August 2018

BOW AND ELBOW RIVER HAZARD STUDY

Channel Stability Investigation Report

Submitted to:
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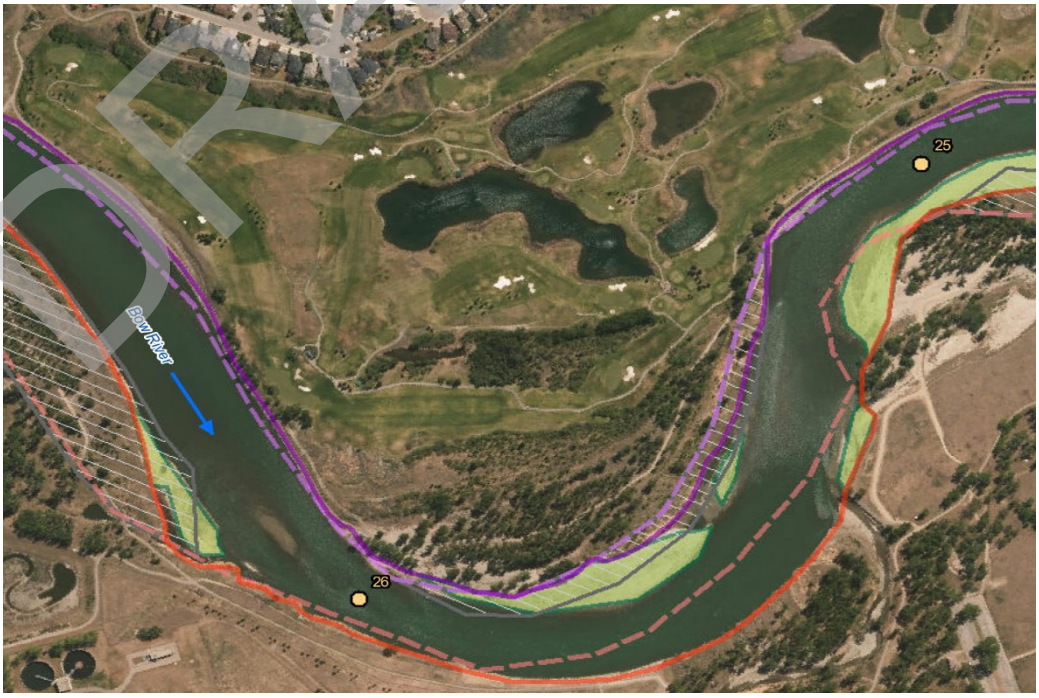

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REPORT

Golder Associates

Executive Summary

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in September 2015 to undertake the Bow and Elbow River Hazard Study. The primary purpose of the study is to identify and assess river and flood hazards along the Bow River (from Bearspaw Dam to the Highwood River confluence) and the Elbow River (from Bragg Creek to the Bow River confluence), including lengths of Bragg and Lott Creeks.

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, local authorities, and the public. Key municipal stakeholders include the City of Calgary, Municipal District of Foothills, and Rocky View County. The project includes working with Tsuut'ina Nation.

The Bow and Elbow 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 includes the stream reaches summarized in Table i.

Table i: Study Area Reaches

River	Reach	Reach Description	Length (km)
Bow River	1	Elbow River confluence to Highwood River confluence	50
	2	Bearspaw Dam to Elbow River confluence	22
Elbow River	3	Glenmore Dam to Bow River confluence	11
	4	Upstream of Bragg Creek to Glenmore Reservoir	52
Bragg Creek	5	Upstream of Centre Avenue in Bragg Creek to Elbow River confluence	1
Lott Creek	6	Upstream of Elbow Valley Residence Club to Elbow River confluence	7

The assessment was conducted by completing the following four tasks: channel bank delineation and comparison, cross section comparison, thalweg comparison, and rating curve comparison.

The channel bank delineation and comparison was completed by delineating the banks and mapping river features in historical and recent imagery datasets. The cross section and thalweg comparisons were completed by assessing changes between historical and recent and historical cross section and thalweg data through qualitative and quantitative analyses. For the rating curve comparison, historical and current rating curves for 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 (i.e., channel bank delineation) was used to inform the interpretations of changes observed in the rating curves.

Reach 1: Bow River from Elbow River confluence to Highwood River confluence

Reach 1 of the Bow River is categorized by a sinuous, single channel confined within a larger incised channel or floodplain. The presence of several large and stable forested islands suggest stability while the presence of side, point, and mid-channel bars indicate that some sediment transport is occurring. The river in this reach could be expected to experience more meander migration if it was less constrained by existing bank erosion protection.

Reach 2: Bow River from Bearspaw Dam to Elbow River confluence

Reach 2 of the Bow River is categorized by a single channel with low sinuosity confined within a larger incised channel (a suspected glacial outwash channel). Limited side and point bars were observed suggesting limited sediment transport. Significant channel bank protection was observed for significant lengths of this reach. Due to the confined nature of the channel and limited lateral migration, this reach is considered to be stable.

Reach 3: Elbow River from Glenmore Dam to Bow River confluence

Reach 3 of the Elbow River is characterized by a sinuous, incised, and single channel. Due to the incised nature of the channel and limited lateral migration, this reach is considered to be stable.

Reach 4: Elbow River from upstream of Bragg Creek to Glenmore Reservoir

Reach 4 of Elbow River is characterized by a sinuous, tortuous, sometimes single channel and sometimes multi-thread channel, in a confined floodplain with actively migrating side, point, and mid-channel bars. As such, it may be considered an anastomosing reach due to its forested islands, multi-channeled sections, and historical indications of avulsion. Relict oxbow channels can be seen in aerial imagery, suggesting a historically mobile channel. As a highly mobile, braided, and anastomosed channel with active bars experiencing a high rate of net bed volume loss, Reach 4 is considered to be unstable.

Reach 5: Bragg Creek from upstream of Centre Avenue in Bragg Creek to Elbow River confluence

Reach 5 of Bragg Creek is characterized by a meandering, single channel partially confined by the larger Elbow River floodplain. As a generally non-mobile channel with limited presence of bars, it is considered to be stable.

Reach 6: Lott Creek from upstream of Elbow Valley Residence Club to Elbow River confluence

Reach 6 of Lott Creek is characterized by a sinuous, single channel that has been highly modified, with significant river training and diking along some of its length, and several retention ponds are present. The natural channel does not appear to have undergone any lateral migration over the study period. Some mid-channel, point, and side bars are present but do not appear to be active in terms of downstream migration. Based on the thalweg profile, limited sediment transport, and limited lateral migration, Lott Creek is considered to be stable.

Acknowledgements

This component of the Bow and Elbow River Hazard Study was led by Rowland Atkins. Overall project management was provided by Dr. Wolf Ploeger and direction by Dr. Dejiang Long. The channel stability investigation team included Morgan Tidd, Gaven Tang, and Vanessa Vallis.

The authors express their special thanks to Peter Onyshko and Abdullah Mamun, Project Managers for Alberta Environment and Parks, who provided overall study management, background data, and technical guidance.

The authors express their thanks to Dennis Lazowski with the Water Survey of Canada for supply of additional background information.

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1.0 INTRODUCTION

1.1 Study Objectives

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in September 2015 to undertake the Bow and Elbow River Hazard Study. The primary purpose of the study is to identify and assess river and flood hazards along the Bow River (from Bearspaw Dam to the Highwood River confluence) and the Elbow River (from Bragg Creek to the Bow River confluence), including lengths of Bragg and Lott Creeks.

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The Bow and Elbow 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 regarding general channel stability along the study reaches.

1.2 Study Area and Reaches

The study area includes approximately 72 km of the Bow River reach between Bearspaw Dam and the Highwood River confluence, approximately 65 km of the Elbow River reach from Bragg Creek to the Bow River confluence in Calgary, approximately 1 km of Bragg Creek upstream of the Elbow River confluence, and approximately 7 km of Lott Creek upstream of the Elbow River confluence (see Figure 1).

The study area includes the following local authorities and communities: Bragg Creek, Calgary, Elbow Valley Residents Club, Municipal District of Foothills, Redwood Meadows, Rocky View County, and Tsuut'ina Nation.

Streams within the study area have been divided into six reaches appropriate for channel stability investigation: two along the Bow River, two along the Elbow River (not including Glenmore Reservoir), one along Bragg Creek, and one along Lott Creek, as outlined in Table 1 and shown in Figure 2a through 2d.

Table 1: Channel Stability Investigation Reaches

River	Reach	Reach Description	Length (km)
Bow River	1	Elbow River confluence to Highwood River confluence	50
	2	Bearspaw Dam to Elbow River confluence	22
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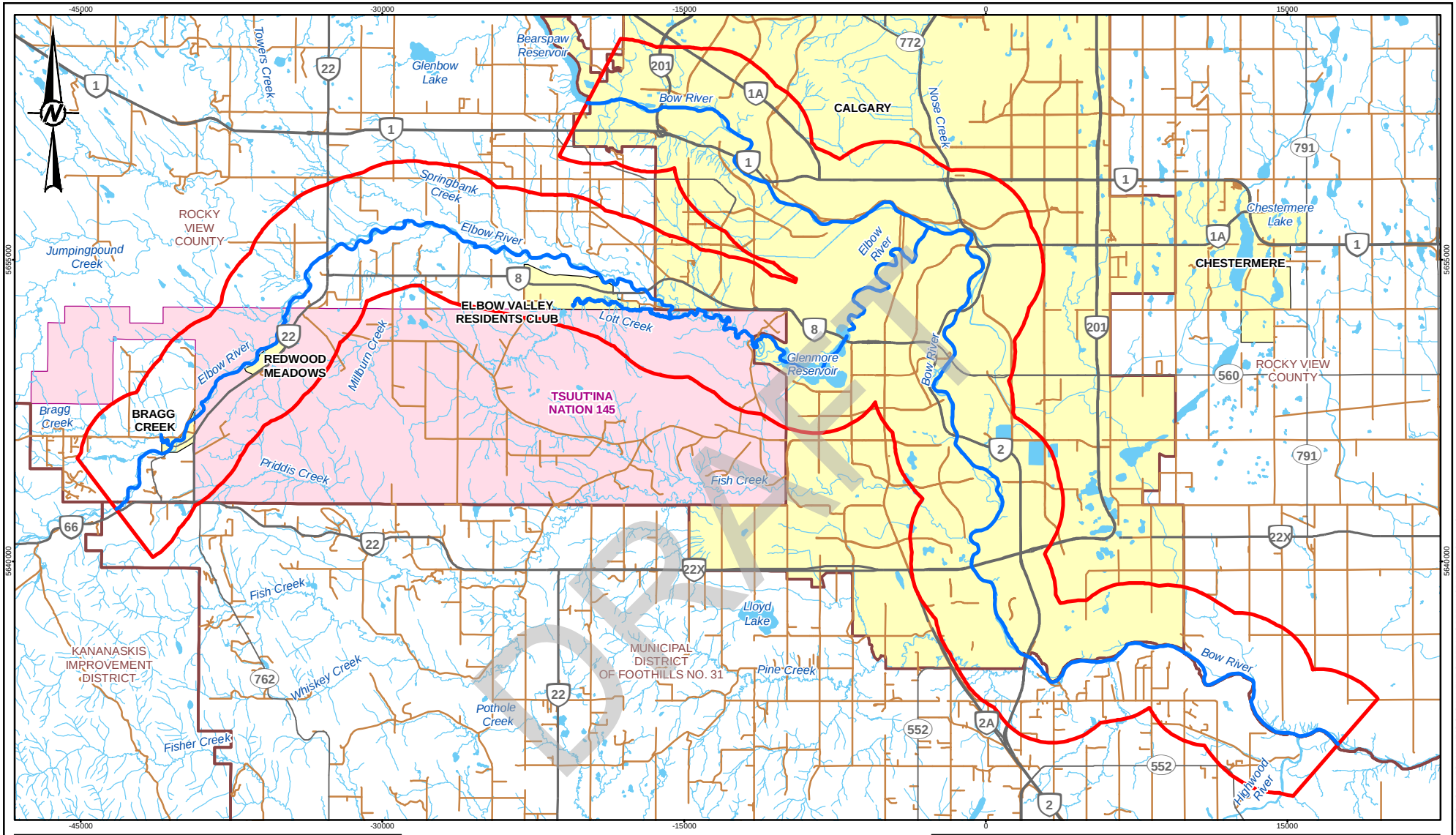

LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERCOURSE
- MUNICIPAL DISTRICT BOUNDARY
- URBAN AREA
- WATERBODY
- FIRST NATION RESERVE
- SURVEY REACH
- RIVER HAZARD STUDY AREA

0 5 10

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REFERENCE(S)

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ALBERTA ENVIRONMENT AND PARKS

Alberta Government

CONSULTANT
Golder Associates

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DESIGNED	W.PLOEGER
PREPARED	P. SHARMA
REVIEWED	M.TIDD
APPROVED	R.ATKINS

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
STUDY AREA

PROJECT NO.	CONTROL	REV.	FIGURE
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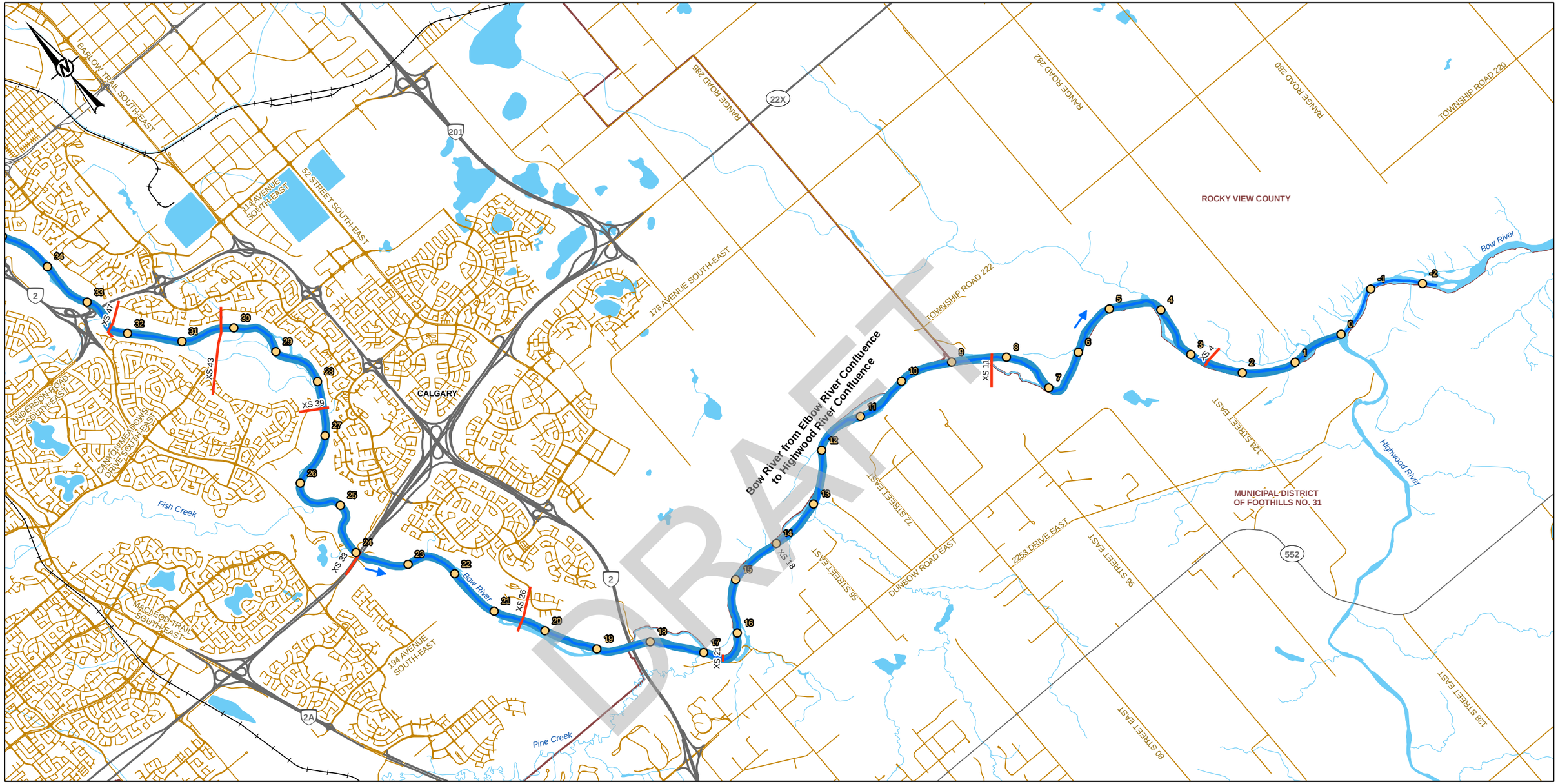

LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILROAD
- WATERCOURSE
- WATERBODY
- FIRST NATION RESERVE
- FLOW DIRECTION
- RIVER STATION POST
- WATER SURVEY OF CANADA GAUGE STATION
- RIVER CENTRELINE
- COMPARISON CROSS SECTION

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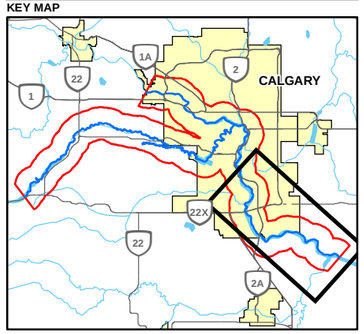
- BOW RIVER FROM BEARSPAW DAM TO ELBOW RIVER CONFLUENCE (2)
- ELBOW RIVER FROM GLENMORE DAM TO BOW RIVER CONFLUENCE (3)
- ELBOW RIVER FROM UPSTREAM OF BRAGG CREEK TO GLENMORE RESERVOIR (4)
- BRAGG CREEK FROM UPSTREAM OF CENTRE AVENUE IN BRAGG CREEK TO ELBOW RIVER CONFLUENCE (5)
- LOTT CREEK FROM UPSTREAM OF ELBOW VALLEY RESIDENCE CLUB TO ELBOW RIVER CONFLUENCE (6)

KEY MAP



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PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
REACH 1 - BOW RIVER FROM ELBOW RIVER CONFLUENCE TO HIGHWOOD RIVER CONFLUENCE

CONSULTANT
Golder Associates

YYYY-MM-DD	2018-08-23
DESIGNED	M.TIDD
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REVIEWED	M.TIDD
APPROVED	R. ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
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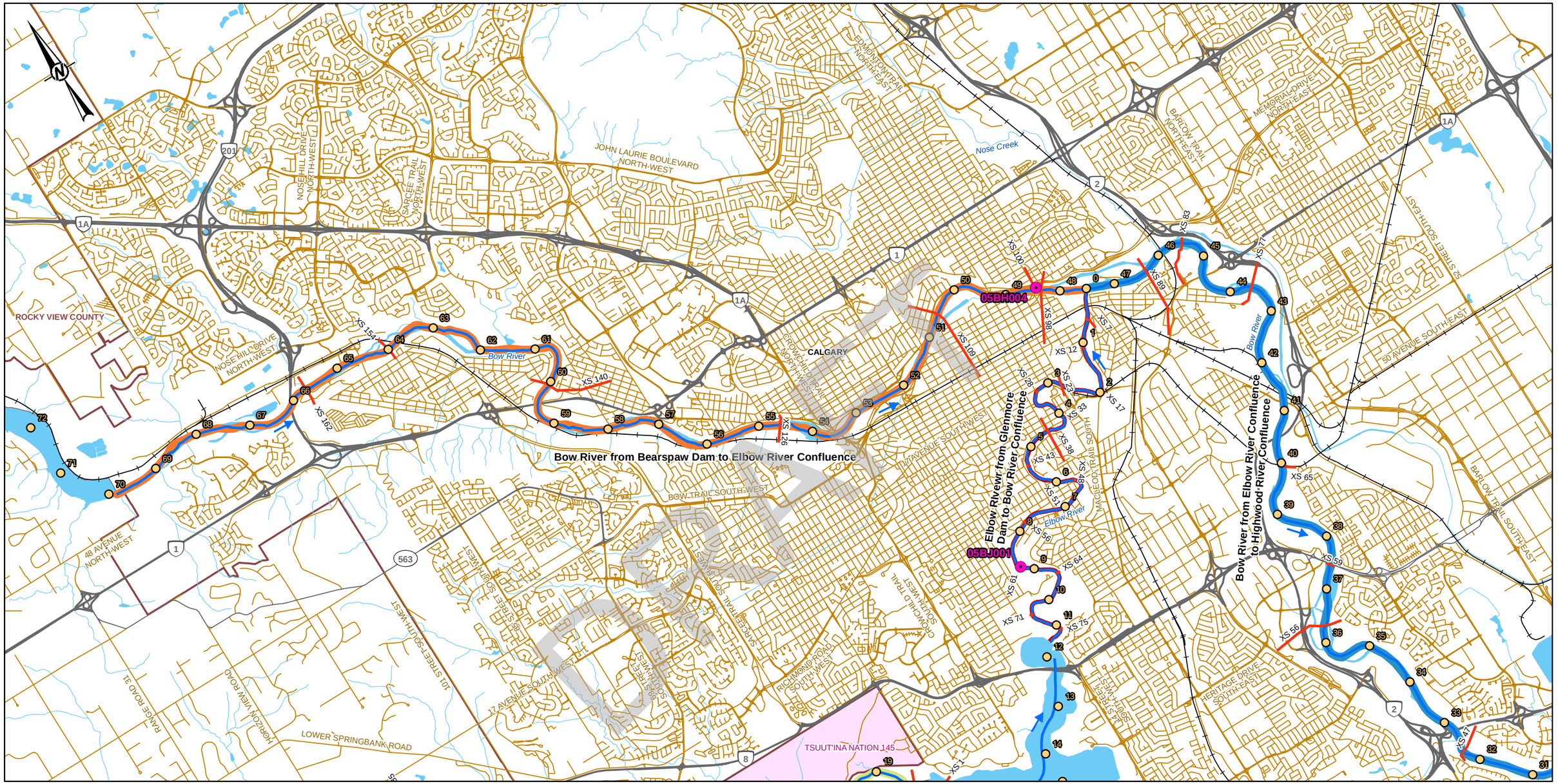

LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILROAD
- WATERCOURSE
- WATERBODY
- FIRST NATION RESERVE
- FLOW DIRECTION
- RIVER STATION POST
- WATER SURVEY OF CANADA GAUGE STATION
- RIVER CENTRELINE
- COMPARISON CROSS SECTION

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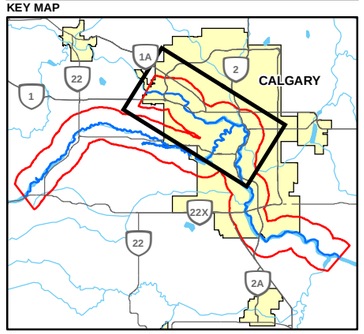
- BOW RIVER FROM ELBOW RIVER CONFLUENCE TO HIGHWOOD RIVER CONFLUENCE (1)
- BOW RIVER FROM BEARSPAW DAM TO ELBOW RIVER CONFLUENCE (2)
- ELBOW RIVER FROM GLENMORE DAM TO BOW RIVER CONFLUENCE (3)
- ELBOW RIVER FROM UPSTREAM OF BRAGG CREEK TO GLENMORE RESERVOIR (4)
- BRAGG CREEK FROM UPSTREAM OF CENTRE AVENUE IN BRAGG CREEK TO ELBOW RIVER CONFLUENCE (5)
- LOTT CREEK FROM UPSTREAM OF ELBOW VALLEY RESIDENCE CLUB TO ELBOW RIVER CONFLUENCE (6)

KEY MAP



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PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
REACH 1 - BOW RIVER FROM ELBOW RIVER CONFLUENCE TO HIGHWOOD RIVER CONFLUENCE AND REACH 2 - BOW RIVER FROM BEARSPAW DAM TO ELBOW RIVER CONFLUENCE

CONSULTANT
Golder Associates

YYYY-MM-DD	2018-08-23
DESIGNED	M.TIDD
PREPARED	P. SHARMA
REVIEWED	M.TIDD
APPROVED	R. ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
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Elbow River from Upstream of Bragg Creek to Glenmore Reservoir

Lott Creek from Upstream of Elbow Valley Residence Club to Elbow River Confluence

Bow River from Bearspaw Dam to Elbow River Confluence

Elbow Rivewr from Glenmore Dam to Bow River Confluence

Bow River from Elbow River Confluence to Highwood River Confluence

05BH004

05BJ001

05BJ010

ROCKY VIEW COUNTY

ELBOW VALLEY RESIDENTS CLUB

TSUUT'INA NATION 145

CALGARY

Glenmore Reservoir

Elbow River

Lott Creek

Bow River

Nose Creek

RANGE ROAD 34

RANGE ROAD 33

RANGE ROAD 32

RANGE ROAD 31

HORIZON VIEW ROAD

LOWER SPRINGBANK ROAD

101 STREET SOUTH-WEST

85 STREET SOUTH-WEST

69 STREET SOUTH-WEST

17 AVENUE SOUTH-WEST

BOW TRAIL SOUTH-WEST

CROWCHILD TRAIL NORTH-WEST

CROWCHILD TRAIL SOUTH-WEST

SARCEE TRAIL SOUTH-WEST

RICHMOND ROAD SOUTH-WEST

MACLEOD TRAIL SOUTH

14 STREET SOUTH-WEST

24 STREET SOUTH-WEST

HERITAGE DRIVE SOUTH-EAST

SOUTHLAND DRIVE SOUTH-WEST

BARLOW TRAIL NORTH-EAST

563

DRAFT

LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILROAD
- WATERCOURSE
- WATERBODY
- FIRST NATION RESERVE
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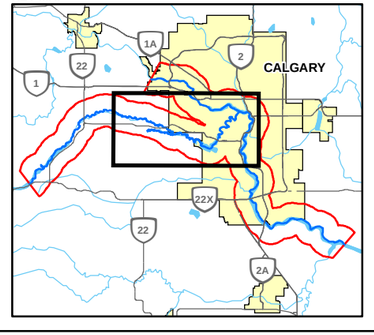

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
REACH 3 - ELBOW RIVER FROM GLENMORE DAM TO BOW RIVER CONFLUENCE, REACH 4 - ELBOW RIVER FROM UPSTREAM OF BRAGG CREEK TO GLENMORE RESERVOIR AND REACH 6 - LOTT CREEK

CONSULTANT
Golder Associates

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REVIEWED	M.TIDD
APPROVED	R. ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
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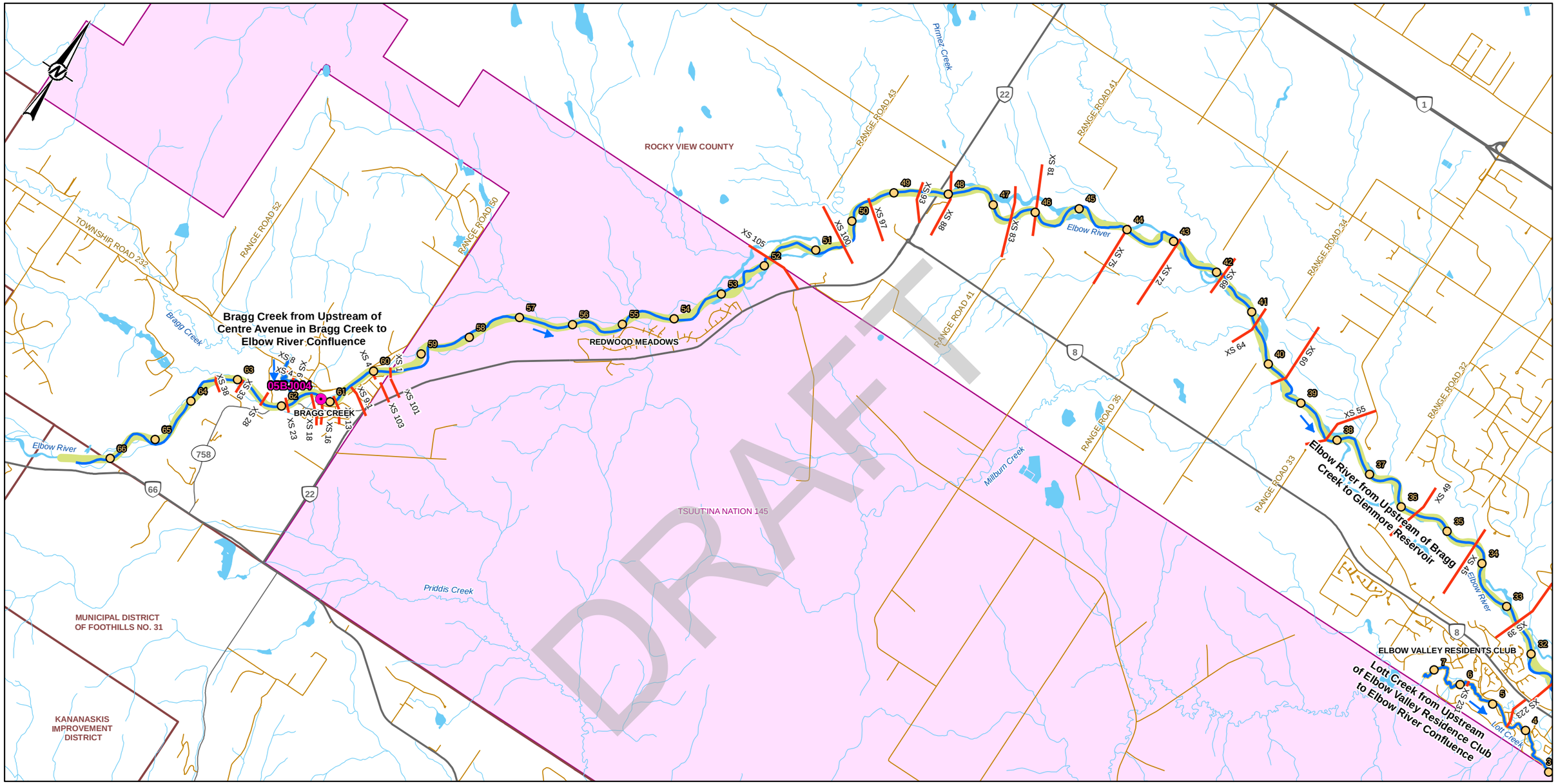

LEGEND

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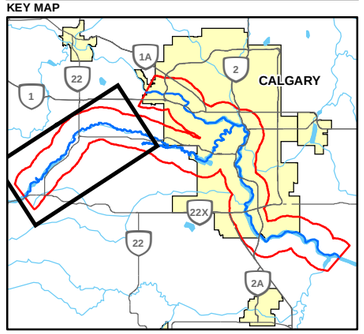
KEY MAP



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PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
REACH 4 - ELBOW RIVER FROM UPSTREAM OF BRAGG CREEK TO GLENMORE RESERVOIR, REACH 5 - BRAGG CREEK AND REACH 6 - LOTT CREEK

CONSULTANT
Golder Associates

YYYY-MM-DD	2018-08-23
DESIGNED	M.TIDD
PREPARED	P. SHARMA
REVIEWED	M.TIDD
APPROVED	R. ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
1536673	7000	0	**2d**

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.

2.0 AVAILABLE DATA

2.1 Aerial Imagery

Aerial imagery obtained for this study included recent imagery collected in 2016, and a historical imagery dataset which consisted of 1950, 1951, and 1966 imagery. Additional historical imagery was available for 1962 and 1999 covering parts of the study area, but this imagery was not used because the 1950/51/66 imagery provided complete coverage. The 1966 imagery was chosen over the 1962 imagery because the extent of coverage was better. The 1951 imagery collected along a portion of the Elbow River along Reach 4, from river station posts (measured upstream from confluences or study limits) KM 18 to KM 30, was of poor quality and could not be processed into digital format, and was not ultimately used for the channel stability investigation. The historical imagery from 1966 for this stretch of Reach 4 was used as an alternative due to its extent of the area of missing data and quality.

Table 2 contains a summary of the dates, scale, resolution, source, and accuracy of recent and historical aerial imagery datasets used for the channel bank delineation and comparison. Details of the methods and results for the aerial photography preparation reported in the following technical memorandums:

- 2016 Aerial Imagery Acquisition Memorandum (Golder 2016b) – for recent 2016 imagery
- Historical Aerial Imagery Processing Memorandum (Golder 2018; Appendix B)

Table 2: Summary of Aerial Imagery

Era	Date(s) of Collection	Scale	Resolution (m)	Source	Accuracy (m)
Recent	5/6/2016	1:15,000	0.50	AEP (Golder 2016)	Horizontal ±0.6 Vertical ±1.0
Historical	4/30/1950, 5/12/1950, 6/09/1950, 7/09/1950, 6/14/1951	1:40,000	0.80	AEP (Golder 2018)	±5-6
	8/09/1966	1:31,680	0.64	AEP (Golder 2018)	±5-6

2.2 Cross Section Data

Cross section data obtained for the cross section comparison task were available from several sources: hydraulic models from previous AEP flood studies for Calgary (AENV 1983), Bragg Creek (UMA 1992), and Rocky View County (AGRA 1996); LiDAR and DEM data collected or created between 2010 and 2015 (Golder 2011, Calgary 2016, and Golder 2017b); and river survey data collected between 2010 and 2016, and 2016 aerial imagery. The 2016 aerial imagery were used to interpret the location of the cross-sections relative to the available cross-section data and validate the cross-section profiles. Table 3 contains a summary of the dates, resolution, source, and accuracy of the datasets used for the cross section comparison.

Table 3: Summary of Cross Section Data

Dataset	Reach or Subreach	Date(s) of Collection	Resolution (m)	Source	Accuracy (m)
1983 Model	1, 2, 3 (within Calgary)	Elbow River: 1977 Bow River: 1980 to 1981	n.a.	AEP (AENV 1983)	Unknown, but vertical elevations reported to ±0.01
1992 Model	4 (at Bragg Creek), 5	Summer 1990	n.a.	AEP (UMA 1992)	Unknown, but vertical elevations reported to ±0.01
1996 Model	4 (through portions of Rocky View County and Tsuut'ina Nation)	Summer 1994	n.a.	AEP (AGRA 1996)	Unknown, but vertical elevations reported to ±0.01
2010 Survey	1, 2, 3 (within Calgary)	4/2010	n.a.	AEP and City of Calgary (Golder 2011)	±0.05-0.10
2013-2014 LiDAR	1, 2, 3 (within Calgary)	9/2013 to 11/2013, 4/2014	0.20	City of Calgary (Calgary 2016)	Horizontal ±0.10 Vertical ±0.05
2015 LiDAR	1 to 6	10/2015	0.30	AEP, obtained for current study (Golder 2017b)	±0.15, at 95% confidence
2013 Survey	1, 2, 3	9/2013 to 11/2013	n.a.	City of Calgary (Golder 2015)	Topographic: ±0.02 Bathymetric: ±0.10
2015-2016 Survey	1 to 6	10/2015 to 11/2015, 6/2016 to 8/2016	n.a.	Golder, collected for current study (Golder 2017b)	Topographic: ±0.02 Bathymetric: ±0.10

Historic cross section data from the 1983, 1992, or 1996 models was not available for the Elbow River within Reach 4 from KM 52 through KM 59, and a comparison along this reach was not possible. The 1992 dataset was available for Reach 4 at Bragg Creek from KM 59 to KM 64, and for Reach 5. The 1996 dataset was only available for Reach 4 from KM 17 to KM 52, through portions of Rocky View County and Tsuut'ina Nation near Calgary.

2.3 Thalweg Profile Data

Thalweg data obtained for the thalweg comparison task was available from several sources: hydraulic models from previous AEP flood studies for Calgary (AENV 1983), Bragg Creek (UMA 1992), and Rocky View County (AGRA 1996); and river survey data collected between 2013 (post-flood) and 2016. Recent aerial imagery was used to interpret current thalweg locations and validate various thalweg profiles. Table 4 contains a summary of the dates, resolution, source, and accuracy of the datasets used for the thalweg comparison.

Table 4: Summary of Thalweg Profile Data

Dataset	Reach or Subreach	Date(s) of Collection	Resolution (m)	Source	Accuracy
1983 Model	1, 2, and 3 (within Calgary)	Elbow River: 1977 Bow River: 1980 to 1981	n.a.	AEP (AENV 1983)	Unknown, but vertical elevations reported to ±0.01
1992 Model	4 (at Bragg Creek), 5	Summer 1990	n.a.	AEP (UMA 1992)	Unknown, but vertical elevations reported to ±0.01
1996 Model	4 (through portions of Rocky View County and Tsuut'ina Nation)	Unknown	n.a.	AEP (AGRA 1996)	Unknown, but vertical elevations reported to ±0.01
2013 Survey	1, 2, 3 (within Calgary)	9/2013 to 11/2013	n.a.	City of Calgary (Golder 2015)	Topographic: ±0.02 Bathymetric: ±0.10
2015-2016 Survey	1 to 6	10/2015 to 11/2015, 6/2016 to 8/2016	n.a.	Golder, collected for current study (Golder 2017b)	Topographic: ±0.02 Bathymetric: ±0.10

Historic thalweg data was not available for the same Elbow River subreaches where cross section data was unavailable, resulting in the same comparison limitations. Historical thalweg data was also not available for the Lott Creek study reach, where a qualitative review of available 2016 data was undertaken as an alternative.

2.4 Rating Curves

Hydrometric records and current and historic rating curves were obtained from the Water Survey of Canada (WSC) or the following four gauge stations within the study area:

- Bow River at Calgary (WSC Station No. 05BH004);
- Elbow River at Bragg Creek (WSC Station No. 05BJ004);
- Elbow River at Sarcee Bridge (WSC Station No. 05BJ010); and
- Elbow River below Glenmore Dam (WSC Station No. 05BJ001).

Historical rating curve datasets were obtained for the gauge stations above. Hydrometric records obtained for this investigation extend to 1936, 1934, 2006, and 1975 for the Bow River at Calgary, Elbow River at Bragg Creek, Elbow River at Sarcee Bridge, and Elbow River below Glenmore Dam stations, respectively. Additional data is available for the Bow River at Calgary that predates 1936, but it was not provided to Golder by WSC. The objective was to compare rating curves from data at the same year as the historical imagery to infer changes in rating curves to changes in river morphology. The following data was used to compare rating curves:

- Records for the Elbow River at Sarcee Bridge and Elbow River below Glenmore Dam stations only go back to 2006 and 1975, respectively. Rating curve comparisons for these stations were based on the oldest and youngest datasets available, and no change in gauge location or survey datum was noted.
- Records for the Bow River at Calgary station extend back to 1934, as previously mentioned, and the data prior to 1950 was not used for rating curve comparison. The 1950 rating curve data was used as it was the same age as the historical imagery to allow for direct comparison of the two datasets.
- Records for the Elbow River at Bragg Creek station cover the period from 1936 to present, but data prior to 1950 was not used for rating curve comparison, as was the case for the Bow River at Calgary. Data was not available for this station for 1981, 1982, and 2006, so the next available datasets from 1983 and 2007 were used in the comparison. The gauge was moved in November 1981 and June 2006, and data is reported with different survey datums. The varying survey datums limit direct interpretation of the relationship between changes in discharge and water level and the channel response to such changes.
- Record for the Elbow River at Bragg Creek stations included data from 1950, 1983, 2007, and 2017.

3.0 METHODS

3.1 Channel Bank Delineation and Comparison

The channel bank delineation and comparison was conducted in electronic format using orthorectified and georeferenced (triangulated) historical air photos. Historical air photos were reviewed using stereo-pairs for use in mapping software. Coverage, resolution and scale of the imagery are discussed in Section 2.1.

Channel banks were delineated directly onscreen from historical and recent aerial imagery, as outlined in Section 2.0. Bank delineation and major river features (i.e., single thread or multi-channel streams, major islands, sediment bars, significant secondary channels, etc.) were identified as they pertain to observed channel bank stability or instability. Once mapped using stereoscopic image display software, the digital channel margins were exported into an ArcGIS 10.2 (ArcMap) database with geospatial attributes.

A comparison of the historically-imaged and most recently-imaged channel banks was undertaken with both channel banklines depicted on the most recent photo base provided by AEP. A select set of figures were developed to highlight example areas of general channel stability and instability. These figures are accompanied by a technical summary discussing the general nature of general channel stability instability in the study area (e.g., observations that channel 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 cross section comparison, a subsample of 80 representative cross sections in Reaches 1 through 6 were selected for review in detail (Figure 2a to 2d). The selected representative cross sections were compared with estimates of meander spacing to validate coverage of major river features.

Following identification of representative cross sections, qualitative and quantitative analyses were conducted. The qualitative analysis included review and documentation of cross section features such as 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), single thread or multiple thread channels, and evidence of aggradation or degradation. The quantitative analysis of channel geometry consisted of the estimation of cross-sectional area, maximum bankfull depth, bankfull width, and average bankfull depth for each cross section. These parameters 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 each reach 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 channel geometry. Historical and current thalweg profiles were compared as part of this analysis. Increases or decreases in thalweg slope were evaluated and documented in context with reviewed cross sections and major river features. Areas of scour or degradation (thalweg slope increase or bed elevation decreases) and sedimentation or aggradation (thalweg slope decrease or bed elevation increase) were identified, and reach-averaged net bed volume changes were calculated.

Historical thalweg data were available only as profiles or in elevation versus river station formats, so a plan view comparison of the thalweg to evaluate channel migration was not made. Migration of the river channel as documented in the channel bank and cross section comparisons is deemed sufficient to address lateral migration.

3.4 Rating Curve Comparison

Changes in main channel geometry or riverbed elevations can result in rating curve changes for a hydrometric gauge. 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 gauge locations within the study area was provided by WSC as described in Section 2.4. 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.

4.0 RESULTS

4.1 Channel Bank Comparison

The results of the channel bank delineation and comparison task are summarized in Table 5 and representative subreaches are shown in Figure 3 through Figure 8. A channel stability overview map of the entire study area is presented in Figure 9. These results are discussed below:

- Reach 1, extending along the Bow River between the Elbow and Highwood River confluences, is typically defined by a stable planform with limited areas of instability. This reach consists of a predominantly single, irregularly meandering, confined channel with limited presence of side, point, and mid-channel bars, and is characterized by limited lateral migration, slightly migrating side bars.

  A generally stable representative subreach is presented in Figure 3. This subreach displays minimal lateral channel migration, with the main examples occurring along meander bends. Several point bars are present in both the historical and current imagery. More bars are present in the historical imagery, and appear to have expanded slightly and shifted slightly downstream to their current positions.

  A generally unstable representative subreach is also presented in Figure 3, upstream of the stable subreach. A side channel has developed over the observable period along the right bank and created a large forested island, possibly following a former relict channel. The main channel has migrated substantially around two meander bends, shifting laterally from the centreline of the river by approximately 40 m to 50 m. The historical point bars have shifted downstream indicating that the river bed is mobile. Several side bars have stabilized over time and are now vegetated.

- Reach 2, extending along the Bow River from Bearspaw Dam to the Elbow River confluence, is typically defined as a stable channel. This reach consists of a single, irregularly meandering, confined channel with limited presence of side and point bars. This entire reach is considered to be stable, so only a stable representative subreach is presented in Figure 4. This reach is characterized by limited lateral migration, with slightly migrating small side and mid-channel bars and forested islands. Figure 4 shows minimal lateral channel migration, with the main examples occurring along meander bends. Some bank protection appears to be present along several outer meander bends, but a comprehensive investigation and inventory of bank protection was not undertaken as part of this study.

- Reach 3, extending along the Elbow River from Glenmore Dam to the Bow River confluence, is typically defined as a stable channel. This reach consists of a single, irregularly meandering, incised channel with limited presence of side, point, and mid-channel bars. This entire reach is considered to be stable, so an unstable sub-reach has not been included. This reach is characterized by limited lateral migration, with limited presence of small side and mid-channel bars and forested islands. A representative subreach is presented in Figure 5. Figure 5 shows minimal lateral channel migration, with the main examples occurring along meander bends. Some bank protection appears to be present along several outer meander bends, but a comprehensive investigation and inventory of bank protection was not undertaken as part of this study.

- Reach 4, extending along Elbow River from Bragg Creek to Glenmore Dam, is typically defined as an unstable channel with limited areas of stability. It is characterized by lateral migration, braiding, and the presence of forested islands and established side channels. Representative subreaches are presented in Figure 6.

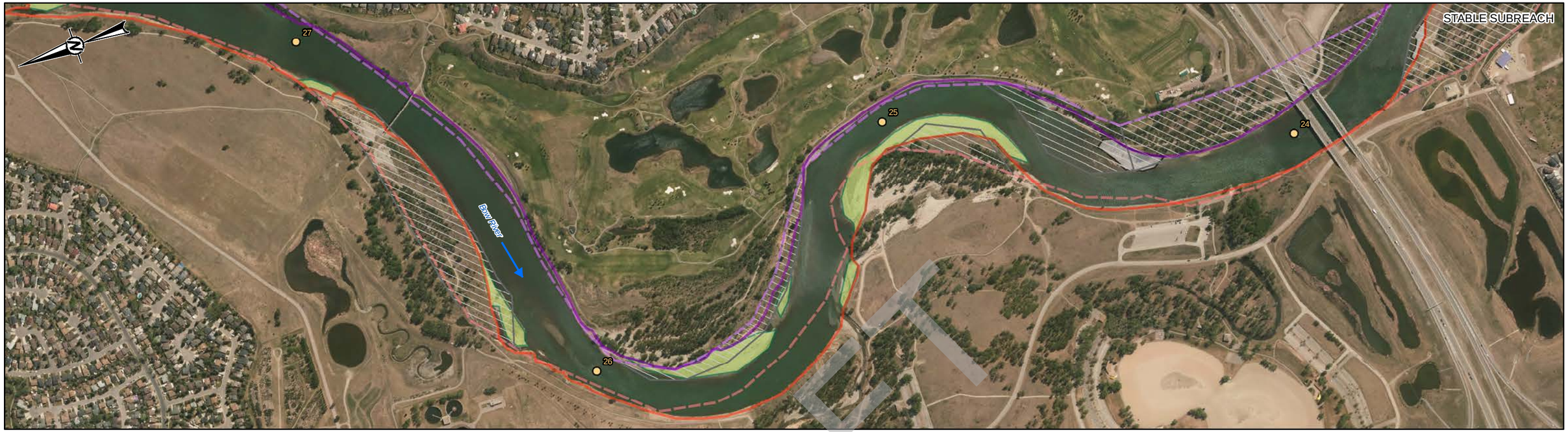
  The unstable subreach consists of tortuous and braided, sometimes anastomosed, multi-thread channels characterized by the presence of numerous side, point, and mid-channel bars. Several forested islands are present in both the historical and recent imagery, but are much more numerous and expansive in the latter. The main braided section of the channel has undergone what appears to be progressive meander migration over the observed period. However, the presence of several well established forested islands and the establishment of several side channels with limited evidence of progressive channel shifts, suggests that the establishment of the side channels occurred during a sudden event, like an avulsion potentially caused by the flood of 2013, rather than through progressive meander migration over time.

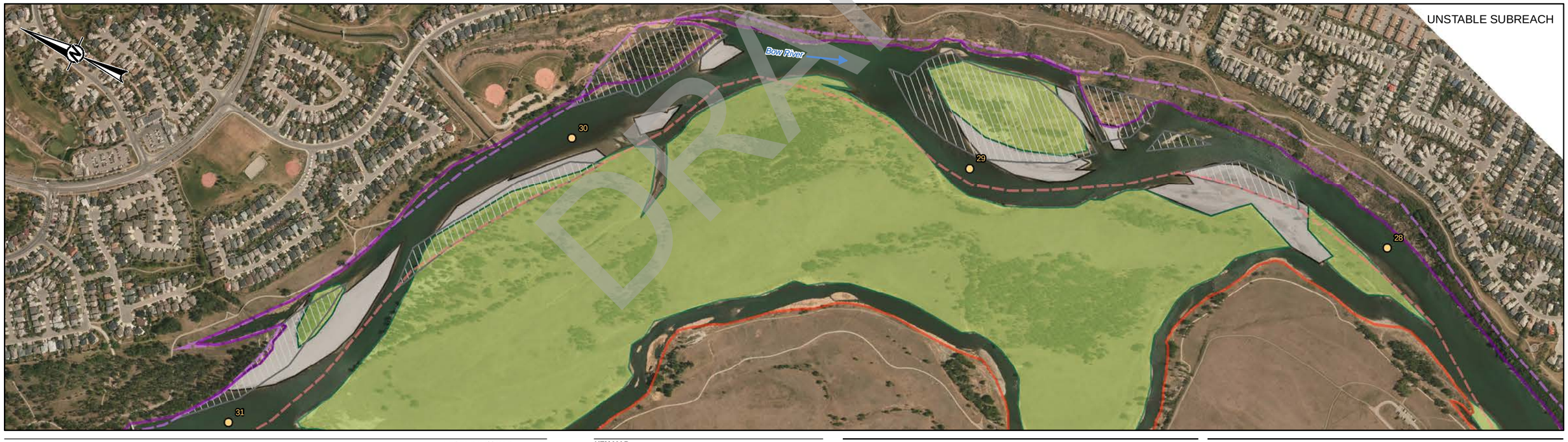
  The stable subreach consists of a sinuous, wandering, and braided channel. Minimal lateral channel migration has occurred along the subreach, with the main examples occurring along meander bends. Several historical and current side and mid-channel bars suggest moderate sediment transport downstream.

  Both the Bragg Creek (Reach 5, Figure 7) and Lott Creek (Reach 6, Figure 8) reaches are defined by a sinuous steams within a slightly incised channel with limited sediment transport. Both reaches are within urbanized environments, but approximately 3 km of the historical Lott Creek channel has been modified and diverted around residential development, retention ponds, and a golf course (see the dashed historical alignment in Figure 8). Minimal lateral channel migration along the majority of both creeks has occurred within the assessment period, with the main occurrences along meander bends. Limited active side or point bars are present, suggesting low sediment loads. Reaches 5 and 6 are characterized by limited lateral migration, low sediment load, and the presence of limited side, point, and mid-channel bars.

Table 5: Channel Bank Delineation Comparison

Reach	Representative Subreach (km)	Description
1 – Bow River from Elbow River confluence to Highwood River confluence	24 to 27	- Confined floodplain - Single channel - Presence of point and side bars - Irregularly meandering - Stabilization of side bars resulting in the narrowing of the active channel - Limited observed migration of the channel outside of bends of meanders
	28 to 31	- Confined floodplain - Predominantly single channel, some multi-channel sections - Presence of point, mid-channel and side bars - Irregularly meandering - Migration of side bars - Lateral migration of 40 m to 50 m of main channel at meander bends - Development of side channel off main stem - Human development within floodplain
2 – Bow River from Bearspaw Dam to Elbow River confluence	52 to 55	- Confined - Single channel - Incised - Limited presence of mid-channel and side bars - Irregularly meandering - Observed channel protection - Human development within floodplain - Limited observed migration of the channel
3 – Elbow River from Glenmore Dam to Bow River confluence	7 to 10	- Confined - Single channel - Incised - Limited presence of mid-channel and side bars - Irregularly meandering - Observed channel protection - Limited observed migration of the channel
4 – Elbow River from upstream of Bragg Creek to Glenmore Reservoir	42 to 45	- Confined floodplain - Multi-channel, braided and anastomosed - Presence of point, mid-channel, and side bars - Presence of forested islands - Significant channel meander migration and complete realignment of main channel - Loss/migration of forested islands - New channels present
	60 to 63	- Confined floodplain - Predominantly single channel, some multi-channel sections - Presence of point, mid-channel, and side bars - Irregularly meandering - Migration of side bars - Limited observed migration of the channel with the main examples of lateral migration occurring along the bends of meanders
5 – Bragg Creek	0 to 1	- Partially confined upstream, unconfined downstream of KM 0.9 - Predominantly single channel - Limited presence of mid-channel and side bars - Development of side channel around forested island - Limited observed migration of the channel
6 – Lott Creek	1 to 4	- Confined upstream of KM 5 - Natural single channel, multichannel with retention ponds due to development - Significant channelization and channel rearrangement due to development - Limited presence of mid-channel and side bars - Development of side channel around forested island





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- RIGHT BANK HISTORICAL (1951)
- LEFT BANK (2016)
- LEFT BANK HISTORICAL (1951)
- CHANNEL BAR (2016)
- CHANNEL BAR HISTORICAL (1951)
- FORESTED ISLAND (2016)
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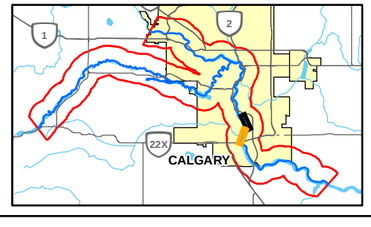
- STABLE SUBREACH
- UNSTABLE SUBREACH

KEY MAP



PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 1 - BOW RIVER FROM ELBOW RIVER CONFLUENCE TO HIGH RIVER CONFLUENCE - REPRESENTATIVE SUBREACHES

REFERENCE(S)
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CONSULTANT

Golder Associates

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REVIEWED	M.TIDD
APPROVED	R.ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
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- RIGHT BANK HISTORICAL (1951)
- LEFT BANK (2016)
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- CHANNEL BAR (2016)
- CHANNEL BAR HISTORICAL (1951)
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- STABLE SUBREACH

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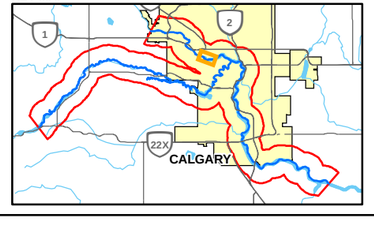

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 2 - BOW RIVER FROM BEARSPAW DAM TO ELBOW RIVER CONFLUENCE - REPRESENTATIVE SUBREACH

REFERENCE(S)
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PROJECT NO.	CONTROL	REV.	FIGURE
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LEGEND

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- CHANNEL BAR (2016)
- CHANNEL BAR HISTORICAL (1951)
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- FORESTED ISLAND HISTORICAL (1951)

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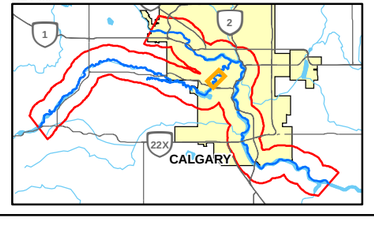
LEGEND KEY MAP

- STABLE SUBREACH

KEY MAP



PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 3 - ELBOW RIVER FROM GLENMORE DAM TO BOW RIVER CONFLUENCE - REPRESENTATIVE SUBREACH

REFERENCE(S)
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REVIEWED	M.TIDD
APPROVED	R.ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
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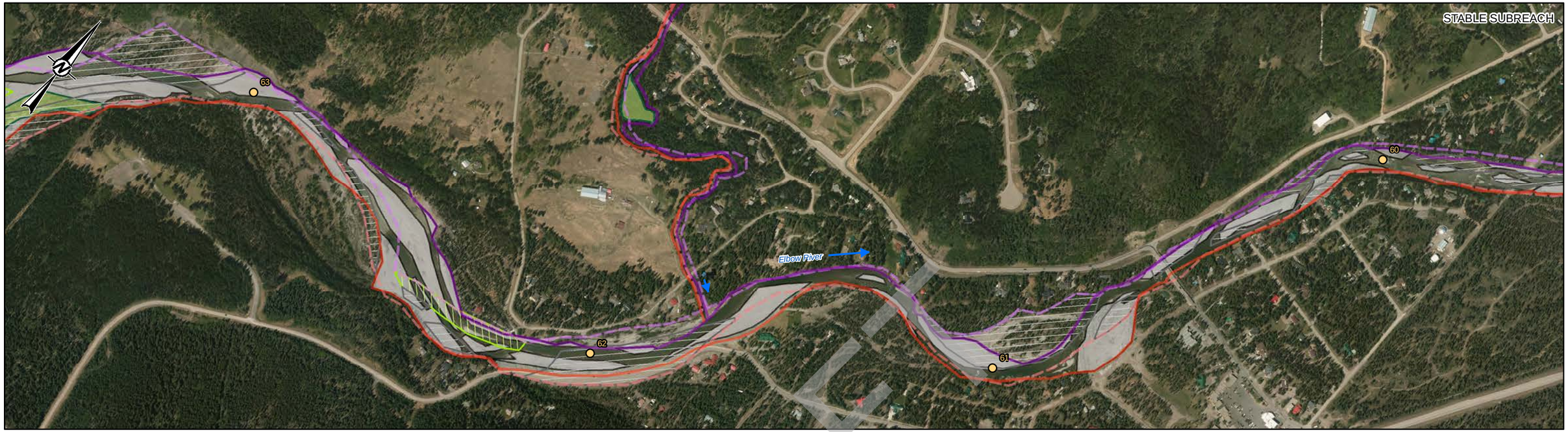

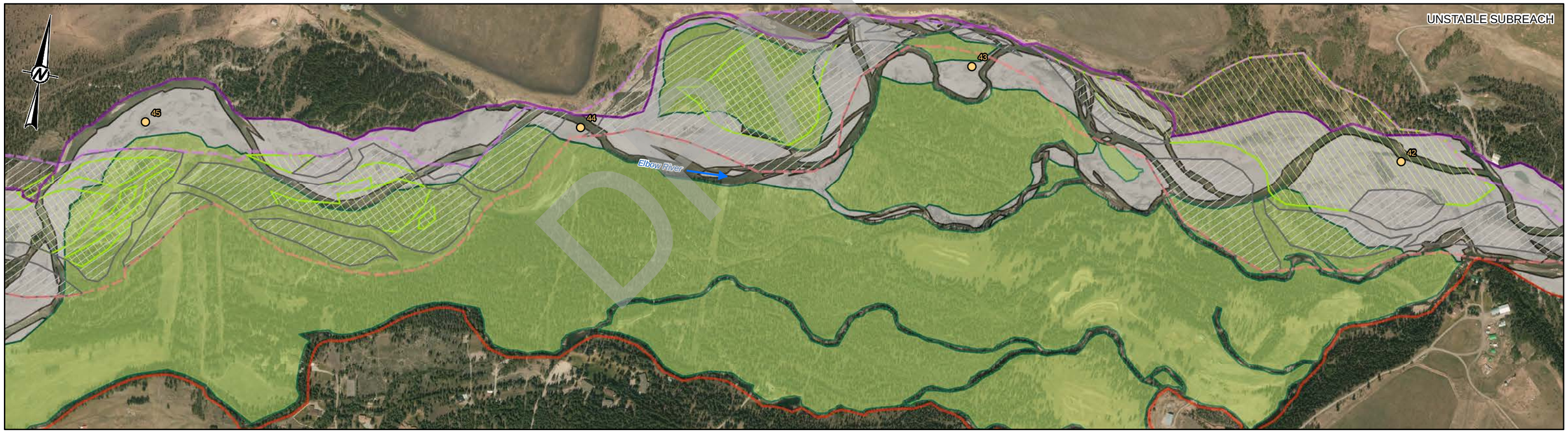

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- CHANNEL BAR (2016)
- CHANNEL BAR HISTORICAL (1951)
- FORESTED ISLAND (2016)
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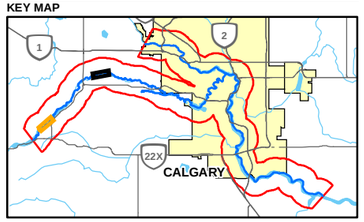
LEGEND KEY MAP

- STABLE SUBREACH
- UNSTABLE SUBREACH

KEY MAP



PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 4 - ELBOW RIVER FROM UPSTREAM OF BRAGG CREEK TO GLENMORE RESERVOIR - REPRESENTATIVE SUBREACHES

REFERENCE(S)
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REVIEWED	M.TIDD
APPROVED	R.ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
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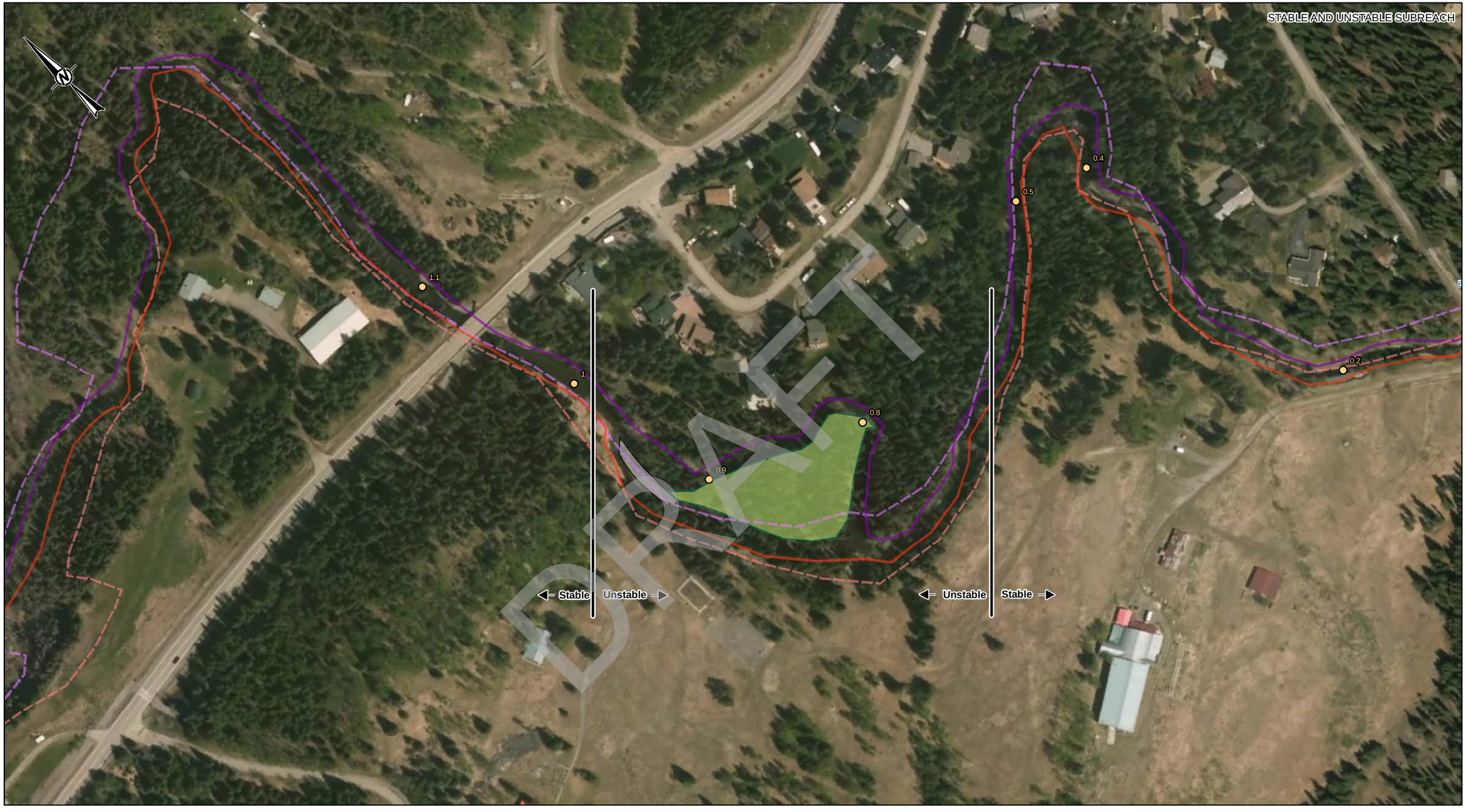

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- CHANNEL BAR (2016)
- CHANNEL BAR HISTORICAL (1951)
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LEGEND KEY MAP

- STABLE SUBREACH
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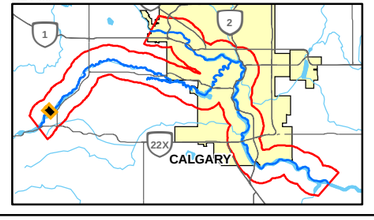
KEY MAP



PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 5 - BRAGG CREEK - ENTIRE REACH

REFERENCE(S)
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PREPARED	P.SHARMA
REVIEWED	M.TIDD
APPROVED	R.ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
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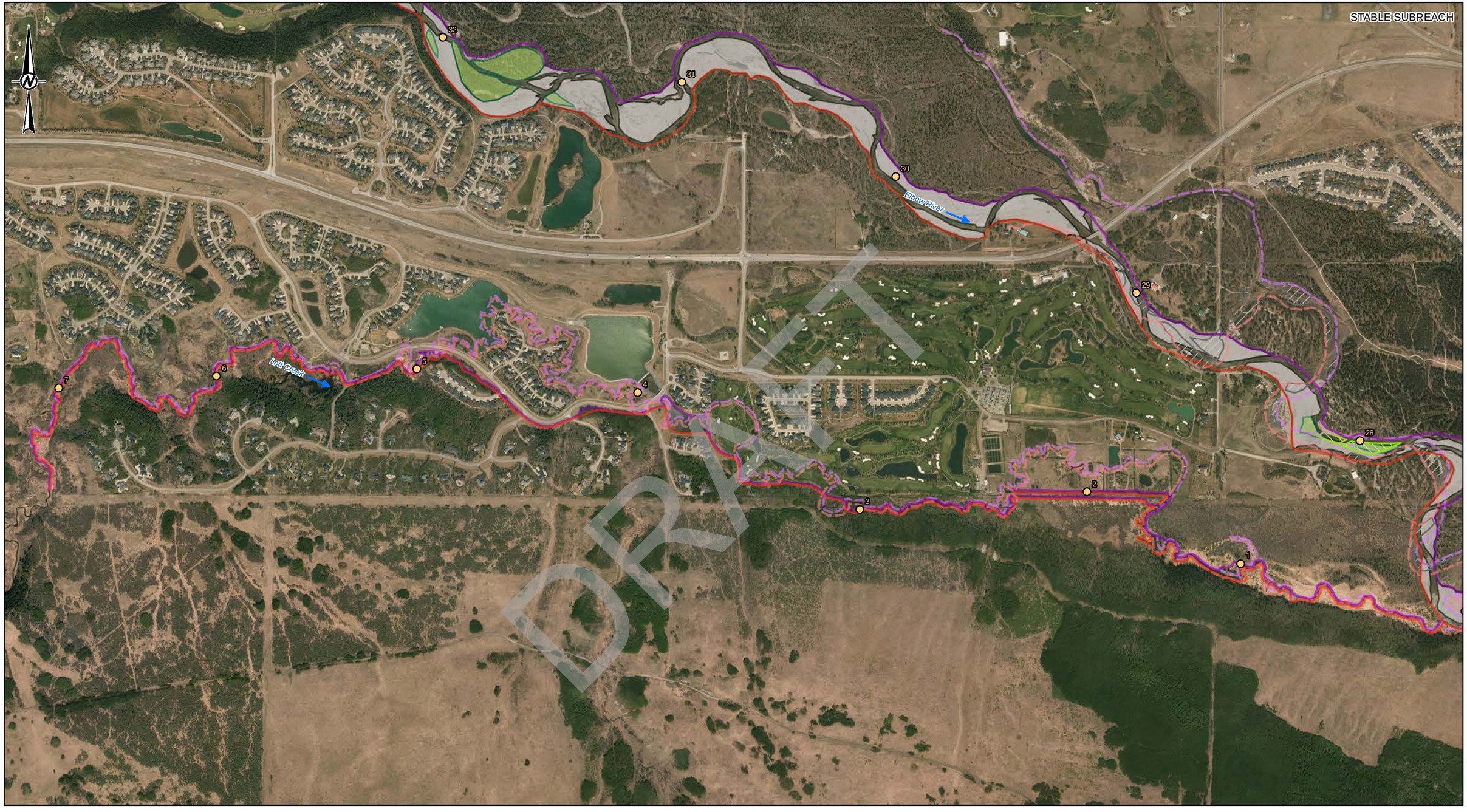

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- CHANNEL BAR (2016)
- CHANNEL BAR HISTORICAL (1966)
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- FORESTED ISLAND HISTORICAL (1966)

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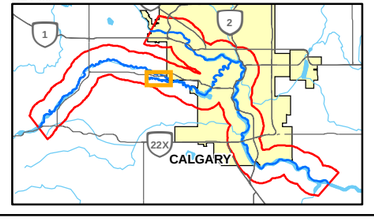
LEGEND KEY MAP

- STABLE SUBREACH

KEY MAP



PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
CHANNEL BANK COMPARISON OF REACH 6 - LOTT CREEK - ENTIRE REACH

REFERENCE(S)
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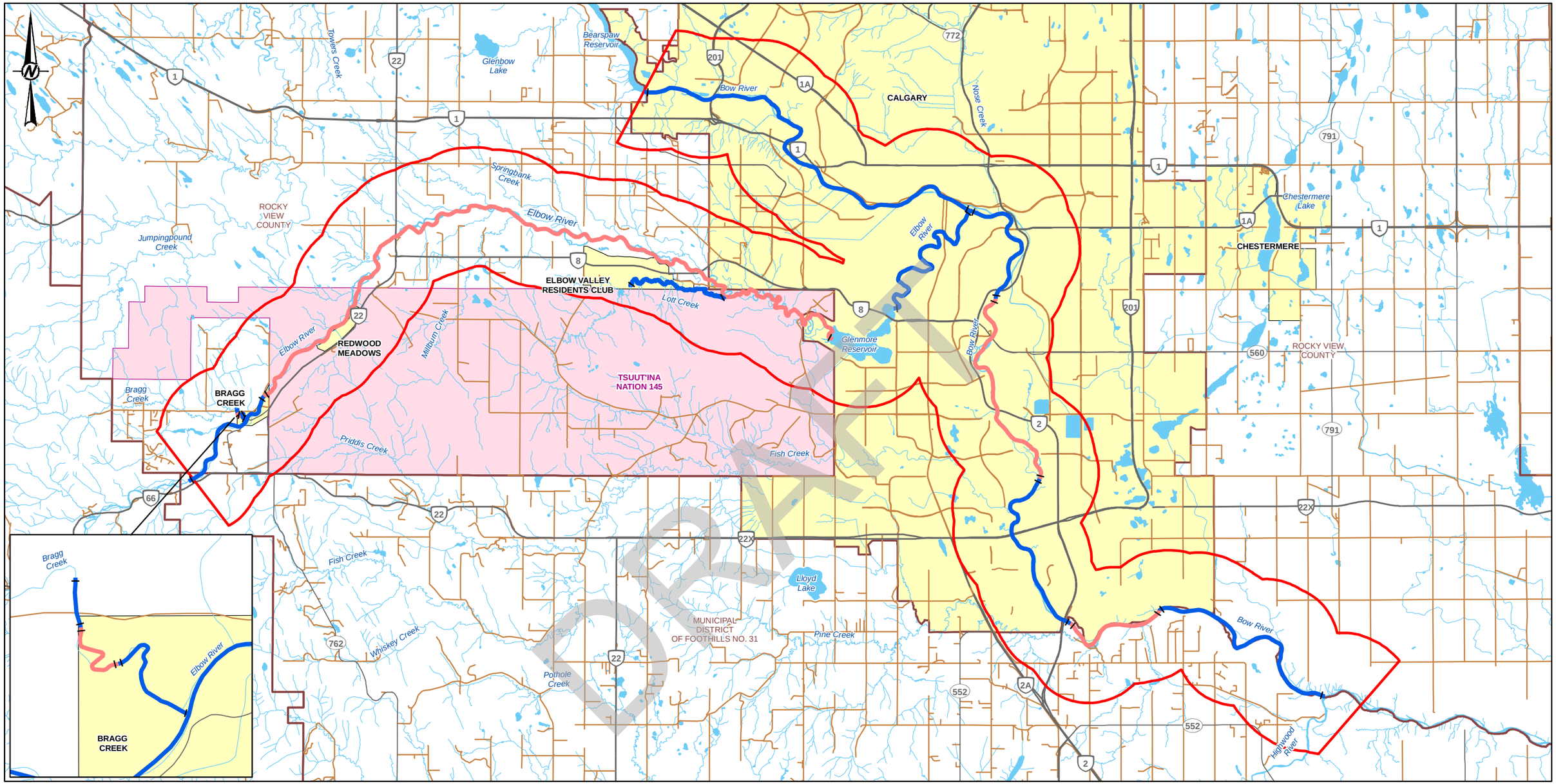
REVIEWED	M.TIDD
APPROVED	R.ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
1536673	7000	0	**8**



LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- WATERCOURSE
- MUNICIPAL DISTRICT BOUNDARY
- URBAN AREA
- WATERBODY
- FIRST NATION RESERVE
- RIVER HAZARD STUDY AREA

RIVER REACH

- STABLE
- UNSTABLE

0 6 12

1:200,000 KILOMETRES

CLIENT
ALBERTA ENVIRONMENT AND PARKS

Alberta Government

REFERENCE(S)
HYDROGRAPHY, MUNICIPAL DISTRICTS AND RAILROADS OBTAINED FROM ALTALIS, © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.ROADS OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
GAUGING STATIONS PROVIDED BY THE WATER SURVEY OF CANADA.
DATUM: NAD 83 CSRS PROJECTION: 3TM 114

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
CHANNEL STABILITY OVERVIEW MAP

CONSULTANT
Golder Associates

YYYY-MM-DD	2018-08-23
DESIGNED	M.TIDD
PREPARED	P. TAN
REVIEWED	M.TIDD
APPROVED	R.ATKINS

PROJECT NO.	CONTROL	REV.	FIGURE
1536673	7000	0	**9**

PATH: I:\2015\1536673\Mapping\MXD\Hydrology\08_Channel Stability Investigation\Rev0\1536673_Fig9_Reaches-Overview_Rev0.mxd PRINTED ON: 2018-08-23 AT: 7:49:40 AM

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4.2 Cross Section Comparison

Detailed qualitative and quantitative descriptions and figures for the cross section comparison are presented in Appendix A. Table 6 provides a summary of representative cross section geometry.

The quantitative observations of channel geometry indicate that the average bankfull width has increased by approximately 38 m along Reach 1 of the Bow River and 15 m along Reach 4 of the Elbow River. This suggests a widening of the channel in these reaches. This was confirmed by the observations made during the channel bank comparison. In most cases this widening of the channel occurred due to erosion of outside meander bends along the river. This would suggest that the river bed is more armoured than the river banks, excluding areas of engineered erosion protection, so erosion occurring during increased flows erodes the river banks prior to eroding the river bed. All other observed changes in bankfull width were between 0 m and 5 m, and within the range of error for this analysis. All observed of bankfull width changes were not statistically significant, at the p=0.05 level.

Similarly, the average bankfull depth has increased along Reaches 2 through 5 (suggesting a deepening of the river) and decreased along Reach 1 (suggesting a shallowing of the river). Cross-sectional area has decreased along Reach 3 and increased along Reaches 1, 2, 4, and 5. Typically, changes observed were not statistically significant, at the p=0.05 level, with the exceptions of the changes to average bankfull depth and cross-sectional area along Reach 4 at Bragg Creek (KM 59 to KM 64) and the maximum bankfull depth along Reach 4 farther downstream (KM 17 to KM 52). These changes were significant at the p=0.05 level.

Where possible, the lateral migration of the channels was documented during the cross section comparison. Lateral migration along Reaches 1 and 4 ranged from 10 m to 80 m, typically resulting in a widening of the channel as the trailing channel margin moved less than the leading channel margin. This may be due to armouring of the river bed. Lateral migration along Reaches 2, 3 and 5 ranged from 0 m to 5 m, and typically resulted in minimal change to the total channel width.

Table 6: Summary of Representative Cross Section Geometry

Reach or Representative Subreach	Maximum Bankfull Depth (m)		Average Bankfull Depth (m)		Bankfull Width (m)		Cross-Sectional Area (m^2)	
	Historical	Recent	Historical	Recent	Historical	Recent	Historical	Recent
1 – Bow River	4.6	4.5	3.7	3.4	147.8	185.6	571.1	658.3
2 – Bow River	5.5	5.8	4.3	5.0	133.3	133.3	580.0	672.5
3 – Elbow River	4.6	4.8	3.9	4.0	57.0	53.3	221.3	215.7
4 – Elbow River (at Bragg Creek)	2.1	2.7	1.1	1.7	50.7	52.9	60.3	88.9
4 – Elbow River (through portions of Rocky View County and Tsuut'ina Nation)	1.9	2.4	1.2	1.4	68.6	83.9	84.0	127.9
5 – Bragg Creek	1.7	2.0	0.9	1.5	14.0	14.5	9.8	21.3
6 – Lott Creek	n.a.	1.2	n.a.	0.6	n.a.	17.2	n.a.	4.9

Note: Historical geometry derived from 1983, 1992, or 1996 models, and recent geometry derived from 2013-2016 surveys.

4.3 Thalweg Profile Comparison

A thalweg profile comparison was made using historical data from 1983, 1992 and 1996 hydraulic models and 2013-2016 surveys. Figure 10 through Figure 12 comparison thalweg profiles for the Bow and Elbow Rivers and Bragg Creek. Due to the scales of the figures, detailed changes are difficult to interpret so bed elevation difference plots were created to highlight the measured changes. The bed elevation difference plots are shown in Figure 14 through Figure 16. Positive numbers are indicative of accretion (or aggradation) and negative numbers are indicative of scour (or degradation). Table 7 summarizes changes of reach-averaged slopes and calculated net bed volumes. Historical thalweg data was not available for Lott Creek so a comparison was not completed. Figure 13 shows the recent Lott Creek thalweg for qualitative analysis only.

Typically, thalwegs exhibiting a concave shape are typical of a stream reach in equilibrium (Ritter *et al.* 1995). The plots for the historical and recent thalwegs for the Bow River (Figure 10) and Bragg Creek (Figure 12) are approximately linear (consistent) and do not follow a monotonically decreasing concave profile. The plots for the historical and recent thalwegs for the Elbow River (Figure 11) and the recent Lott Creek thalweg (Figure 13) generally do follow a monotonically decreasing concave profile indicative of generally stable conditions.

Bow River

Inspection of the Bow River thalweg profiles suggests that Reaches 1 and 2 follow a general consistent slope profiles, with slopes of 0.0018 m/m and 0.0019 m/m respectively. These values are consistent with those recently reported by others (Klohn 2016). The undulating thalweg morphology with an approximately linear (consistent) slope within the study area, as seen in Figure 10, suggests that this channel could be a non-alluvial system under the current flow regime, where the river channel has not developed in sediments carried by the river itself, or is a former outwash channel shape. If the latter, then the channel slope and thalweg profile are relict features of processes no longer operating in the modern environment.

In addition, due to the presence of Bearspaw Dam, much of the sediment originated in the Bow River headwaters is trapped by the dam, limiting the river's ability to behave as an alluvial channel immediately downstream. Bed scour may be expected downstream of the dam as the river reconstitutes its sediment load.

The net bed volume changes for the Bow River were calculated where historical thalweg data was available for Reaches 1 and 2. An increase in bed elevation was generally observed along Reach 1 while a decrease in bed elevation was generally observed along Reach 2. Figure 14 shows a relatively even fluctuation between areas of scour and accretion. The total net bed volume along both reaches decreased by about 110 m^3 over the assessment period, which is consistent with a river bed in equilibrium with the flow regime. While small for the overall river length this net decrease that some winnowing of river bed sediments is occurring in Reach 2.

Some aggradation and degradation appears to have occurred upstream and downstream, respectively, of the WID Weir (near KM 45) which may affect flood frequency immediately downstream of the Calgary Zoo (KM 47). A minor increase in riverbed sediment median grain size was recently reported in this area (Klohn 2016), but the change is small and potentially statistically insignificant.

Elbow River

Inspection of the Elbow River thalweg profiles suggests that Reaches 3 and 4 follow a general monotonically decreasing concave profile. The average slope of the Elbow River thalweg decreases from upstream to downstream: Reach 4 has a slope of 0.0057 m/m and Reach 3 has a slope of 0.0018 m/m. The monotonically decreasing concave profile within the study area, as seen in Figure 11, suggests that this is an active alluvial channel in equilibrium with a generally stable planform.

Bed volume change was calculated where historical thalweg data was available for Reaches 3 and 4. A net decrease in bed elevation was observed along both reaches, although the majority of scour appears to be occurring upstream of Glenmore Reservoir (Figure 15). The net bed volume calculated along both reaches decreased by about 19,690 m^3 over the assessment period.

Bragg Creek

Inspection of the Bragg Creek thalweg suggests that Reach 5 has an undulating thalweg morphology and follows an approximately linear (consistent) slope of 0.0081 m/m (Figure 12). Bed volume change was calculated where historical thalweg data was available, and the net bed volume calculated along the reach decreased by about 280 m^3 over the assessment period.

The study area contains the most downstream subreach of Bragg Creek, where it flows through its alluvial fan and to the Elbow River confluence. The expected concave thalweg profile could not be observed due to the short reach length, but the linear slope is consistent with slope profiles on alluvial fans.

Lott Creek

A thalweg comparison could not be made for Lott Creek along Reach 6 because historic data was not available. Figure 13 presents the recent thalweg profile, and shows a highly undulating river bed with an average slope of 0.0042 m/m. The undulating thalweg morphology with a monotonically decreasing upward-facing convex profile suggests an alluvial channel in equilibrium.

Lott Creek originates in Tsuut'ina Nation and flows through both Tsuut'ina Nation lands and Rock View County as it drains northeast towards the Elbow River valley. As discussed in Section 4.1, Lott Creek is highly modified over 3 km of the 7 km study reach, and is redirected through several culverts and retention ponds downstream of KM 5.

Table 7: Summary of Net Bed Volume Change

River	Reach and Description	Assessed River Stations (km)	Average Reach Slope (m/m)	Net Bed Volume Change (m^3)
Bow River	1 - Highwood River confluence to Elbow River confluence	0 to 48	0.0019	+380
	2 – Elbow River confluence to Bearspaw Dam	48 to 70	0.0018	-490
			Total Net Bed Volume Change for Bow River	-110
Elbow River	3 – Glenmore Dam to Bow River confluence	0 to 11	0.0018	-1,450
	4 – Upstream of Bragg Creek to Glenmore Reservoir	17 to 52	0.0057	-17,200
		59 to 64		-1,040
			Total Net Bed Volume Change for Elbow River	-19,690
Bragg Creek	5 – Upstream of Centre Avenue in Bragg Creek to Elbow River confluence	0 to 1	0.0081	-280
Lott Creek	6 – Upstream of Elbow Valley Residence Club to Elbow River confluence	0 to 7	0.0042	n.a.

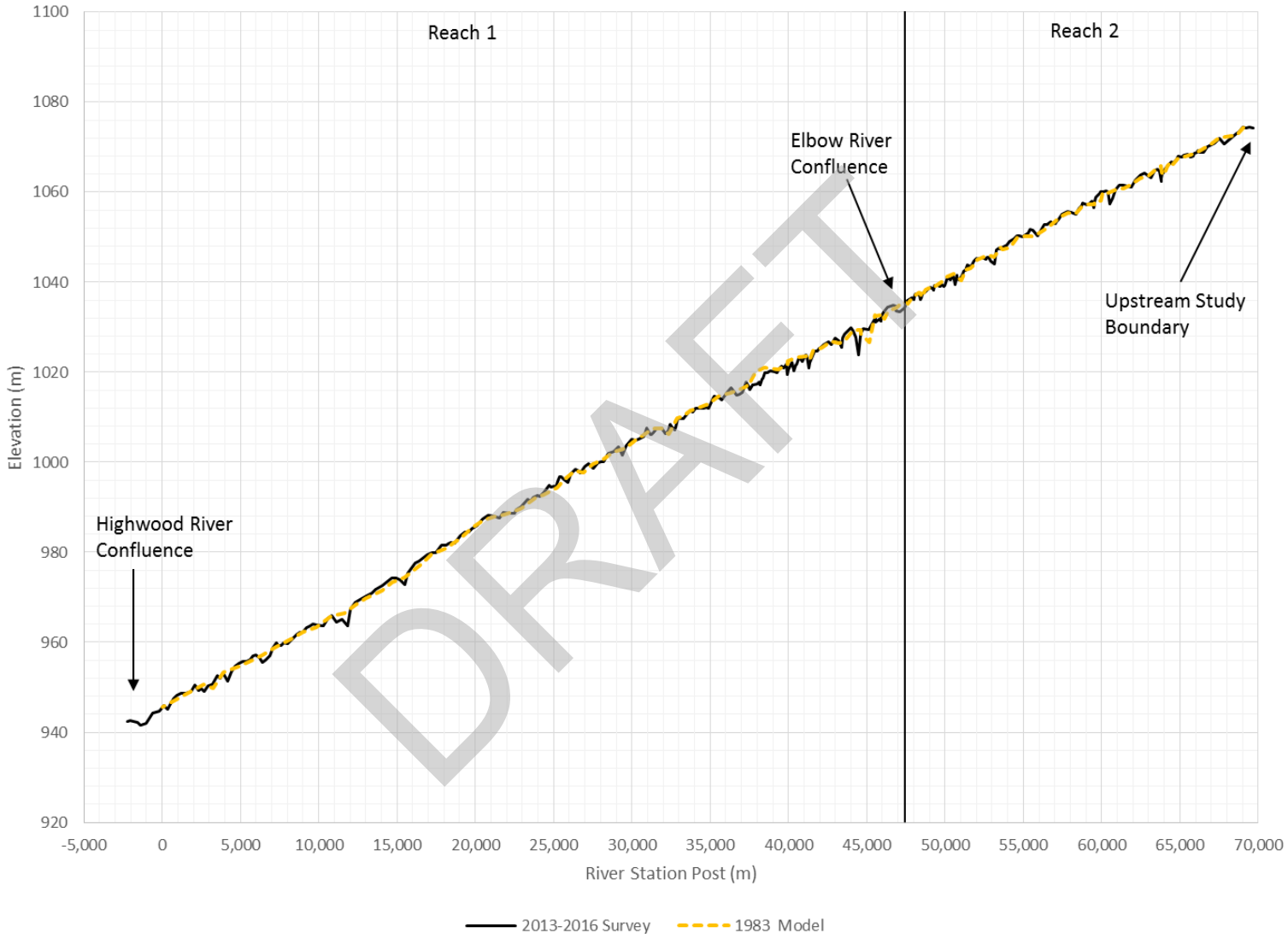

Figure 10: Bow River Thalweg Comparison

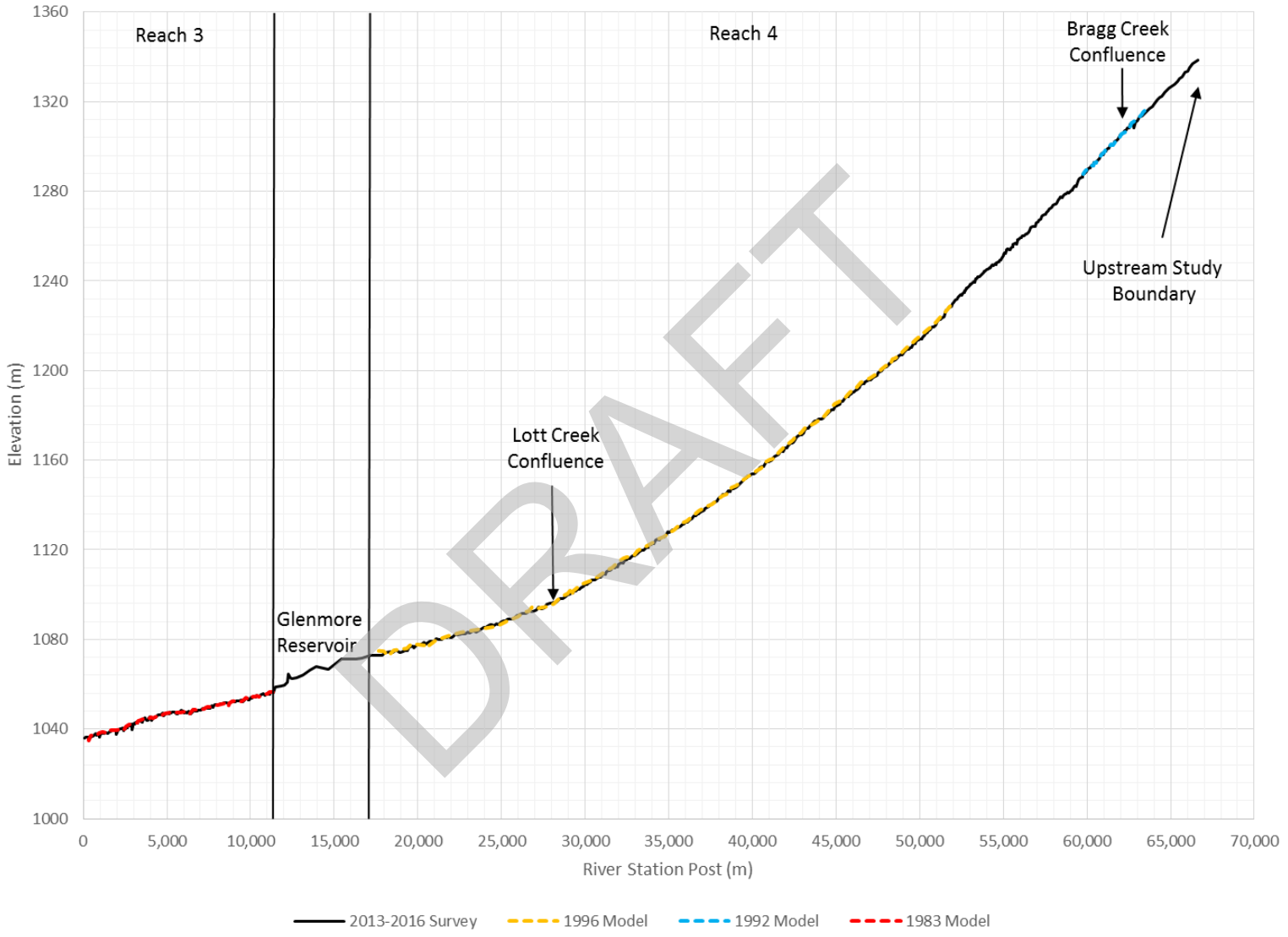

Figure 11: Elbow River Historical Thalweg Comparison

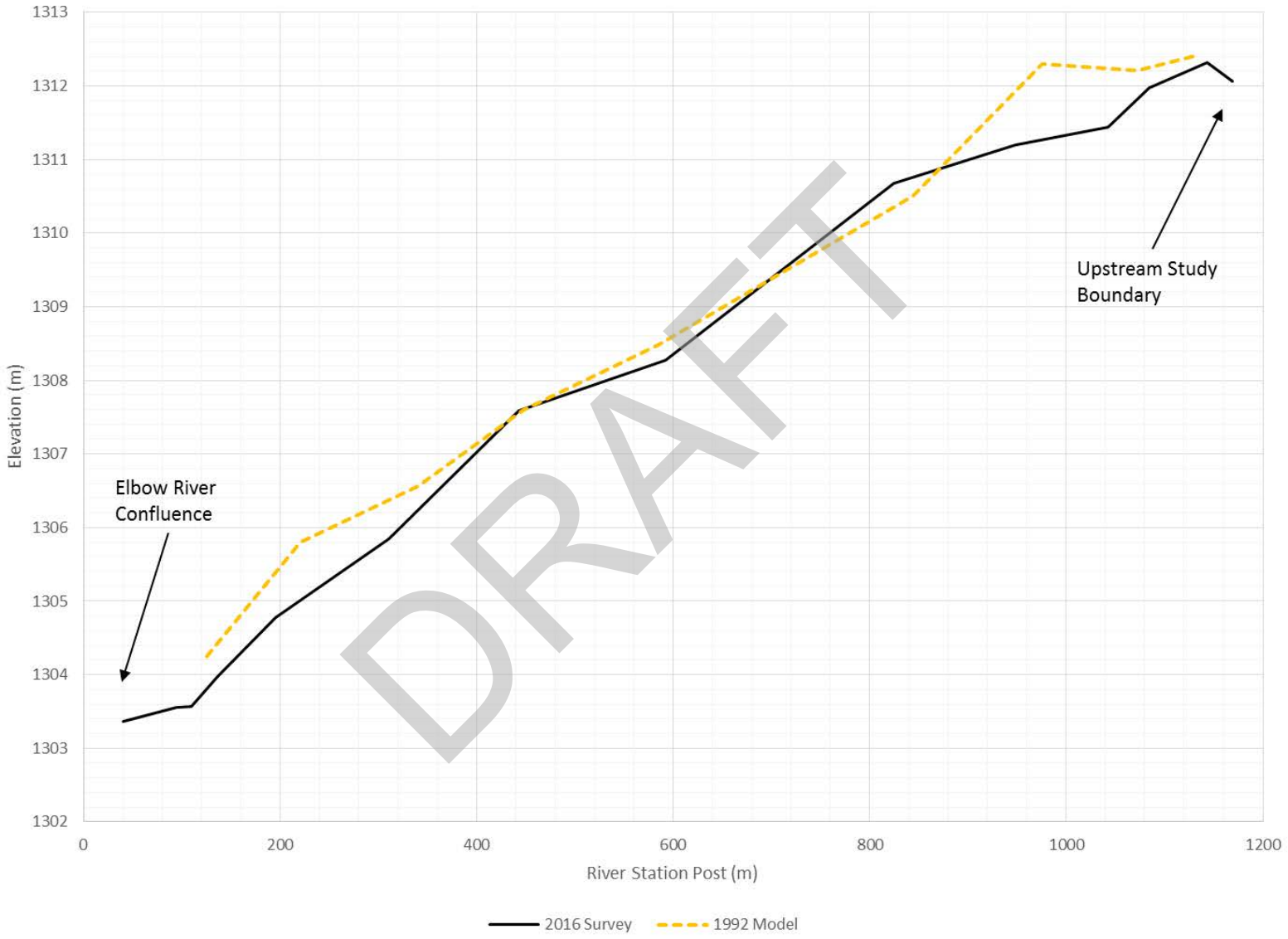

Figure 12: Bragg Creek Thalweg Comparison

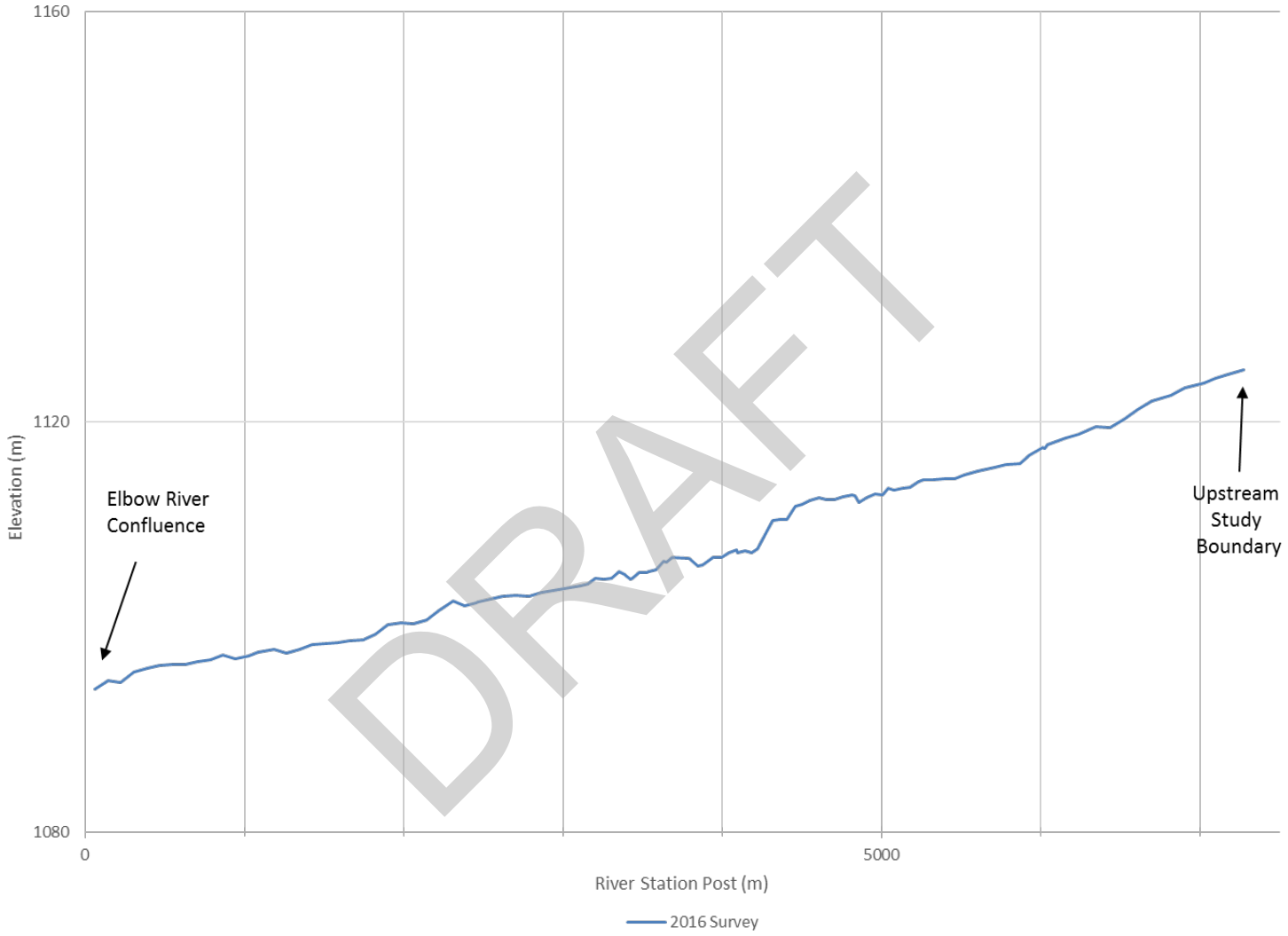

Figure 13: Lott Creek Thalweg

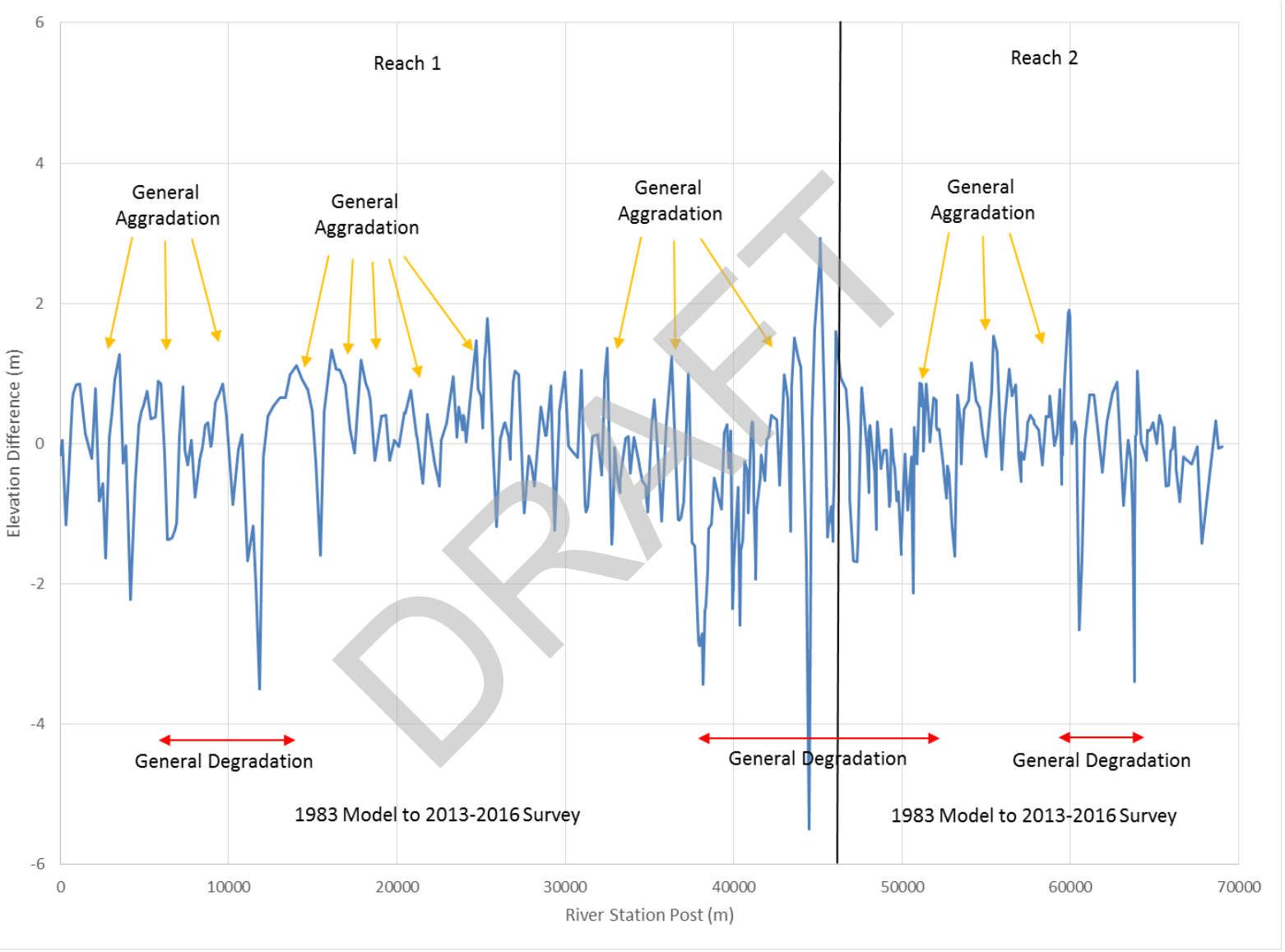

Figure 14: Bow River Thalweg Elevation Difference

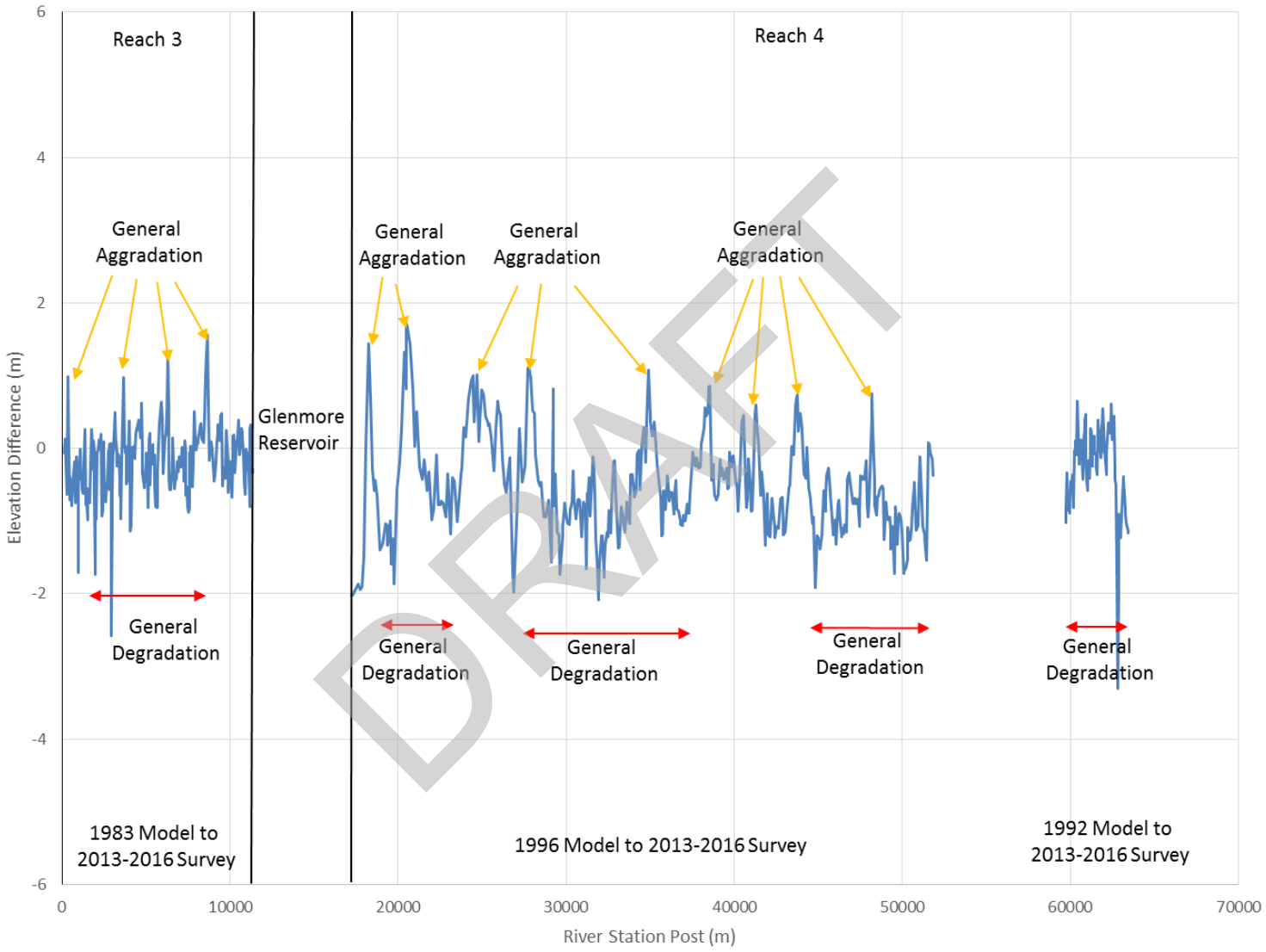

Figure 15: Elbow River Thalweg Elevation Difference

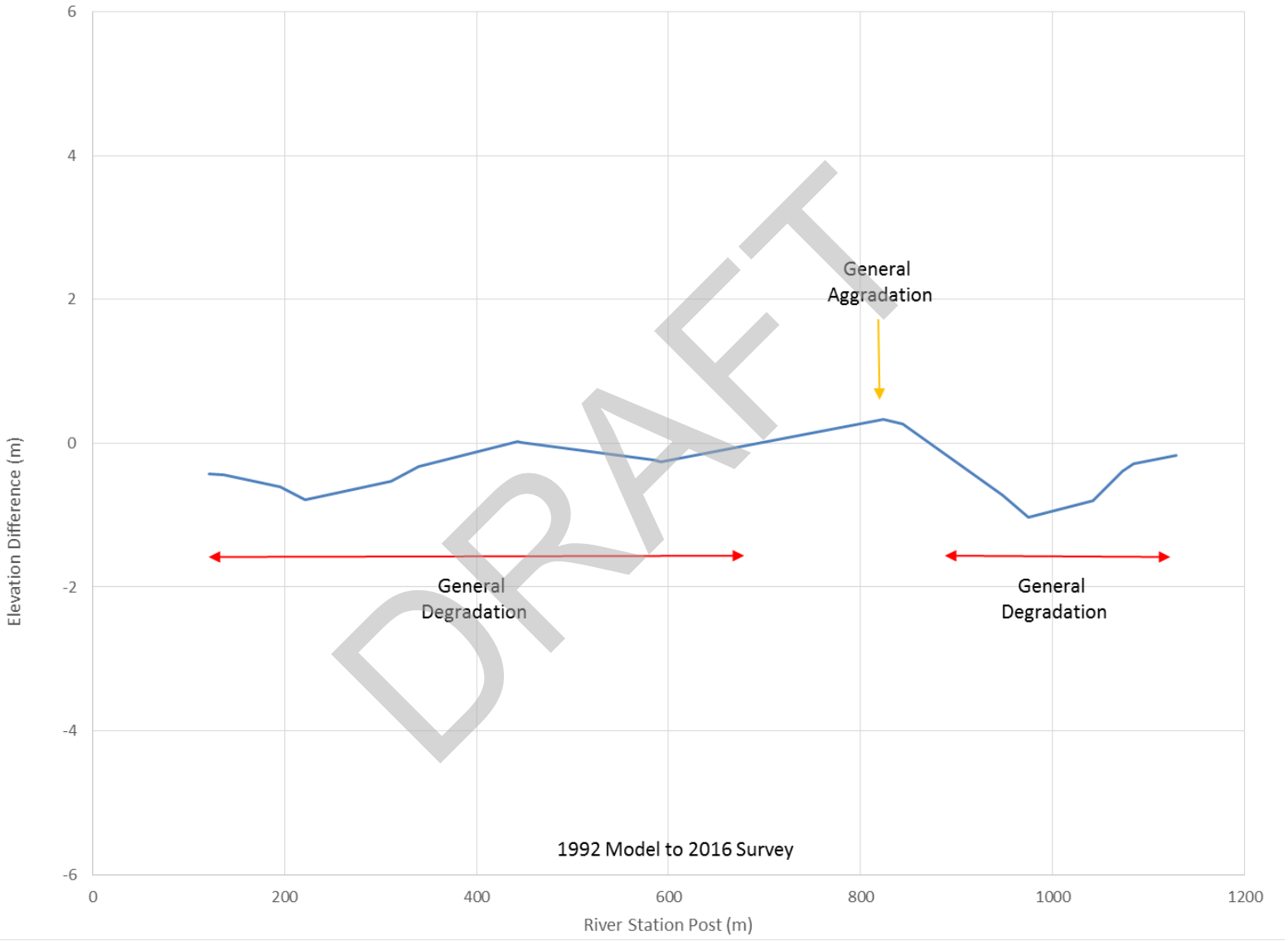

Figure 16: Bragg Creek Thalweg Elevation Difference

4.4 Rating Curve Comparison

The results of the rating curve comparison are shown in Figure 17 through Figure 20.

Bow River

Figure 17 compares select rating curves for the Bow River at Calgary (WSC Station No. 05BH004). This station is located near KM 49 within Reach 2, which extends from Bearspaw Dam to the Elbow River confluence. The observed change suggest a deepening (caused by bed degradation) or widening (caused by bank erosion) of the channel. However, based on the cross section comparison, it appears that a likely physical cause would be bed degradation, as the main channel has not significantly widened over the assessment period. The rating comparison suggests that the river flowing at the same water level would convey more flow in 2016 than in 1950. It is also possible that the newer curve is based on a larger set of measurements and may be more representative of the stage-discharge relationship than the earlier curve. Regardless, lowering of the bed at this site could be a function of head-cutting of a nickpoint, due to loss of bed material as the river tries to recoup its sediment load downstream of Bearspaw Dam, or as a result of the 2013 flood event. It is unlikely to be due to channel excavation due to the presence of the WSC gauge at this location.

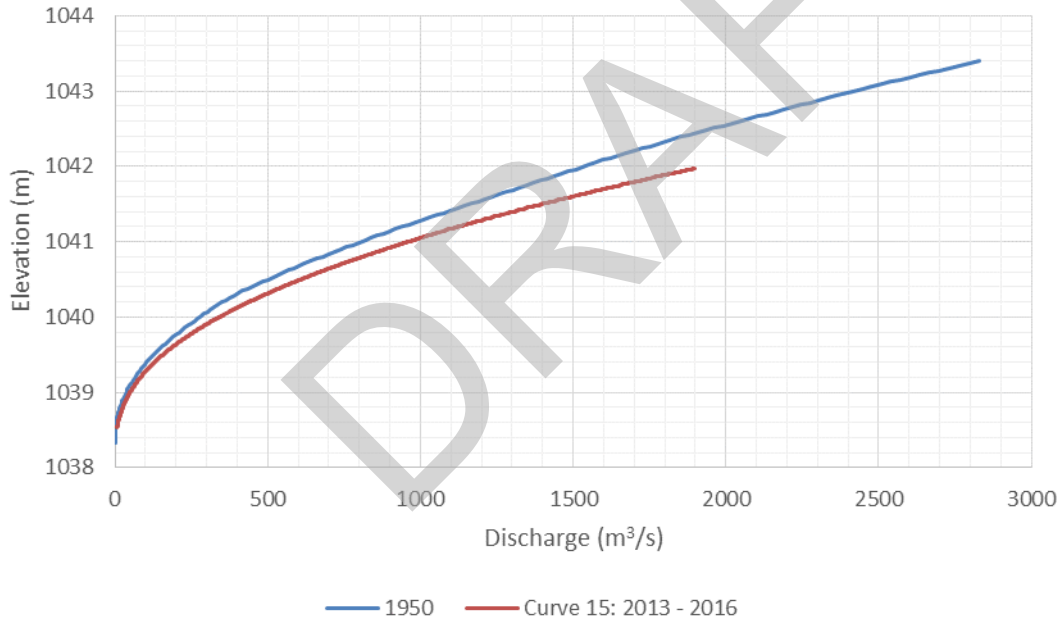

Figure 17: Bow River at Calgary (WSC Station No. 05BH004)

Elbow River

Figure 18 compares select rating curves for the Elbow River below Glenmore Dam (WSC Station No. 05BJ001). This station is located near KM 9 within Reach 3, which extends from Glenmore Dam to the Bow River confluence. Although the rating curve change suggests that a narrowing or shoaling of the channel (accretion) could be a factor, the range of comparable data is too small to be confident. It may also be possible that the newer rating curve is based on a larger set of flow measurements and is simply more representative. Glenmore Dam was completed in 1932 and flow was regulated thereafter, limiting high flow measurements for rating curves; however, this would not affect rating curve measurements at lower flows whereas the increase in density of flow measurements for a given discharge may have resulted in more representative discharges for a given stage.

Since this station is downstream of Glenmore Dam, seasonal peak flows would have been reduced though regulation. The river would be expected to narrow over time, as a geomorphic response to conveying lower peak flows. The cross section comparison at the gauge location did not show a discernible difference between cross section from the 1983 model and the 2013-2016 survey. Although two of the three cross sections located between Glenmore Reservoir and the gauge showed narrowing and shallowing of the channel, interpretation may be limited by not assessing cross section data from other periods.

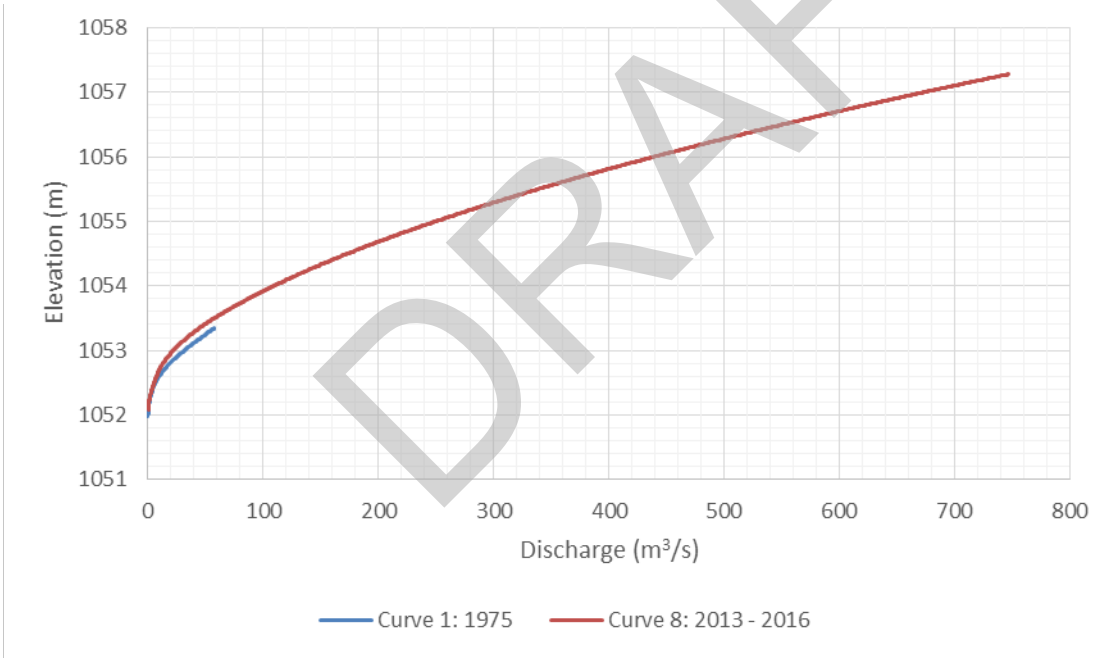

Figure 18: Elbow River below Glenmore Dam (WSC Station No. 05BJ001)

Figure 19 shows the rating curve for Elbow River at Sarcee Bridge (WSC Station No. 05BJ010), located upstream of Glenmore Dam. The change in rating curves between 2006 and 2016 (Figure 19) suggests a widening or deepening of channel (erosion), which was confirmed during the cross section comparison. This suggests that the river flowing at the same water level would convey more flow now than ten years ago, but it may also be possible that the newer rating curve is simply more representative. Regardless, lowering of the bed could be a function of nearby channel engineering or excavation (unlikely to occur at a WSC gauge site).

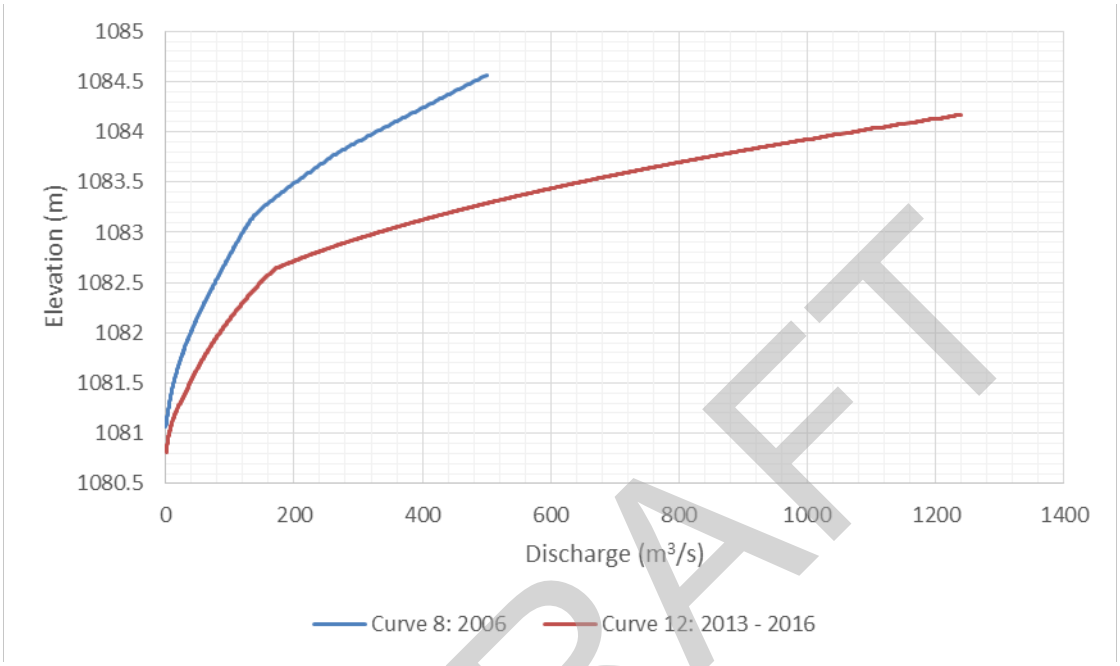

Figure 19: Elbow River at Sarcee Bridge (WSC Station No. 05BJ010)

Figure 20 shows the rating curve for Elbow River at Bragg Creek (WSC Station No. 05BJ004), located slightly downstream of the Bragg Creek confluence. Changes in the rating curve between 2007 and 2016 change suggest that when the river is flowing at the same water level, it conveys less flow now than in the past for lower flows (less than 160 m^3), but the opposite for higher flows. The low flow change suggests narrowing or shoaling of channel (accretion), whereas the higher flow change suggests widening or deepening of the channel.

Because the latter was observed in the cross section comparison, the apparent loss of conveyance for lower flows is likely due to a slight narrowing or shoaling (or accretion) of the low flow channel which could be due to the aggradation caused by sediment inputs from Bragg Creek. This type of channel change was observed: an accreting side bar is present in the recent data in both the channel bank and cross section comparisons. Under higher flow conditions, the channel actually has a larger bankfull cross section area due to a deepening of the channel, which is why the 2007 rating curve crosses the 2016 rating curve at a threshold discharge.

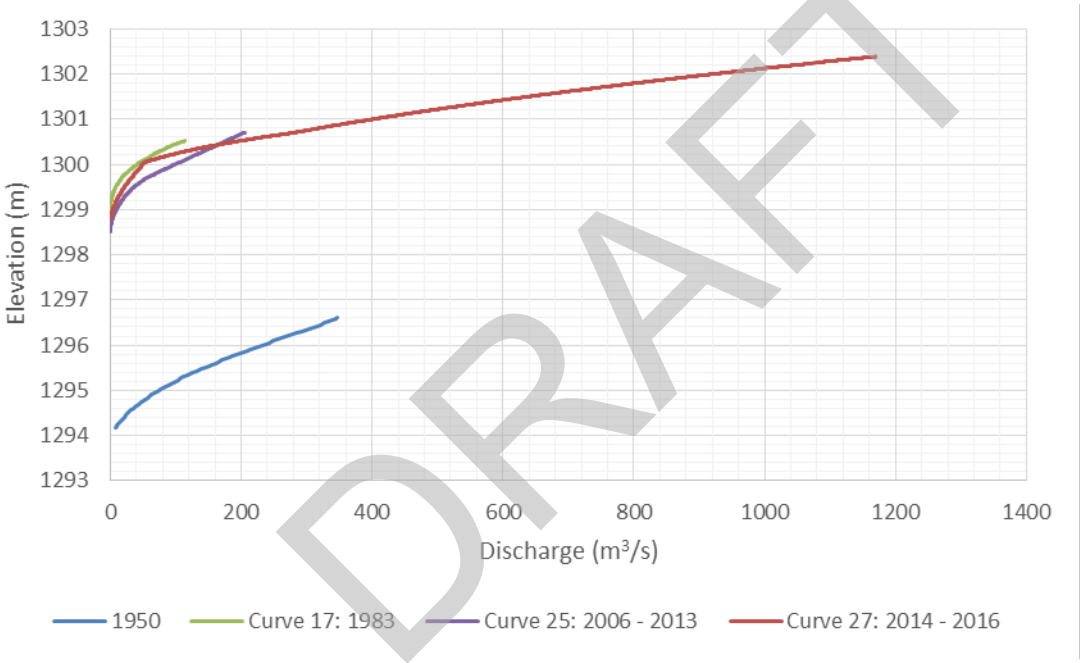

Figure 20: Elbow River at Bragg Creek (Station 05BJ004)

Notes: (1) This gauge was moved in 1981 and 2006, resulting in vertical datum shift between the 1950, 1983, and 2007 rating curves.
(2) Rating curves for 2007 and 2016 are on the same vertical datum.

5.0 CONCLUSIONS

The results from the channel bank, cross section, thalweg profile, and rating curve comparisons are summarized and discussed below for the various study reaches.

- Reach 1 of the Bow River is categorized by a sinuous, single channel confined within a larger incised channel or floodplain (a suspected glacial outwash channel). Encroachment of infrastructure is occurring within the floodplain contributing to the confinement of the channel. Due to the confined nature of the channel within this reach, limited lateral migration is occurring except for at the outer bank of several meander bends as well as the presence of several avulsed channels.

  The presence of several large and stable forested islands suggest stability while the presence of side, point and mid-channel bars indicate that some sediment transport is occurring. While widening of the channel in this reach was observed in the cross section comparison, the change is not statistically significant. A net bed volume gain of about 380 m^3 was calculated based on analysis of available thalweg profile data. The cross section comparison confirmed that shallowing of the channel bed is occurring.

  The river in this reach could be expected to experience more meander migration if the river was less constrained by existing bank erosion protection. It is noted that 2013 flood levels overtopped the channel banks along this reach, which could have contributed to more recent changes.

- Reach 2 of the Bow River is categorized by a single channel with low sinuosity confined within a larger incised channel (a suspected glacial outwash channel). Limited side and point bars were observed suggesting limited sediment transport. Significant channel bank protection was observed for significant lengths of this reach.

  A net bed volume loss of about 490 m^3 was calculated based on analysis of available thalweg profile data. This suggests that a slight deepening or down-cutting of the channel is occurring, which was confirmed in the cross section and rating curve comparisons. This may be the result of the river attempting to adjust the dynamic balance between fluid energy and sediment transport by increasing the volume of sediment it is carrying. The presence of Bearspaw Dam at the upstream boundary of this reach would potentially limit sediment supply from farther upstream, creating a sediment starved environment downstream of the dam. However, the inferred narrowing or down-cutting along Reach 2 are considered to be statistically insignificant.

  Due to the confined nature of the channel and limited lateral migration, this reach is considered to be stable. It is noted that 2013 flood levels overtopped the channel banks along this reach, which could have contributed to more recent changes in overbank topography.

- Reach 3 of the Elbow River is characterized by a sinuous, incised, and single channel. Reach 3 is different from Reaches 1 and 2 in that it is not contained within a larger confined channel and is incising through bedrock deposits (Klohn 2016).

  The net bed volume decrease along this reach is about 1,450 m^3 based on analysis of thalweg profile data over the assessment period. However, only three of the fifteen cross sections along Reach 3 showed a deepening of the thalweg in the cross section comparison, (Cross Sections 7, 17, and 33, Appendix A). Two cross sections showed a shallowing of the bed likely due to bed aggradation and effecting an overall reduction in available cross-section area (Cross Sections 56 and 71, Appendix A). The remaining cross sections had no discernible difference in depth. However, the inferred down-cutting along Reach 3 is considered to be statistically insignificant.

Due to the incised nature of the channel and limited lateral migration, this reach is considered to be stable. It is noted that 2013 flood levels overtopped the channel banks along this reach, which could have contributed to more recent changes in overbank topography

- Reach 4 of Elbow River is characterized by a sinuous, tortuous, sometimes single channel and sometimes multi-thread channel, in a confined floodplain with actively migrating side, point, and mid-channel bars. As such, it may be considered an anastomosing reach due to its forested islands, multi-channeled sections, and historical indications of avulsion.

  Relict oxbow channels can be seen in aerial imagery, suggesting a historically mobile channel. The reach is relatively close to the Elbow River headwaters and has a slope of 0.0057 m/m (Figure 10), which is more steeply sloped than Reach 3 farther downstream. This reach has an estimated net bed volume loss of about 18,240 m^3 was calculated based on analysis of available thalweg profile data. Thalweg profiles suggest that the Elbow River in Reach 4 is an alluvial channel in equilibrium.

  As a highly mobile, braided, and anastomosed channel with active bars experiencing a high rate of net bed volume loss, Reach 4 is considered to be unstable. Changes to channel depth and cross-sectional area are considered to be statistically significant, and have increased conveyance capacity of through Reach 4.

- Reach 5 of Bragg Creek is characterized by a meandering, single channel partially confined upstream of the larger Elbow River floodplain. Reach 5 has a relative steep slope of 0.0081 m/m, (Figure 12). This reach has a net bed volume loss of about 280 m^3 based on analysis of available thalweg profile data. No statistically significant changes to channel geometry were observed. Lateral channel migration was limited to a 200 m section of the reach, in the form of a side channel which was diverted around a forested island. It is believed this was caused by a log jam farther downstream based on observations of a log jam feature in aerial imagery.

  As a generally non-mobile channel with limited presence of bars, Reach 5 is considered to be stable. It is noted that 2013 flood levels overtopped the channel banks along this reach.

- Reach 6 of Lott Creek is characterized by a sinuous, single channel that has been highly modified. Reach 6 is confined upstream of KM 5. Downstream of KM 5, the creek has significant river training and diking along some of its length, and several retention ponds are present.

  The natural channel does not appear to have undergone any lateral migration over the study period. Some mid-channel, point, and side bars are present but do not appear to be active in terms of downstream migration. Many historical side and point bars have stabilized into channel banks. The general shape of the thalweg profile for this reach tends to suggest that it is an alluvial channel in equilibrium.

  Based on the thalweg profile, limited sediment transport, and limited lateral migration, Lott Creek is considered to be stable. It is noted that 2013 flood level did not overtop the channel banks along this reach.

Channel stability investigation reach characteristics are summarized in Table 8 and an overview of channel stability is provided in Figure 9.

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 – Bow River from Elbow River confluence to Highwood River confluence	54	0.0018	1.4	■ Confined floodplain ■ Predominantly single channel ■ Sinuous/meandering ■ Partially controlled flow ■ Limited lateral migration except at meander bends ■ Presence of side, point, mid-channel and forested bars ■ Increase in channel bank protection upstream ■ Widening of channel ■ Thalweg shape suggests previous outwash channel or limited sediment supply ■ Net bed volume change = +380 m^3
2 – Bow River from Bearspaw Dam to Elbow River confluence	27	0.0019	1.1	■ Confined ■ Single channel ■ Low sinuosity ■ Partially controlled flow ■ Limited presence of side, point and mid-channel bars ■ Significant channel bank protection ■ Human development within floodplain ■ Limited observed migration of the channel ■ Thalweg shape suggests previous outwash channel or limited sediment supply ■ Net bed volume change = -490 m^3
3 – Elbow River from Glenmore Dam to Bow River confluence	13	0.0018	1.7	■ Single channel ■ Sinuous with irregular meandering ■ Incised ■ Controlled flow ■ Limited presence of mid-channel and side bars ■ Some channel bank protection present ■ Limited observed migration of the channel ■ Thalweg shape suggests an alluvial channel in equilibrium ■ Net bed volume change = -1,450 m^3

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
4 – Elbow River from upstream of Bragg Creek to Glenmore Reservoir	45	0.0057	1.4	■ Confined floodplain ■ Single and multi-thread channel ■ Tortuous, braided, and sometimes anastomosed ■ Uncontrolled flow ■ Large forested islands ■ Numerous side, point, and mid-channel bars ■ Avulsion scars ■ Significant lateral migration ■ Relict oxbows ■ Increase in cross-sectional area ■ Deepening of channel ■ Widening of channel ■ Thalweg shape suggests an alluvial channel in equilibrium ■ Net bed volume change = -18,240 m^3
5 – Bragg Creek from upstream of Centre Avenue in Bragg Creek to Elbow River confluence	10	0.0081	1.6	■ Partially confined upstream, unconfined downstream of KM 0.9 ■ Predominantly single channel ■ Sinuous/meandering ■ Uncontrolled flow ■ Limited presence of mid-channel and side bars ■ Development of side channel around forested island ■ Limited observed migration of the channel ■ Net bed volume change = -280 m^3
6 – Lott Creek from upstream of Elbow Valley Residence Club to Elbow River confluence	29	0.0042	1.5	■ Confined upstream of KM 5 ■ Natural single channel, multichannel with retention ponds due to development ■ Sinuous/meandering ■ Partially controlled flow ■ Channelized/diked/diverted ■ Limited presence of mid-channel and side bars ■ Limited lateral migration ■ No bars ■ Widening of channel ■ Thalweg shape suggests an alluvial channel in equilibrium

6.0 CLOSURE

This report is prepared and reviewed by the undersigned.

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MT/RA/GT/DL/ak/crm/al

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APPENDIX A

Cross Section Comparison

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
1 – Bow River: Bow River from Elbow River Confluence to Highwood River Confluence	11		300	360	120	120	3.0	4.0	2.5	2.5	- left-handedness - skewed to left - single channel - deepening of channel by approx. 1.0 m in depth
	18		520	390	130	130	4.5	3.5	4	3.0	- righthandedness - not skewed - single channel - shallowing of channel by approx. 1.0 m in depth
	26		160	420	80	210	2.5	2.5	2	2	- righthandedness - skewed to right - changes from single channel to 2 channel - secondary channel developed with forested island in centre of channel
	39		560	595	160	170	4	4	3.5	3.5	- left-handedness - skewed to left - single channel - lateral migration of right bank 10 m to right - widening of channel
	47		600	800	120	200	7	7	5	4	- righthandedness - skewed to right - single channel with mid-channel bar development - lateral migration of left bank 80 m to right - widening of channel
	59		560	640	160	160	4	5.2	3.5	4	- left-handedness - skewed to left - single channel - deepening of channel by approx. 1.2 m in depth

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
1 – Bow River: Bow River from Elbow River Confluence to Highwood River Confluence (con't)	77		800	720	160	180	6	5	5	4	- changes from righthandedness to left-handedness - skewed to left - approx. 20 m lateral migration of right bank to the right - shallowing of the channel by approx.1.0 m
	83		640	500	200	200	4.2	3	3.2	2.5	- left-handedness - skewed to left - single channel - shallowing of channel by approx. 1.2 m in depth
	89		1000	1000	200	200	6	6	5	5	- central thalweg - left-handedness - two channels divided by forested island. - 1983 elevation for historical island is not correct. May be an over exaggeration in topography required by the HEC-2 model at the time. - no lateral migration
2 – Bow River: Bow River from Bearspaw Dam to Elbow River Confluence	98	48.4	450	550	100	100	6	7	4.5	5.5	- left-handedness - skewed to left - single channel - located at a bridge - left bank increased (or modified) 1.0 m in height - deepening of channel by approx. 1.0 m in depth

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
2 – Bow River: Bow River from Bearspaw Dam to Elbow River Confluence (con't)	100 (Station 05BH004)	48.5	250	300	100	100	3.6	5.0	2.5	3.0	- left-handedness - skewed to left - single channel - located at a gauging station and between bridges - channel bed for 2015 suspected to be water surface so 2013 cross-section used - deepening of channel by approx. 1.4 m in depth
	109		720	800	160	160	5.5	5.5	4.5	5.0	- right-handedness - skewed to left - two channels divided by forested island. - deepening of channel right channel by approx. 1.0 m in depth
	126		675	675	150	150	5	5	4.5	4.5	- central thalweg - skewed to right - single channel - no lateral migration
	140		750	1050	150	150	7	7	5	7	- left-handedness - skewed to right - single channel - channel bed accreted approximately 2.0 m, channel banks also accreted almost 2 m
	154		495	440	110	110	5.2	4.6	4.5	4	- right-handedness - skewed to right - two channels divided by forested island. - shallowing of right and left channels by approx. 0.8 m in depth

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
2 – Bow River: Bow River from Bearspaw Dam to Elbow River Confluence (con't)	162		390	520	130	130	4	5.5	3.0	4.0	- left-handedness - skewed to left - main channel and small secondary channel divided by forested island. - deepening of main channel by 1.5 m - no lateral migration
3 – Lower Elbow: Elbow River from Glenmore Dam to Bow River Confluence	7		200	225	50	50	4.5	5	4	4.5	- centered thalweg - skewed to right - single channel - no lateral migration - deepening of channel by approx. 0.5 m in depth
	12		135	120	45	40	3.6	3.6	3	3	- centred thalweg - skewed to right - single channel - no lateral migration
	17		200	225	50	50	4.6	5.8	4	4.5	- centered thalweg - skewed to right - single channel - no lateral migration - deepening of channel by approx. 0.8 m in depth
	23		300	350	60	50	5.4	6.0	5	5.5	- centered thalweg - skewed to left - single channel - approx. 10 m lateral migration of right bank to left - accretion of channel banks by approx. 0.6 m in height - narrowing of the channel top width by approx. 10 m
	28		440	440	80	80	7	7	5.5	5.5	- lefthandedness - skewed to left - single channel - no lateral migration

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
3 – Lower Elbow: Elbow River from Glenmore Dam to Bow River Confluence (con't)	33		210	210	60	60	4	4.5	3.5	3.5	- righthandedness - skewed to right - single channel - no lateral migration - deepening of the channel by 0.5 m
	38		140	140	40	40	4	4	3.5	3.5	- centered thalweg - skewed to left - single channel - no lateral migration
	43		195	195	65	65	3.8	3.8	3	3	- lefthandedness - skewed to left - single channel - no lateral migration
	48		80	80	20	20	6.0	6.0	4	4	- righthandedness - skewed to right - single channel - no lateral migration
	51		240	240	80	80	3.8	3.8	3	3	- righthandedness - skewed to right - single channel - no lateral migration
	56	7.8	280	240	80	80	4	4	3.5	3	- righthandedness - skewed to left - single channel - no lateral migration - approx. accretion of 1.0 m in centre of channel
	61 (Station 05BJ001)	8.7	240	240	60	60	4.5	4.5	4	4	- lefthandedness - skewed to left - single channel - no lateral migration
	64	9.4	180	180	45	45	4.5	4.5	4	4	- righthandedness - skewed to left - single channel - no lateral migration

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
3 – Lower Elbow: Elbow River from Glenmore Dam to Bow River Confluence (con't)	71	10.5	200	160	50	40	5	4.5	4	4	- lefthandedness - skewed to left - single channel - shallowing of channel by 0.5 m - approx. 10 m lateral migration of right bank to right
	75	11.1	280	160	70	40	5	5	4	4	- righthandedness - skewed to left - single channel - approx. 20 m and 10 m narrowing of left and right bank
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir	Elbow at Rockyview 7		288	640	160	320	2.5	3.0	1.8	2.0	- left-handedness - skewed to left - multi-channel - historic channels still present with an additional larger channel near the left bank - deepening of one of the historic channels by approx. 1.0 m
	Elbow at Rockyview 8 (Station 05BJ010)	20.5	135	153	45	45	5.0	4.0	3.0	3.4	- right-handedness - skewed to left - single channel - located at bridge and gauge station which may account for the high structures within the river channel - widening of the channel near the bed creating a larger average depth and larger cross-sectional area.

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir (con't)	Elbow at Rockyview 12		60	160	40	80	2.5	2.5	1.5	2	- left-handedness - skewed to left - multi-channel - approx. 40 m lateral migration of right bank to the right - widening of channel
	Elbow at Rockyview 17		80	135	40	90	3.0	2.5	2	1.5	- skewed to left - multi-channel - main channel now 200 m to the right of historic main channel caused by deepening and widening of side channel
	Elbow at Rockyview 22		180	140	120	140	3.5	2.0	1.5	1.0	- central thalweg - multi-channel - shallowing of main channel by approximately 1.5 m - widening of the main channel by approx. 20 m to left
	Elbow at Rockyview 26		40	140	40	70	2.0	3.0	1.0	2.0	- lefthandedness - skewed to left - multi-channel - deepening of main channel by approximately 1.0 m - widening of the main channel by approx. 30 m to left
	Elbow at Rockyview 39		70	90	70	60	1.0	2.0	1.0	1.5	- righthandedness - skewed to right - multi-channel - deepening of main channel by approximately 1.0 m - narrowing of the main channel by approx. 10 m to left

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir (con't)	Elbow at Rockyview 45		40	60	40	40	1.5	2.5	1.0	1.5	- lefthandedness - skewed to left - multi-channel - deepening of main channel by approximately 1.0 m - no lateral migration
	Elbow at Rockyview 49		60	160	60	80	1.2	3.0	1.0	2.0	- lefthandedness - skewed to left - multi-channel - deepening of main channel by approximately 1.8 m - widening of the main channel by approx. 20 m to left - lateral migration of the left bank 40 m to the right and of the right bank 20 m to the right
	Elbow at Rockyview 55		60	20	40	20	2.0	1.5	1.5	1.0	- lefthandedness - skewed to left - multi-channel - shallowing of main channel by approximately 0.5 m - narrowing of the main channel by approx. 20 m to right

Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir (con't)	Elbow at Rockyview 60		48	144	60	80	1.0	2.4	0.8	1.8	- righthandedness - skewed to right - multi-channel - deepening of main channel by approximately 1.4 m - widening of the main channel by approx. 20 m to left - lateral migration of the left bank 80 m to the left and of the right bank 60 m to the left
	Elbow at Rockyview 64		20	40	20	40	1.5	1.8	1.0	1.0	- righthandedness - skewed to right - multi-channel - deepening of main channel by approximately 0.3 m - widening of the main channel by approx. 20 m to left
	Elbow at Rockyview 72		100	120	100	100	1.8	3.0	1.0	1.2	- thalweg migrated from righthandedness to lefthandedness - skewed to left - multi-channel - deepening of main channel by approximately 1.2 m
	Elbow at Rockyview 75		60	52	40	40	2.0	2.0	1.5	1.3	- lefthandedness - skewed to left - multi-channel - river bed and right bank accreted 0.4 m - no lateral migration

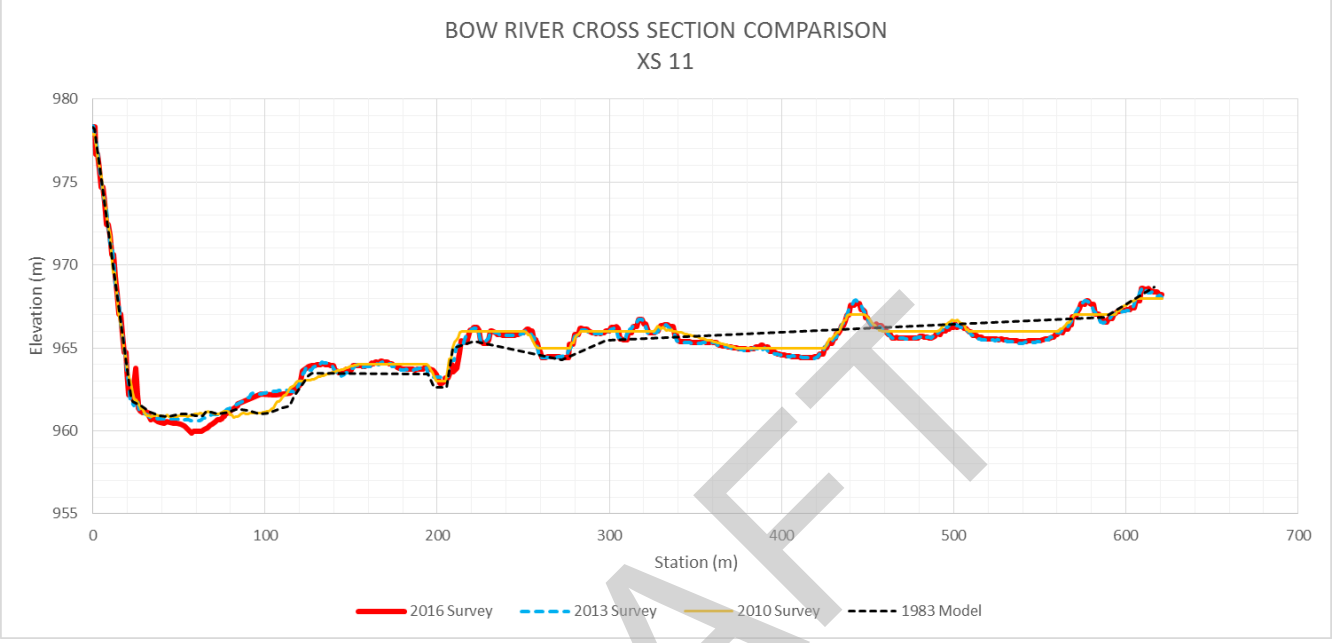
Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir (con't)	Elbow at Rockyview 81		32	40	40	40	1.8	2.2	0.8	1.0	- lefthandedness - skewed to left - multi-channel - deepening of main channel by approximately 0.4 m - lateral migration of the channel 20 m to the left
	Elbow at Rockyview 88		36	84	45	70	0.9	2.0	0.8	1.2	- central thalweg to righthandedness - skewed to left - single channel - deepening of main channel by approximately 1.1 m - widening of the channel by 25 m to the right - lateral migration of the channel 30 m to the right
	Elbow at Rockyview 93		140	100	70	50	2.4	3.0	2.0	2.0	- lefthandedness to righthandedness - skewed to left - single channel - deepening of main channel by approximately 0.6 m - narrowing of the channel by 20 m to the left
	Elbow at Rockyview 100		78	108	130	90	1.2	2.0	0.6	1.2	- lefthandedness to righthandedness - skewed to right - single channel - deepening of main channel by approximately 0.8 m - narrowing of the channel by 40 m to the left - lateral migration of the channel 40 m to right

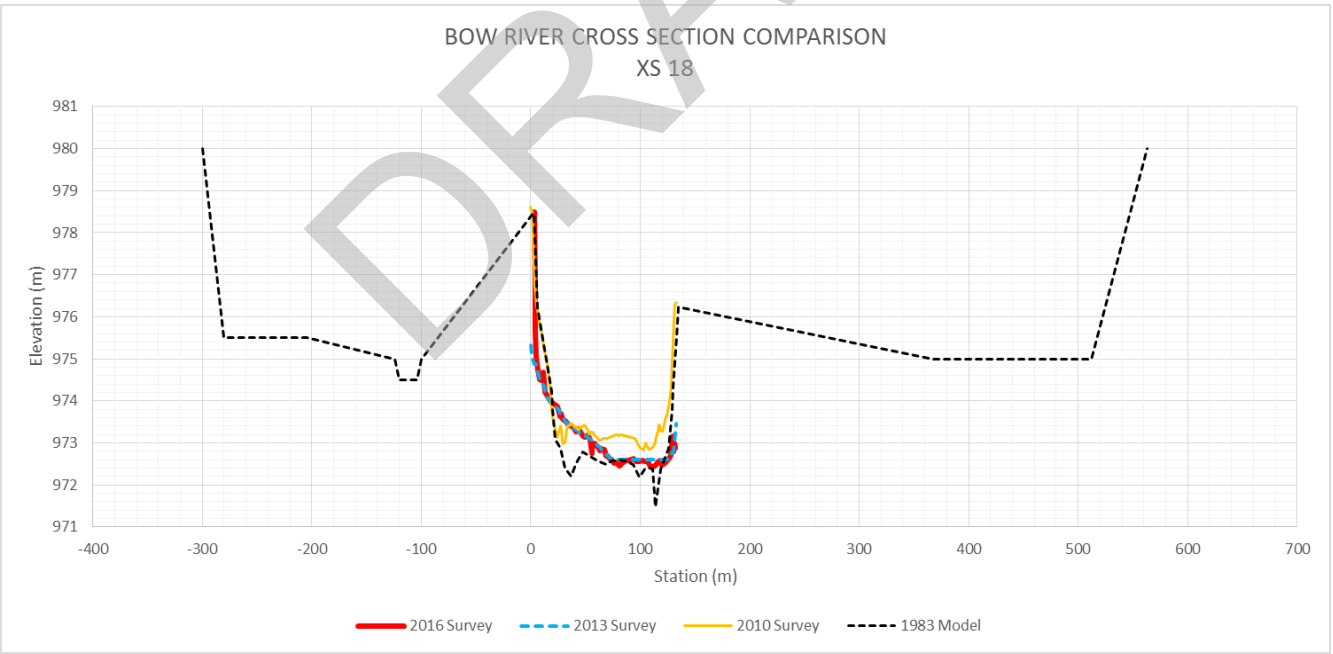
Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir (con't)	Elbow at Rockyview 105		120	70	120	100	2.5	2.2	1.0	0.7	- righthandedness to lefthandedness - multi-channel - formation of bar in former main channel - shallowing of main channel by approx. 0.3 m - narrowing of total channel width by approx. 20 m
	Elbow at Bragg 1		60	120	60	60	1.6	2.8	1.0	2.0	- central thalweg - uniform geometry to skewed to left - multi-channel - formation of bar in former main channel - deepening of main channel by approx. 1.2 m - no lateral migration
	Elbow at Bragg 13		140	150	70	60	3.6	3.8	2.0	2.5	- righthandedness to central thalweg - skewed to right - single channel - accretion of right bank by 0.4 m - slight shallowing of channel by approx. 0.2 m - narrowing of channel by approx. 10 m

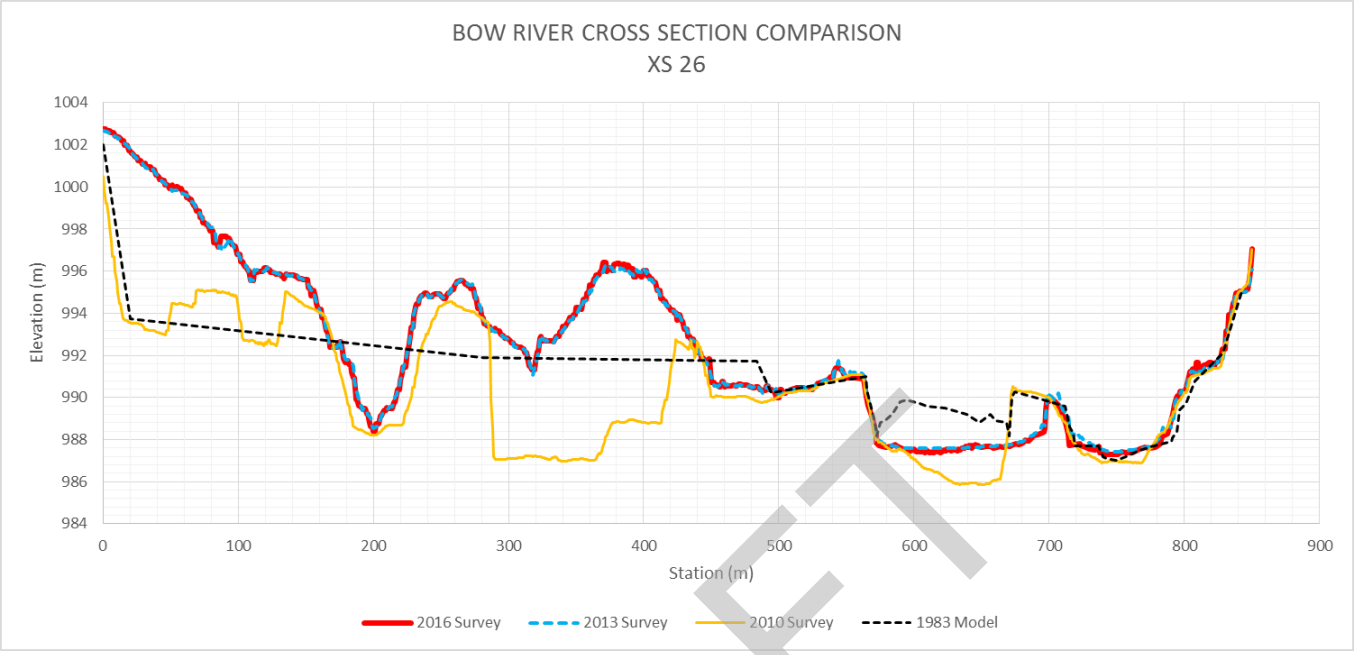
Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir (con't)	Elbow at Bragg 16 (Station 05BJ004)		50	67.5	50	45	2.4	3.2	1.0	1.5	- lefthandedness to righthandedness - skewed to left - single channel - deepening of channel by approx. 0.8 m - narrowing of channel by approx. 5 m from the right bank - a side bar is appears to be accreting, decreasing the overall cross-sectional area under low flow conditions
	Elbow at Bragg 23		28	80	35	40	1.2	2.4	0.8	2.0	- righthandedness - skewed to right - single channel - deepening of channel by approx. 0.8 m due to slight erosion of the bed and accretion of the left bank - widening of channel by approx. 5 m from the left bank
	Elbow at Bragg 28		60	40	50	50	3.4	1.0	1.2	0.8	- righthandedness - skewed to right - single channel to multi-channel - shallowing of channel by approx. 2.4 m due to erosion of the left bank - lateral migration of the channel 50 m to left
	Elbow at Bragg 33		60	100	60	50	1.5	3.0	1.0	2.0	- lefthandedness - skewed to left - single channel - deepening of channel by approx. 1.5 m - narrowing of channel by approx. 10 m from the right bank

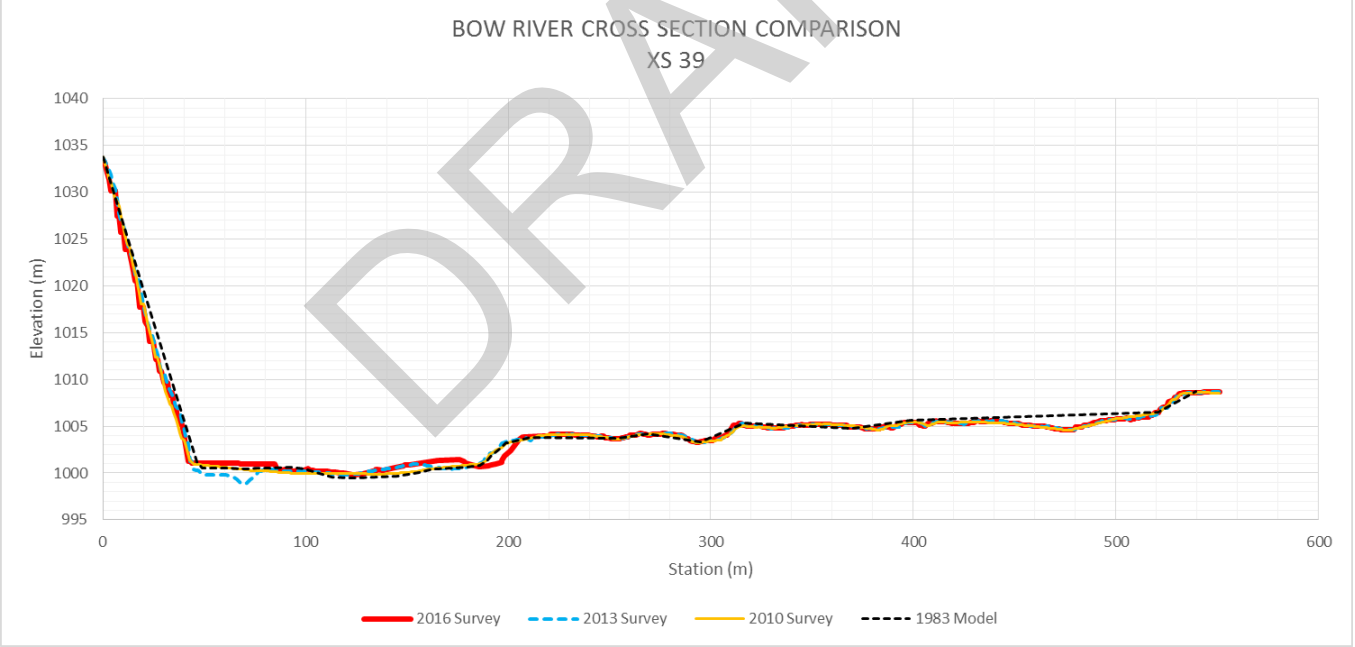
Reach	Cross Section ID	Km	Cross Sectional Area (m^2)		Bankfull Width		Maximum Bankfull Depth		Average Bankfull Depth		Description
			Historical	2015	Historical	2015	Historical	2015	Historical	2015	
4 – Upper Elbow: Elbow River from Upstream of Bragg Creek to Glenmore Reservoir (con't)	Elbow at Bragg 38		24	65	30	65	1.0	2.6	0.8	1.0	- righthandedness - skewed to right - deepening of channel by approx. 1.6 m - widening of channel by approx. 25 m from the left bank and 10 from right bank
5 – Bragg Creek	4		10	23.4	20	13	1.5	2.2	0.5	1.8	- right-handedness - skewed to right - single channel - approx. 16 m lateral migration of channel to the right - slight narrowing of the channel - deepening of channel by 0.6 m
	6		9.6	19.2	8	16	1.8	1.8	1.2	1.2	- central thalweg to right-handedness - skewed to right - single channel - approx. 40 m migration to the left - widening of the channel

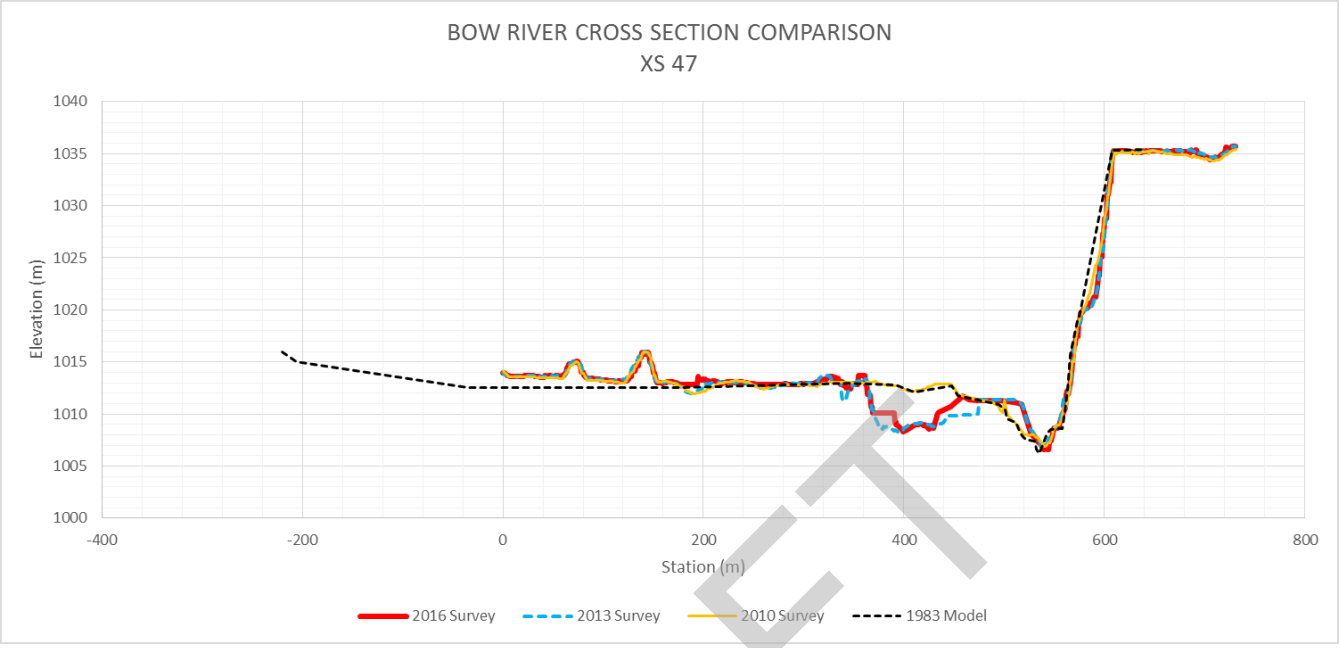
1.0 REACH 1: BOW RIVER FROM ELBOW RIVER CONFLUENCE TO HIGHWOOD RIVER CONFLUENCE

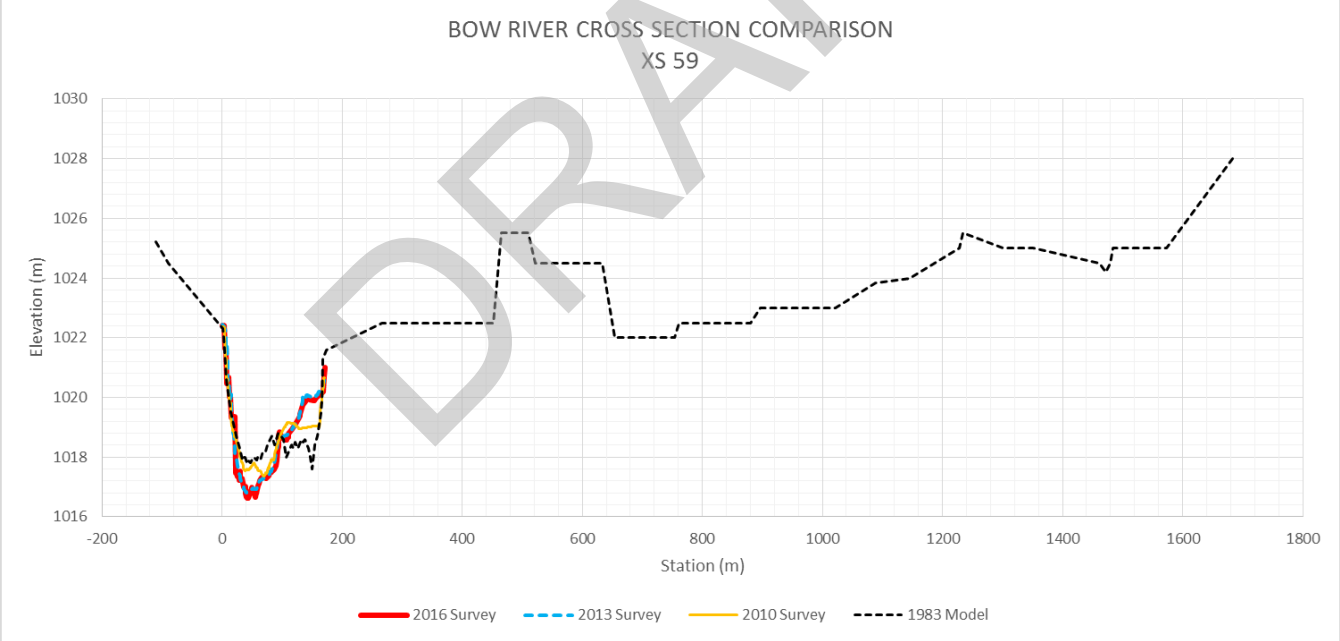


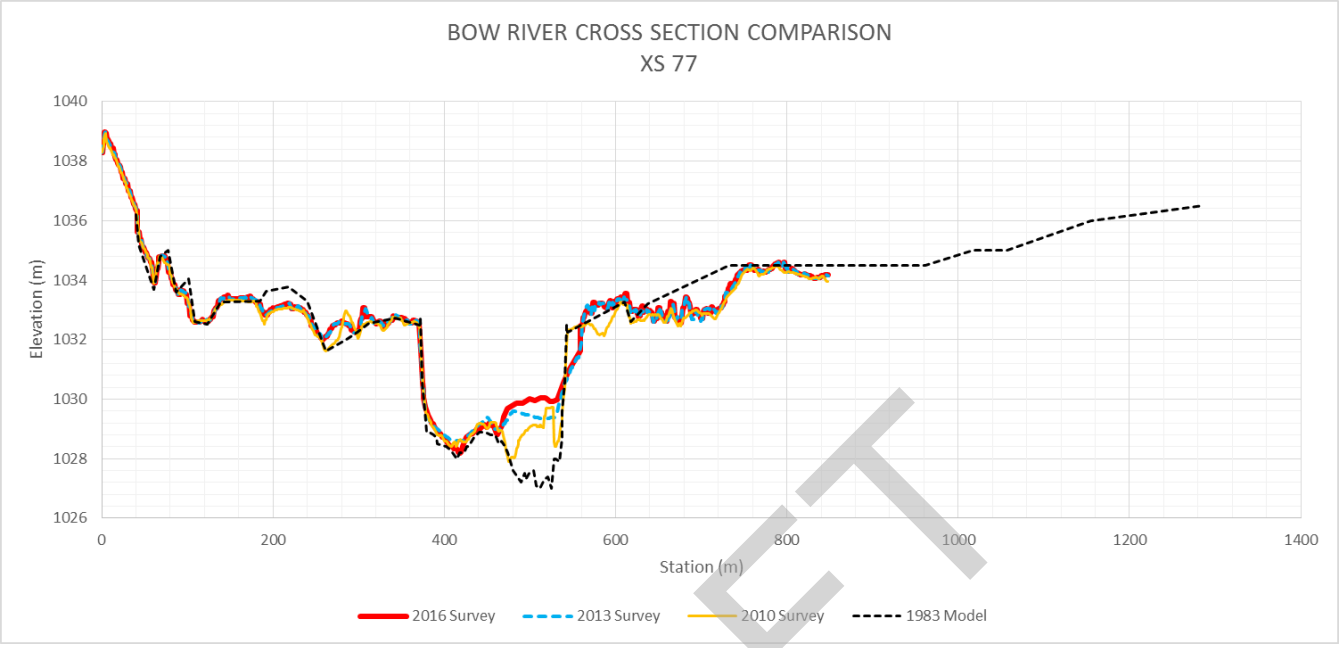


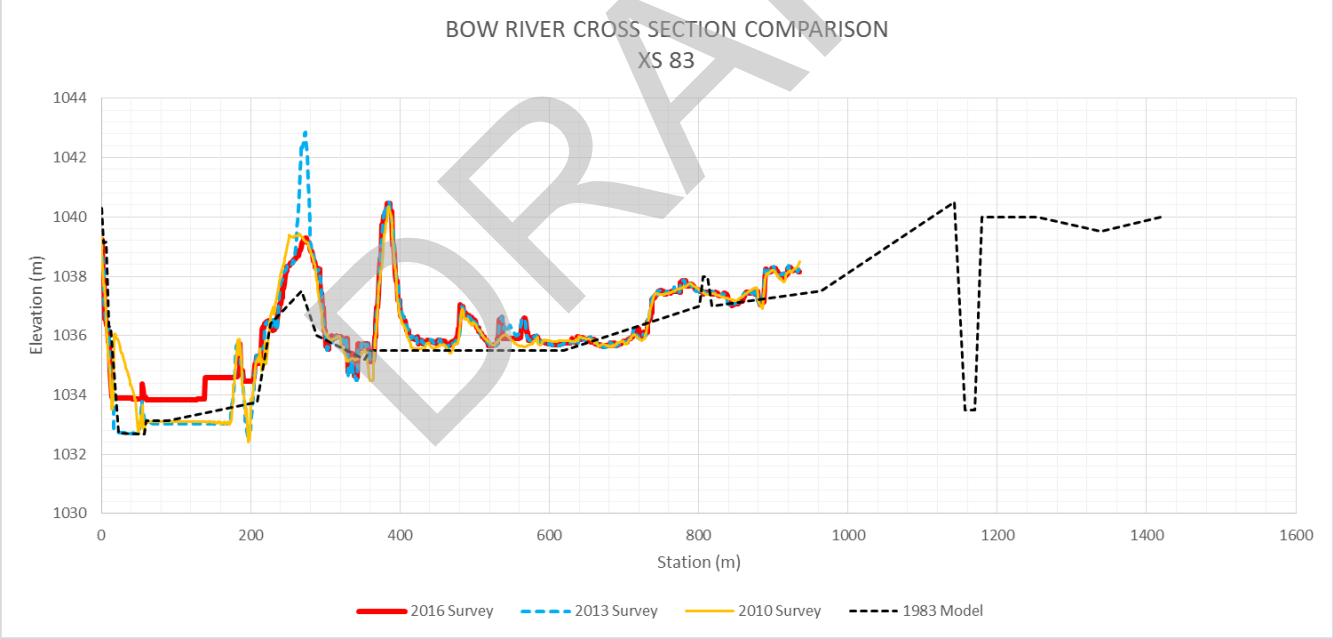


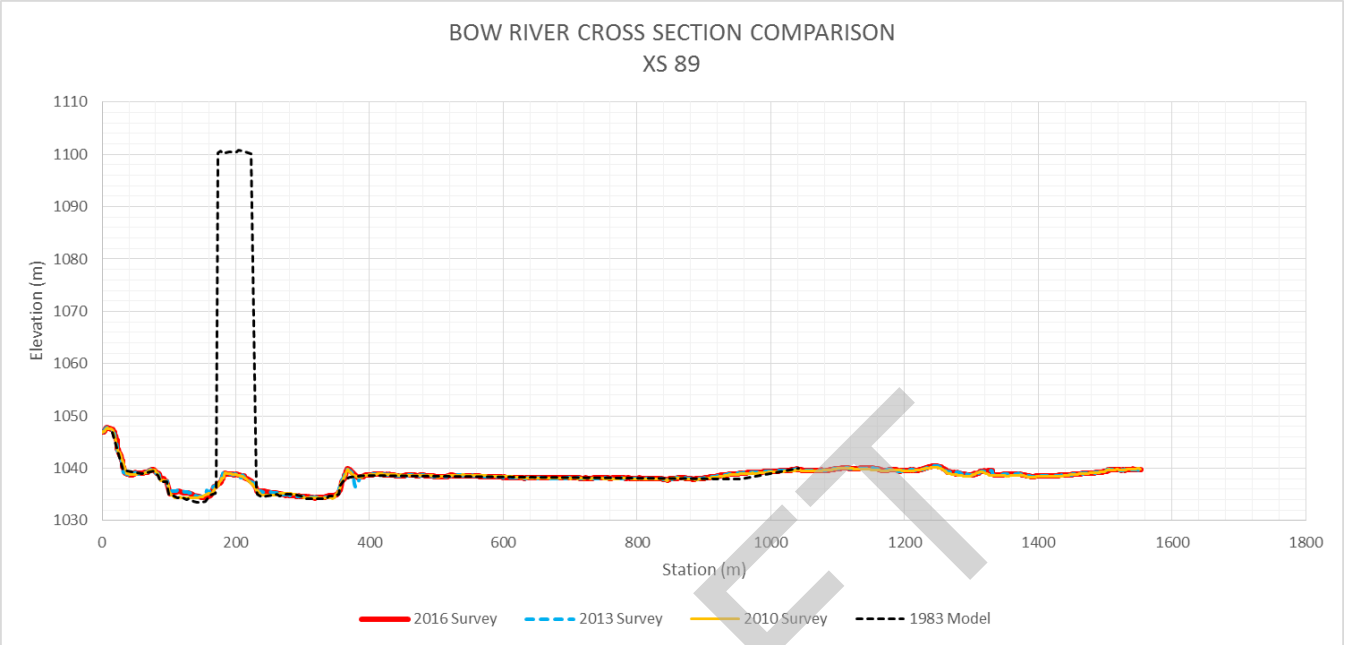




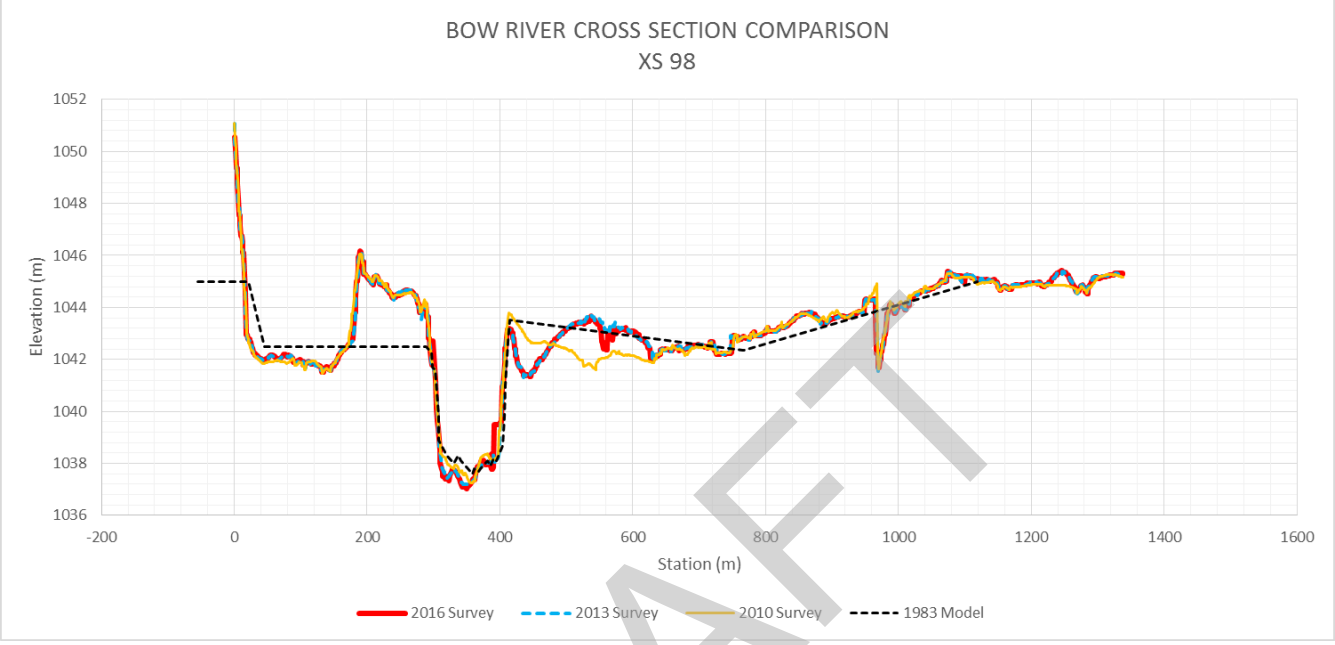


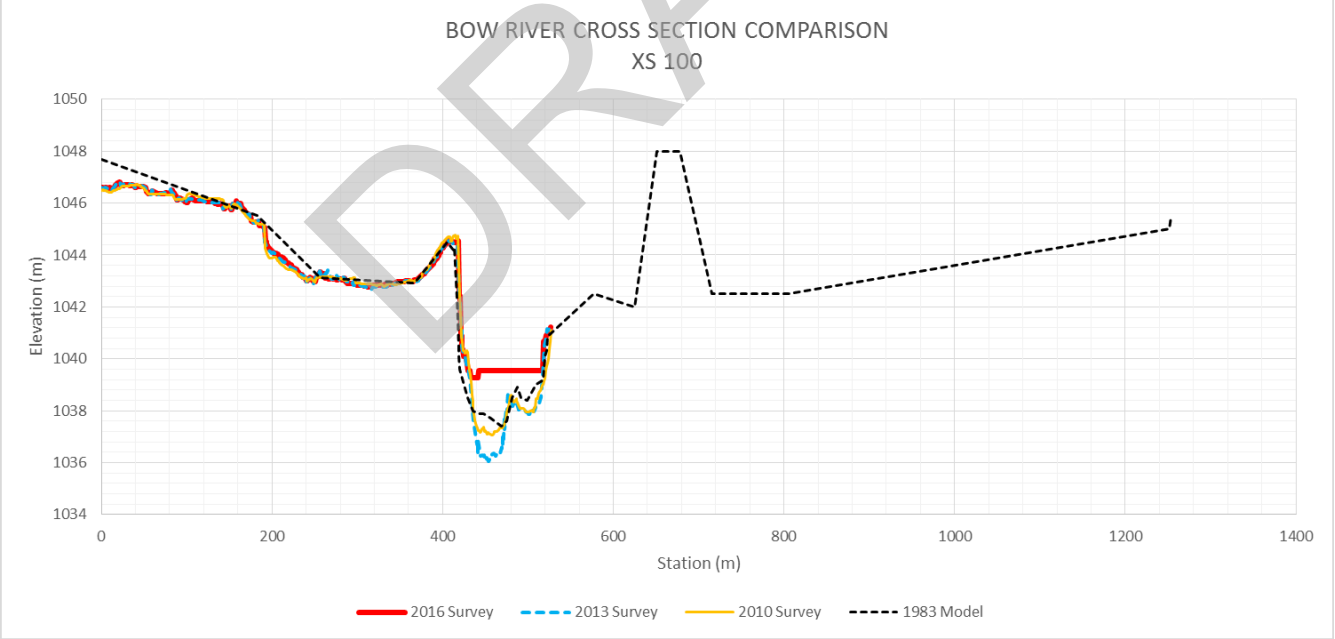


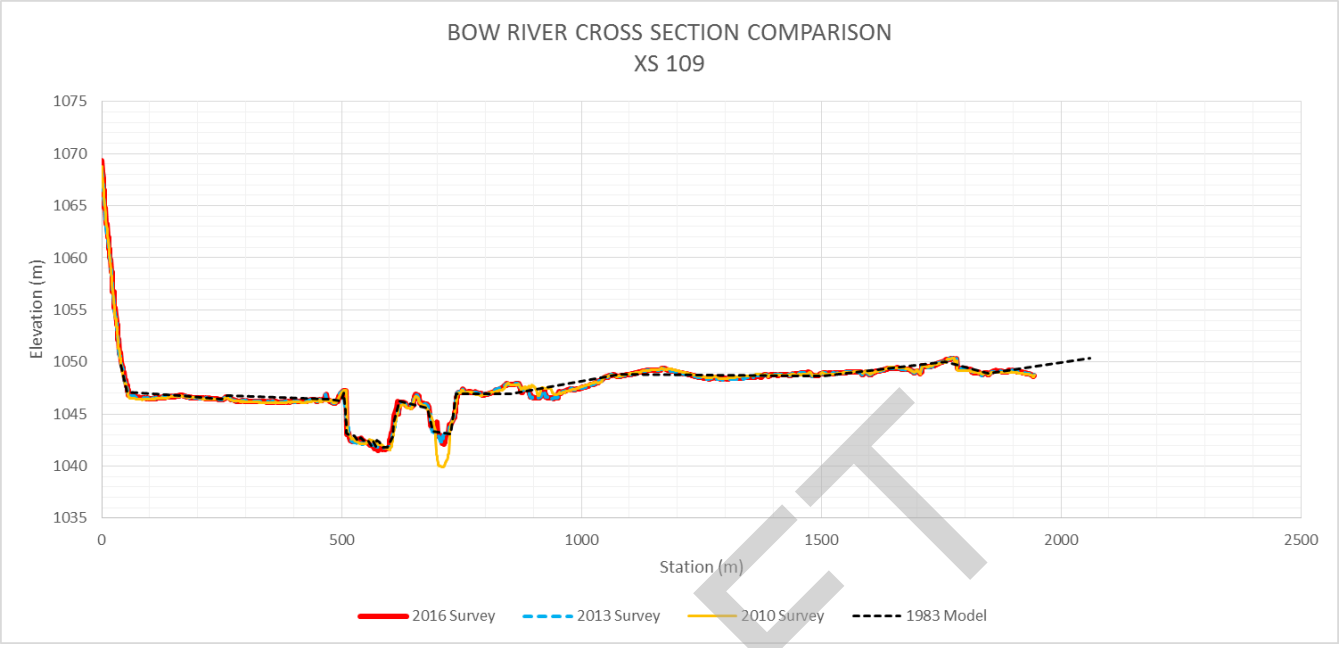


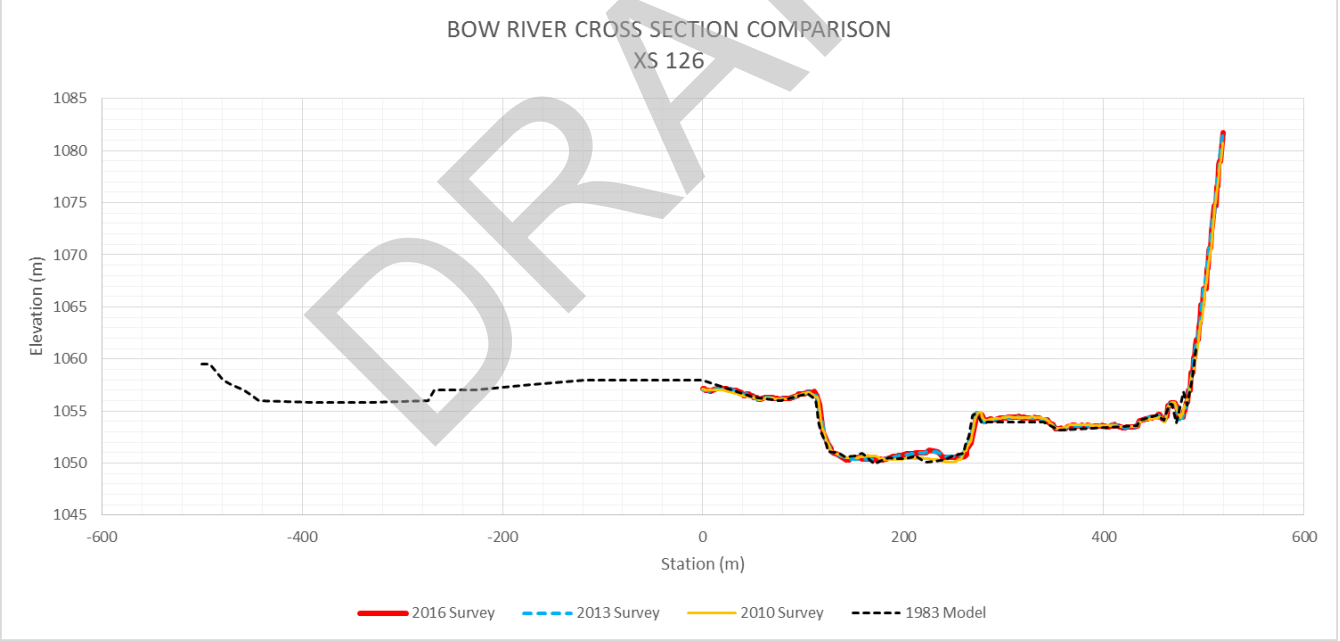


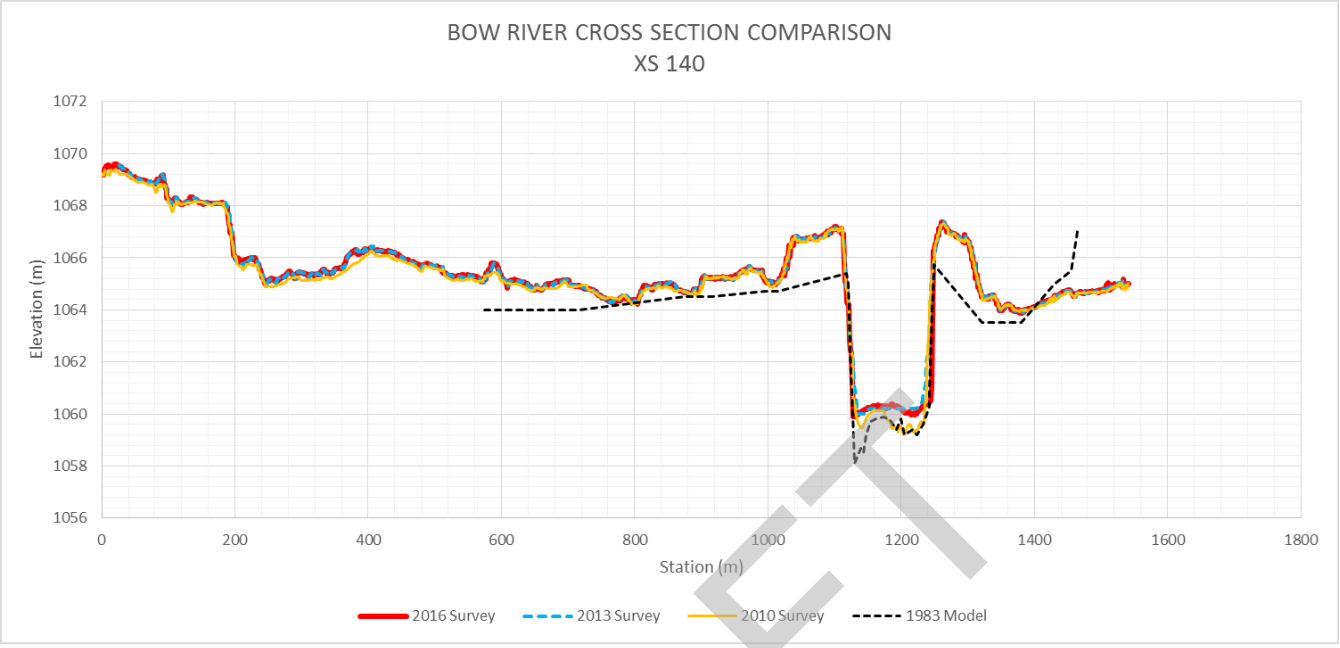
2.0 REACH 2: BOW RIVER FROM BEARSPAW DAM TO ELBOW RIVER CONFLUENCE

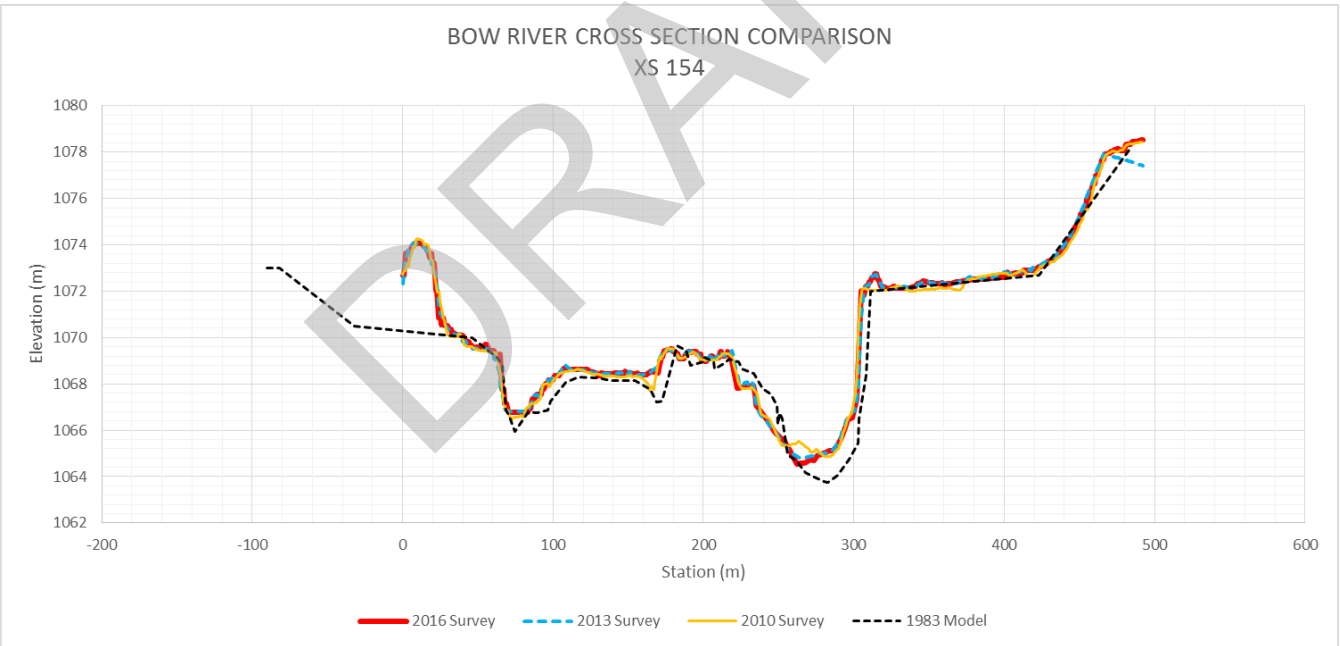


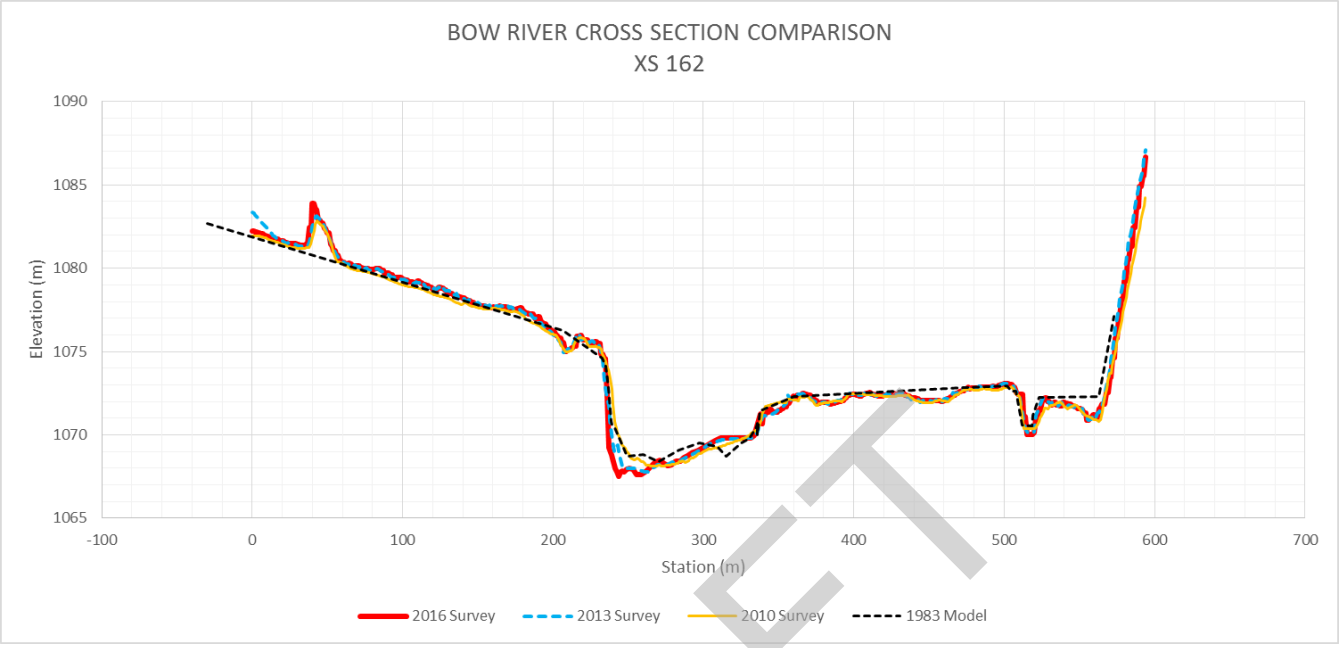




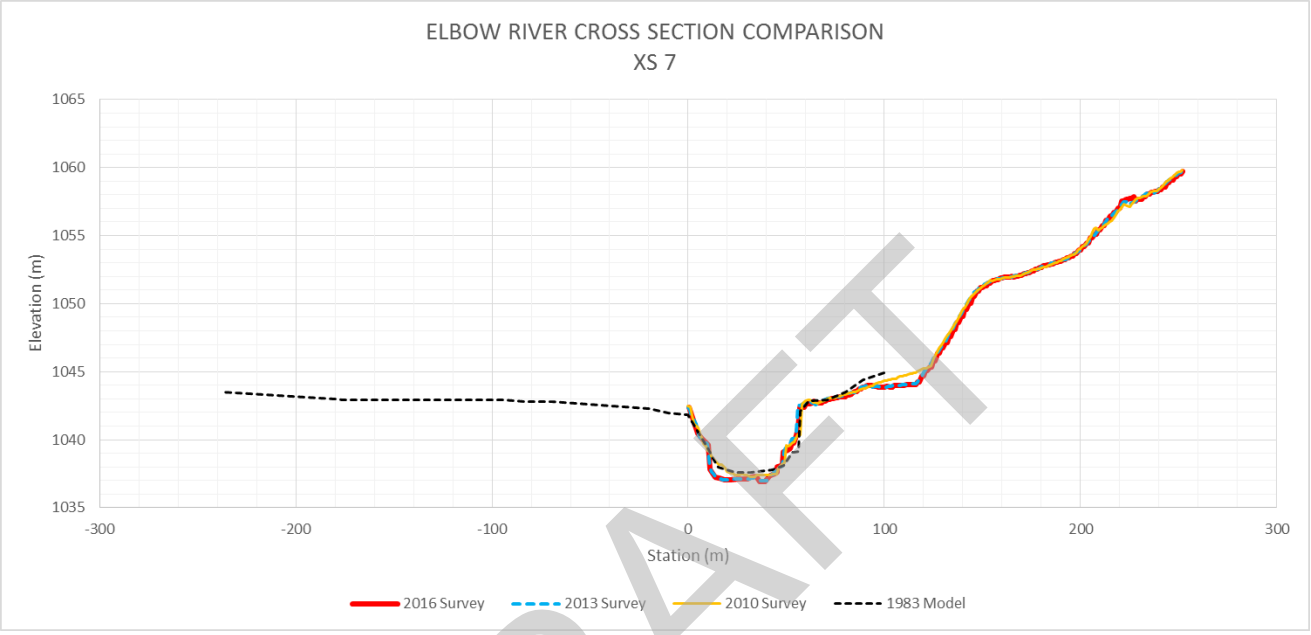


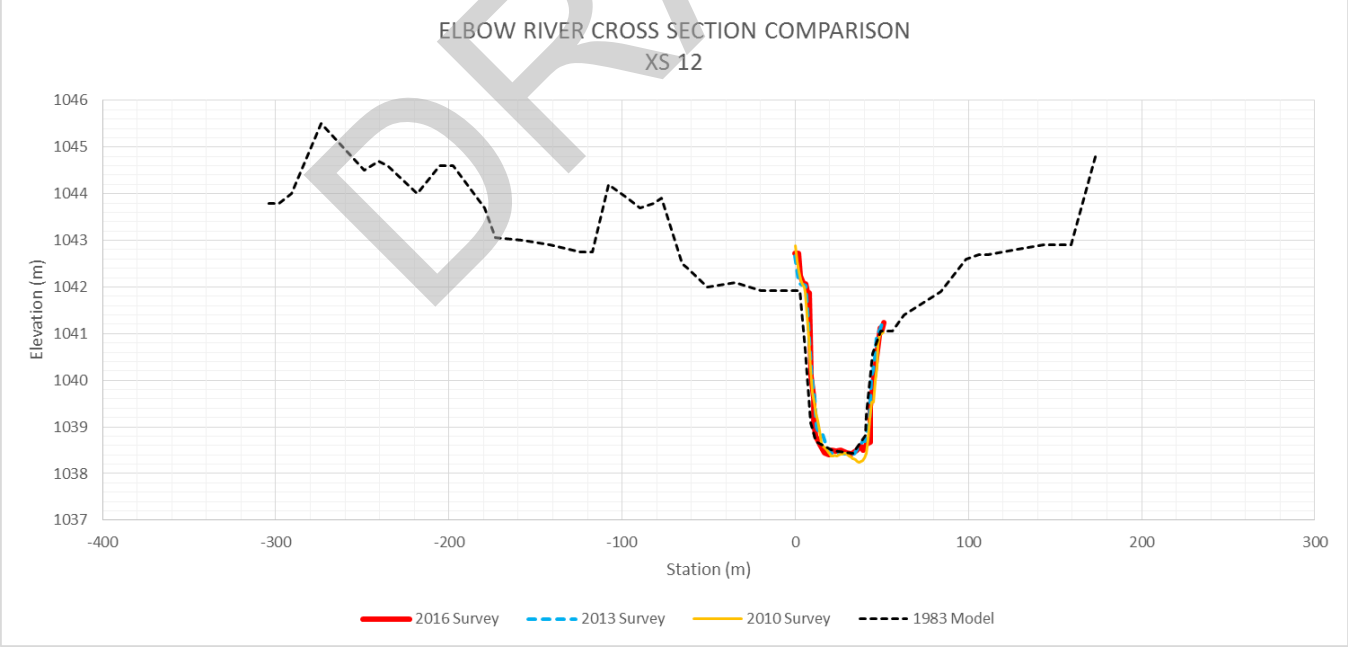


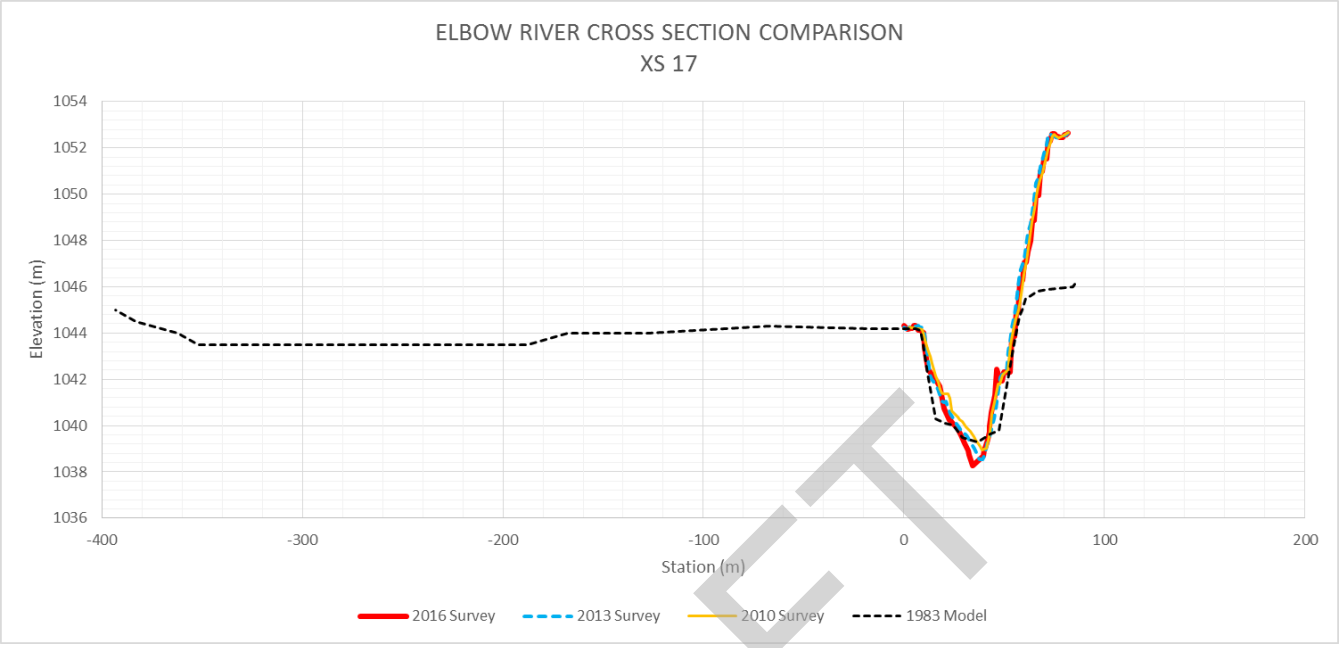


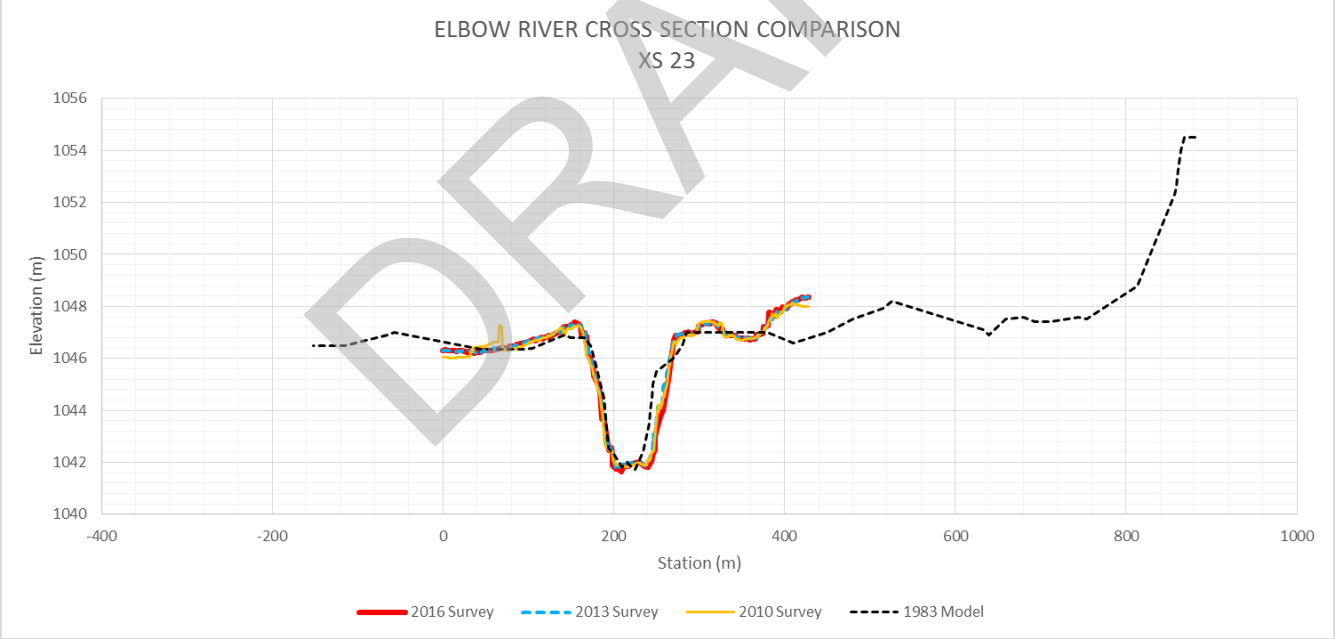


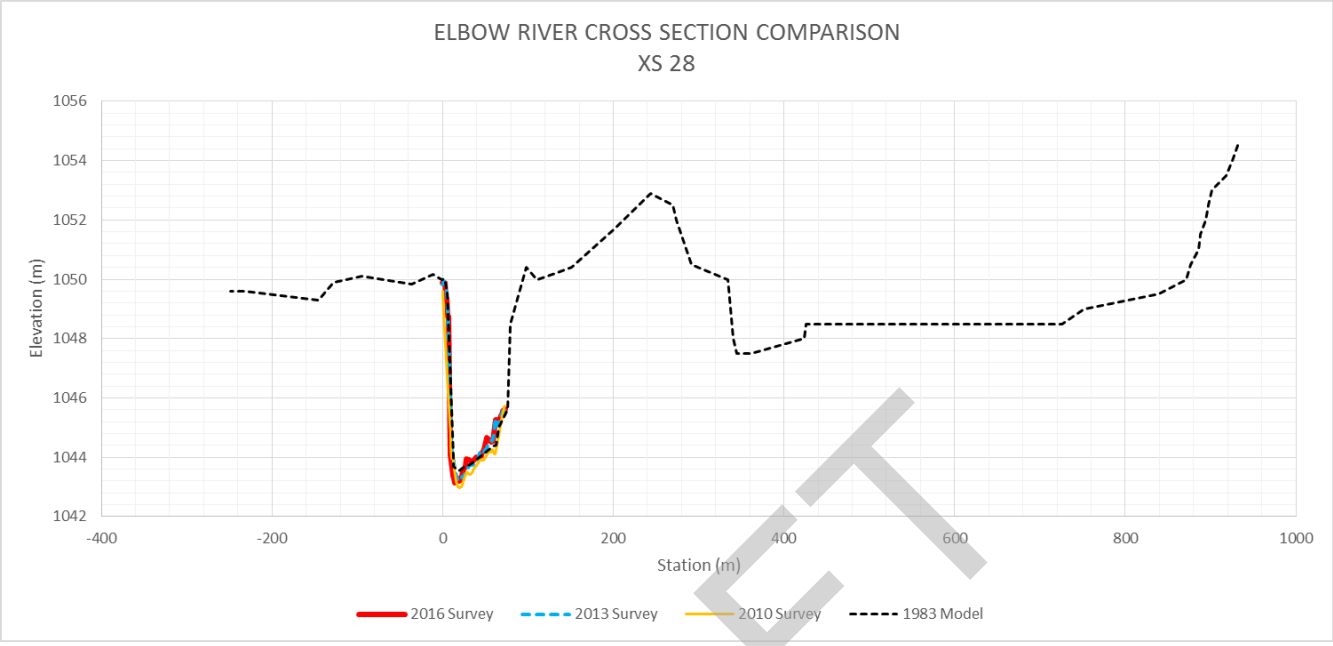
3.0 REACH 3: ELBOW RIVER FROM GLENMORE DAM TO BOW RIVER CONFLUENCE

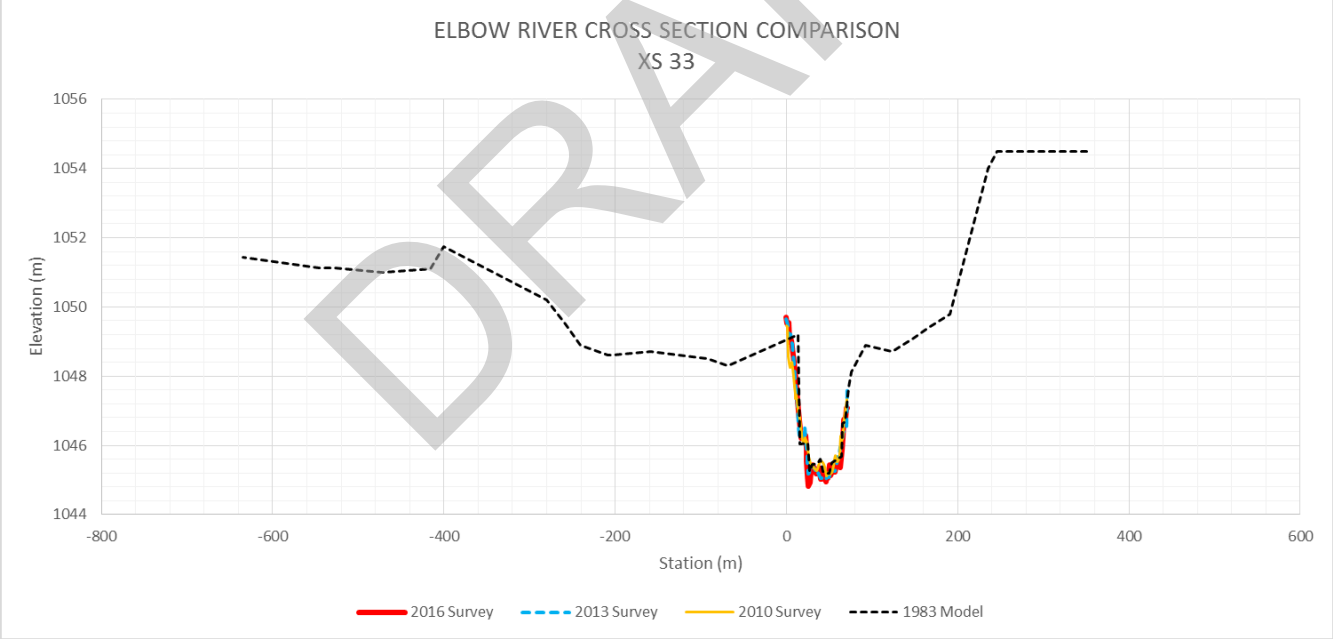


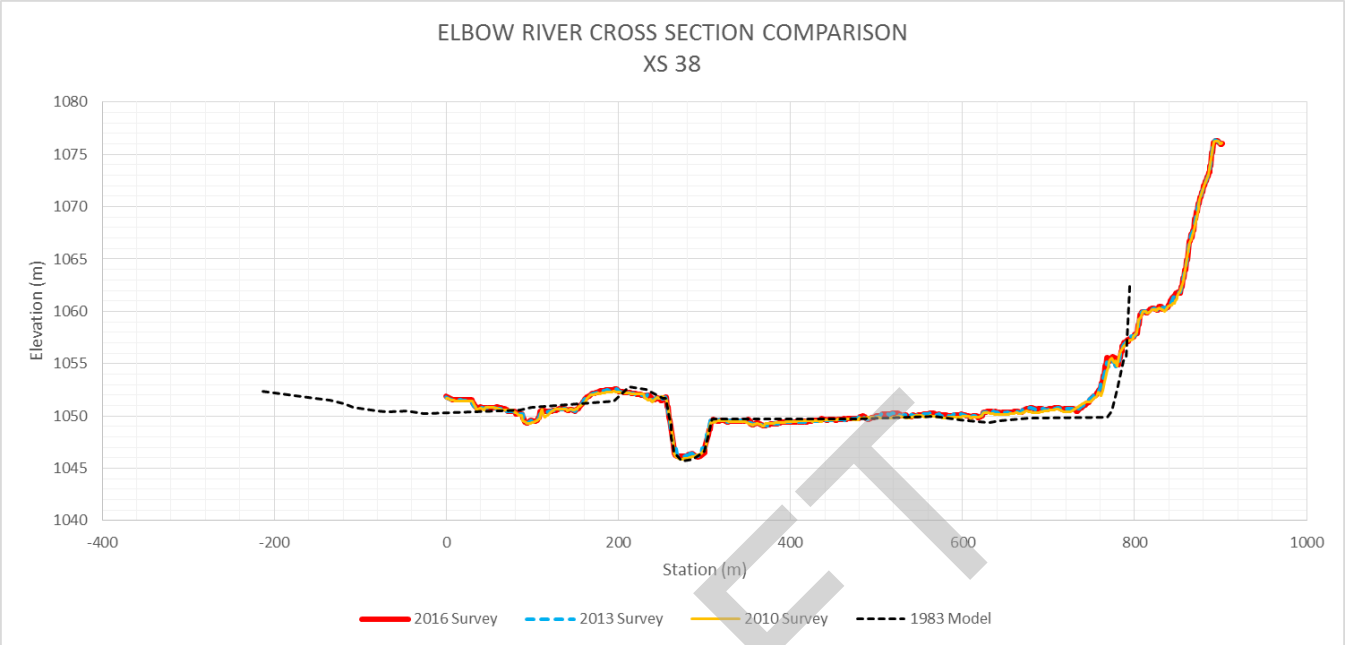


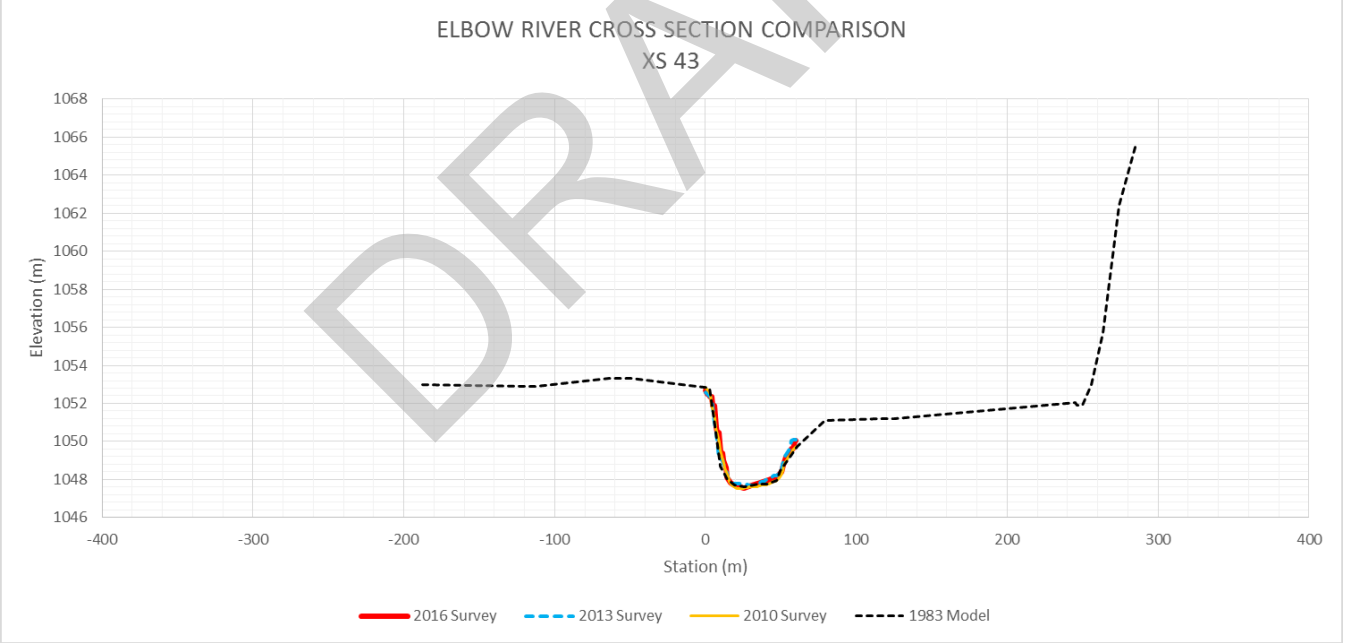


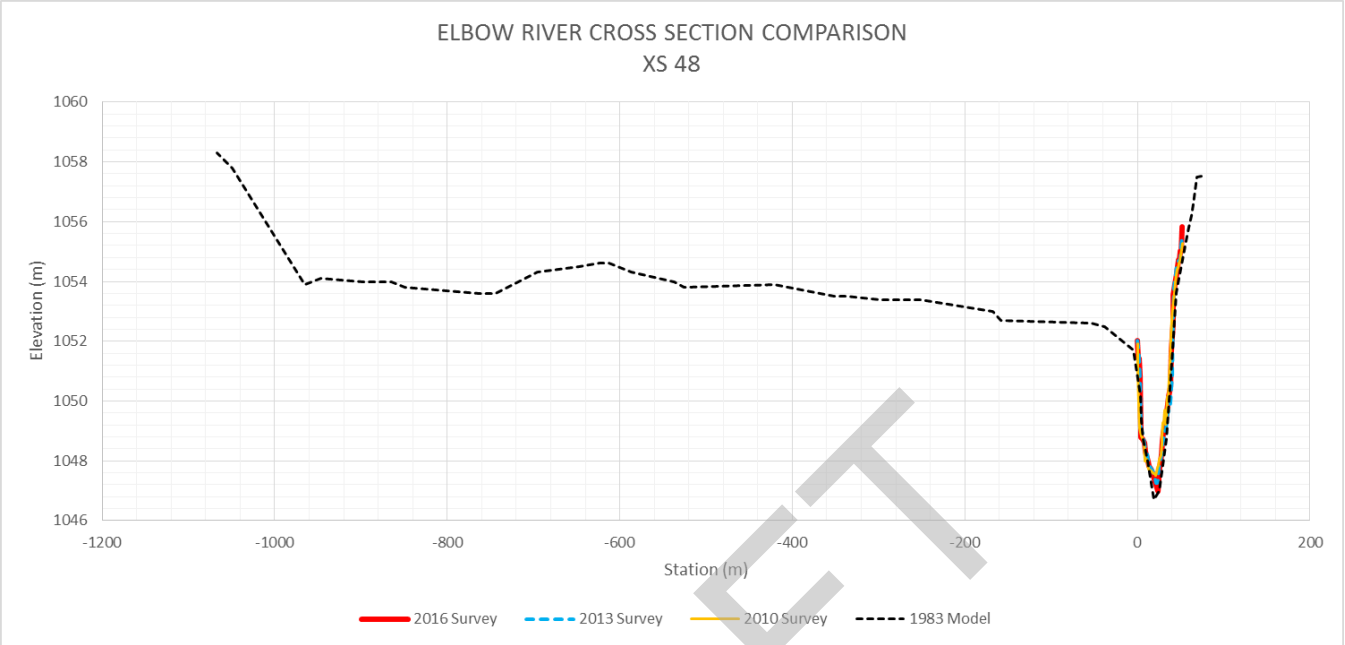


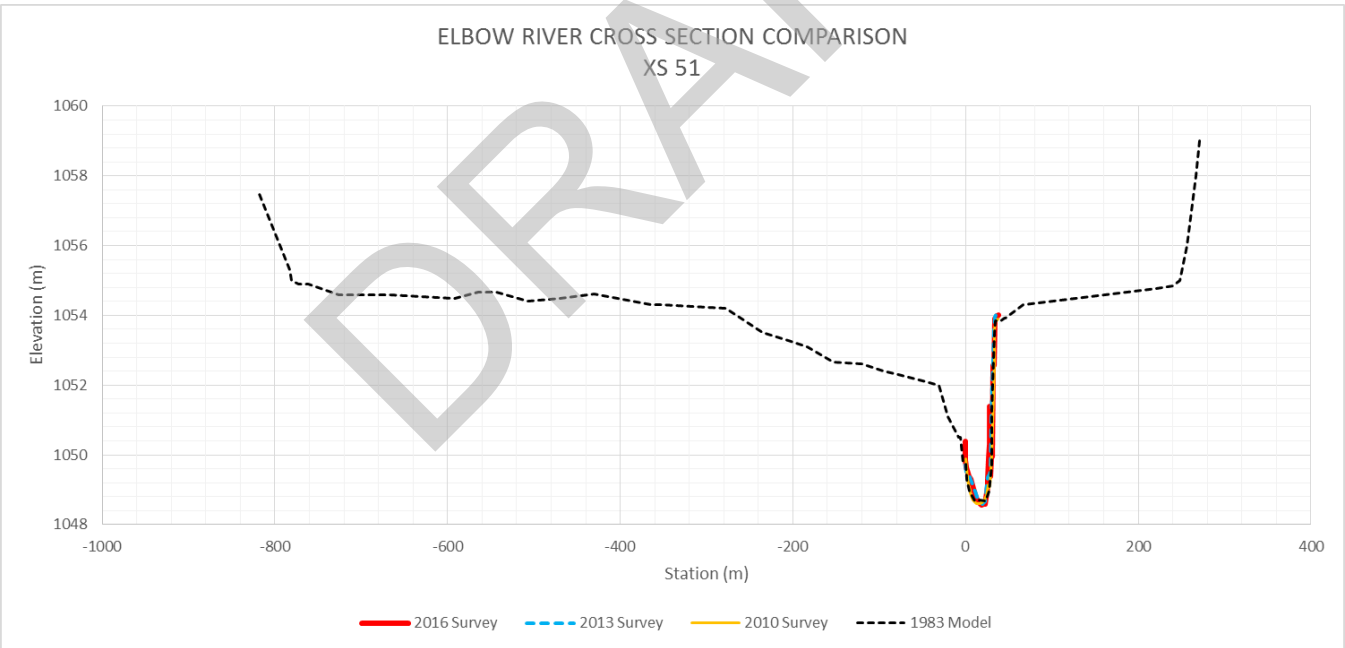


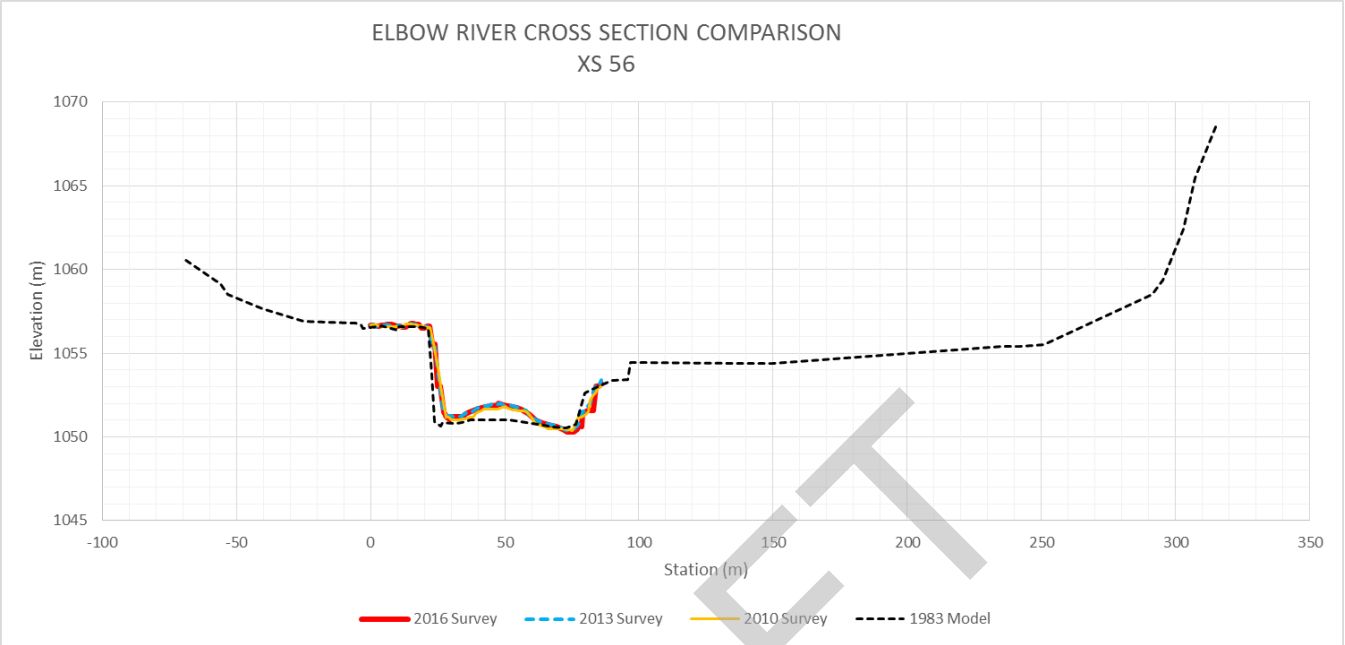


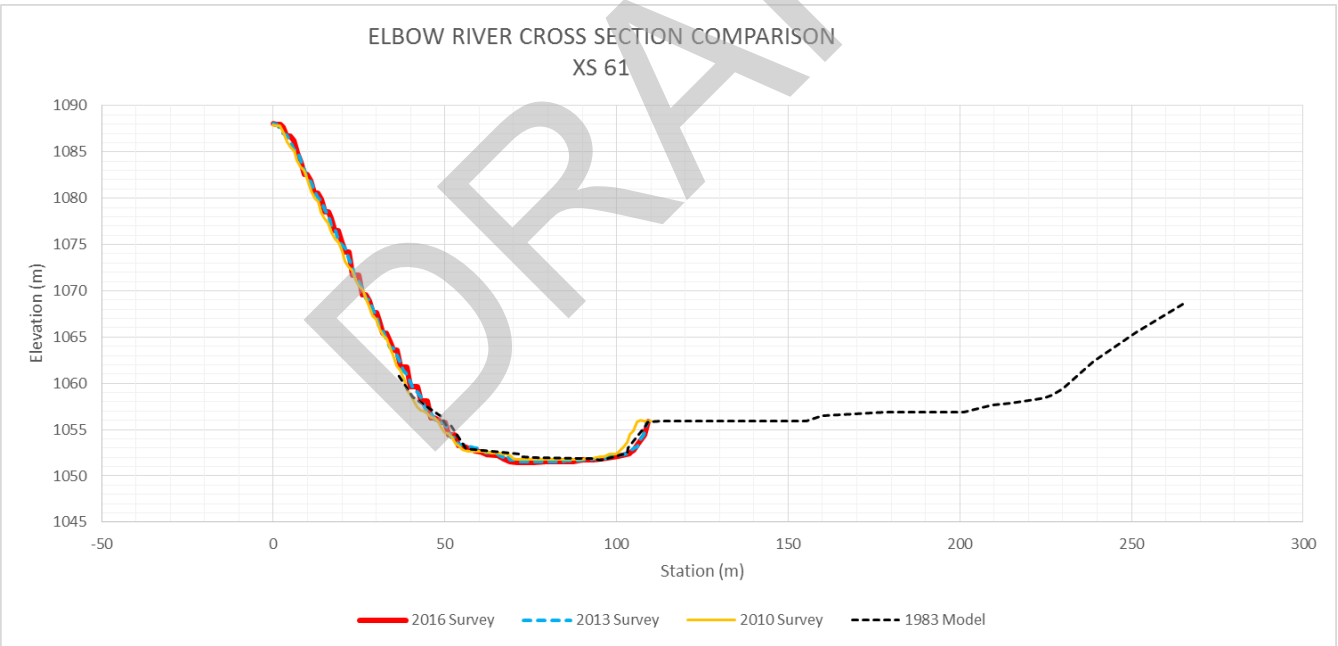


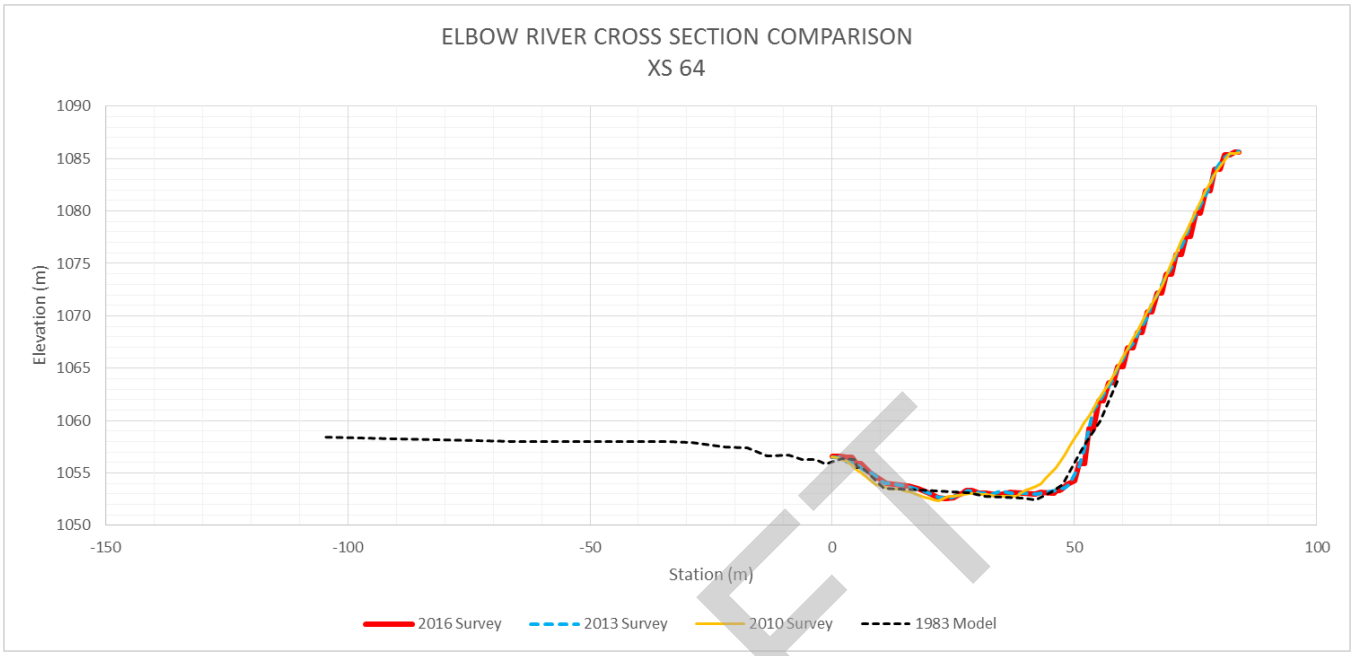


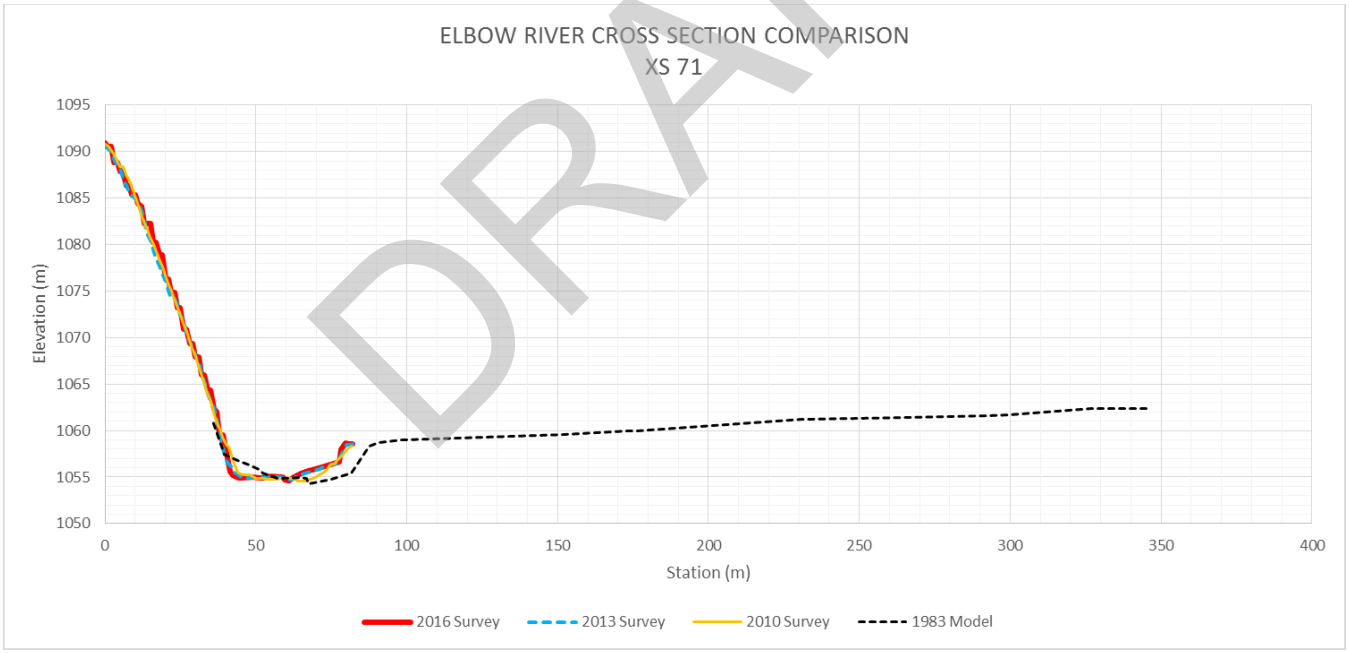


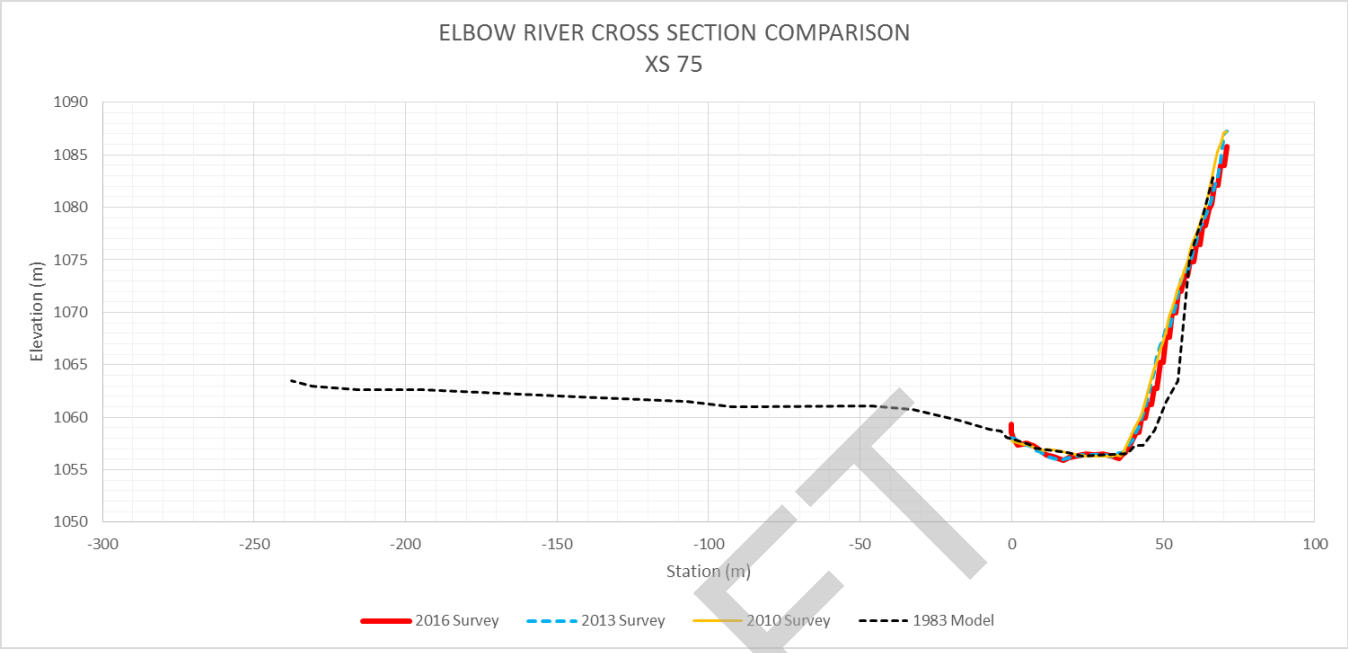




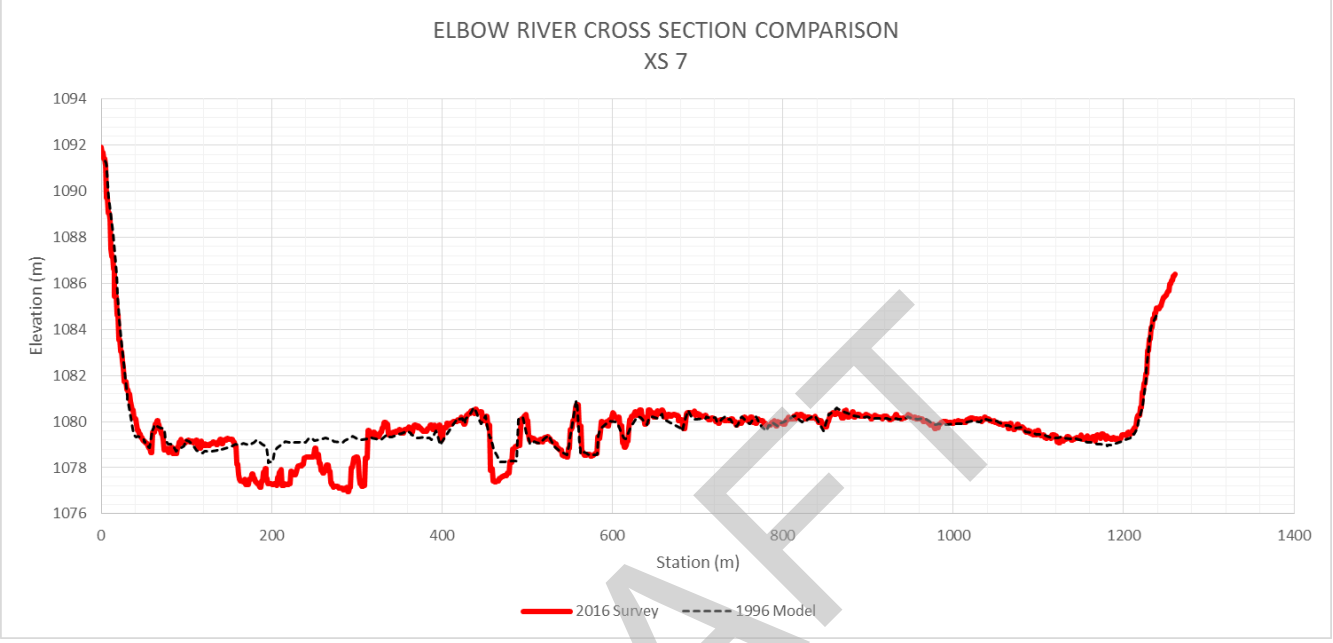


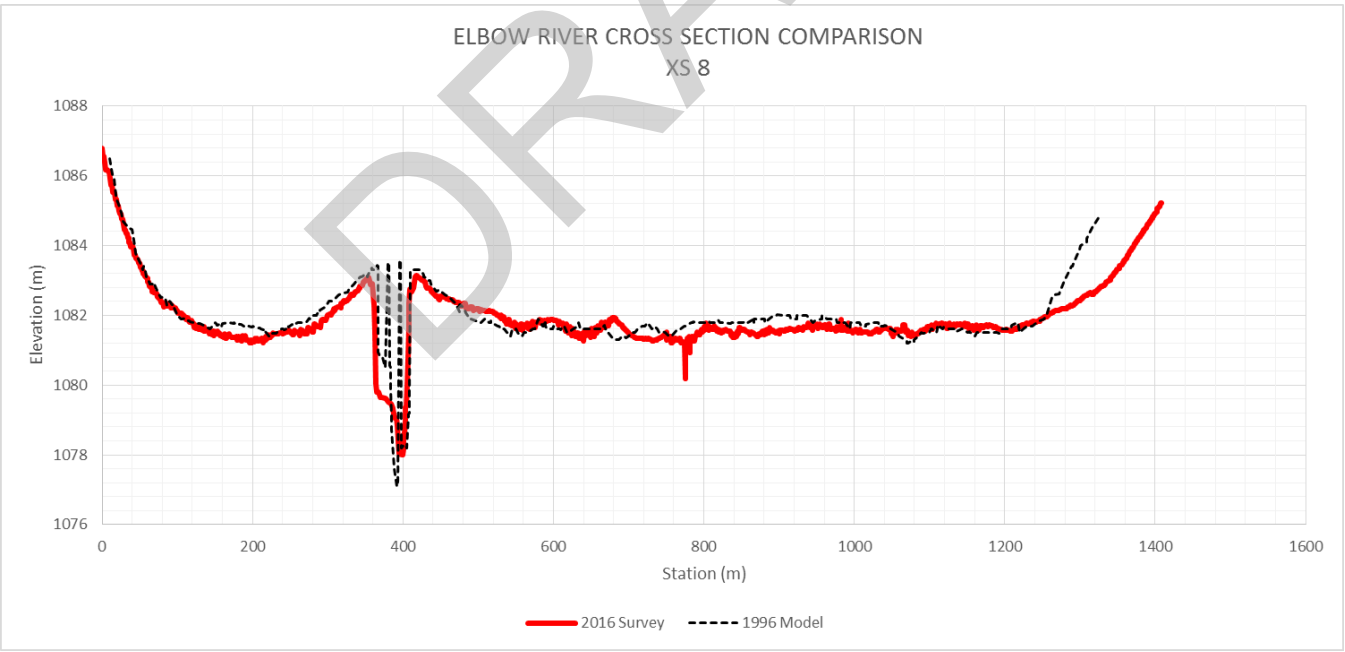


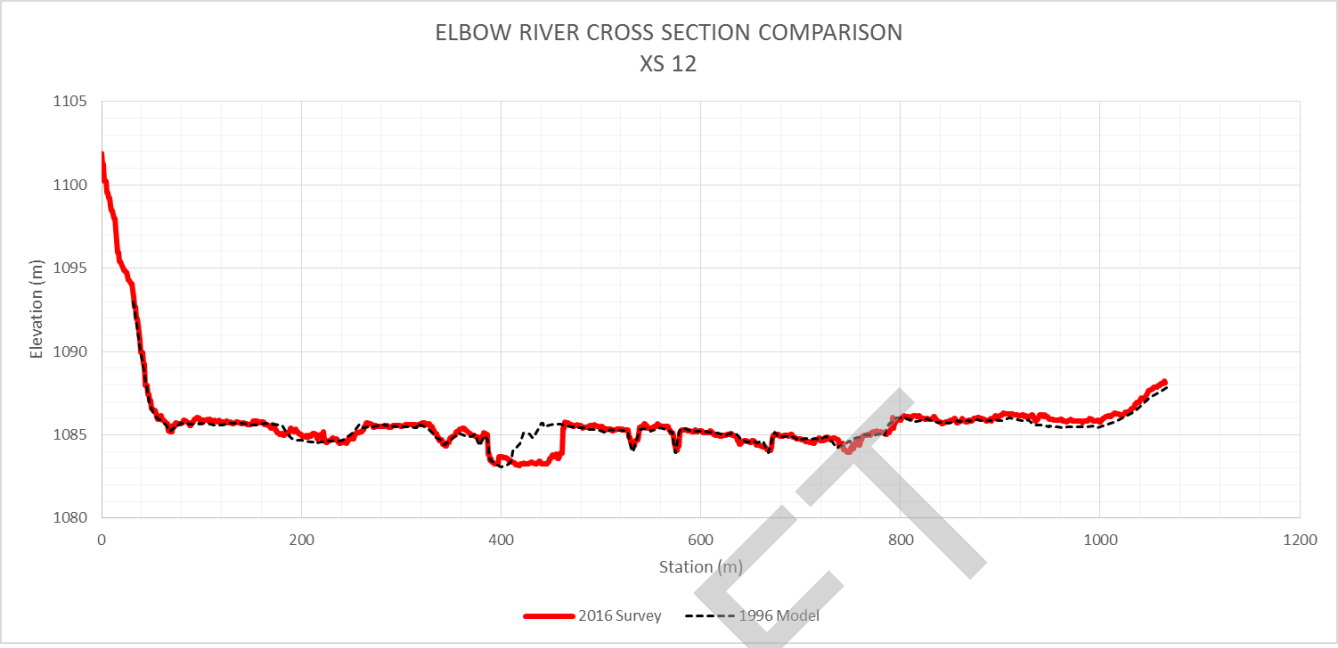


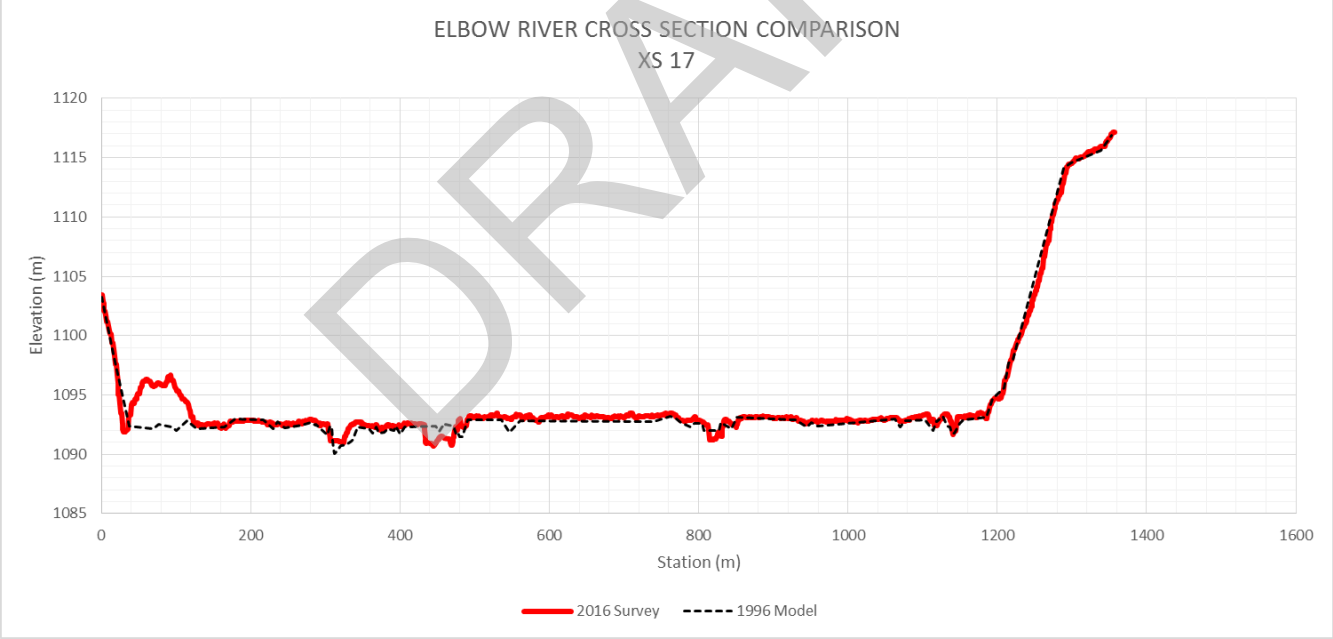


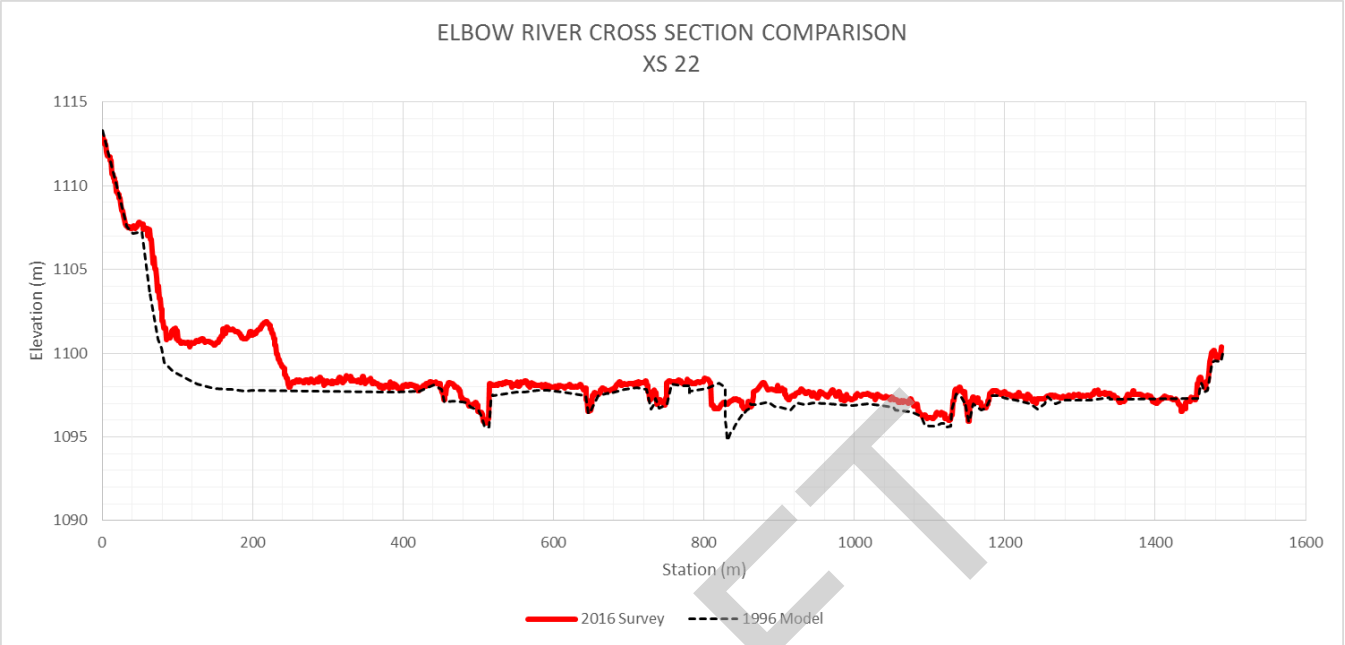
4.0 REACH 4: ELBOW FROM UPSTREAM OF BRAGG CREEK TO GLENMORE RESERVOIR

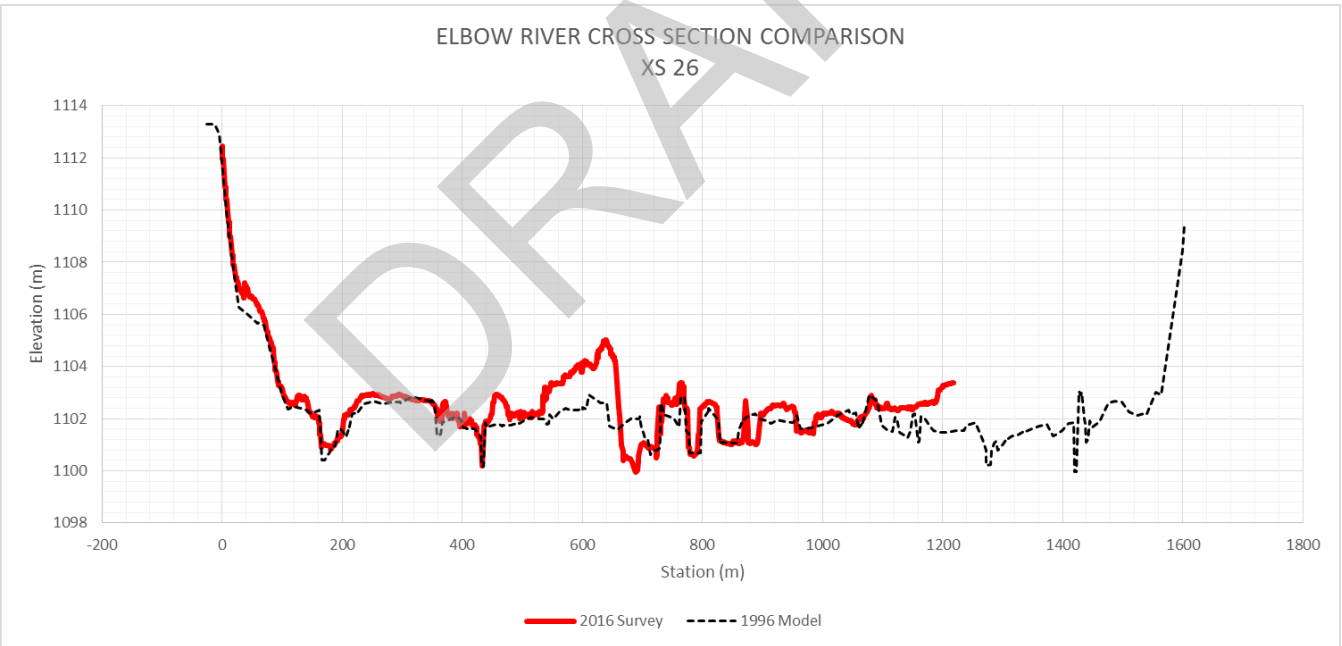


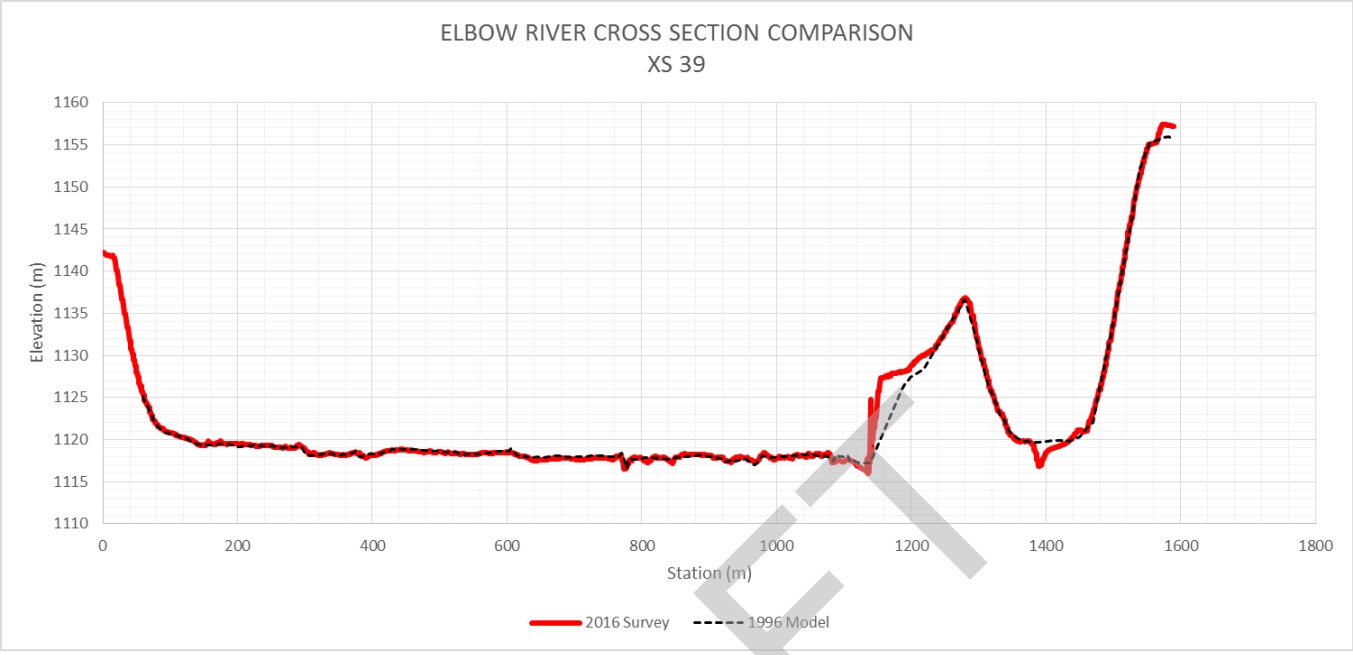


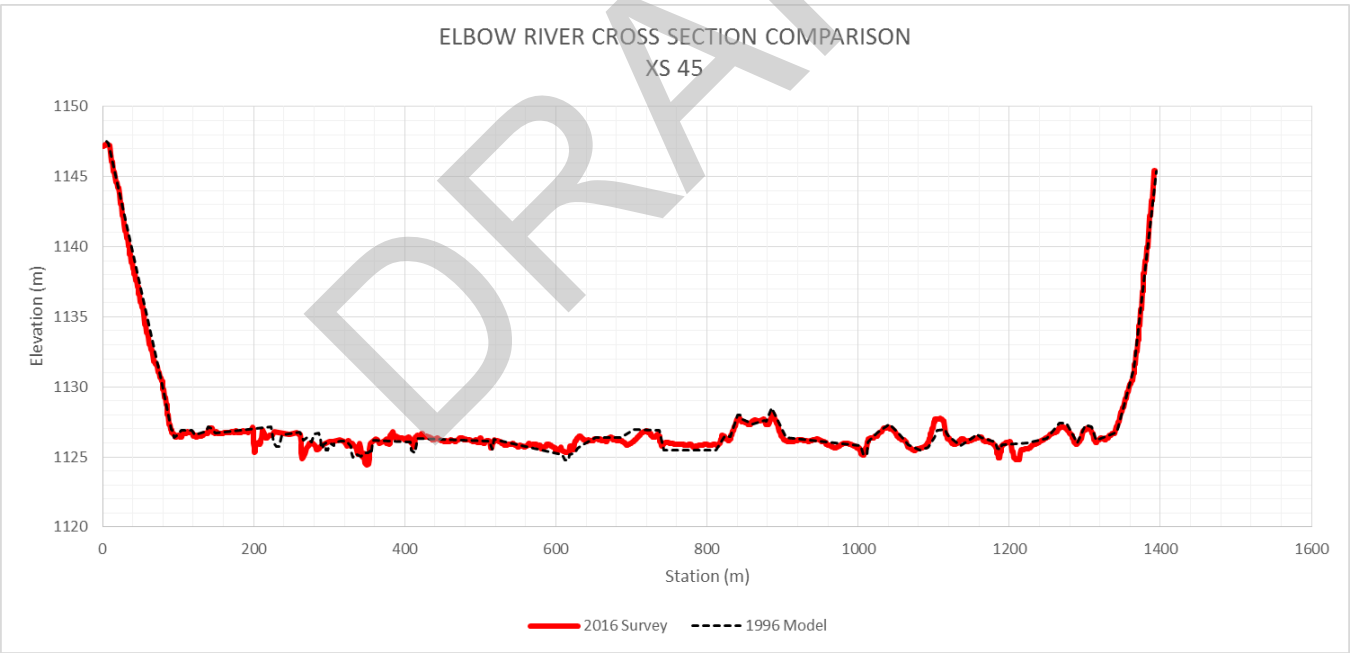


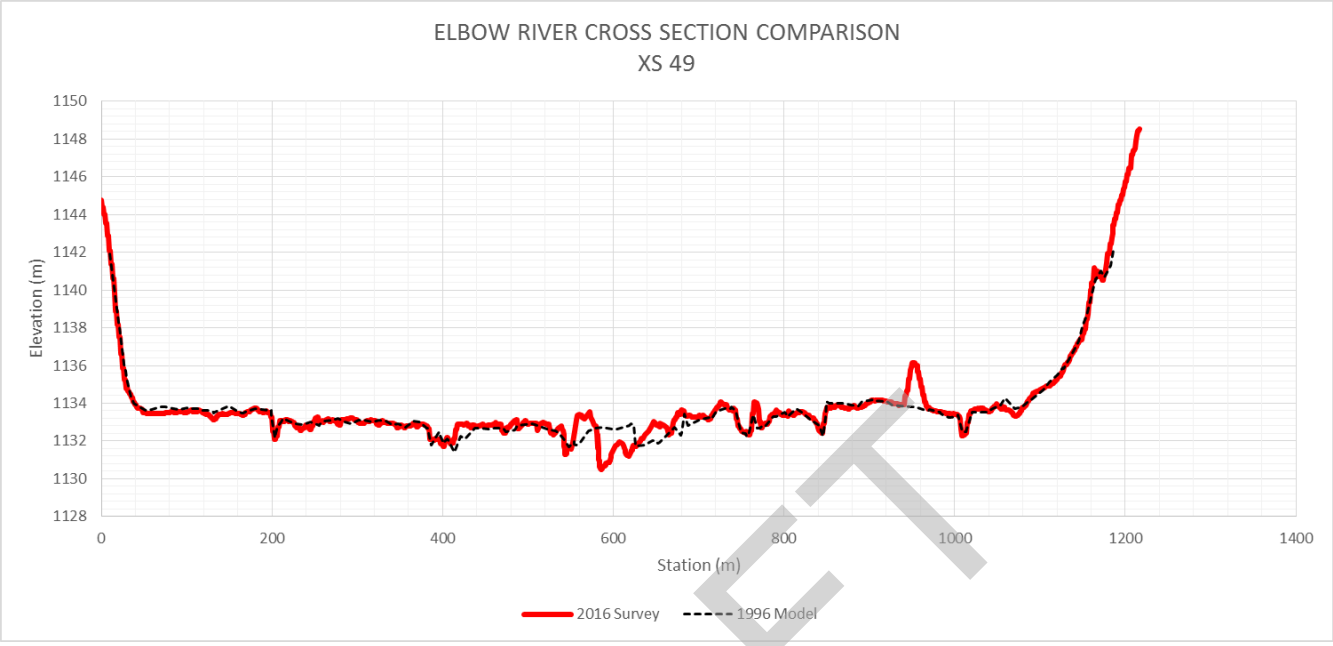


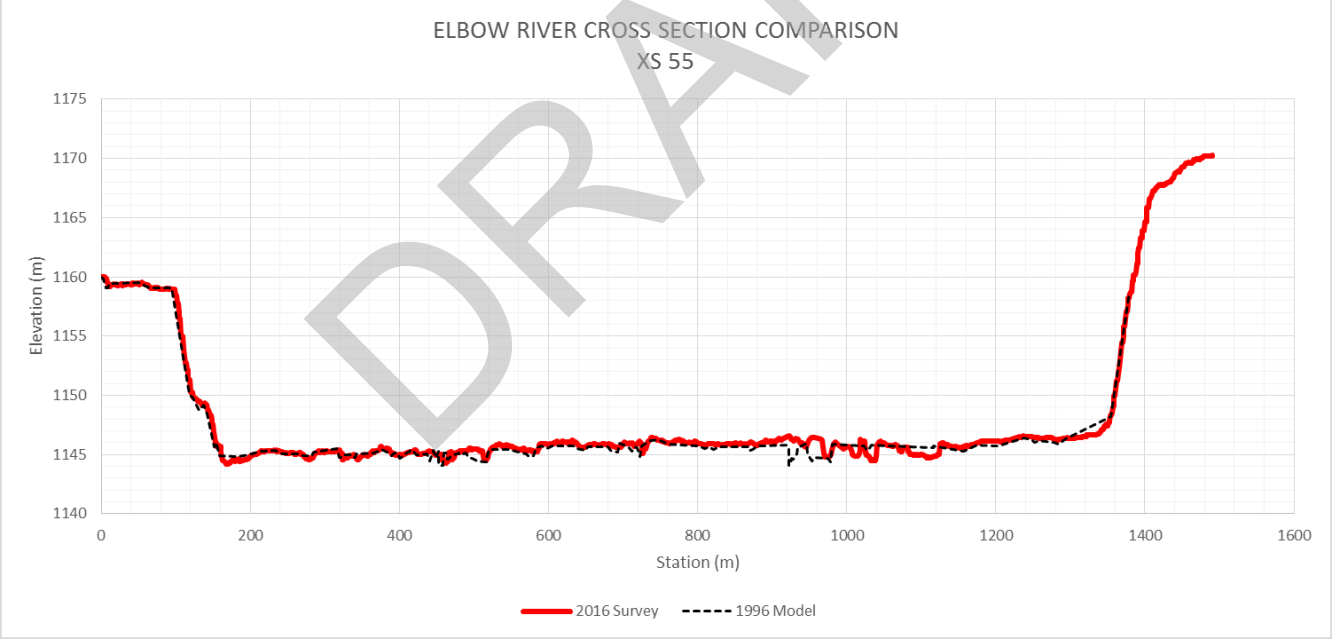


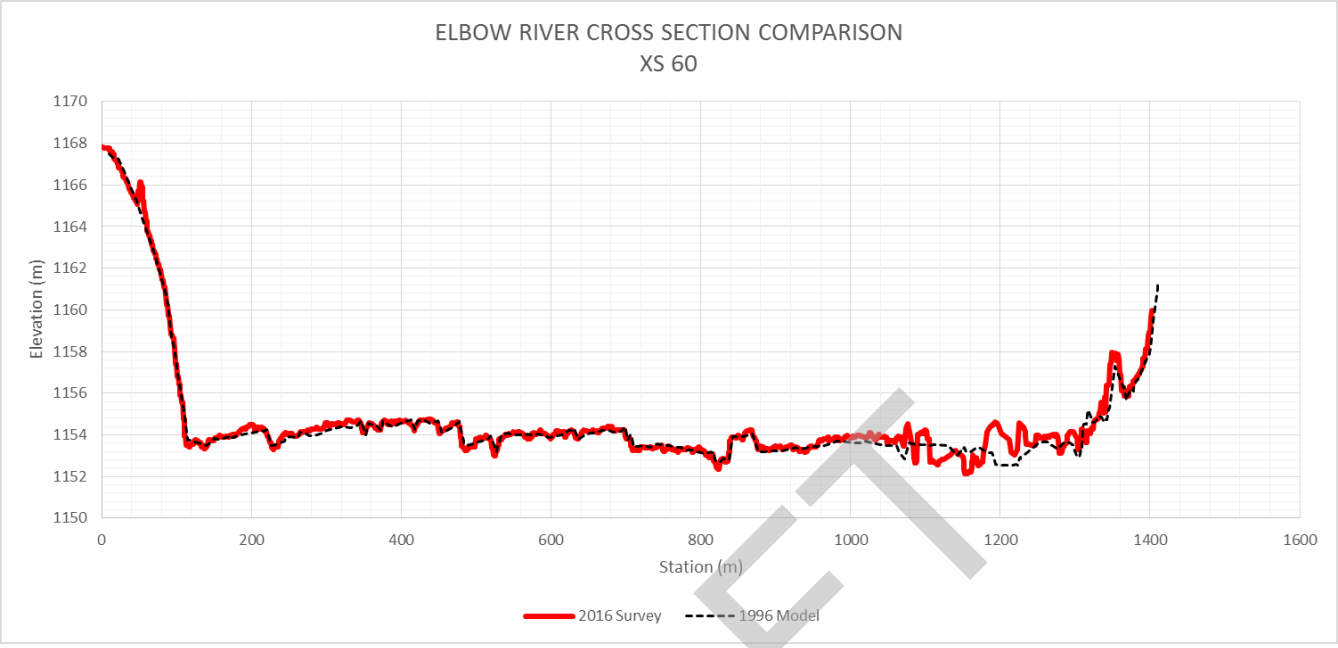


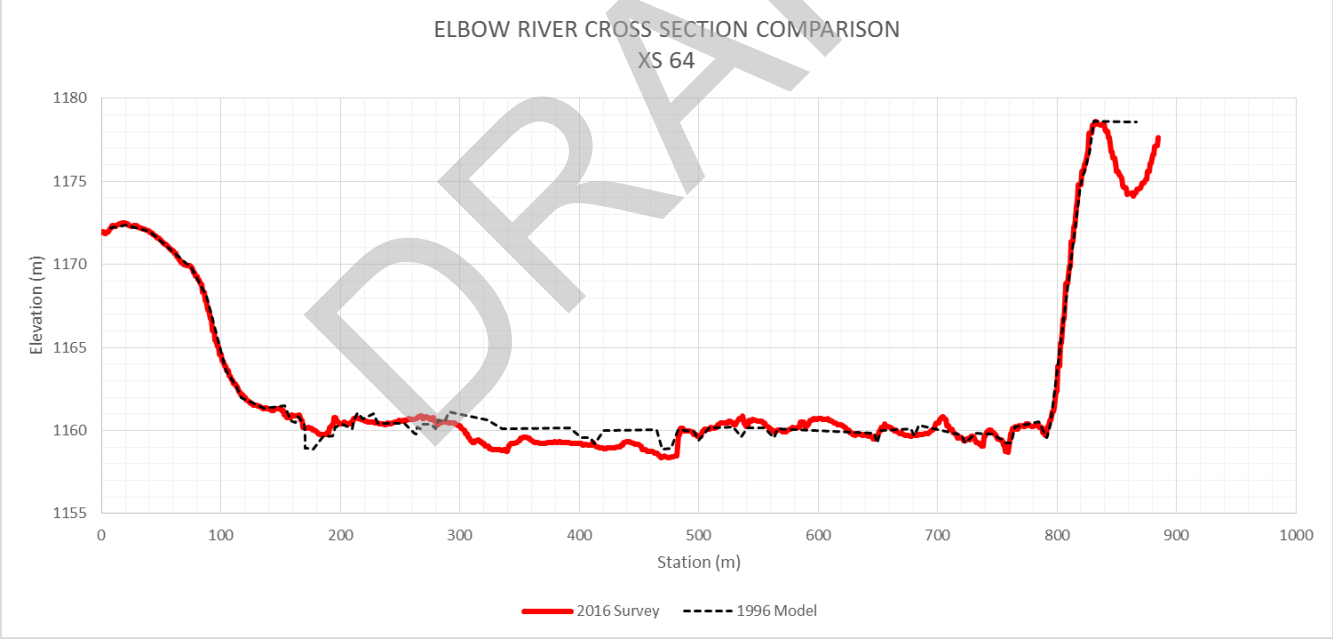


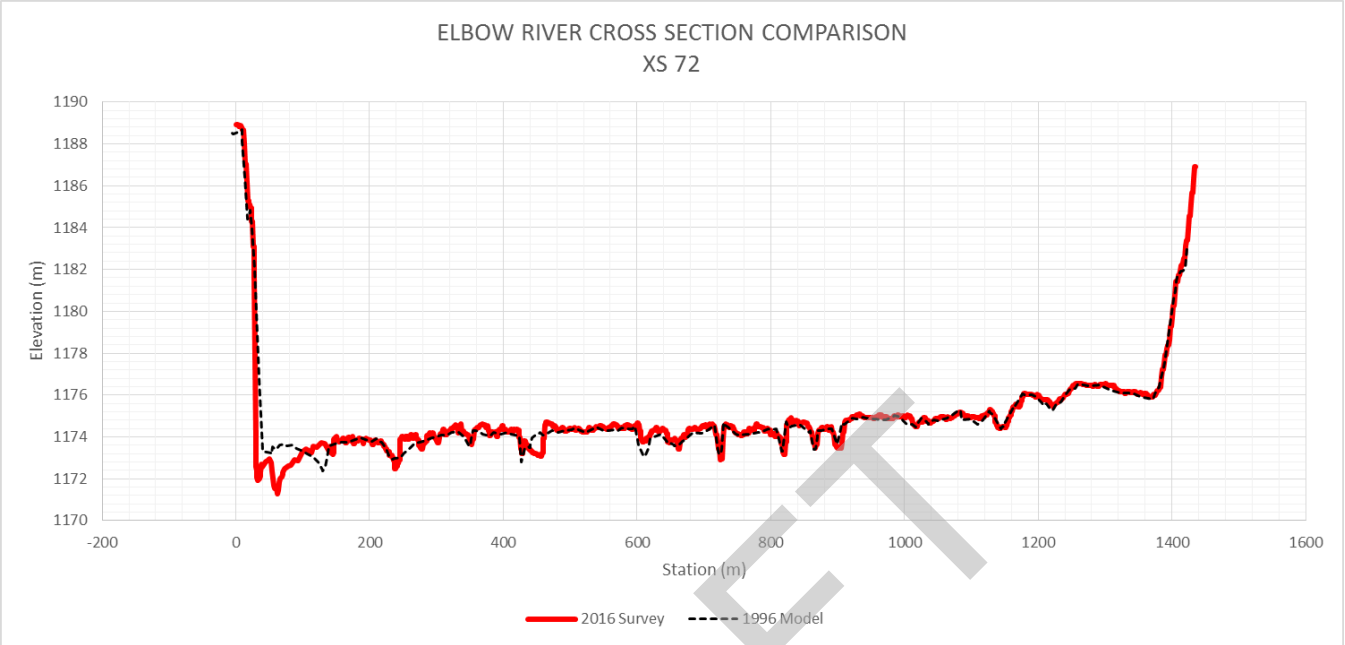


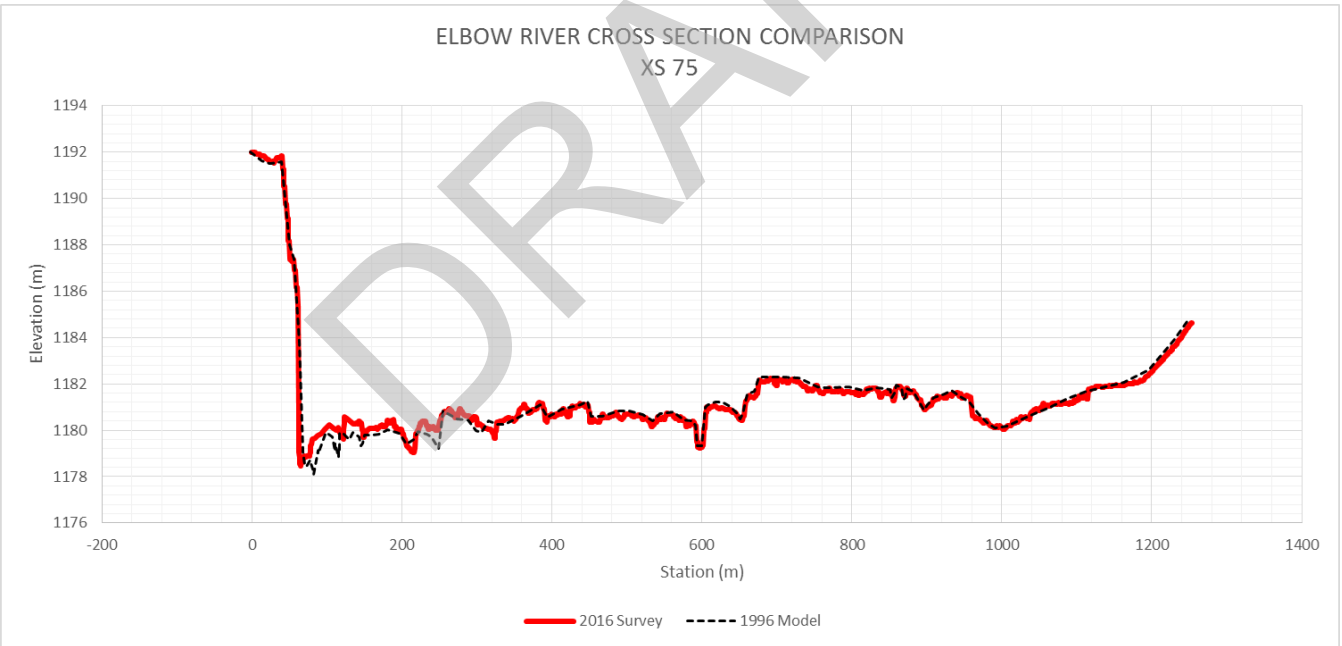


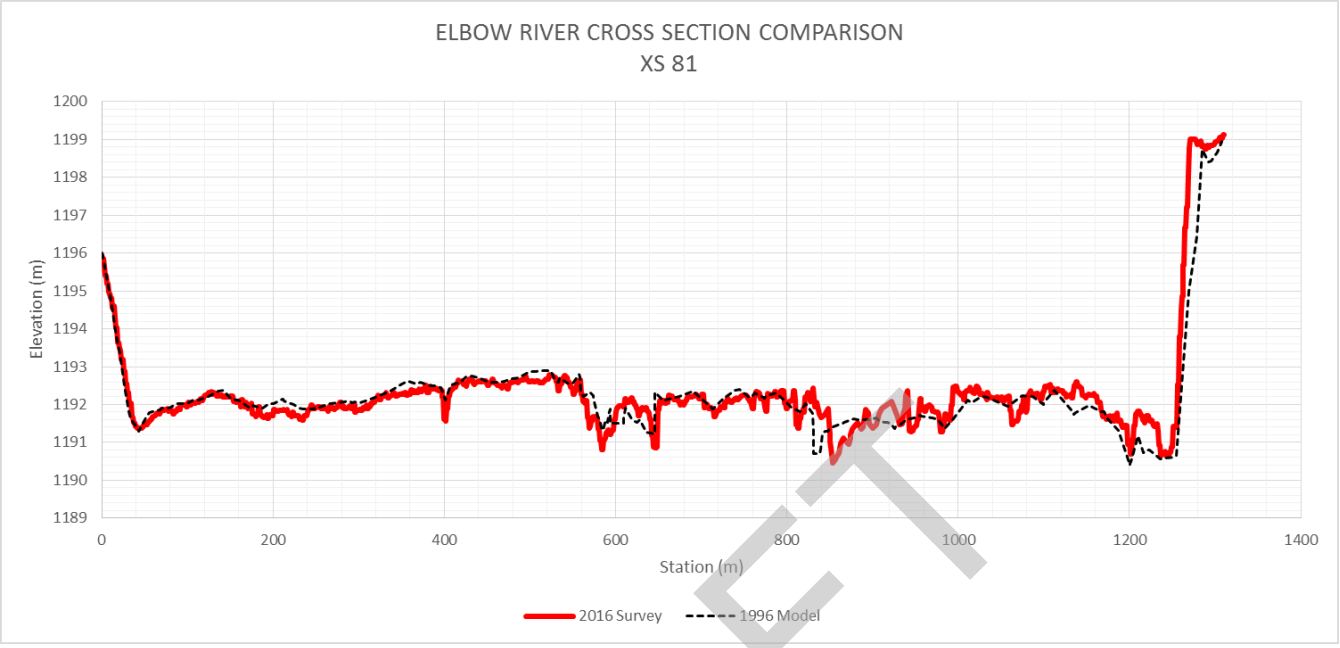


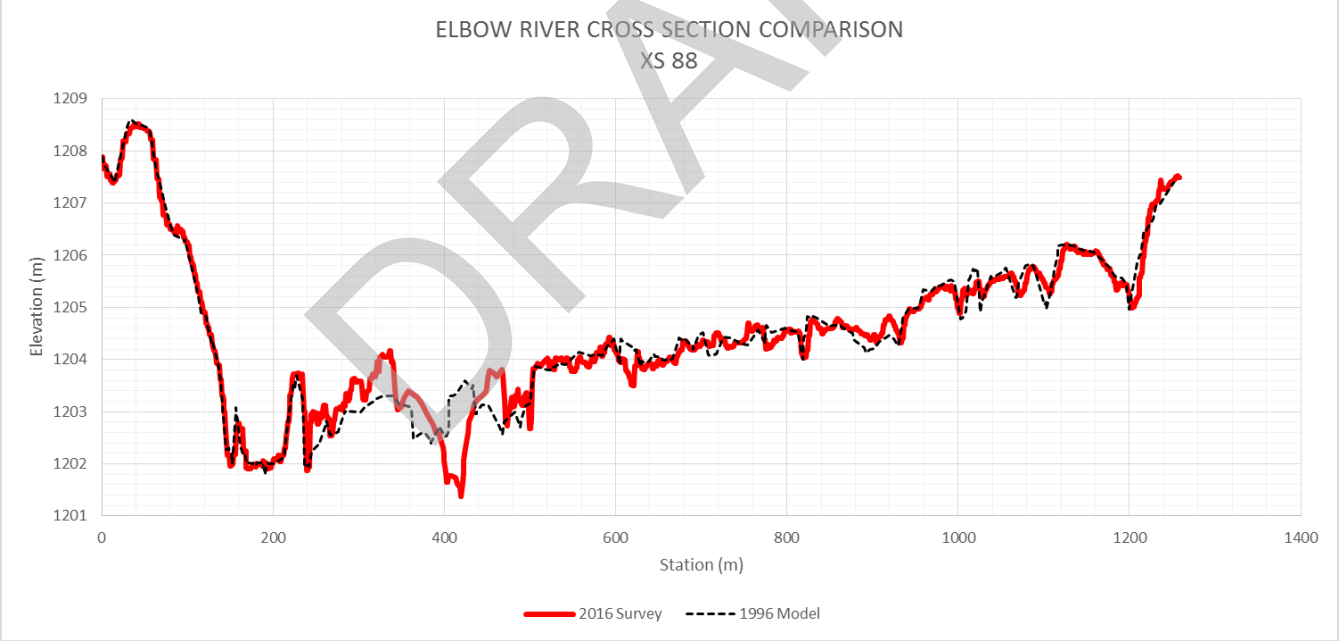


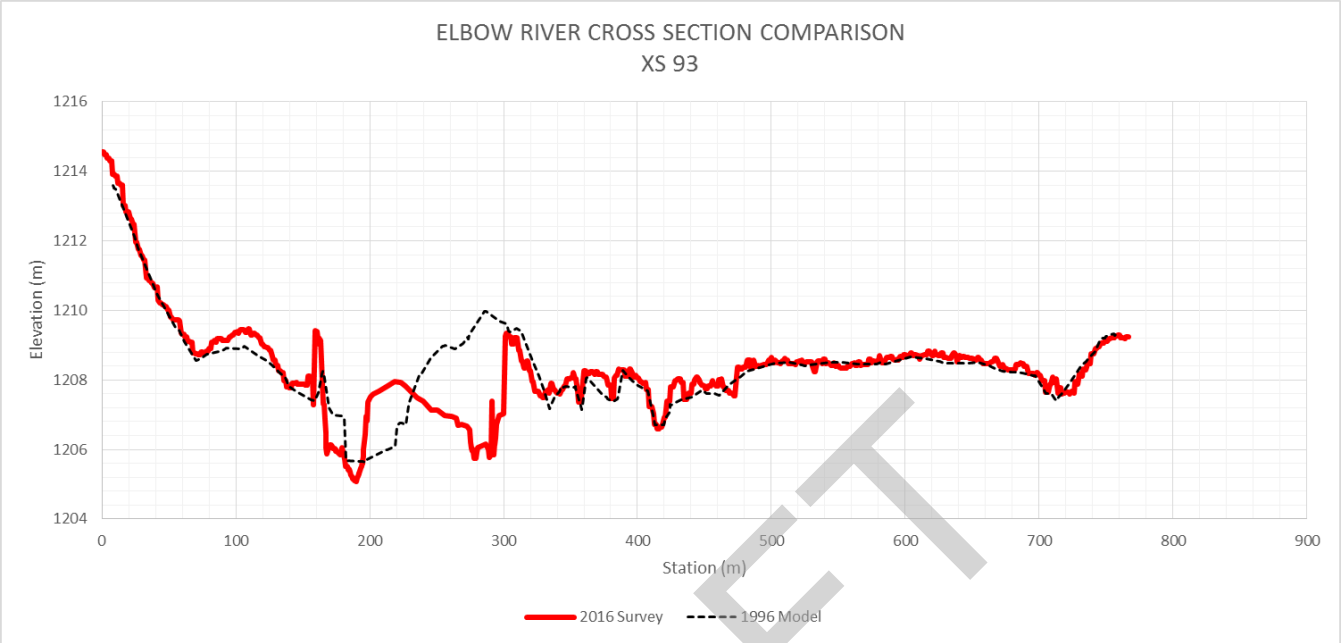


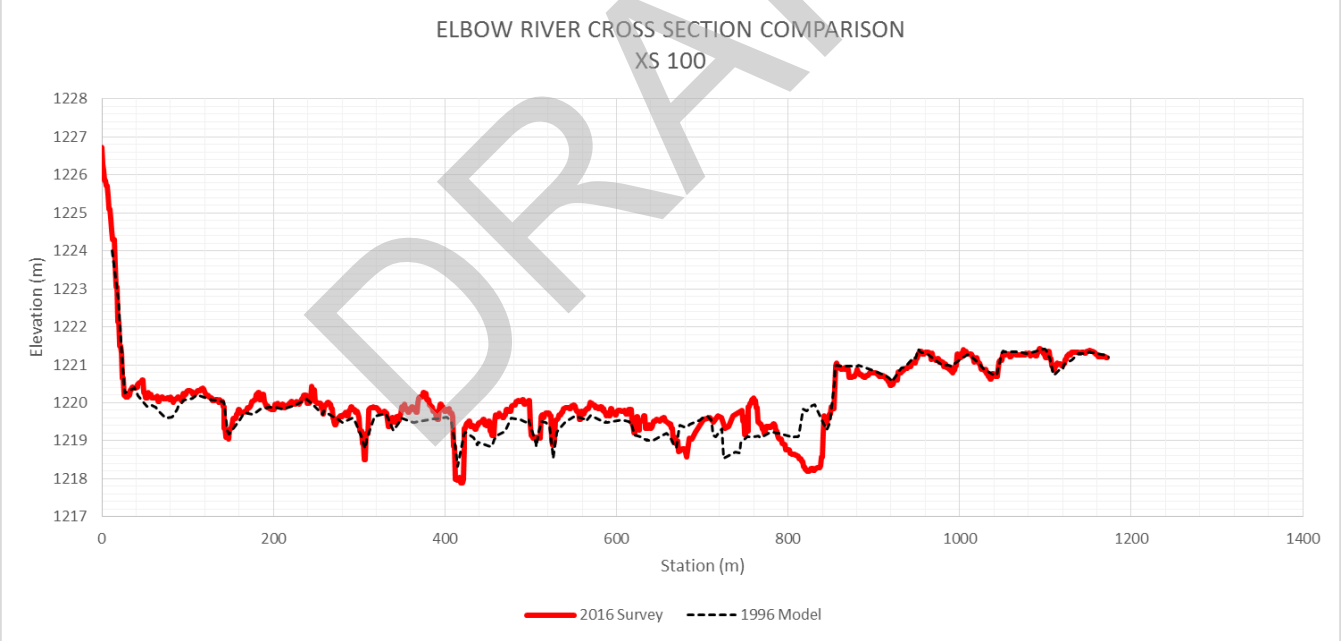


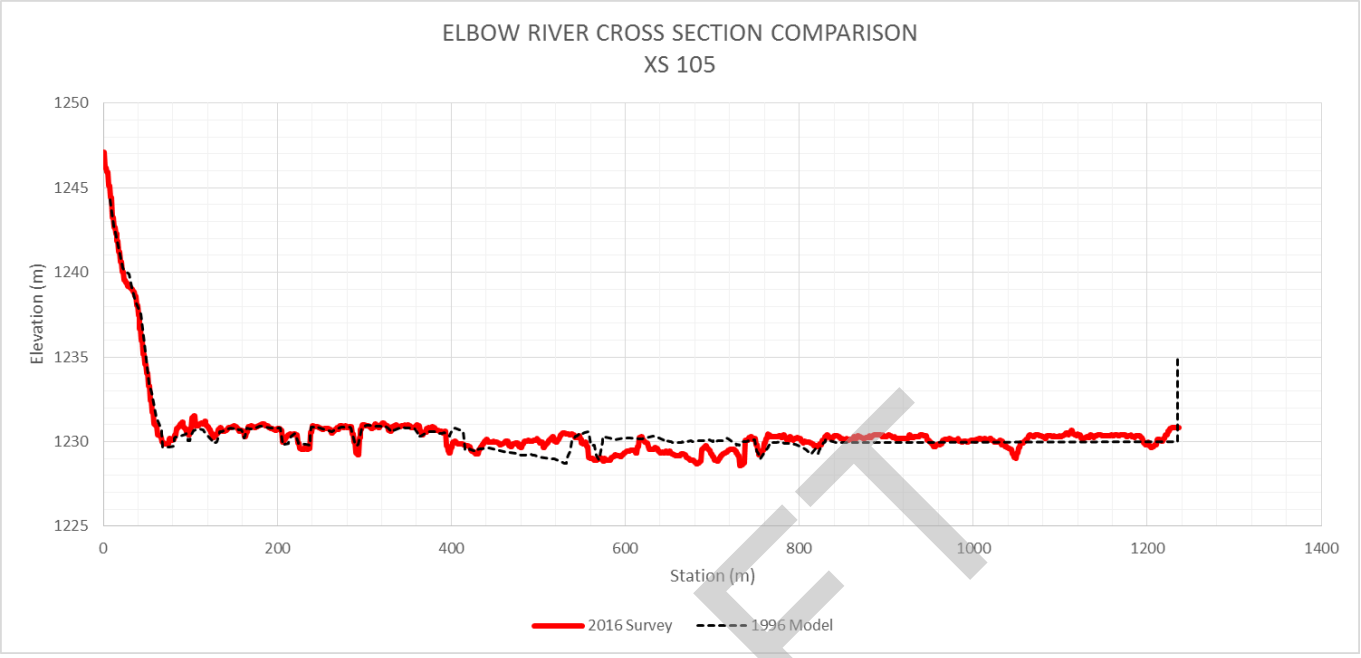


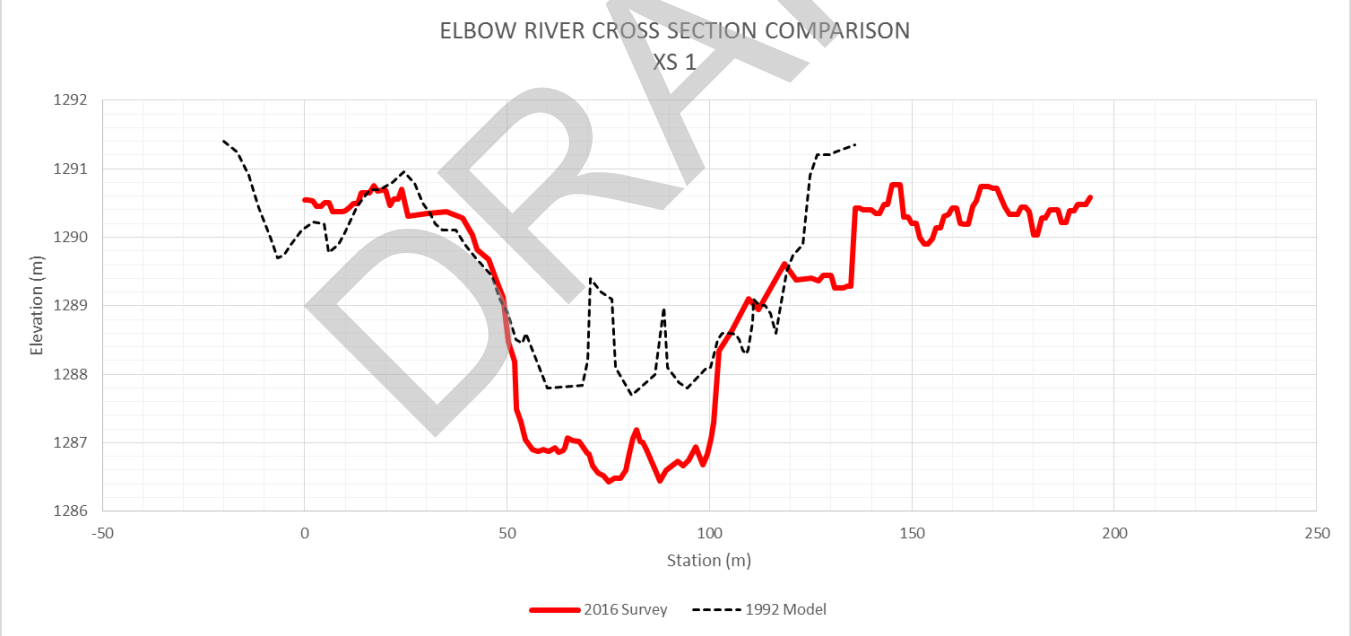


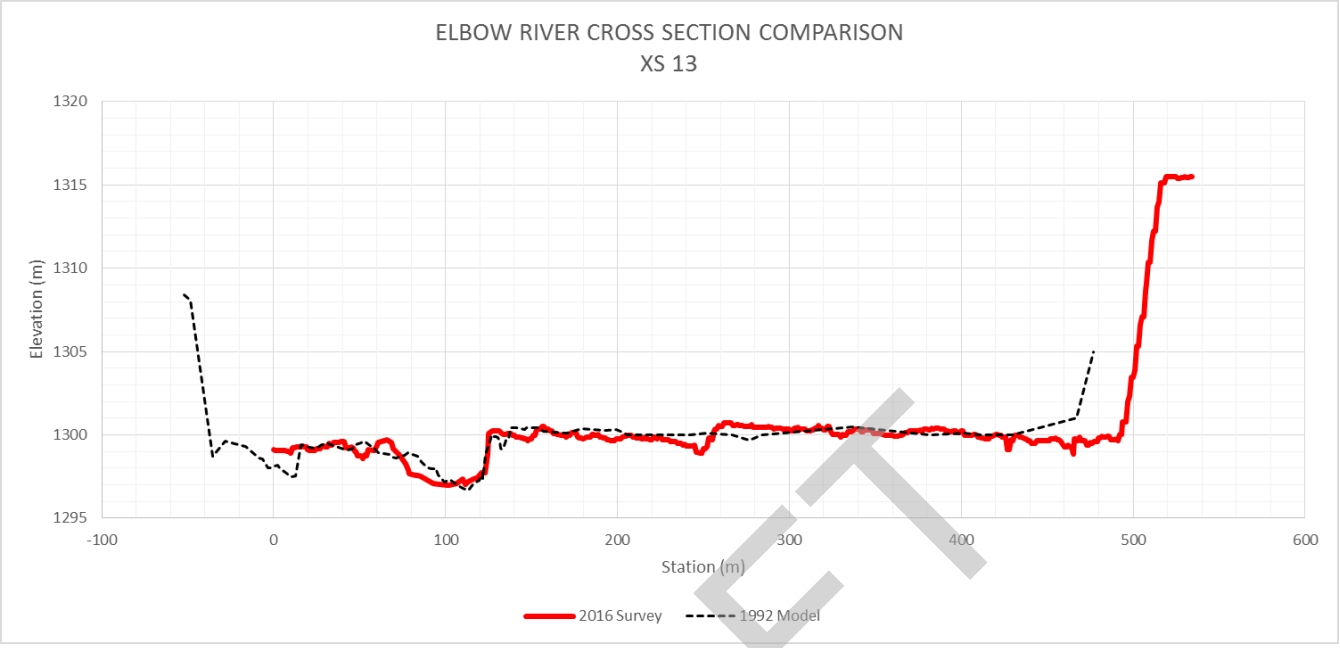


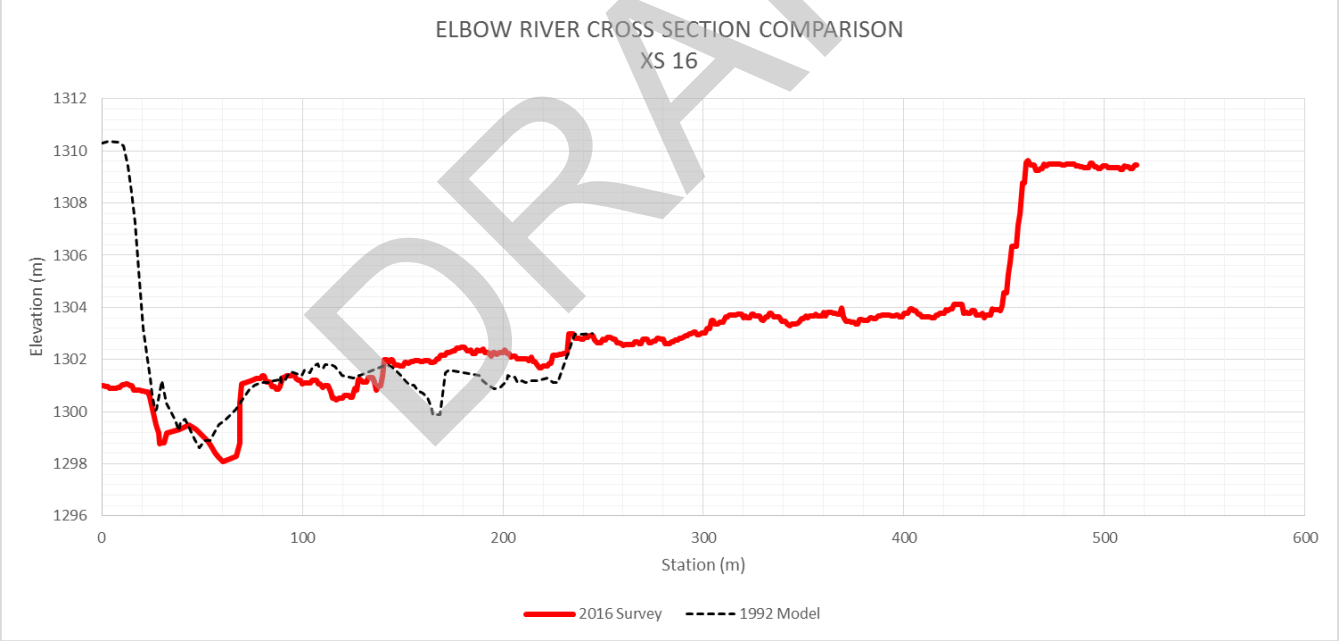


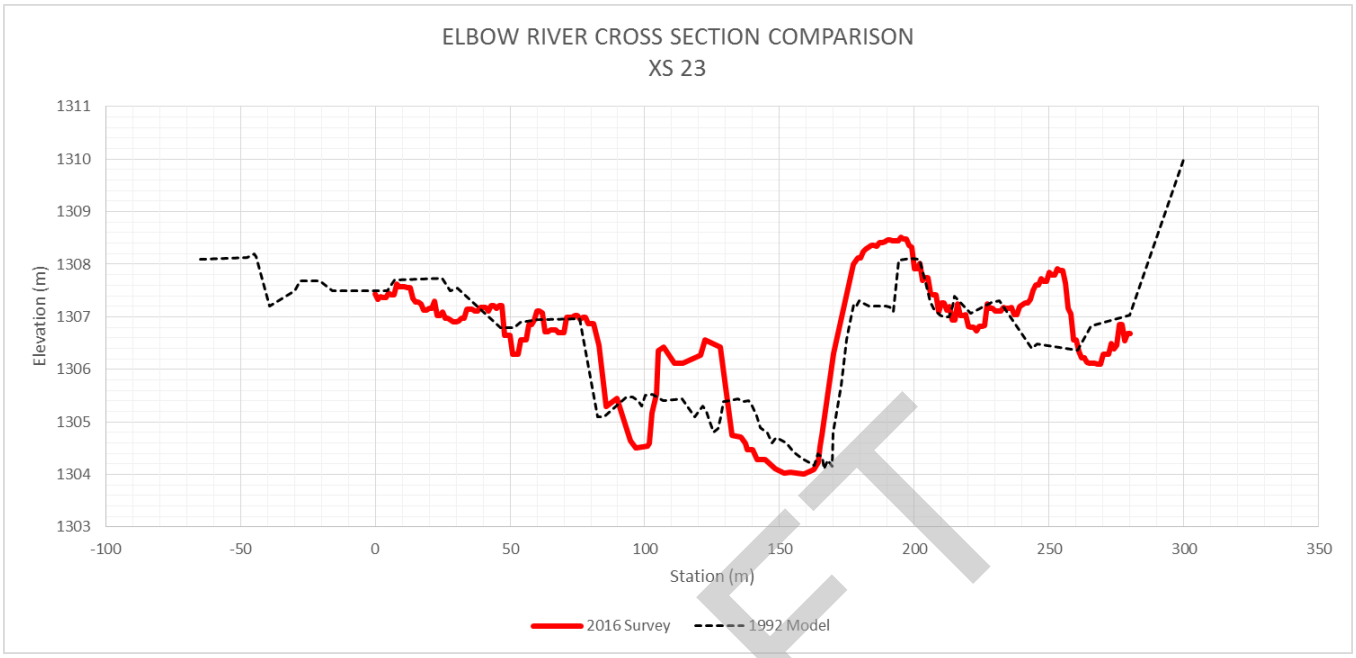


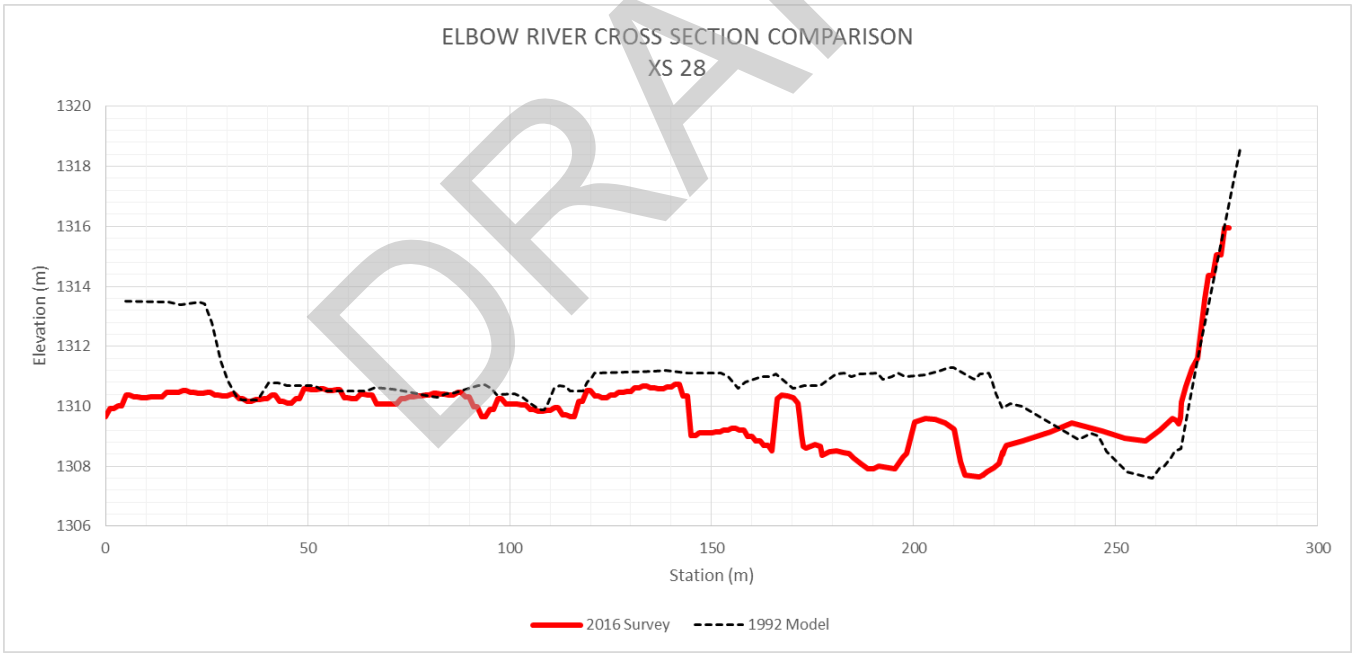


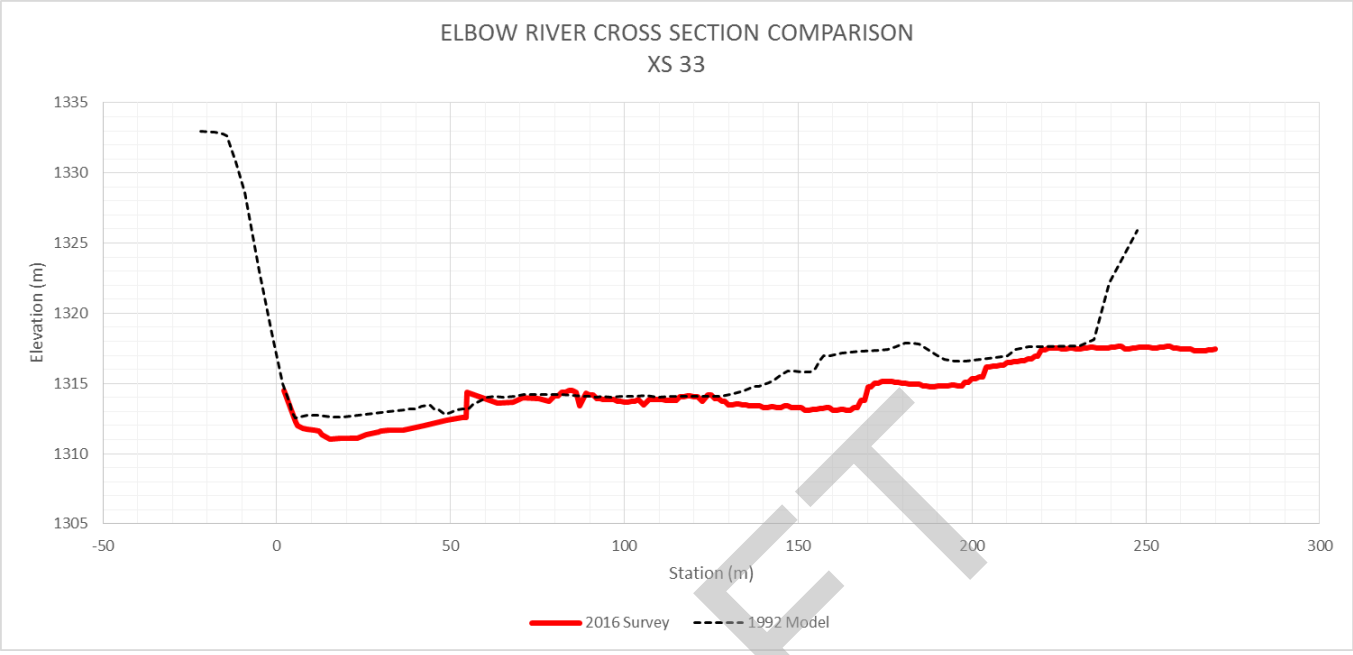


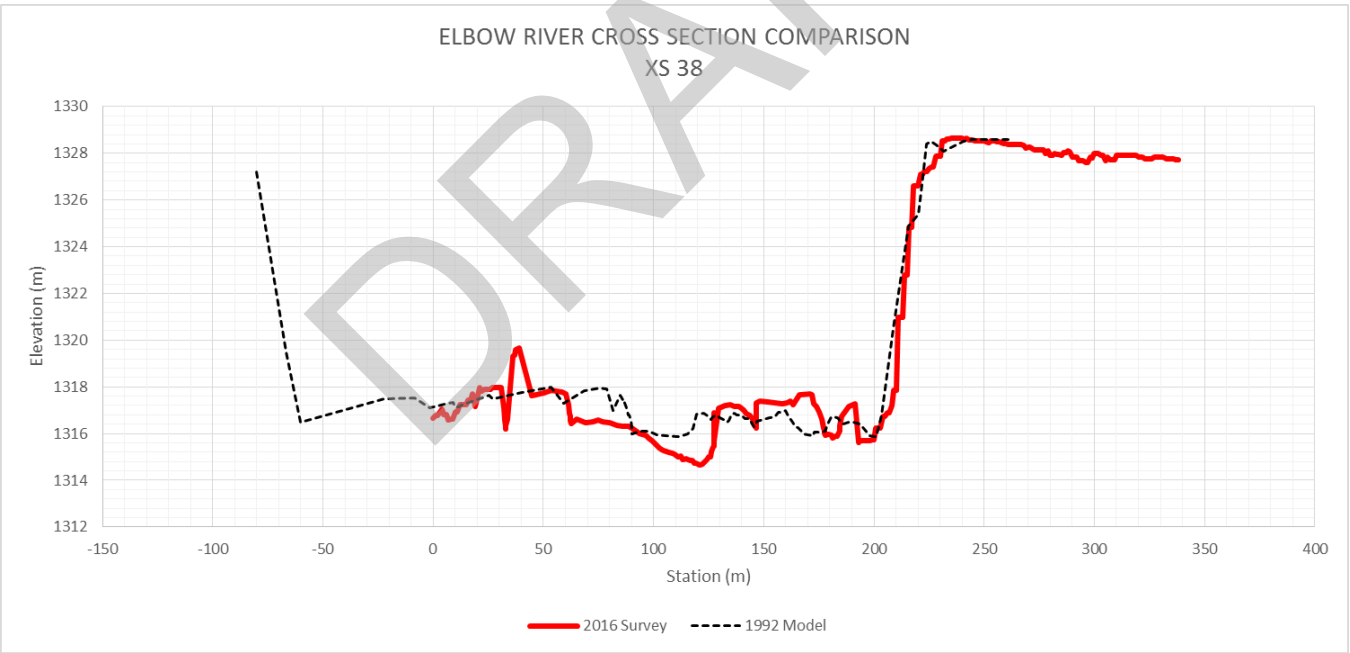




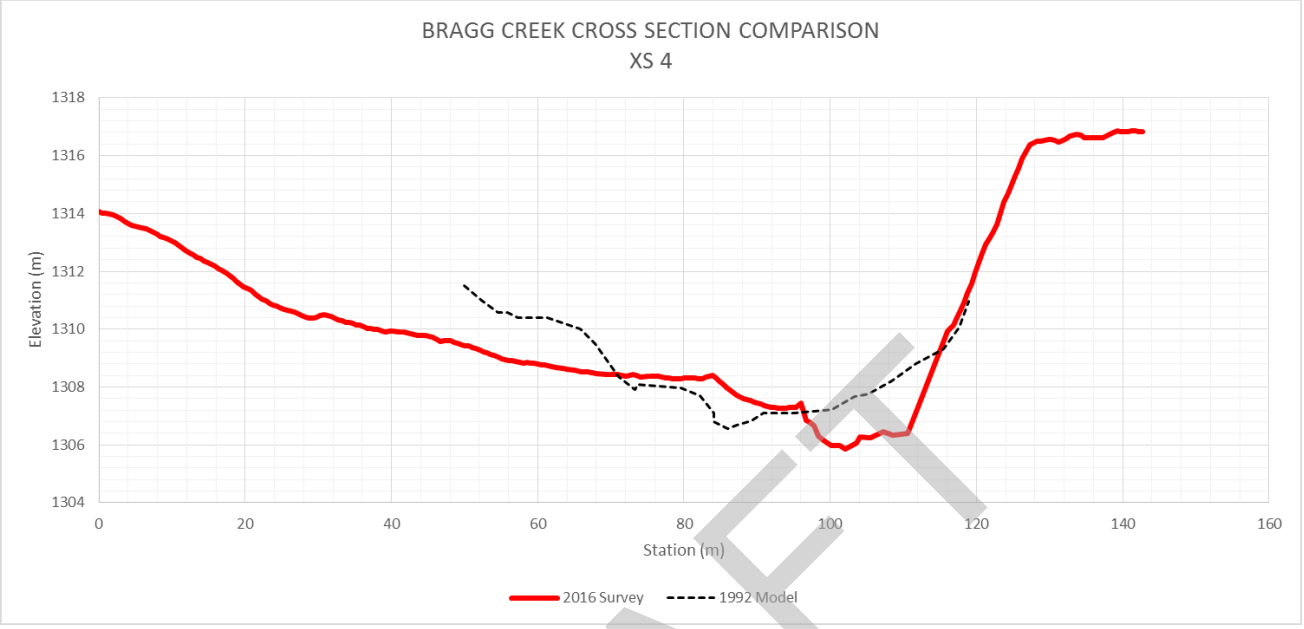


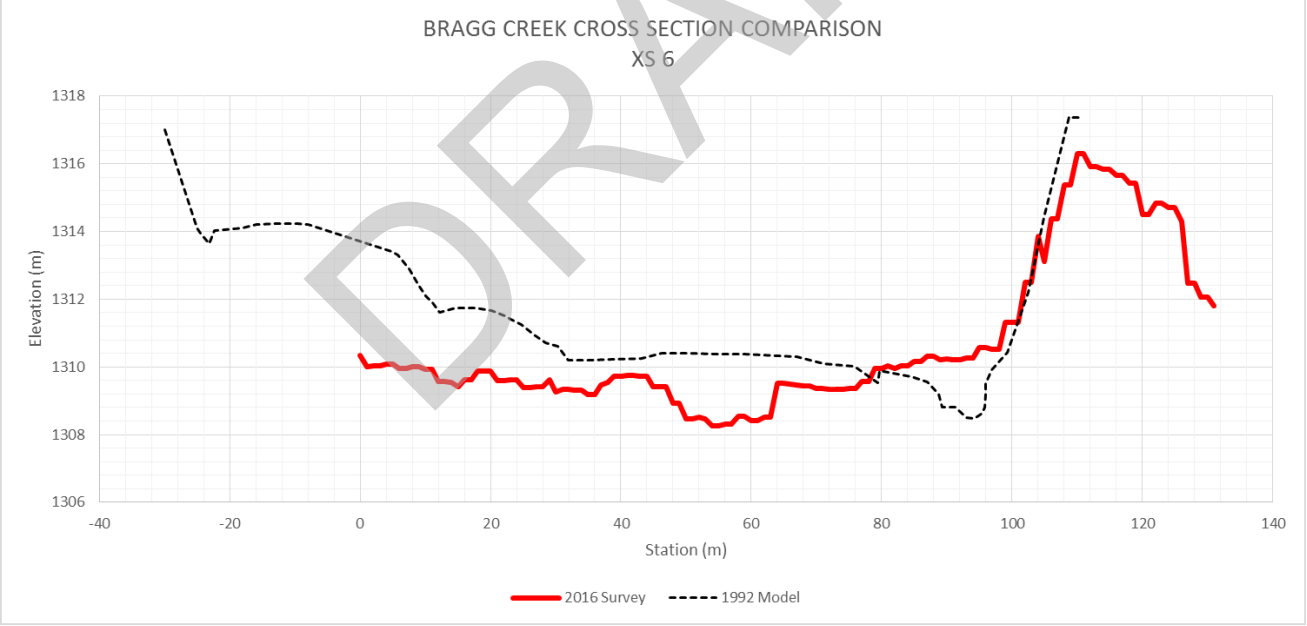






5.0 REACH 5: BRAGG CREEK





APPENDIX B

Historical Aerial Imagery Processing Memorandum

TECHNICAL MEMORANDUM

DATE May 29, 2018 **PROJECT No.** 1536673 TM005, Rev. 0

TO Peter Onyshko, Project Manager
Alberta Environment and Parks (AEP)

CC Dejiang Long, Wolf Ploeger and Vanessa Vallis (Golder)

FROM Rowland Atkins, Golder Associates Ltd. (Golder) **EMAIL** wolf_ploeger@golder.com

BOW AND ELBOW RIVER HAZARD STUDY
HISTORICAL AERIAL IMAGERY PROCESSING MEMORANDUM

1.0 INTRODUCTION

The Channel Stability Investigation component of the Bow and Elbow 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 processing the historical aerial imagery with the aerial triangulation and stereo-model tasks outsourced to Tarin Resource Services Ltd. (Tarin). This memorandum provides an overview of the processing methodology, the results of quality assurance checks, and description of historical aerial imagery deliverables.

2.0 METHODOLOGY

The historical aerial images selected for use in the Bow and Elbow River Hazard Study were obtained from Alberta Environment and Parks (AEP) in June 2016 and processed according to the specifications stated in the project Terms of Reference (TOR) and the provincial *General Specifications for Acquiring Aerial Photography* (April 2015) guidelines document. Photos from 1950 and 1951 were chosen to cover most of the streams in the study area. As some photos from the 1950s were severely damaged, additional photos from 1962 were obtained to fill gaps in coverage. Additional photos from 1966 and 1999 were obtained for the Lott Creek area, where the stream has been heavily modified. Table 1 provides an overview of the photography used, images scale, and acquisition dates.

Associated camera calibration reports were also provided by AEP. Specific lenses used for the 1950s photographic surveys were unknown or not recorded, thus focal lengths were estimated without knowing which specific lens was used. The estimated focal length used was the average calibrated value for the five lenses used during the same time period in the provided calibration reports: 152.7 mm (also the most frequently noted length). All other years of imagery were processed using the associated camera calibration reports and calibrated focal lengths.

The raw greyscale images were reviewed for quality assurance and spatial coverage of the project area. Overall, there was some variability in the quality and consistency of the images provided by AEP. Most images were provided in a high quality scanned .TIF format. Some photos had photogrammetric stretches previously applied or had been scanned from a desktop scanner (rather than a photogrammetric scanner). Many of the photos from 1950/1951 had been scanned from scratched or torn negatives (repaired with tape), had annotations marked on the image, or were missing clear fiducial markings. Although image artefacts and defects were noted, these were deemed to be acceptable due to the vintage of the project photography.

Table 1: Historical Imagery Processed for the Bow and Elbow River Hazard Study

Extent	Photo Year	Photo Scale	Film Roll No.	Frames used in orthomosaic	Frames processed for AT	Acquisition date(s)
Bow River, Elbow River, and Bragg Creek Study Areas	1950	1: 40,000	AS0167	66, 67, 68,	65, 66, 67, 68	6/09/1950
			AS0168	25, 26, 27, 28, 29, 30, 35, 36, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167	25, 26, 27, 28, 29, 30, 35, 36, 37	6/09/1950 and 7/09/1950
					158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168	6/09/1950 and 7/09/1950
	1951		AS0169	None	3,4,5	6/14/1951
	1950			129, 130, 140, 139, 138,137	128, 129, 130, 137, 138, 139, 140, 141	4/30/1950 and 5/12/1950
				17, 19, 21,	16, 17, 18, 19, 20, 21, 22, 23	4/30/1950 and 5/12/1950
			AS0170	99, 101, 103,	98, 99, 100, 101, 102, 103, 104	4/30/1950
	1962	1: 31,680	AS0830	None	89, 90, 91	9/19/1962
			AS0831	178, 179, 180	178, 179, 180, 181, 182, 183	9/19/1962
			AS0831	33, 34, 35	33, 34, 35, 36	9/19/1962
			AS0833	None	62, 63, 64, 65, 66, 67	10/01/1962
Lott Creek Study Area	1966	1: 31,680	AS0954	236, 237	235, 236, 237, 238	8/09/1966
	1999	1: 20,000	AS5053	111, 112,113, 114	110, 111, 112, 113, 114, 115	7/11/1999

Images with normal fiducial markings were orthorectified by Golder using PCI OrthoEngine Software (v10.3) and the AltaLIS 1:20,000 scale digital elevation model (DEM). Any images without clearly marked fiducials were orthorectified by Tarin using OrthoMaster software by Trimble Inpho and the same AltaLIS 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, six to eight features suitable as ground control points (GCP) were identified on each image with tie points used to tie adjacent images together. GCPs were typically anthropogenic features such as roads, trails and buildings. However, it was necessary to use natural features in some areas where roads were absent. The root mean squared error (RMSE) of the 1950s GCP data was typically within 5.05 (X) to 5.13 (Y) image pixels, with a few outliers exceeding this. Initially the RMSE of the 1950s imagery was considerably higher, however, GCPs and tie points were adjusted to reduce the RMSE and improve results as best as possible. Due to amount of damage, tape-repaired tears, and the presence of poorly marked fiducials; this RMSE can be considered very good. For comparison, GCPs used to orthorectify images had an RMSE of 4.84 (X) to 3.61 (Y) image pixels in 1962, 3.73 (X) to 5.15 (Y) image pixels in 1966 and 1.20 (X) to 1.31 (Y) image pixels in 1999.

Air photos from the 1950s with a scale of 1:40,000 were orthorectified to produce 80 cm resolution orthophotos covering most of the study area. Additional photos from 1962 with a scale of 1:31,680 were orthorectified to produce 64 cm resolution orthophotos, which were used to cover gaps in the 1950s imagery coverage. Depending on the amount of overlap, image margins were cropped to remove 5% to 30% 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.

Following the same methodology as described above, air photos for the Lott Creek study area were orthorectified and cropped to remove image margins. These air photos had scales of 1:31,680 (1966) and 1:20,000 (1999) and produced 64 cm and 45 cm resolution orthophotos respectively.

Orthorectified photos were reviewed on screen at a scale of 1:10,000 in order to check the positional accuracy, then adjacent images were mosaiced together using ENVI (v5.3) software. Note that no 1951 images were used to produce the 1950 mosaic. All historical orthomosaics were produced using automated colour balancing to match the colour of adjacent images based on the statistics of the overlapping regions. Each historical orthomosaic was produced using a cubic convolution resampling method and an output resolution of 80 cm (1:40,000 scale), 64 m (1:31,680 scale) or 45 cm (1:20,000 scale), as dependant on the original image scale. Each completed orthomosaic was then split into single township tiles and populated with metadata. Index maps of the historical orthomosaic tiles are attached as Appendices A through D.

The aerial triangulation (AT) data processed by Tarin were created using PHOTOMOD (v6 Lite x64) software in conjunction with recent May 2016 aerial imagery, which was used to identify GCP locations. The AT process was completed in separate blocks for northern and southern 1950/1951 and 1962 photos, and the bundle adjustment accuracy was set to 'high accuracy' which runs up to ten iterations. The overall accuracy can be estimated by using the sigma naught value, which was between 2.210 (south) and 2.350 (north) in 1950/1951, 1.054 (north) and 0.585 (south) in 1962, 0.58 in 1966, and 0.78 in 1999. 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 by Year and Block

	1950/1951 North				**1950/1951 South**			
	X	**Y**	**Z**	**Exy (m)**	**X**	**Y**	**Z**	**Exy (m)**
GCP RMSE:	0.477	0.348	0.134	0.59	0.474	0.427	0.292	0.639
Tie Point RMSE (on images):	0.053	0.047	N/A	0.071	0.053	0.044	N/A	0.068
Sigma naught:	**2.35**				**2.21**			
	1962 North				**1962 South**			
	X	**Y**	**Z**	**Exy (m)**	**X**	**Y**	**Z**	**Exy (m)**
GCP RMSE:	0.589	0.523	0.183	0.788	0.232	0.486	0.084	0.539
Tie Point RMSE (on images):	0.012	0.009	N/A	0.015	0.002	0.005	N/A	0.005
Sigma naught:	**1.054**				**0.585**			
	1966				**1999**			
	X	**Y**	**Z**	**Exy (m)**	**X**	**Y**	**Z**	**Exy (m)**
GCP RMSE:	0.961	0.604	0.527	1.135	0.281	0.228	0.139	0.362
Tie Point RMSE (on images):	0.003	0.004	N/A	0.005	0.001	0.004	N/A	0.004
Sigma naught:	**0.578**				**0.783**			

3.0 RESULTS

Each tiled orthomosaic was reviewed on-screen at a scale of 1:10,000 with additional spot checks made 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 recent May 2016 aerial imagery collected for the Bow and Elbow River Hazard Study. In some cases where roads and land use had changed significantly, it was necessary to check 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. Most linear features are continuous across mosaic seams; however, a few exceptions were noted. An attempt was made to correct this issue; however, it was determined that the AltaLIS DEM was not detailed enough to improve the results, or that the image was too warped to achieve better results. An example of the historical and modern imagery alignment is shown in Figure 1.

All tiles in the 1950 mosaic were found to be accurate within 6 m at least 90% of the time, when stationary features free of modifications were measured. Positional errors greater than 6 m may exist near Glenmore Reservoir and along the Bow River near the community of Riverbend, and the 1962 mosaic should be used instead of 1950s imagery in these areas. Errors may also exceed 6 m in areas with steep or complex terrain.

The positional accuracy of 1962 imagery was found to be accurate within 5 m at least 90% of the time, when stationary features free of modification were measured. Likewise the accuracy of 1966 and 1999 Lott Creek imagery was found to be accurate within 5 m at least 90% of the time. Some road features were difficult to compare due to the widening and straightening of the routes over time.

The automated colour balancing used to produce the orthomosaics was not able to completely minimize the appearance of seams between images. Some areas 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. Additionally, some of the provided images had limited snow cover (e.g., images acquired on April 30, 1950), which further complicated the colour balancing process. Overall, considering the age and variable quality of the provided images, all orthomosaics were assessed to be very good.

Figure 1: Example of an Orthomosaic Quality Assurance Check at 1:5,000 Scale
(The historical 1950 orthomosaic (greyscale image; at left) is peeled back to reveal the modern landscape (colour image; at 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 stereomodel (external orientation) files using the Purview Extension for Esri ArcGIS (v10.2) to ensure that the requested models yielded a satisfactory visual effect when viewed in 3D view software. It was not possible to check the stereomodels created in other software specific formats (DATEM, SOCET SET and ZI), 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 specifications. Metadata files for each image were also checked for completeness in Esri ArcCatalog® (v10.2).

4.0 DELIVERABLES

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

- Tiled historical 1950 and 1962 orthomosaics (patch) covering the Bow River, Elbow River, and Bragg Creek study areas, accompanied by metadata;
- Tiled historical 1966 and 1999 orthomosaics covering the Lott Creek study area, accompanied by metadata;
- Aerial triangulation image adjustment reports for historical images; and
- Aerial triangulation (external orientation) data in plain text, DATEM, SOCET SET, 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 Wolf Ploeger at (403) 216-8934.

Yours truly,

GOLDER ASSOCIATES LTD.

Prepared by:

Original signed by

Wolf Ploeger, Dr.-Ing.
Associate, Senior Water Resources Specialist

Reviewed by:

Original signed by

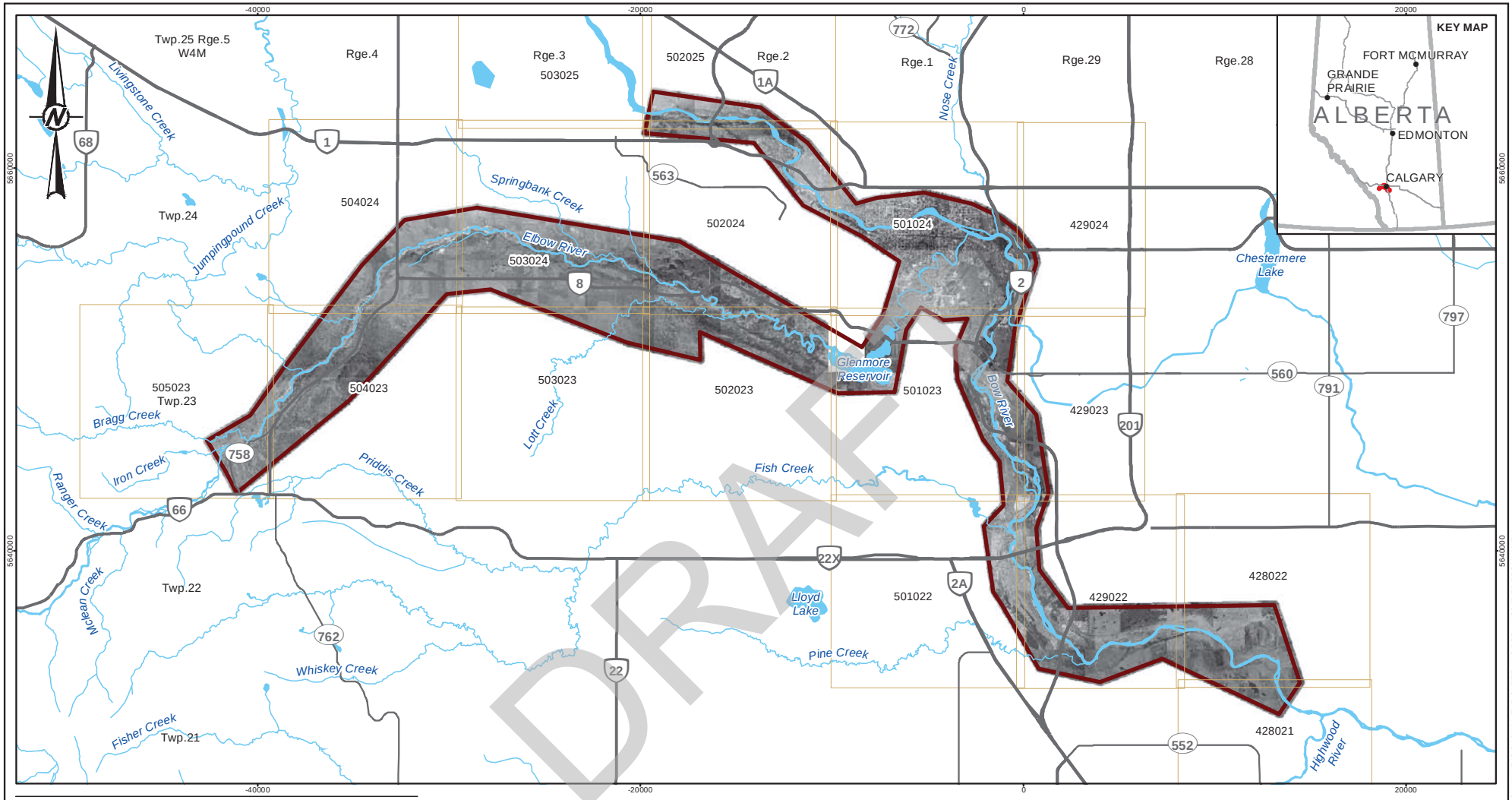
Rowland Atkins, M.Sc., P.Geo
Associate, Senior Geomorphologist

WP/RA/crm/al

APPENDIX A

1950 Historical Orthomosaic Index Map

PATH: I:\2015\1536673\Mapping\MXD\Aerial_Imagery_memo\Historical_1950_orthomosaic_overview_Rev0.mxd PRINTED ON: 2017-07-11 AT: 4:45:31 PM



LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- ORTHOPHOTO TILE
- PROJECT STUDY AREA
- PROJECT LOCATION
- WATERBODY

NOTE: ORTHOMOSAIC TILE NAMES ARE SHOWN WITH ABBREVIATED FILE NAMES FOR MAPPING PURPOSES.

0 5,000 10,000

1:300,000 METRES

REFERENCE(S)

1. TRANSPORTATION FEATURES OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
2. TOWNSHIP DATA OBTAINED FROM © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.
3. HYDROLOGY DATA OBTAINED FROM IHS ENERGY INC.
4. 80 CM BOW AND ELBOW RIVER ORTHOMOSAIC PRODUCED FROM IMAGES ACQUIRED BETWEEN APRIL 30, 1950 AND JULY 9, 1950.
5. COORDINATE SYSTEM: CSRS 3TM 114 DATUM: NAD 83

CLIENT
ALBERTA ENVIRONMENT AND PARKS

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-07-11
DESIGNED	V. VALLIS
PREPARED	V. VALLIS
REVIEWED	W. PLOEGER
APPROVED	D. LONG

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
1950 ORTHOMOSAIC INDEX MAP

PROJECT NO.	CONTROL	REV.	FIGURE
1536673	7000	0	A

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

25mm

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APPENDIX B

1962 Historical Orthomosaic Index Map

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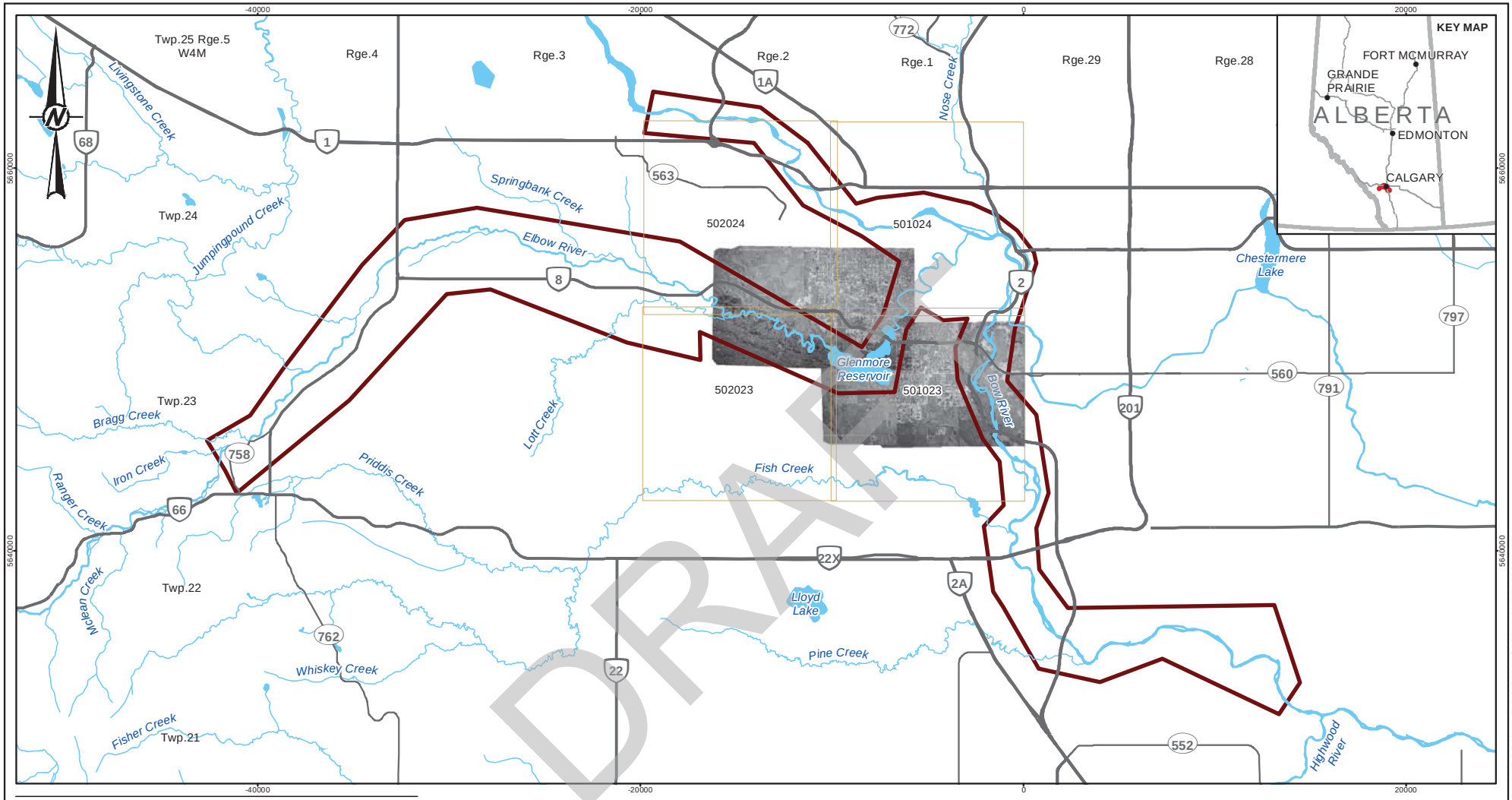

LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- ORTHOPHOTO TILE
- PROJECT STUDY AREA
- PROJECT LOCATION
- WATERBODY

NOTE: ORTHOMOSAIC TILE NAMES ARE SHOWN WITH ABBREVIATED FILE NAMES FOR MAPPING PURPOSES.

0 5,000 10,000

1:300,000 METRES

REFERENCE(S)

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2. TOWNSHIP DATA OBTAINED FROM © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.
3. HYDROLOGY DATA OBTAINED FROM IHS ENERGY INC.
4. 64 CM BOW AND ELBOW RIVER ORTHOMOSAIC PATCH PRODUCED FROM IMAGES ACQUIRED BETWEEN SEPTEMBER 19, 1962 AND OCTOBER 1, 1962.
5. COORDINATE SYSTEM: CSRS 3TM 114 DATUM: NAD 83

CLIENT
ALBERTA ENVIRONMENT AND PARKS

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-07-11
DESIGNED	V. VALLIS
PREPARED	V. VALLIS
REVIEWED	W. PLOEGER
APPROVED	D. LONG

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
1962 ORTHOMOSAIC INDEX MAP

PROJECT NO.	CONTROL	REV.	FIGURE
1536673	7000	0	B

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

25mm

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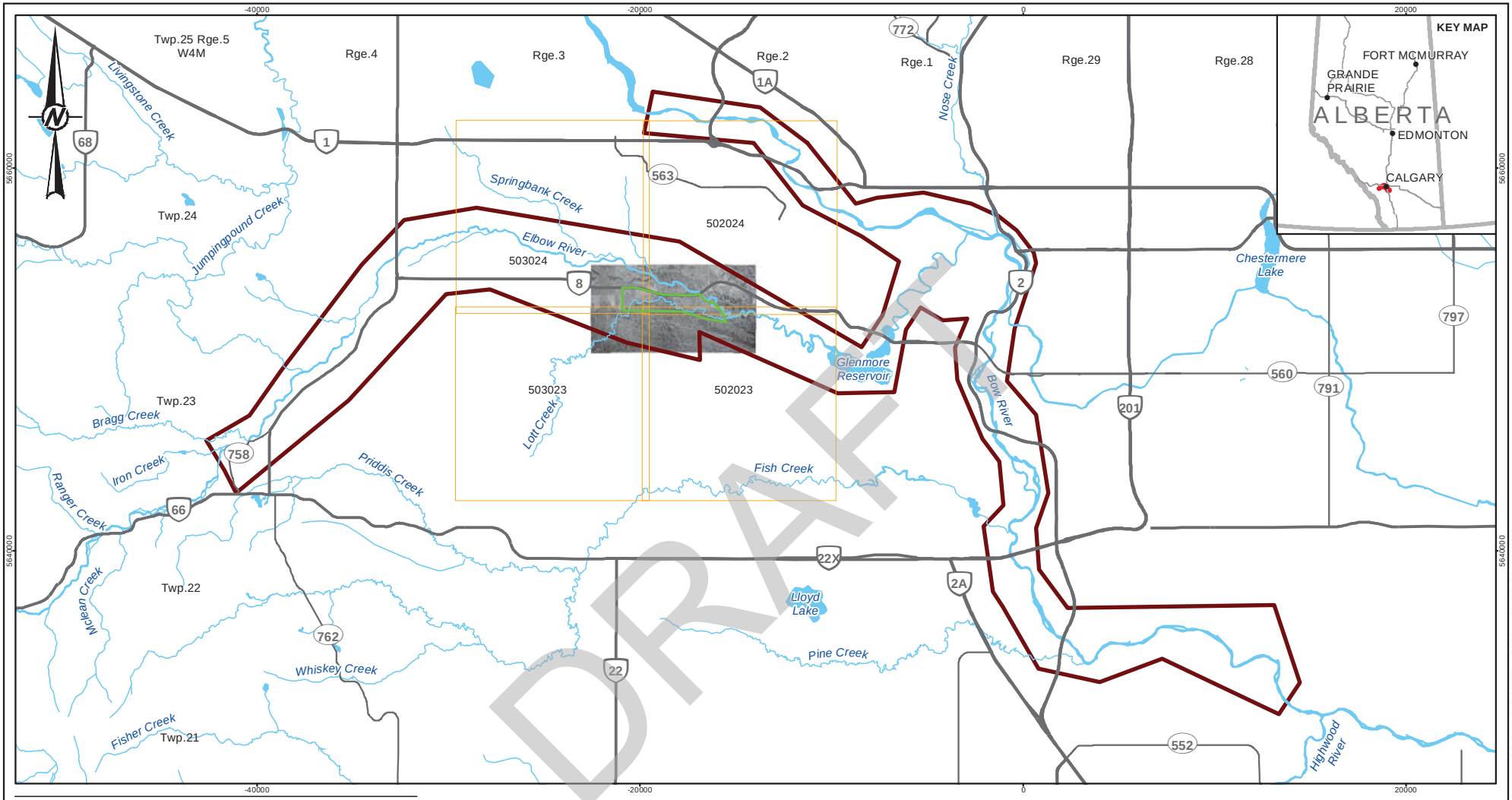
APPENDIX C

1966 Historical Orthomosaic Index Map – Lott Creek

PATH: I:\2015\1536673\Mapping\MXD\Aerial_Imagery_memo\Lott_Creek_1966_Historical_orthomosaic_index_Rev0.mxd PRINTED ON: 2017-07-11 AT: 4:55:20 PM



LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOTT CREEK STUDY AREA
- ORTHOPHOTO TILE
- PROJECT STUDY AREA
- PROJECT LOCATION
- WATERBODY

NOTE: ORTHOMOSAIC TILE NAMES ARE SHOWN WITH ABBREVIATED FILE NAMES FOR MAPPING PURPOSES.

0 5,000 10,000

1:300,000 METRES

REFERENCE(S)

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2. TOWNSHIP DATA OBTAINED FROM © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.
3. HYDROLOGY DATA OBTAINED FROM IHS ENERGY INC.
4. 64 CM LOTT CREEK ORTHOMOSAIC PRODUCED FROM IMAGES ACQUIRED ON AUGUST 9, 1966.
5. COORDINATE SYSTEM: CSRS 3TM 114 DATUM: NAD 83

CLIENT
ALBERTA ENVIRONMENT AND PARKS

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-07-11
DESIGNED	V. VALLIS
PREPARED	V. VALLIS
REVIEWED	W. PLOEGER
APPROVED	D. LONG

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
1966 LOTT CREEK ORTHOMOSAIC INDEX MAP

PROJECT NO.	CONTROL	REV.	FIGURE
1536673	7000	0	C

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

25mm

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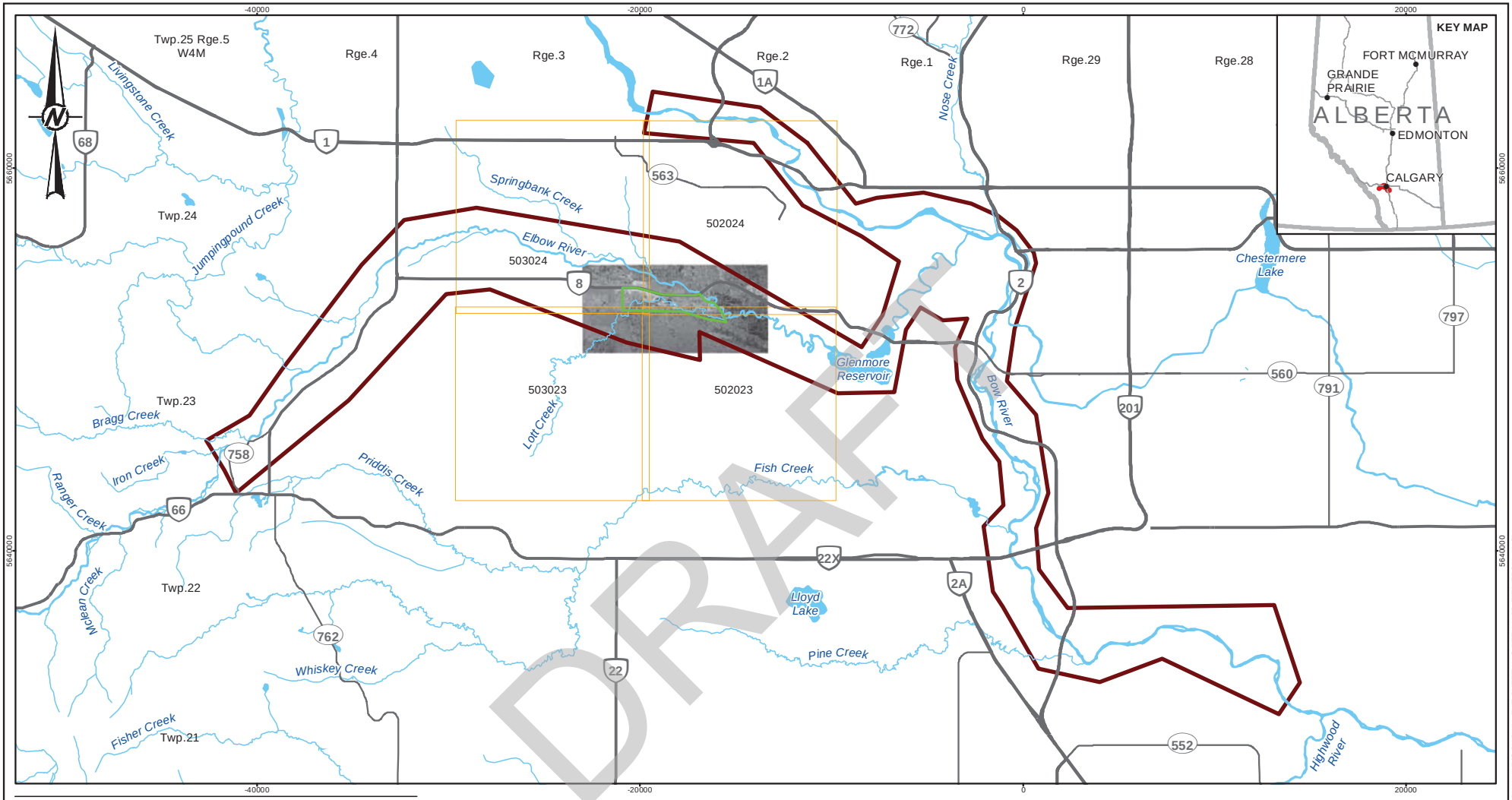
APPENDIX D

1999 Historical Orthomosaic Index Map – Lott Creek

PATH: I:\2015\1536673\Mapping\MXD\Aerial_Imagery_memo\Lott_Creek_1999_Historical_orthomosaic_index_Rev0.mxd PRINTED ON: 2017-07-11 AT: 5:06:03 PM



LEGEND

- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOTT CREEK STUDY AREA
- ORTHOPHOTO TILE
- PROJECT STUDY AREA
- PROJECT LOCATION
- WATERBODY

NOTE: ORTHOMOSAIC TILE NAMES ARE SHOWN WITH ABBREVIATED FILE NAMES FOR MAPPING PURPOSES.

0 5,000 10,000

1:300,000 METRES

REFERENCE(S)

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2. TOWNSHIP DATA OBTAINED FROM © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.
3. HYDROLOGY DATA OBTAINED FROM IHS ENERGY INC.
4. 45 CM LOTT CREEK ORTHOMOSAIC PRODUCED FROM IMAGES ACQUIRED ON JULY 11, 1999.
5. COORDINATE SYSTEM: CSRS 3TM 114 DATUM: NAD 83

CLIENT
ALBERTA ENVIRONMENT AND PARKS

CONSULTANT
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YYYY-MM-DD	2017-07-11
DESIGNED	V. VALLIS
PREPARED	V. VALLIS
REVIEWED	W. PLOEGER
APPROVED	D. LONG

PROJECT
BOW AND ELBOW RIVER HAZARD STUDY

TITLE
1999 LOTT CREEK ORTHOMOSAIC INDEX MAP

PROJECT NO.	CONTROL	REV.	FIGURE
1536673	7000	0	D

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

25mm

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