated to right by a couple metres ■ Aggradation of approximately 0.1 metres
	2008	5.2	26.8	11	13	15	18	1.1	1.1	0.7	0.7	■ Located approximately halfway between meander apexes just upstream of a road crossing ■ Single-threaded channel ■ Changes from uniform with no skew to slightly right-handed with no skew ■ Channel widened by approximately 2 metres ■ Channel migrated to the left approximately 1 metre ■ No major aggradation or degradation

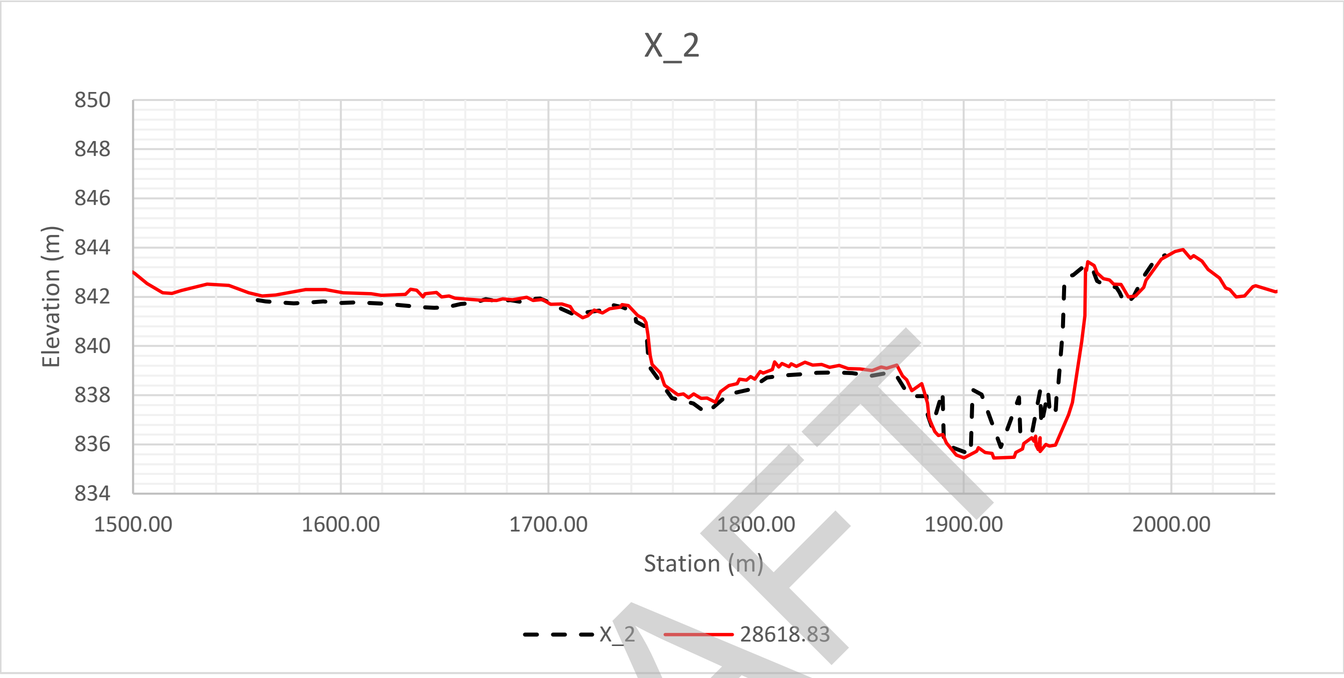
Table 1: Cross Section Geometry for the historical and modern periods

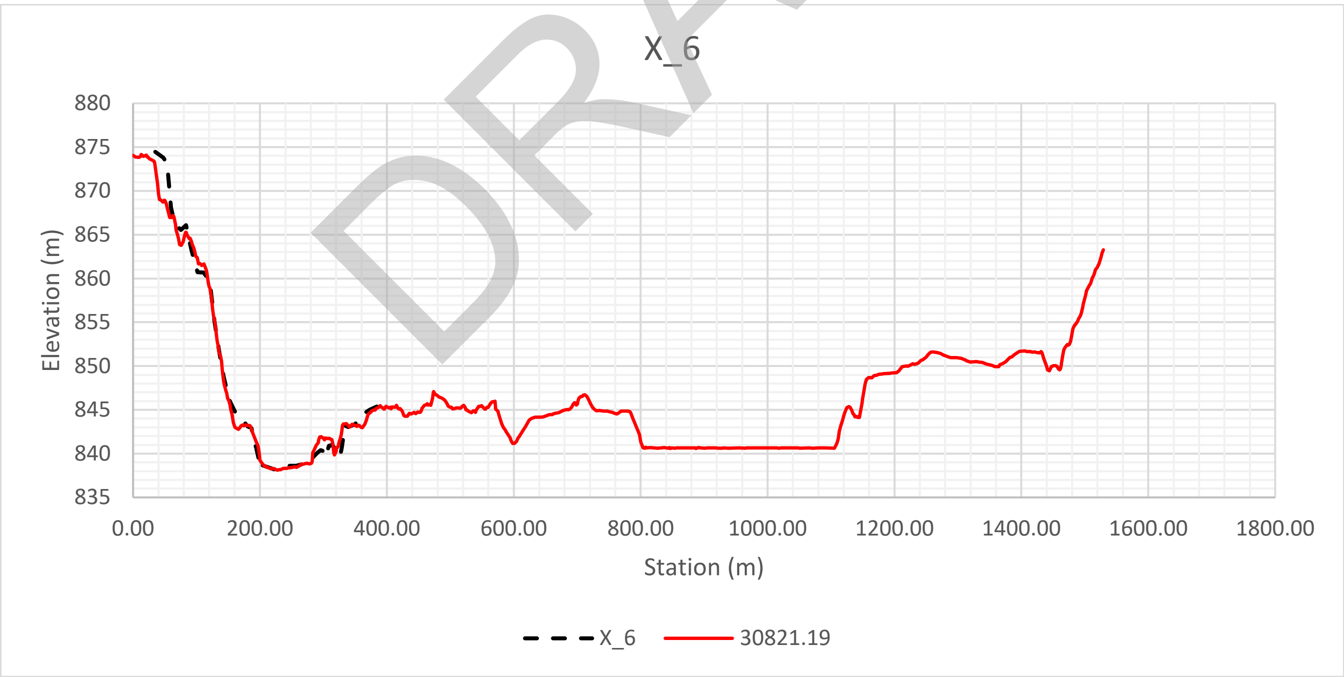
Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 7—Waskasoo Creek from Range Road 275 to STN 34+600	2008	8.1	30.0	8	81	9	81	1.2	1.3	0.9	0.9	■ Located on straight channel segment ■ Changes from small, single-threaded channel to multi-threaded channel with large, dominant channel and smaller sub-dominant channel ■ 2008 channel is left-handed and not skewed. 2017 channel is right-handed and not skewed on the dominant channel ■ Channel width increases by almost 70 metres due to the apparent construction of a new channel. Depth increases by approximately 0.1 m ■ Sub-dominant channel appears to have migrated approximately 10 metres to the left ■ Degradation of approximately 0.1 m ■ Creation of new dominant channel has apparently resulted in the occurrence of an island
	2008	11.1	32.1	23	33	21	25	1.9	2.6	1.1	1.3	■ Located on a straight section of channel ■ Single-threaded channel ■ Changes from right-handed and not skewed to left-handed and not skewed ■ Channel widens by a couple metres and deepens by approximately 0.2 m ■ Channel migrates to left a couple metres ■ Degradation of approximately 0.4 metres ■ Elevation of banks increase: possible overbank floodplain sedimentation
	2008	13.1	33.6	1	2	10	10	0.2	0.5	0.1	0.2	■ Stream at this crossing is not well channelized. HEC-RAS model shows significant flooding at 2-year flow. ■ Located near apex of gentle meander bend ■ Single-threaded channel feature ■ Changes from slightly left-handed and not skewed to uniform and not skewed ■ Channel becomes approximately twice as deep ■ Thalweg migrates a couple metres to the right ■ Degradation of approximately 0.1 m

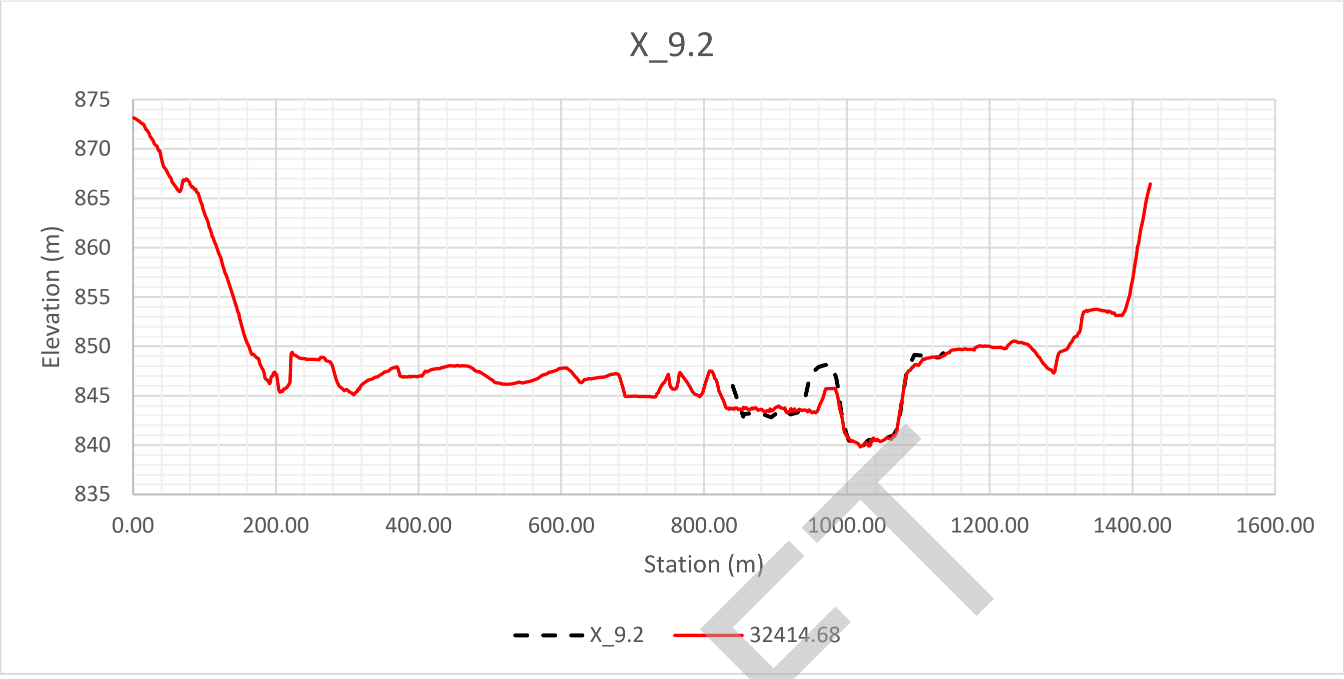
Table 1: Cross Section Geometry for the historical and modern periods

Reach	Year of historical cross section	Cross Section ID	Km	Cross sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
				Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	Hist.	Mod.	
Reach 7—Waskasoo Creek from Range Road 275 to STN 34+600	2008	15.1	34.6	4	2	11	12	0.6	0.5	0.4	0.2	▪ Stream at this crossing is not well channelized. HEC-RAS model shows significant flooding at 2-year flow ▪ Located approximately halfway between meander apexes at road crossing ▪ Single-threaded channel feature ▪ Changes from left-handed and not skewed to right-handed and not skewed ▪ Channel becomes slightly shallower ▪ Migration of a couple metres to the left ▪ Degrades approximately 0.1 metres

1.0 REACH 2: RED DEER RIVER FROM BLINDMAN RIVER TO WASKASOO CREEK



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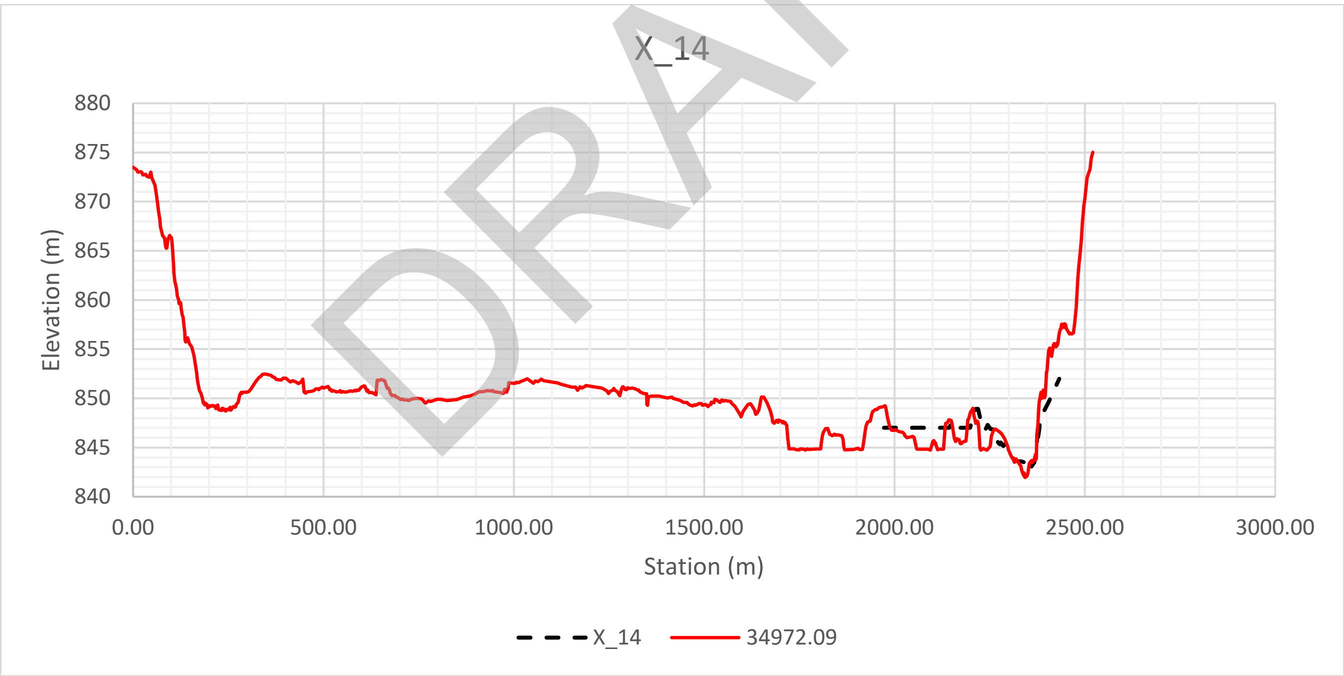
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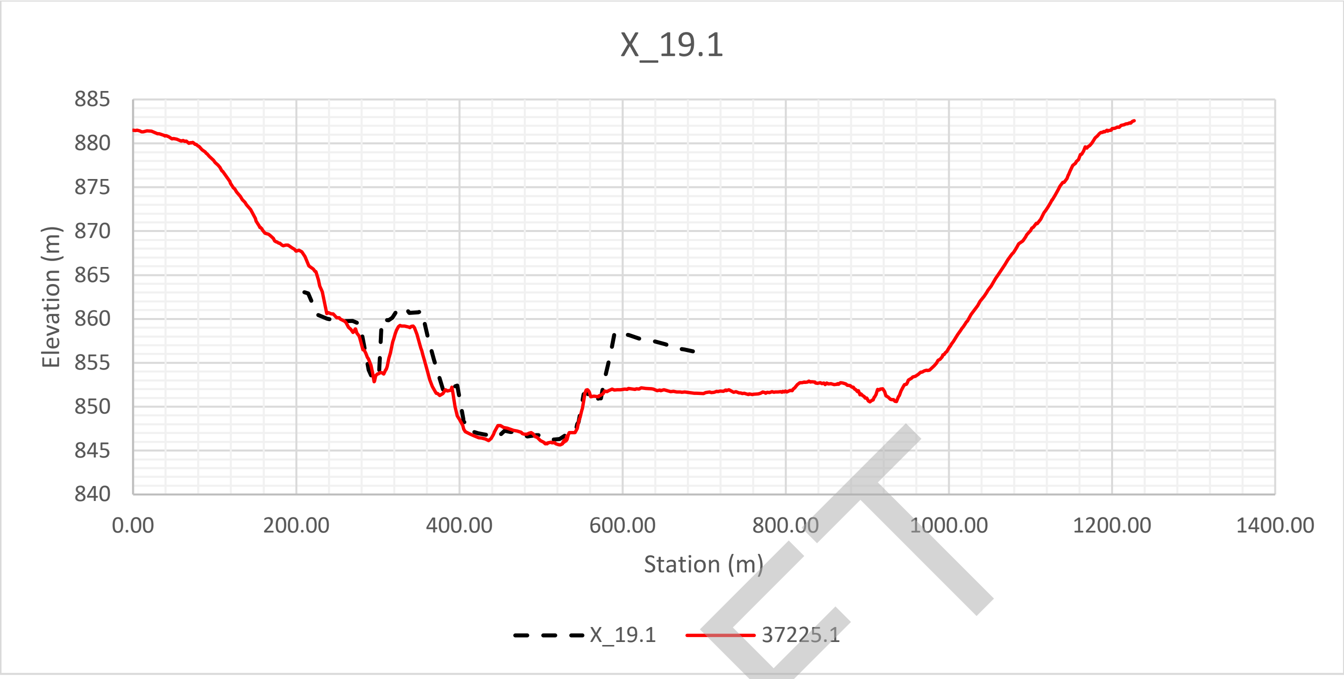
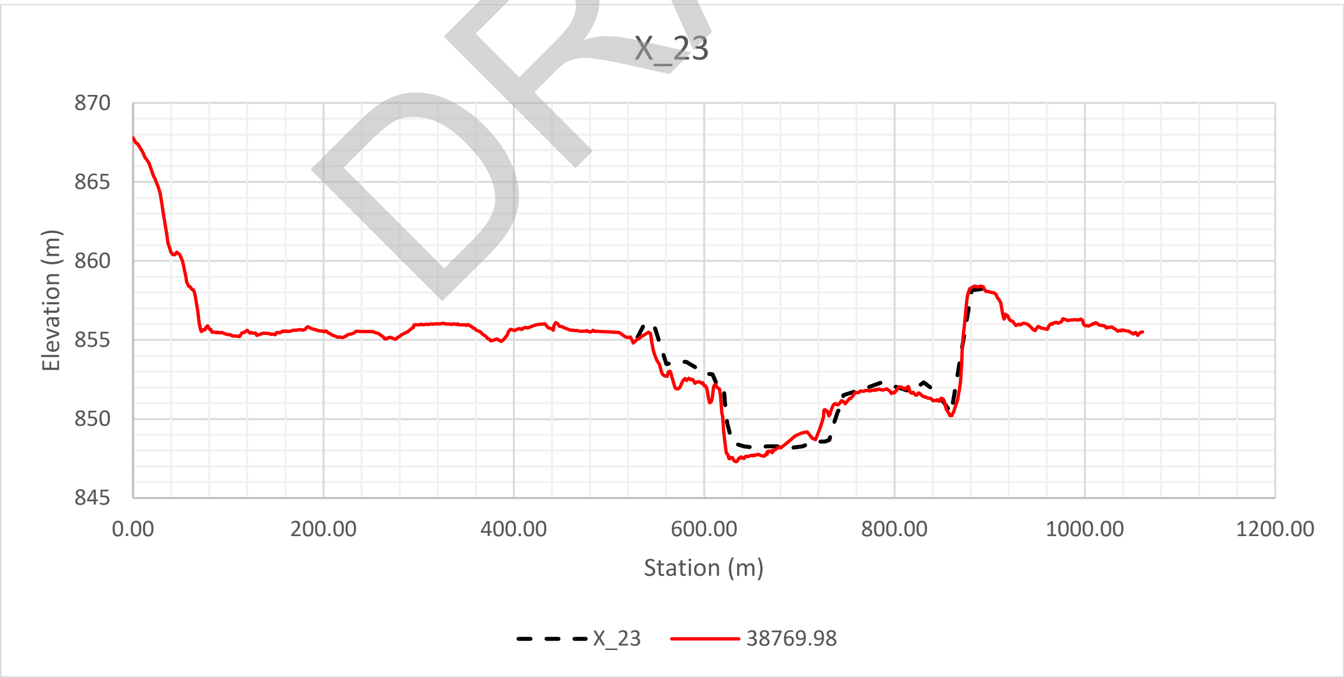
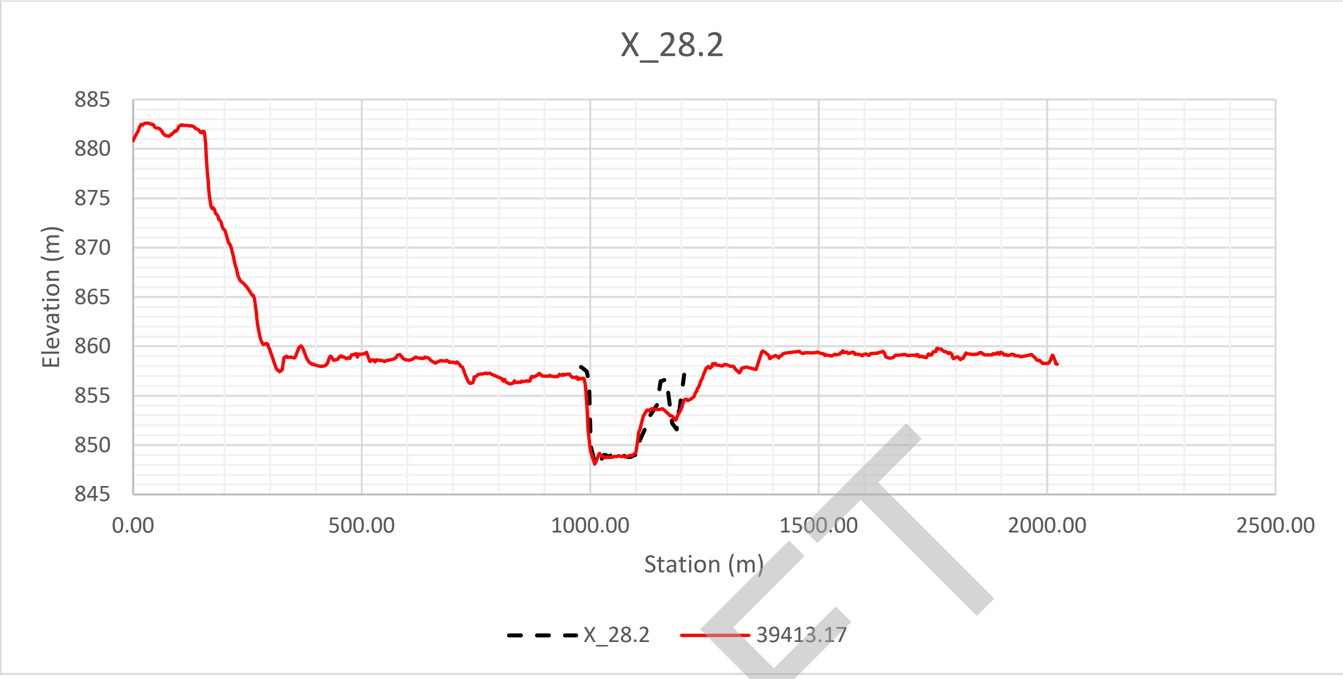


2.0 REACH 3: RED DEER RIVER FROM WASKASOO CREEK TO STN 50+200

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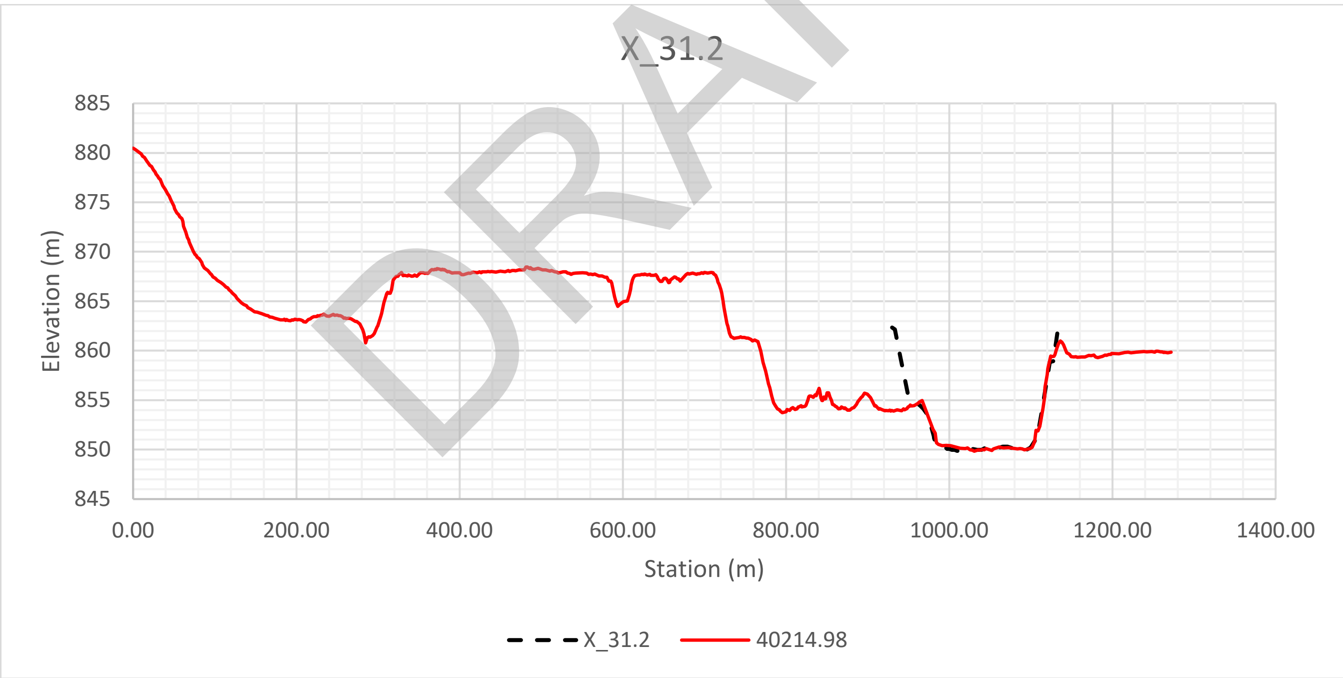
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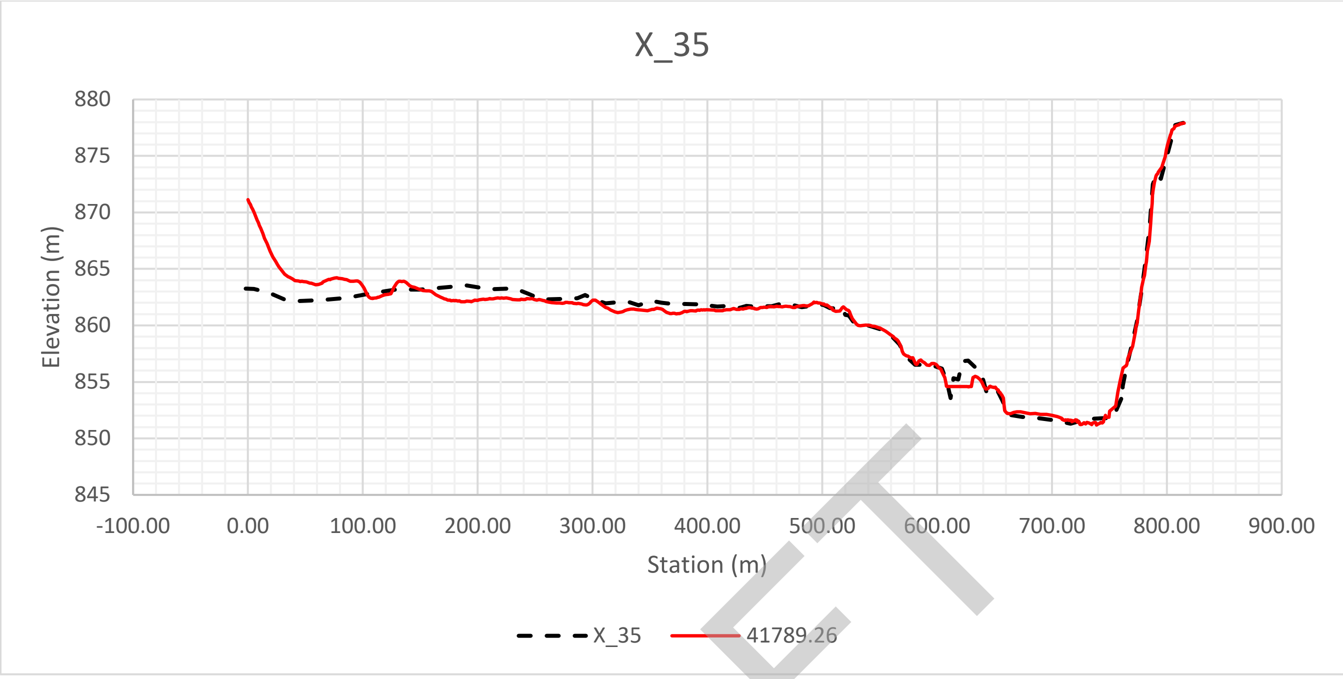
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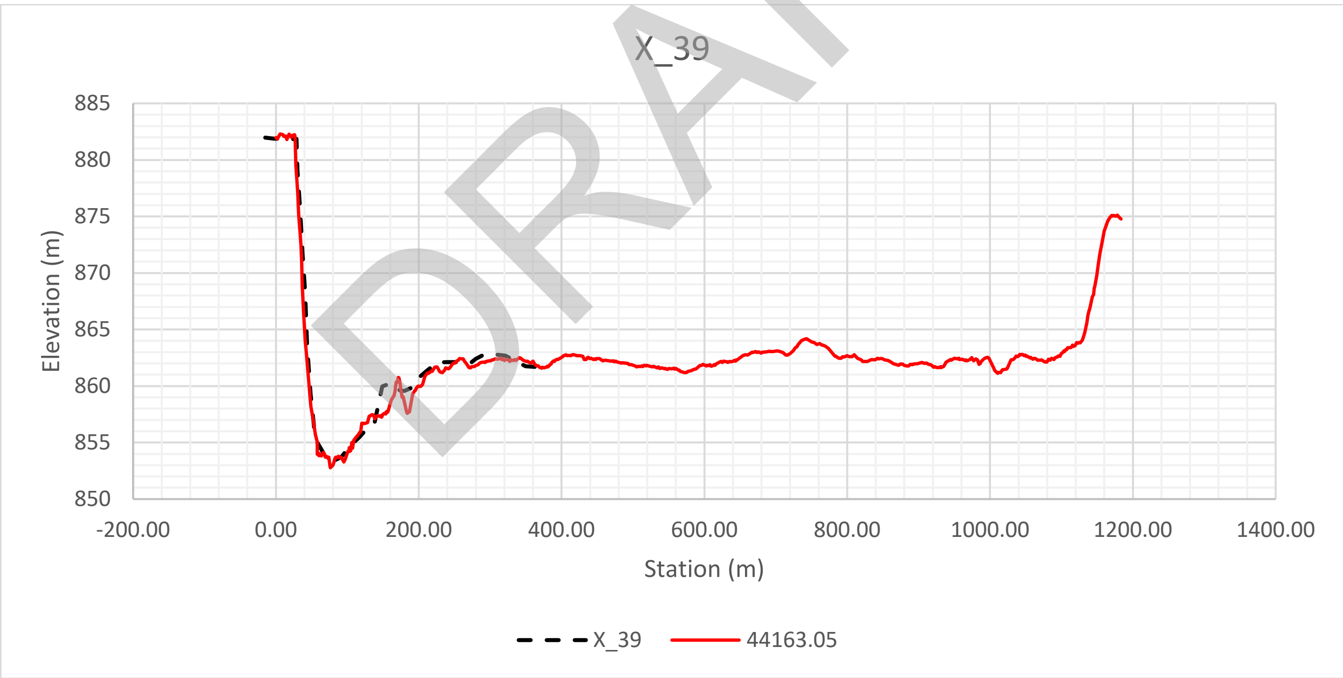
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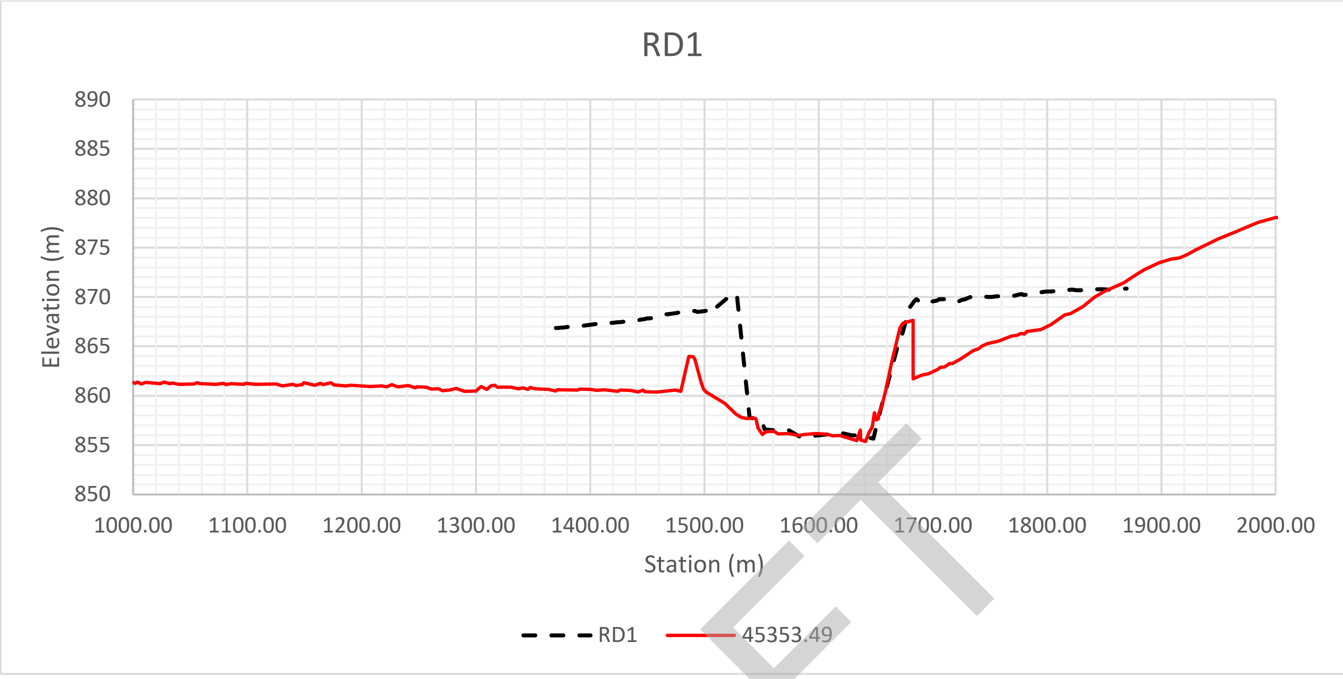
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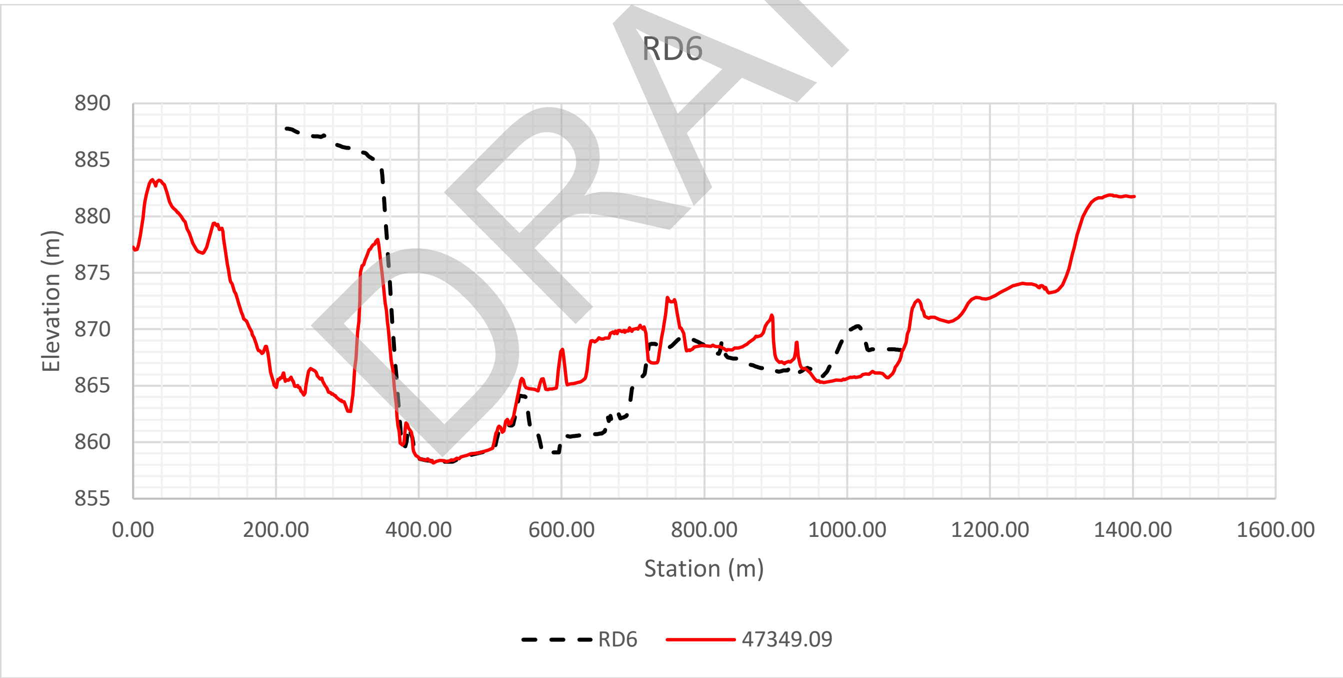
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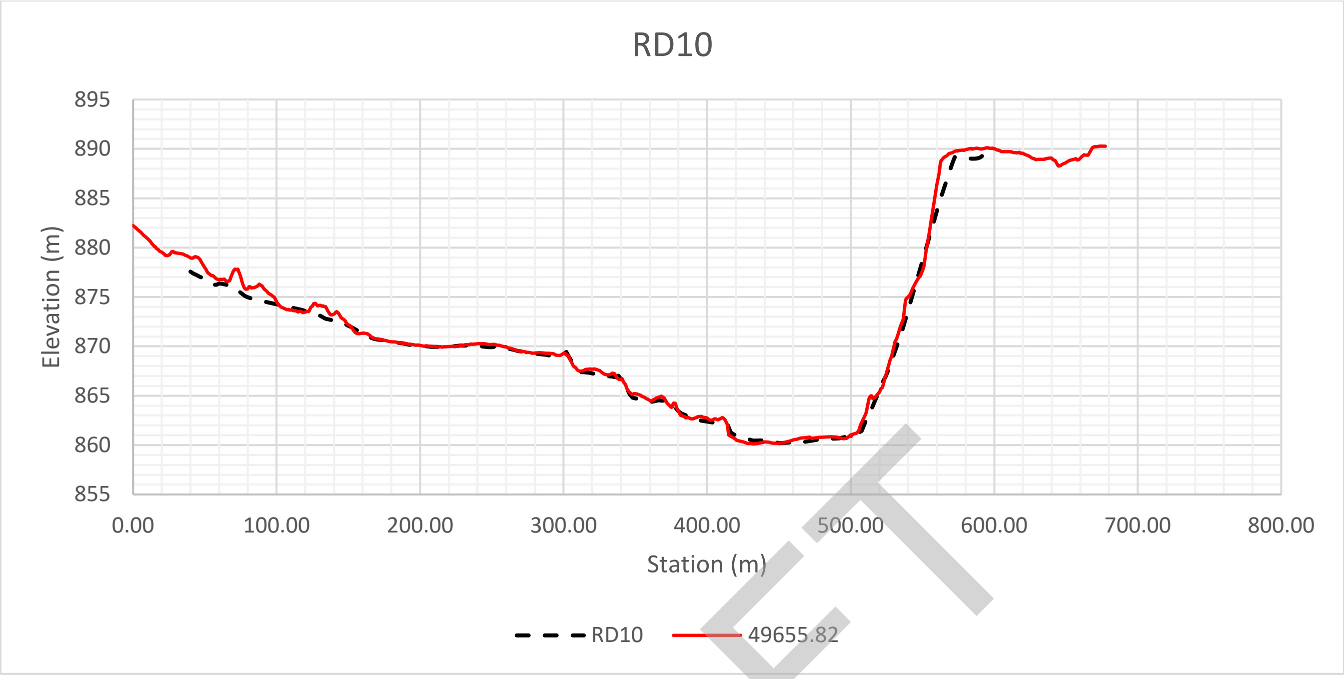
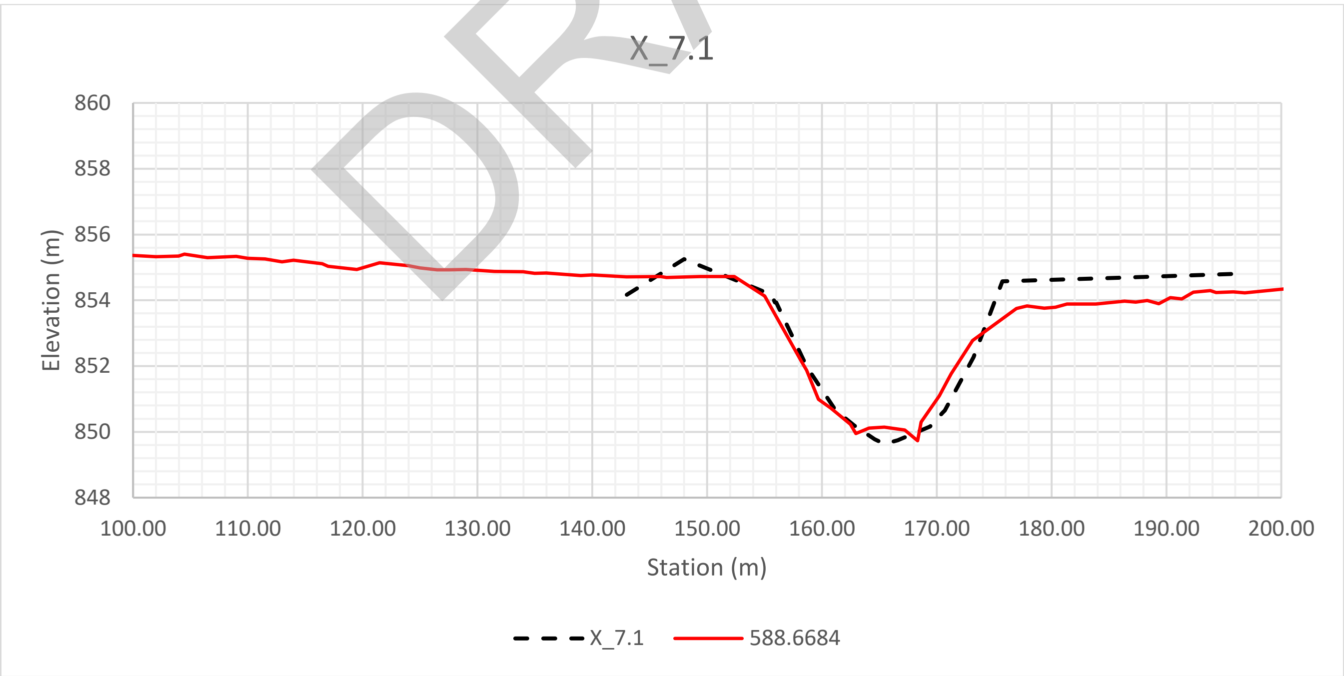
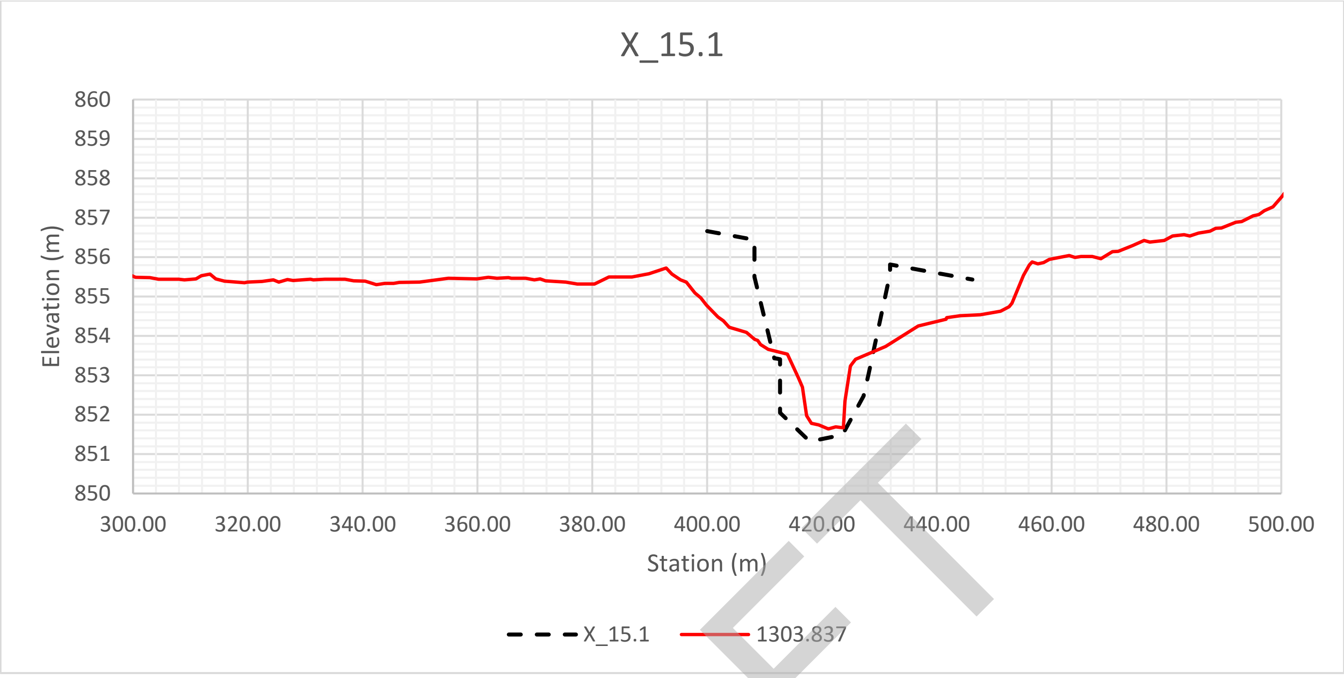


3.0 REACH 4: WASKASOO CREEK FROM ITS OUTLET AT RED DEER RIVER TO PIPER CREEK

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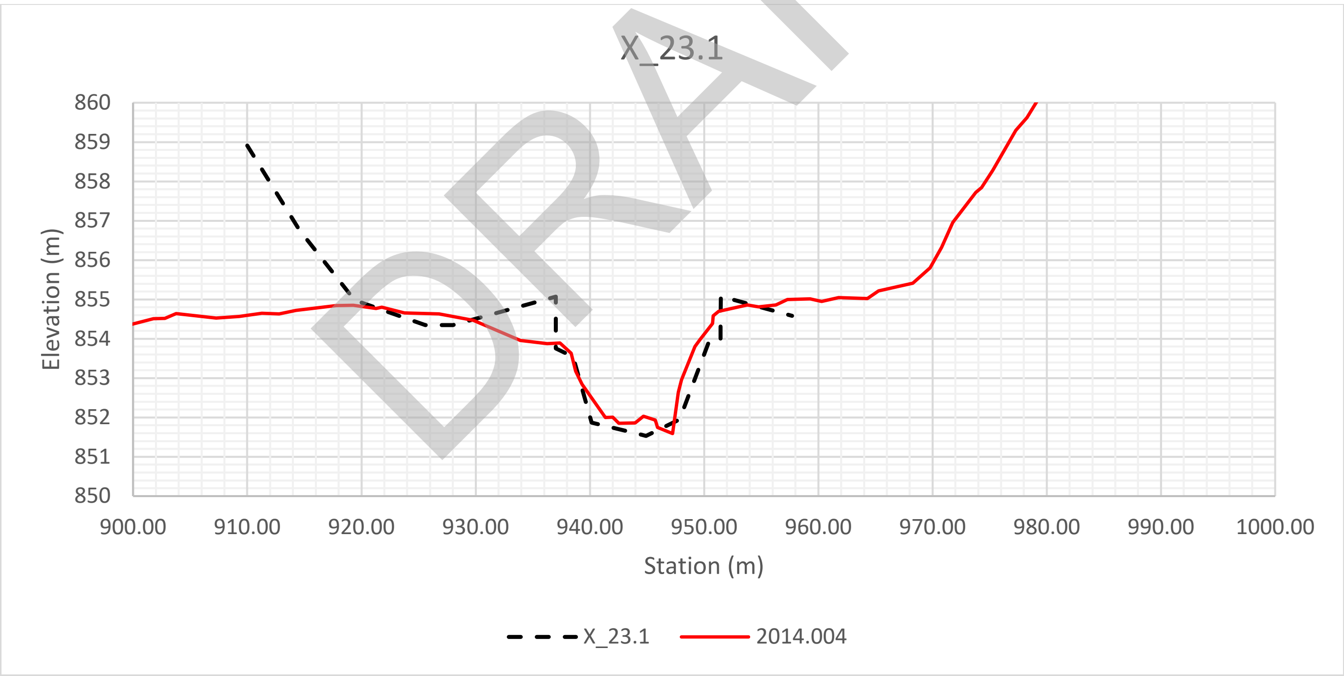
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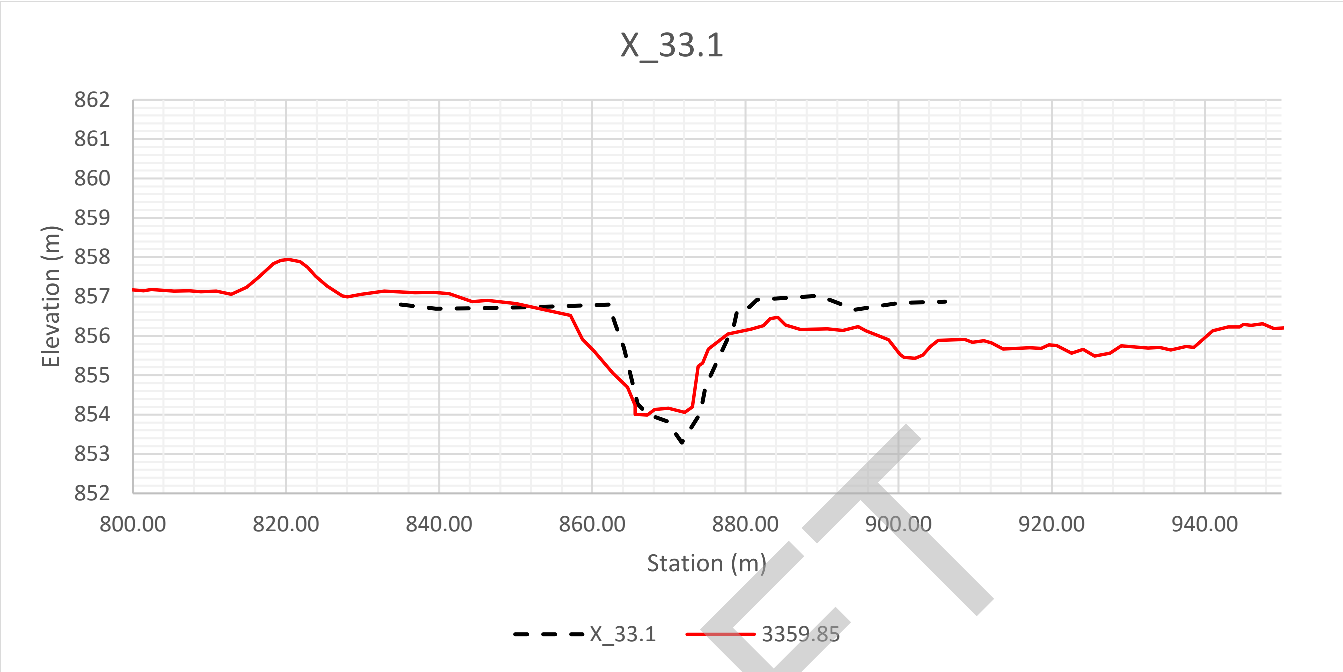
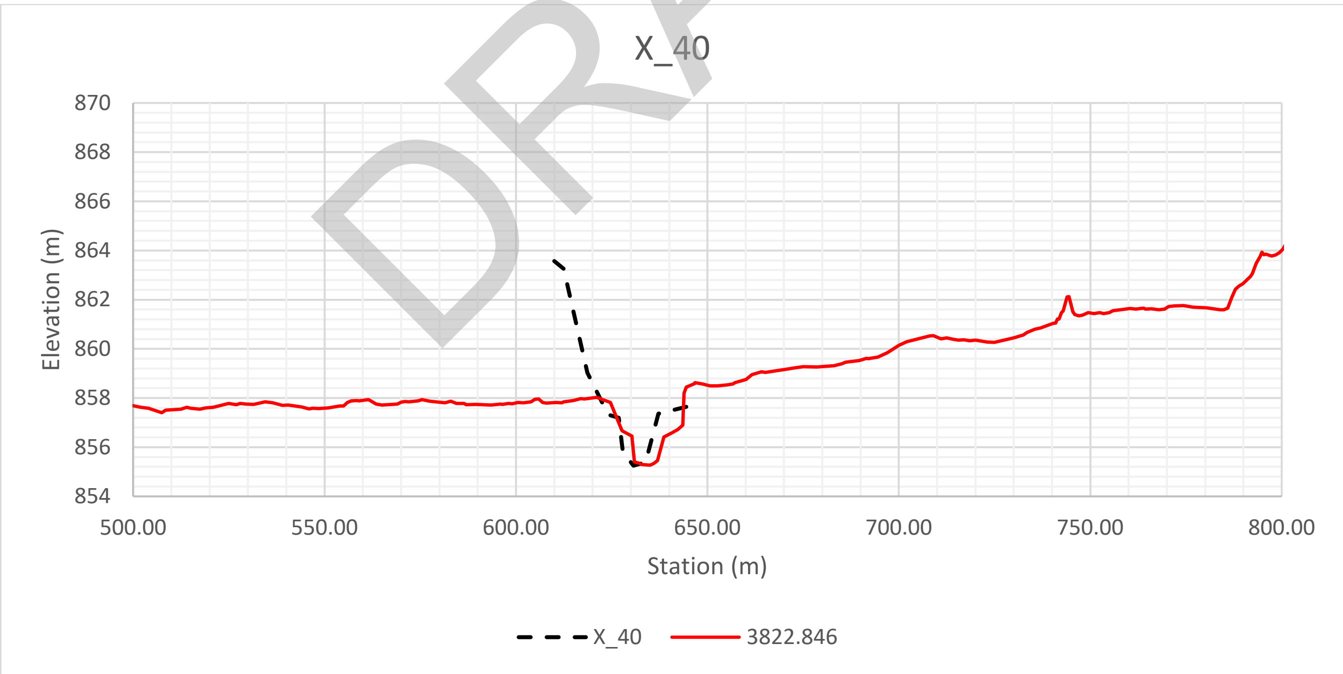
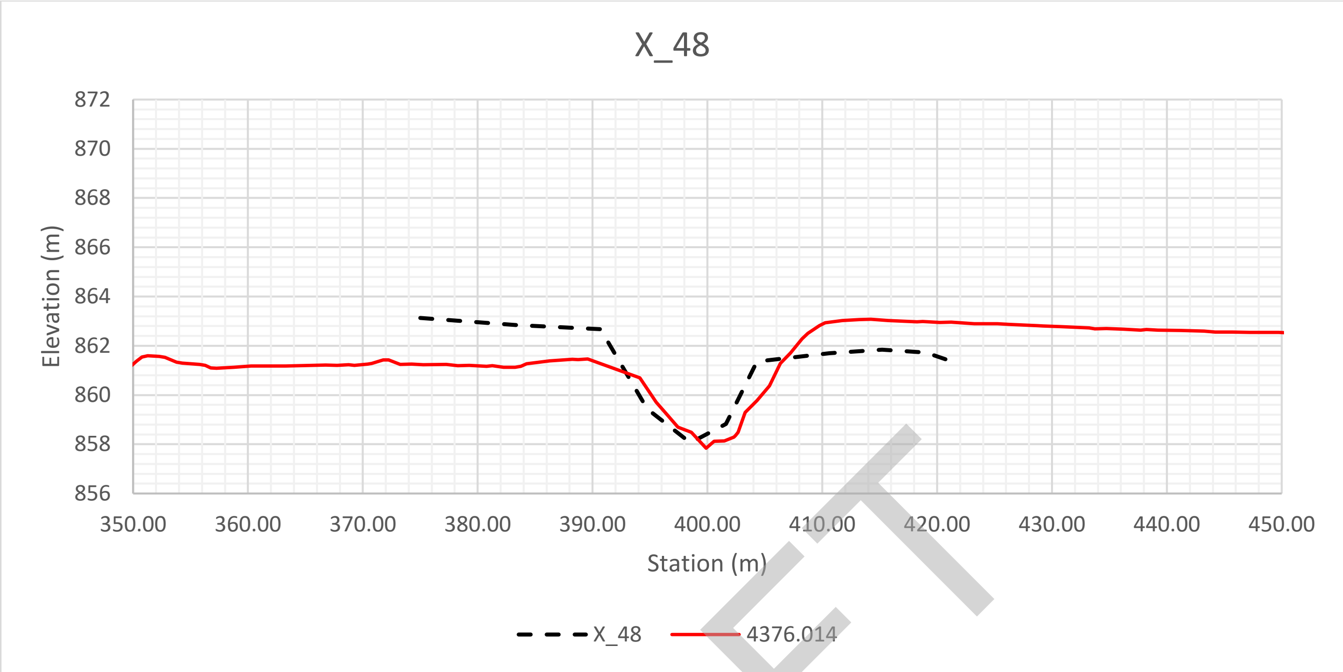
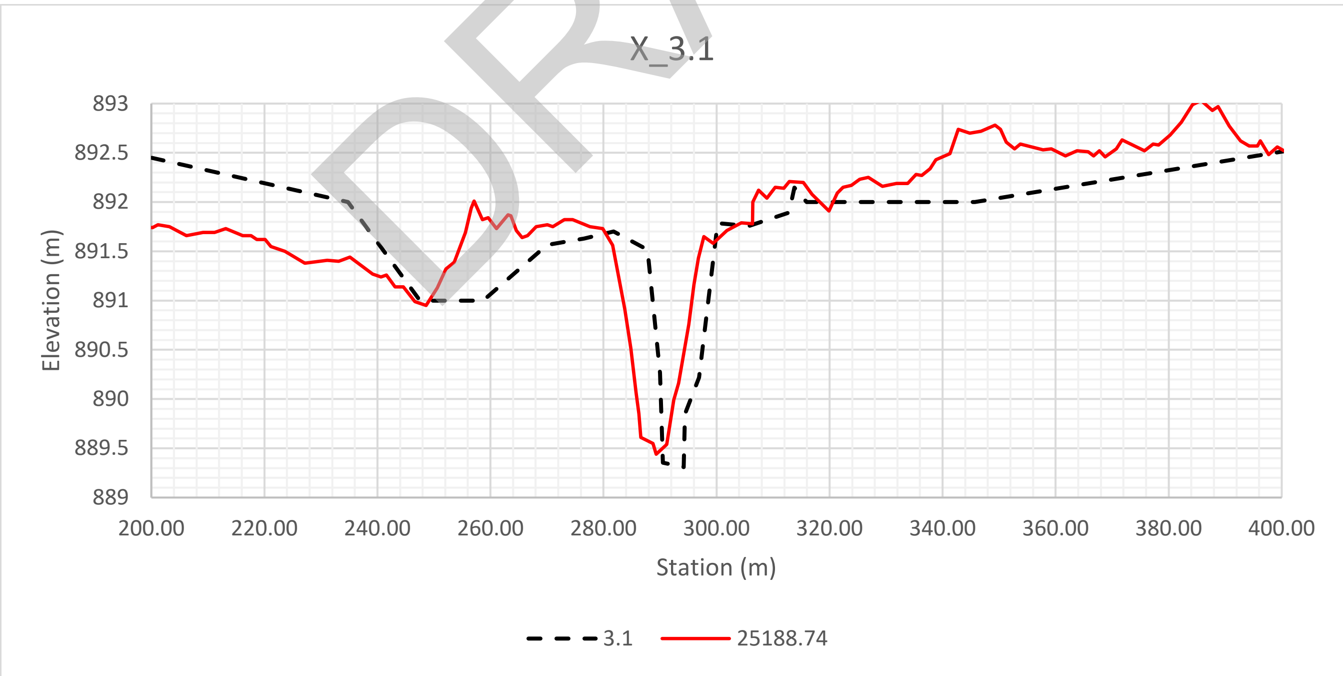


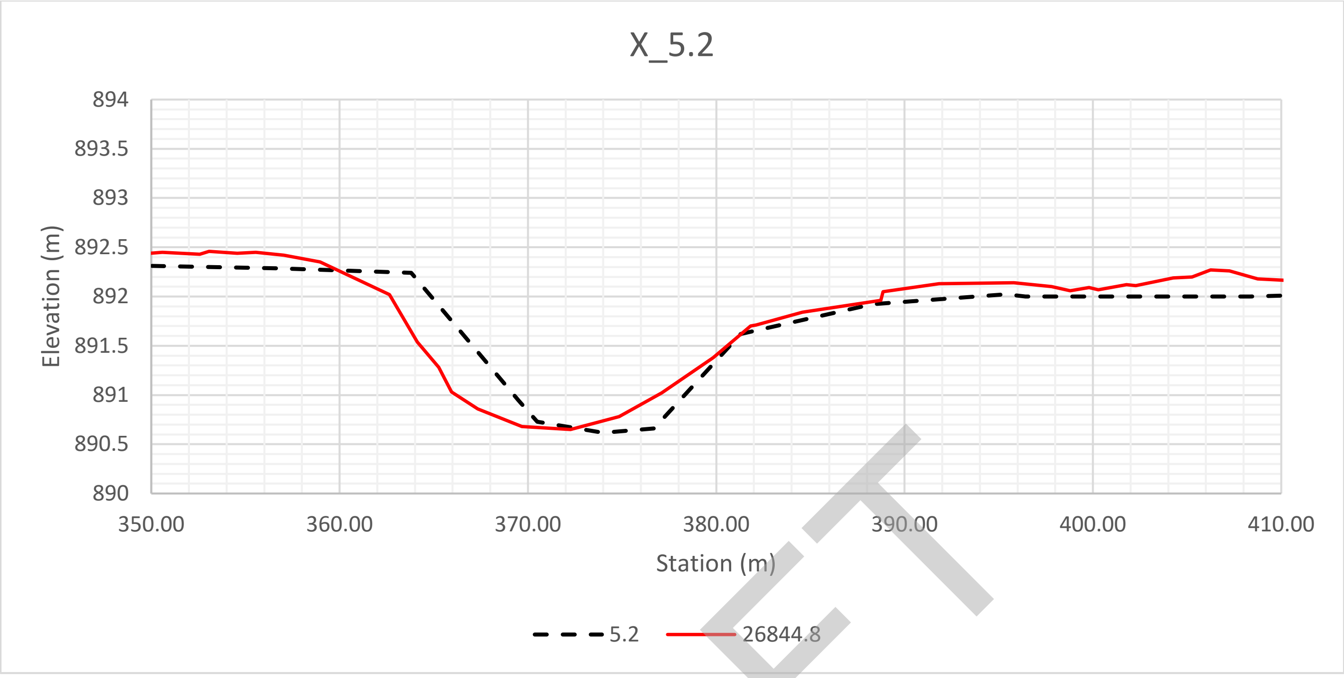
4.0 REACH 5: WASKASOO CREEK FROM PIPER CREEK TO STN 7+000





5.0 REACH 7: WASKASOO CREEK FROM RANGE ROAD 275 TO STN 34+600

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893.5
893
892.5
892
891.5
891
890.5
890
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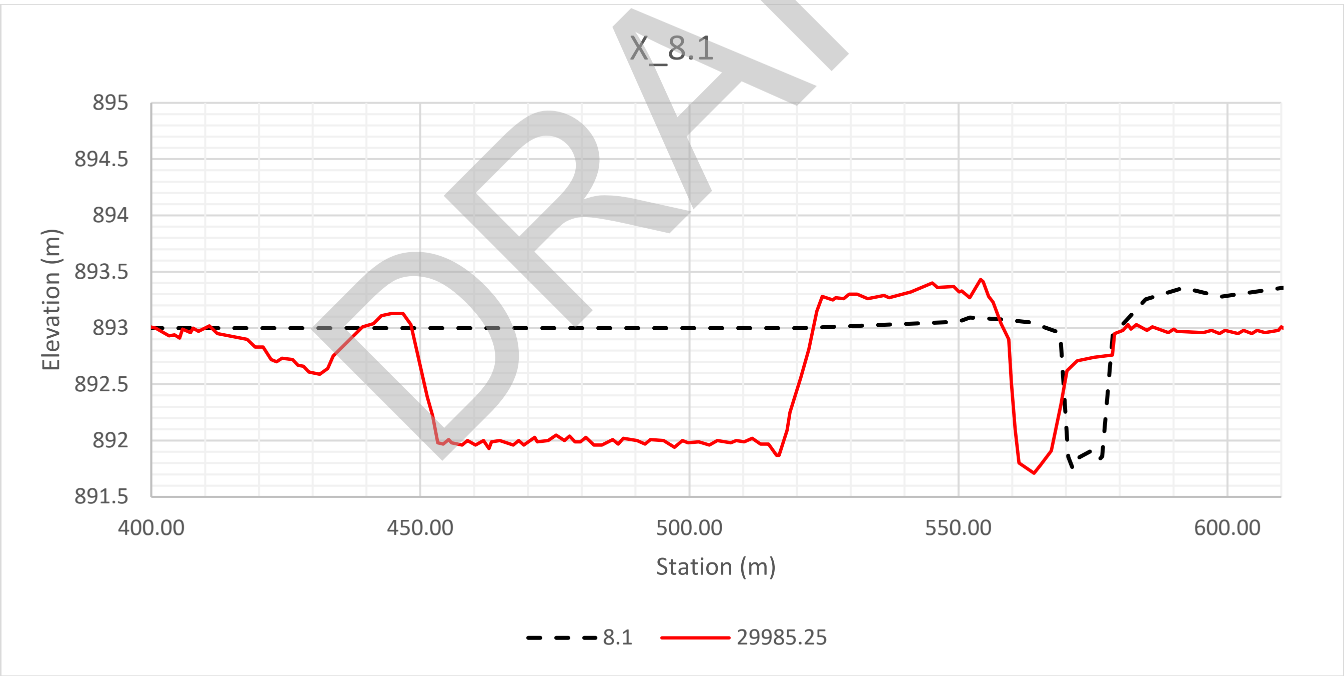
360.00
370.00
380.00
390.00
400.00
410.00
Station (m)
5.2
26844.8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550.00
600.00
Station (m)
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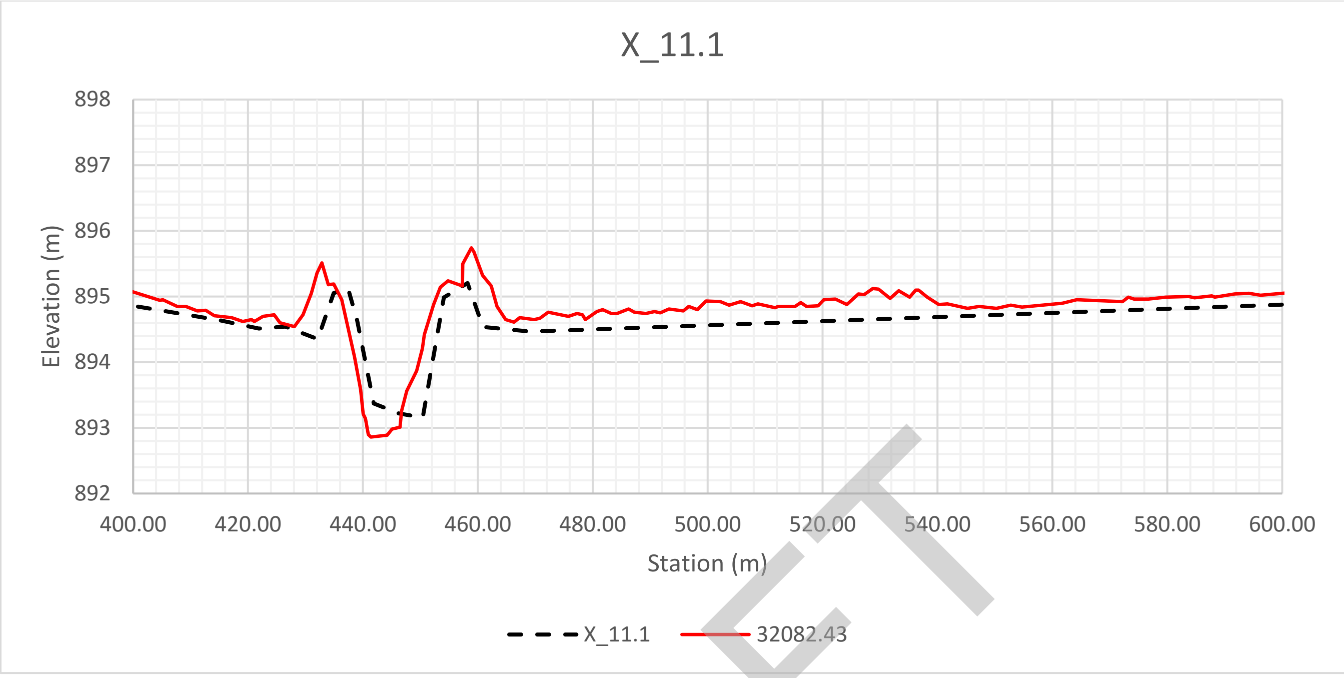
29985.25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894
893
892
Elevation (m)
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520.00
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560.00
580.00
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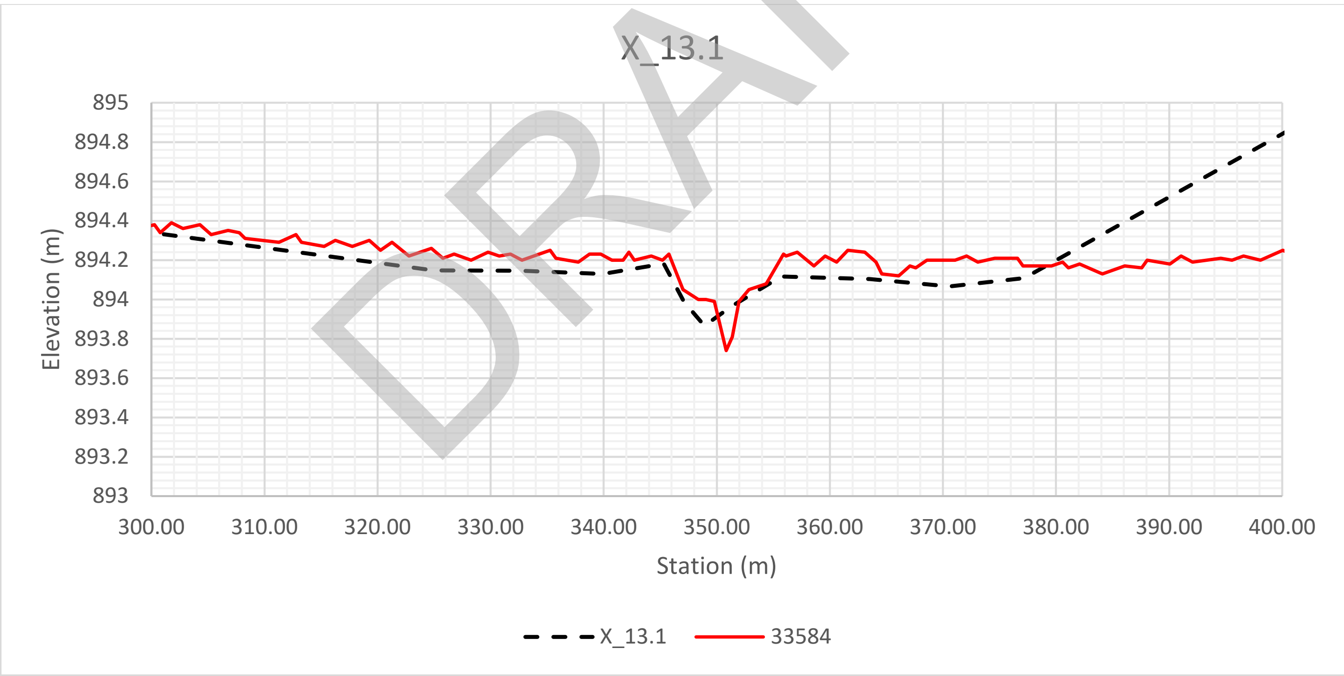
32082.43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894
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893.4
893.2
893
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310.00
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380.00
390.00
400.00
Station (m)
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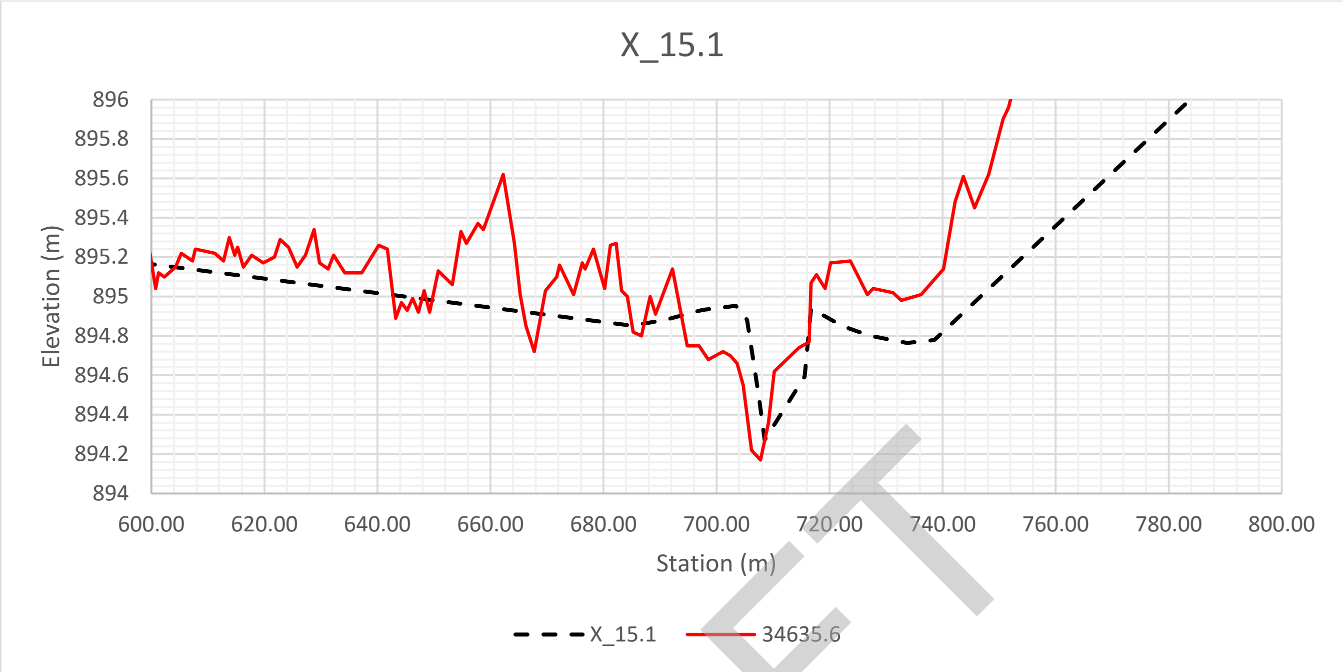
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894
600.00
620.00
640.00
660.00
680.00
700.00
720.00
740.00
760.00
780.00
800.00
Station (m)
X_15.1
34635.6

APPENDIX B

Historical Aerial Imagery Processing Memorandum

TECHNICAL MEMORANDUM

DATE July 17, 2019 **Project No.** 1783039-067-TM-Rev0

TO Abdullah Mamun
Alberta Environment and Parks

CC Rowland Atkins, Gaven Tang, Wolf Ploeger, and Dejiang Long

FROM Peter Thiede
Golder Associates **EMAIL Peter_Thiede@Golder.com**

HISTORICAL AERIAL IMAGERY PROCESSING RED DEER RIVER HAZARD STUDY

1.0 INTRODUCTION

The Channel Stability Component of the Red Deer River Hazard Study required the use of historical aerial photography to support technical analysis and mapping activities. Golder Associates Ltd. (Golder) took a lead role in obtaining and processing the historical aerial imagery with the aerial triangulation, stereo-model and orthorectification tasks outsourced to Tarin Resource Services Ltd. (Tarin). This memorandum provides an overview of the processing methodology, the results of quality assurance checks, and a description of the historical aerial imagery deliverables.

2.0 METHODOLOGY

The historical aerial images selected for the Red Deer River Hazard Study were obtained in a scanned .TIF format from Alberta Environment and Parks (AEP) in April 2018. The images were processed according to the specifications as stated in AEP's Terms of Reference (TOR) and the guidelines published in '*General Specifications for Acquiring Aerial Photography*' (2014). Photographs from 1962 were chosen to cover the Red Deer River, Waskasoo Creek and Piper Creek in the study area. Table 1 provides an overview of the photography used, image scale, and acquisition dates.

Camera calibration reports (for 1962) and calibrated focal lengths were also provided by AEP and were used in the image processing.

The raw greyscale images were reviewed for quality assurance and spatial coverage of the project area. The quality and consistency of all images was found to be good. No significant physically damage of the negatives (e.g., scratches), or missing fiducial markings were identified.

Overall, the image quality was considered sufficient to proceed with aerial triangulation, stereo model creation and orthorectification.

Table 1: Historical Imagery Processed for the Red Deer River Hazard Study

Extent	Photo Year	Photo Scale	Film Roll No.	Frames used in orthomosaic	Frames processed for AT	Acquisition date(s)
Red Deer River, Waskasoo Creek and Piper Creek	1962	1: 31,680	AS0824	3, 4, 5, 6, 7, 93, 94, 95, 96	3, 4, 5, 6, 7, 93, 94, 95, 96, 186	06/30/1962 and 08/01/1962
			AS0825	39, 40, 41, 42, 43, 44, 45, 134, 135, 136, 137, 138, 139, 147, 148, 149, 150, 236, 237, 238, 239	39, 40, 41, 42, 43, 44, 45, 134, 135, 136, 137, 138, 139, 147, 148, 149, 150, 236, 237, 2387, 239	07/03/1962, 07/09/1962, 07/18/1962 and 08/01/1962
			AS0826	69, 70, 71, 72, 160, 161, 162, 163	69, 70, 71, 72, 160, 161, 162, 163	07/09/1962 and 07/18/1962

The images were orthorectified using OrthoMaster software by Trimble Inpho and the AltaLIS 1:20,000 scale digital elevation model (DEM). Image fiducials were identified on each image, however this could only be done accurately on the images with clear fiducials; all others were approximate. Prior to orthorectifying images, OrthoEngine was configured to run at least 30 iterations for the bundle adjustment with an earth curvature value of 6,378,110.

During the orthorectification process, a total of thirty-four (34) features suitable as ground control points (GCP) were selected. GCPs were typically anthropogenic features such as roads, trails and buildings, positively identifiable on a LiDAR hillshade image, a supplied current orthophoto and on the historical images. The distribution of Ground Control Points (GCPs) followed the recommendation of '*General Specifications for Acquiring Aerial Photography*'. Most images contained at least one GCP. The root mean squared error (RMSE) of the GCP data was within 2.26 (X), 1.44 (Y) and to 0.34 (Z) m.

The air photos with a scale of 1:31,680 were orthorectified to produce 64 cm resolution orthophotos. Depending on the amount of overlap, image margins were cropped to remove approximately 25% from each image. Flight lines with low side overlap (<20%) resulted in some colour/tone variations where vignette effect (darker image corners) or specular reflections (e.g., off water) could not always be removed.

Orthorectified photos were reviewed on screen at a scale of 1:10,000 to check the positional accuracy, then adjacent images were mosaiced together using ArcGIS (v10.4.1) software. The historical orthomosaic was produced using automated colour balancing to match the colour of adjacent images, applying the dodging algorithm. The completed orthomosaic was then split into single township tiles and populated with metadata. An index map of the historical orthomosaic tiles is attached as Appendix A.

The aerial triangulation (AT) data were created using PHOTOMOD (v6 Lite x64) software in conjunction with recent July 2018 aerial imagery, which was used to identify GCP locations. The bundle block adjustment was run in multiple iterations until acceptable residuals on ground controls were achieved. No self-calibration process was required during the aerial triangulation bundle block adjustment. The overall accuracy can be estimated by using the sigma naught value, which was 0.712. The elevation values calculated during the AT process are referenced to the CGVD28 datum. Additional information pertaining to the accuracy of AT data is provided in Table 2. The processed historical aerial imagery and associated AT data were then used to create stereomodels using ApplicationMaster (v7.02.49920) within Trimble Inpho software.

Table 2: Aerial Triangulation Accuracy

	X	Y	Z	Exy (m)
GCP RMSE:	0.878	0.663	0.130	1.101
Tie Point RMSE (on images):	0.008	0.008	N/A	0.011
Sigma naught:	**0.712**			

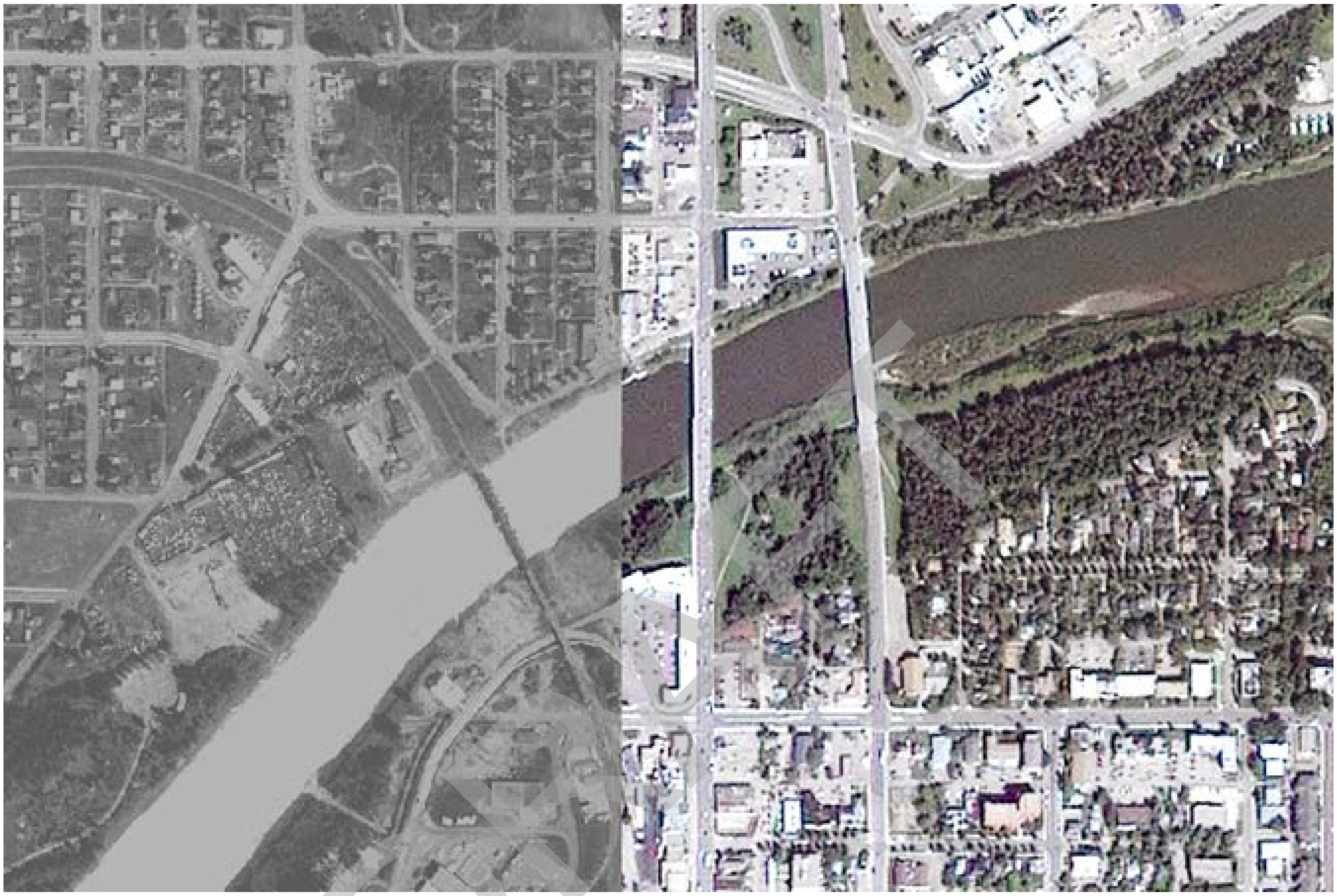
3.0 RESULTS

Each tiled orthomosaic was reviewed on-screen at a scale of 1:10,000 with additional spot checks at a scale of 1:5,000. The positional accuracy of historical imagery was assessed by measuring the positional offset to the same feature as captured in the July 2018 Red Deer River aerial imagery. In some cases where roads and land use had changed significantly, it was necessary to check the accuracy using the locations of residential homes, farm buildings and natural terrain features. Continuous features such as roads, railways and streams were checked for continuity between adjacent images. An example of the historical and modern imagery alignment is shown in Figure 1.

All the tiles in the orthomosaic were found to be accurate within 6 m at least 90% of the time, when stationary features free of modifications were measured (checked at least 3 points per tile, except for tile 42538 which is small and has no identifiable feature to accurately compare imagery). Errors may exceed 6 m in areas with steep or complex terrain.

The automated colour balancing used to produce the orthomosaic was not able to completely minimize the appearance of seams between images. Some areas, especially at the downstream end of the study area and the upstream end of Waskasoo and Piper Creeks, were particularly problematic to correct because the dark corners of the images could not be cropped away (due to low side overlap). In other instances, the existing photogrammetric stretch (inherent in the source data) created oversaturated and overexposed areas, which were problematic to correct via automated means.

Figure 1: Example of an Orthomosaic Quality Assurance Check at 1:5,000 scale. The historical 1962 orthomosaic (greyscale on left) is peeled back to reveal the modern landscape (colour image on right).



Golder undertook a completeness and quality assurance check of the AT data provided by Tarin to ensure that all requested deliverables were received and that the quality of the deliverables would meet the needs of the project and conform to AEP's general specifications. A visual check was conducted on a random sample of the stereo model (external orientation) files using the Purview Extension for ArcGIS to ensure that the requested models yielded a satisfactory visual effect when viewed in 3D view software. It was not possible to check the stereo models created in other software specific formats (DATEM), but the plain text files were checked for completeness.

The number of aerial triangulation files delivered by Tarin were counted to confirm that they matched the number of processed photos with a few randomly selected files opened and visually inspected. The spatial reference of the data was also checked to ensure that all data is projected in the 3-degree Transverse Mercator (3TM) projection using the NAD83 Canadian Spatial Reference System (CSRS) datum. The attributes of the AT photo centres and orthomosaic tile index data were checked to ensure that they contained the correct information and that file naming schemas matched AEP's guidelines. Metadata files for each image were also checked for completeness in ArcCatalog® (v 10.4).

4.0 DELIVERABLES

The following files and deliverables are submitted along with this memorandum:

- Historical 1962 orthomosaic covering the Red Deer River study area;
- Aerial triangulation image adjustment reports for historical images; and
- Aerial triangulation (external orientation) data in plain text format, DATEM, and Purview compatible file formats.

One digital copy of the above deliverables is provided on the accompanying USB drive.

5.0 CLOSURE

We trust that the enclosed data meets your present requirements. If you have any questions or require additional details, please contact Peter Thiede at (403) 216-8935.

Yours truly,

GOLDER ASSOCIATES LTD.

APEGA PERMIT TO PRACTICE #05122

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PT/WP/GT/pls

REFERENCES

Alberta Environment and Sustainable Resource Development. 2014. General Specifications for Acquiring Aerial Photography. Edmonton, AB: Corporate Services Division Informatics Branch; [accessed May 2019]. http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/documents/GeneralSpecsAcquiringAerialPhoto-2014.pdf

APPENDIX A

1962/1963 Orthomosaic Index Map

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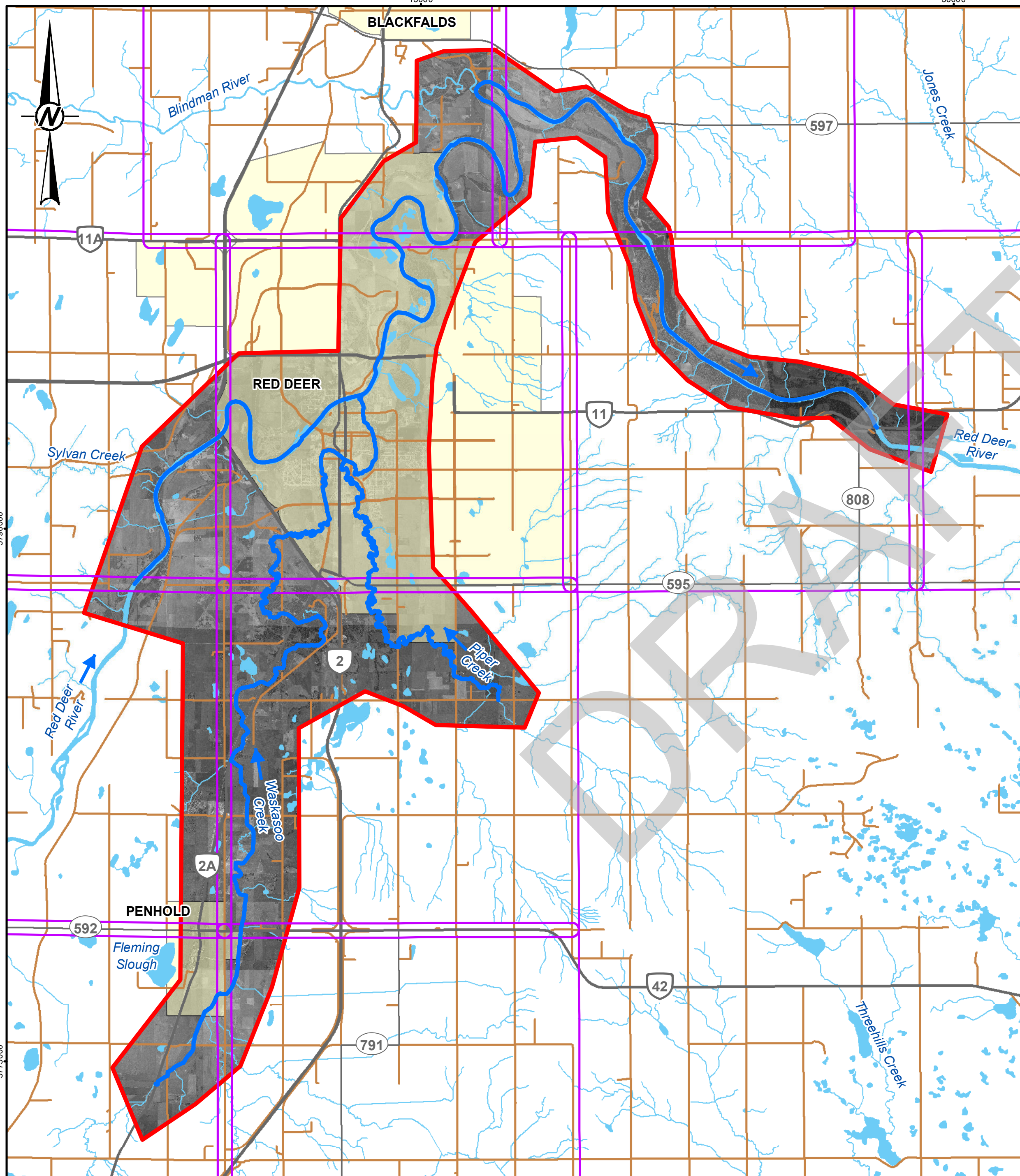

LEGEND

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

0 5 10

1:175,000 KILOMETRES

REFERENCE(S)

POPULATED PLACES AND HYDROGRAPHY OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2017. ALL RIGHTS RESERVED.
ROADS OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. SPOT 6 IMAGERY PROVIDED BY CLIENT, CAPTURED 02/04/2016 & 15/08/2016.
DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
RED DEER RIVER HAZARD STUDY

TITLE
1962 ORTHOMOSAIC INDEX MAP

CONSULTANT

GOLDER

YYYY-MM-DD	2019-07-12
DESIGNED	G.TANG
PREPARED	S.GORDON
REVIEWED	G.TANG
APPROVED	W.PLOEGER

PROJECT NO.	CONTROL	REV.	FIGURE
1783039	8000	0	A

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

25mm

0

Classification: Public

GOLDER

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