SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

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EXECUTIVE SUMMARY

The Sheep River Hazard Study evaluates river and flood hazards along approximately 50 km of the Sheep River, and 35 km of Threepoint Creek in the Municipal District of Foothills No. 31, the Towns of Black Diamond, Turner Valley and Okotoks and the Hamlet of Millarville. This report covers the channel stability investigation, which is one component of the overall study.

The dominant pattern of planform channel changes from 1951 to 2015 involves the uppermost parts of Sheep River and Threepoint Creek showing the smallest changes whereas larger changes appear below the downstream boundary of the foothills. Above this boundary, the streams are to a greater extent hemmed in within narrow bedrock-controlled valleys, while below, the valleys open up with larger floodplains where the channels are afforded greater opportunity to migrate. If the parts of these streams between their confluence and the downstream edge of the foothills are isolated, reductions in channel length of about 20% for Sheep River and 5% for Threepoint Creek are indicated from 1951 to 2015, and a Landsat image revealed that most of these length changes had already occurred by July 1990. Although the most dramatic channel changes have occurred downstream of the foothills, dynamic behaviour is observed throughout the study area. Relatively stable segments are present locally, where in some cases engineering or geological controls may have restricted migration. System wide, 38% of the 2015 channel segments can be thought of as having been relatively stable, with no deviations exceeding 30 m from the 1951 centreline. Stable channel segment percentages found along the upper and lower Sheep River reaches and along Threepoint Creek are 44, 39 and 30%, respectively.

Historical cross-sections on Sheep River near the communities of Okotoks and Black Diamond – Turner Valley have been examined to document major geomorphic changes that have occurred from 1992 to 2016. Changes observed in each reach tend to be different and are reflective of different channel conditions at these locations. At the most upstream reach, near Turner Valley, the main cross section classification is one that shows changes dominated by lateral migration of the channel across the floodplain. The cross sections showed both increases and decreases in bankfull area and width, illustrating that the channel is highly variable. Further downstream at Black Diamond, the main trend in the cross-sections showed increases in the bankfull area and a tendency for the main channel to be dominated by downcutting of the thalweg. At Okotoks, the cross sections tended to show the same trend as Black Diamond with downcutting of the thalweg but differing in that the main trend was for the bankfull areas and widths to decrease throughout this reach along with downcutting of the channel.

The thalweg comparison showed that the thalweg has undergone downcutting on the Sheep River at Okotoks and Black Diamond – Turner Valley. The largest rates of downcutting occurred near the communities of Okotoks and Black Diamond, with the river in Turner Valley showing the least amount of downcutting and even some aggradation in places. The overall trend at both Okotoks and Black Diamond – Turner Valley is for both channel reaches to have increased in slope, which is consistent with channel morphology mapping from historical imagery. However, at a larger scale changes in slope tend to be more variable.

The rating curve analysis shows that the channel at both Okotoks and Black Diamond – Turner Valley aggrades and downcuts over time. The most variable locations were Sheep River at Black Diamond and Threepoint Creek near Millarville. The hydrometric gauges at these locations showed the most dynamic morphological changes in the channel. The hydrometric gauge at Okotoks on Sheep River showed significantly less change, but the period of record on this station only extends from 2007-2014, a much smaller period than at the other two gauges.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

1 INTRODUCTION

The purpose of the Sheep River Hazard Study is to assess and identify river and flood hazards along approximately 50 km of the Sheep River, and 35 km of Threepoint Creek in the Municipal District of Foothills No. 31, the Towns of Black Diamond, Turner Valley and Okotoks and the Hamlet of Millarville (Map 1). This report covers the channel stability investigation, which is one component of the overall study.

1.1 STUDY BACKGROUND

The study was completed 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 provincial government, local authorities, and the public.

Originally, the study was initiated in September 2015 by AMEC Foster Wheeler (AFW). The contract ended before the work was finished and Alberta Environment and Parks (AEP) reissued the study to Hatch Ltd. and their subconsultants in December 2017.

1.2 STUDY OBJECTIVES

The primary tasks, services, and deliverables of the channel stability investigation component include:

- Channel Centreline Comparison
- Cross Section & Thalweg Profile Comparison
- Rating Curve Comparison

The objectives of this component are to provide qualitative insight and limited quantitative information about general channel stability along the study reach. This was accomplished by comparing current and historical channel centrelines, cross sections, thalweg profiles and rating curves. A comprehensive study of bank erosion or channel migration rates is not the intended outcome of this component, and not within the project scope.

1.3 STUDY AREA & REACH

The study area identified for the channel stability investigation is identified as the lowest 50 km of the Sheep River and the lowest 35 km of Threepoint Creek (Map 1, Figure 1). Sheep River and Threepoint Creek are in southwest Alberta, situated southwest of Calgary. These streams drain into Highwood River, which eventually drains into the Bow River, forming part of the larger South Saskatchewan River basin.

The Sheep River study reach extends from its confluence with the Highwood River, upstream to the west boundary of Section 20-19-03-W5M. The communities of Okotoks, Black Diamond and Turner Valley are located along the Sheep River study reach.

The community of Millarville is located near the reach of Threepoint Creek that is being studied. Threepoint Creek flows into Sheep River downstream of Black Diamond. The portion of Threepoint Creek within the study area extends 35 km upstream from the Threepoint Creek / Sheep River confluence, through and beyond the community of Millarville.

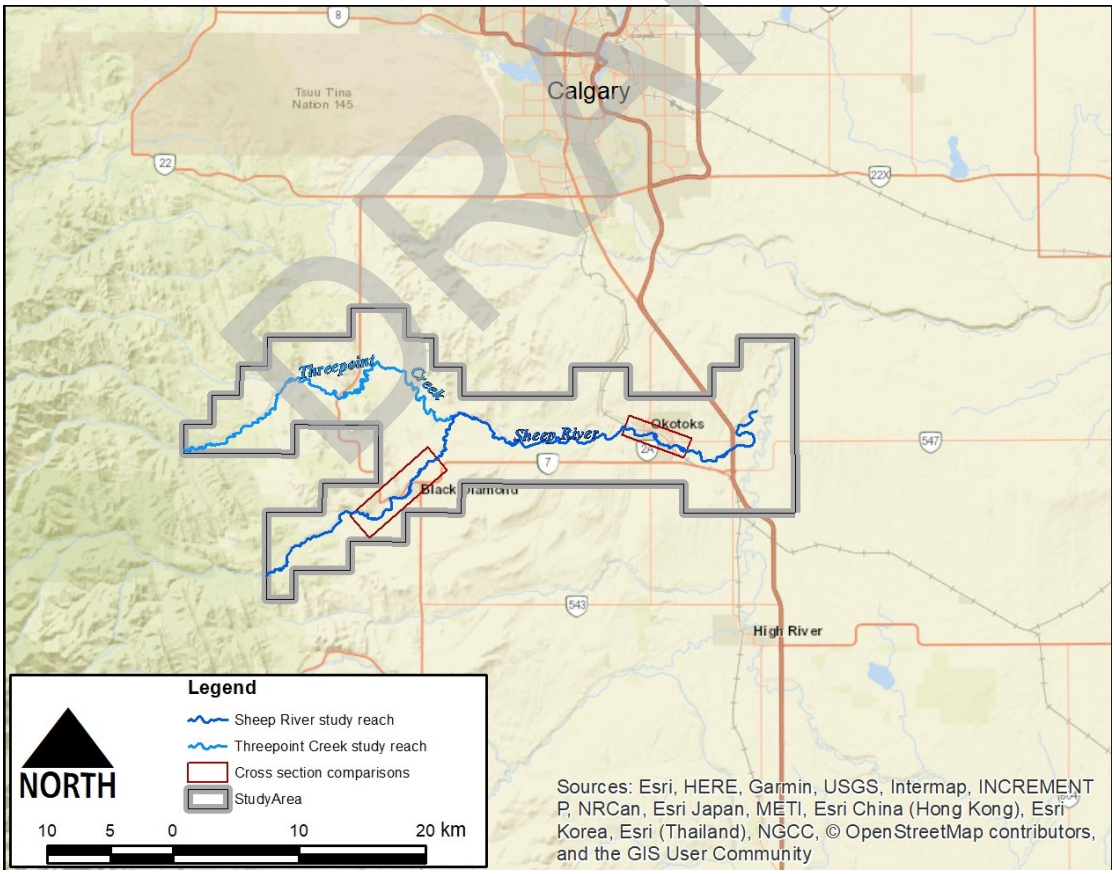

Figure 1: Overview map of the study area

2 AVAILABLE DATA

Data used for the channel stability investigation report were supplied by Alberta Environment and Parks (AEP). AEP obtained these data from the report *Sheep River Hazard Study Survey and Base Collection Report* – Prepared by AFW (February 2017). In some instances, additional data sources were sought, or datasets were updated from more current or accurate sources.

2.1 AERIAL AND SATELLITE IMAGERY

All aerial imagery listed in Table 1 conforms to AEP's *General Specifications for Acquiring Aerial Photography* (April 2015) using the appropriate local 3-Degree Transverse Mercator (3TM) Zone, referenced to NAD83 (CSRS) horizontally and was previously selected by AFW for this study. See AFW's report *Sheep River Hazard Study Survey and Base Collection Report* (2017) for more details on aerial imagery specifications. In addition to the aerial imagery acquired specifically for this project (Table 1), freely available satellite imagery covering the full extent of the study area were reviewed, including 2015 colour imagery (50 cm resolution) served by Environmental Research Systems Incorporated (ESRI) as well as multispectral Landsat imagery of various vintages ranging from 1985 to 2018 (Table 2).

Table 1: Aerial imagery reviewed in this study

Acquisition date	Raster depth	Resolution	River reach
October 10, 1951	Three band, 8-bit	90 cm	Sheep River, Threepoint Creek
June 19, 2005	Single band, 8-bit	25 cm	Sheep River
June 19, 2005	Single band, 8-bit	25 cm	Threepoint Creek
June 23, 2013	Three band, 8-bit	16 cm	Sheep River
September 10, 2013	Three band, 8-bit	20 cm	Sheep River, Threepoint Creek
April 20, 2016	Three band, 8-bit	30 cm	Sheep River, Threepoint Creek

Table 2: Selection of satellite imagery reviewed in this study

Acquisition date	Source	Resolution	Data type
2015	ESRI	50 cm	Colour visible
08 Jul 1990	NASA	10-30 m	Panchromatic and multispectral
10 Jul 2014	NASA	10-30 m	Panchromatic and multispectral
22 Aug 2018	NASA	10-30 m	Panchromatic and multispectral

2.2 CROSS SECTION DATA

Initial cross section data were provided by AEP. Cross sections were provided as a PDF document titled *Channel Stability Investigation – Interim Deliverable Cross Section and Thalweg Profile* Comparison (April 18, 2017) and as in spreadsheet format.

JDMA updated cross section data at select locations from data provided from the HEC-RAS 5.0.5 geometry file, *SheepRiverHazard.g24*, in the hydraulic model for the study reach that was prepared by Hatch Ltd. (June 28, 2018). The updated JDMA cross sections were created to show a representative sampling of cross sections across the reach. For the qualitative analysis (see Section 3.2), the full set of AFW's cross sections were used and for the quantitative analysis the updated JDMA cross sections were used.

Sufficient historical cross section data for comparison are only available in the urban areas of the Sheep River reach (Figure 1). As a result, the cross section portion of this study is limited to the area immediately in and around Okotoks and Black Diamond / Turner Valley (BDTV).

2.3 THALWEG PROFILE DATA

Initial thalweg data were provided by AEP. Thalweg positions and elevations were provided as a PDF document titled *Channel Stability Investigation – Interim Deliverable Cross Section and Thalweg Profile* Comparison (April 18, 2017).

Updated thalweg data were provided from the HEC-RAS 5.0.5 geometry file, *SheepRiverHazard.g24,* in the hydraulic model for the study reach prepared by Hatch Ltd. (June 28, 2018). Thalweg data were extracted from the cross section data provided from geometric data in the hydraulic model.

2.4 RATING CURVES

Rating curves were provided by AEP and were initially constructed by AFW. There are three hydrometric gauges located in the study reach where historical rating curves are available. Rating curves and their associated station documents were provided by AEP to JDMA at each of these three sites (Table 3) operated by the Water Survey of Canada, Environment Canada (WSC).

Table 3: Rating curves for the channel stability investigation

Sheep River at Okotoks (05BL012)		Threepoint Creek near Millarville (05BL013)		Sheep River at Black Diamond (05BL014)	
Curve number	**Years effective**	**Curve number**	**Years effective**	**Curve number**	**Years effective**
Curve 2	2007	Curve 6	1973-1995	Curve 9	1990-1995
Curve 3	2008-2010	Curve 7	1996-1997	Curve 10	1995-1996
Curve 4	2010-2011	Curve 8	1998	Curve 11	1997
Curve 5	2011-2013	Curve 9	1999-2003	Curve 12	1998
Curve 6	2013-2014	Curve 10	2004-2005	Curve 13	1999-2002
Curve 7	2014-onwards	Curve 11	2005-2006	Curve 14	2003-2005
		Curve 12	2007	Curve 15	2005-2008
		Curve 13	2008	Curve 16	2009-2013
		Curve 14	2009-onwards		

3 METHODS AND RESULTS

3.1 CHANNEL CENTRELINE COMPARISON

3.1.1 CHANNEL CENTRELINE DELINEATION

This study delineated river centrelines as the mapping feature used for evaluating river morphology changes from 1951 to 2015 (Maps 2-21), whereas the previous work delineated what were referred to as 'banklines' (Maps 22-30). The planform channel centreline analysis described in this section (Maps 2-21) provides quantitative information on channel changes throughout the study area.

The 2016 'banklines' appear to represent the edge of the unvegetated 'active' part of the valley, which in many cases coincides with a bank crest or bank toe. A drawback of using edge of vegetation is that it corresponds with a wide range of morphological features. For example, in some locations the edge of vegetation corresponds with the toe of an eroding bank at the slope toe, while in other cases it corresponds with the crest of an active slope failure at the top of valley. Another issue with using lack of vegetation as an indication for the active part of the valley is that it is strongly influenced by the time since the last major flood, and this can lead to problems if the times since the last major flood captured by the historical and recent imagery are not equal. Another drawback of using reference to a bank crest or toe is that banks are highly discontinuous features, starting and stopping, transitioning into scroll bars, and there are often multiple banks of different ages at different elevations. Banks represent excellent reference features for use in site-specific analysis when mapped accurately, but in many cases may not represent the best choice for regional studies.

A mapping feature that can be of considerable use for channel migration studies is the edge of water. Edge of water is delineated from two sets of images both captured at times of similar flow (e.g., 50-75th percentile flow). Edge of water is often easily interpreted when mapping, rendering it a much more reliable feature for mapping. Further, unlike banks, which are highly discontinuous, the edge of water is continuous. Unfortunately, mapping based on edge of water, like banklines, is subject to challenges associated with poor image quality, thick riparian vegetation overhanging into the channel, or strong shadows obscuring the channel margin. As none of the available recent and historical imagery provided were acquired under similar flow conditions, edge of water could not be used for channel delineation in this study. Given these circumstances, it was determined that channel centreline was a feature that could be for the most part easily mapped and would allow for an effective means of visualizing historical channel changes (Maps 2-21).

The generalized centrelines of wetted channels were delineated from the 1951 imagery and from the 2015 ESRI imagery. In general, limited contrast in the 1951 imagery rendered it difficult to identify the channel in some locations or to identify which channels were wetted. The 2015 imagery was selected as it represents the only high-resolution imagery available covering the full extent of the study area. In contrast, the 2016 imagery provided for this study extends only as far downstream as Okotoks, and water levels in the 2016 imagery were slightly lower than in the 2015 imagery. Centreline mapping is strongly influenced by differences in flow conditions between the historical and recent imagery. Channels appear to be somewhat more swollen in the 1951 imagery, though no flow data are available to confirm flow conditions. Elevated water levels in 1951 are expected to result in some channels being wetted at that time which were dry in the 2015 imagery, and higher water levels in 1951 also influenced the exact lateral positioning of the centreline in some locations. In addition to the use of the 2015 imagery, the 2016 LiDAR was used to assist in locations where the exact position of the channel was obscured in the imagery, such as by thick riparian vegetation or by shadows casted across part of the channel. Despite the limitations inherent to the centreline delineation, given that the intent of the channel change analysis was to provide a high-level overview of changes, the centreline mapping was found to be more than adequate for this application.

Upon completing the centreline delineation, the analysis of changes focussed on identifying locations where the 2015 channel deviated by at least 30 m from the 1951 channel. The threshold of 30 m was selected as it appeared to represent a reasonable value for distinguishing locations where changes have occurred well in excess of measurement uncertainties. Segments of the 2015 centreline deviating more than 30 m from the 1951 centreline were further classified according to whether the length of the segment exceeded 1 km. The lengths of all the 1951 and 2015 channel segments were totalled to identify any net changes in channel length. For purpose of describing results, the study area was divided into three reaches: Threepoint Creek, Sheep River above Threepoint Creek, and Sheep River below Threepoint Creek.

In addition to analysis of the 1951 and 2015 high-resolution imagery, Landsat imagery from 08 July 1990 and 10 July 2014, which were closely matched for flow conditions, were analyzed to obtain an approximate indication for how much of the change observed from 1951 to 2015 may have occurred prior to 1990. However, as channel delineation from Landsat imagery for these channels can only be achieved with low precision and the accuracy of the mapping is strongly limited locally due to various factors, such as shadow effects below steep north-facing valley sides, the delineated channels are not presented on maps.

3.1.2 CHANNEL STABILITY COMMENTARY

The 1951 to 2015 channel centreline analysis indicated a net reduction in total length of all wetted channel segments for the Sheep River, whereas the change indicated for Threepoint Creek is thought of as negligible given methodological uncertainties (Table 4). Net changes in total channel length based on Landsat images from 1990 and 2014 were of insufficient size (less than 2 to 5% of reach length) for both streams to be of mention given limitations of the data. Given that the Landsat images were matched for flow conditions, this might point to some of the apparent length reductions on Sheep River from 1951 to 2015 as perhaps being related to higher water levels in 1951. However, upon inspection of the locations where channels active in 1951 appeared abandoned in 2015, it is apparent that the reductions between Turner Valley and Black Diamond are indeed real reductions which appear to be related dominantly to construction of Highway 22. Most of these changes were made prior to 1990. The other two locations where channel segments appear to have been abandoned from 1951 to 2015 were immediately above and below the Sheep River confluence with Threepoint Creek. Many of these abandonments also occurred prior to 1990.

Table 4: Historical changes in length of all channel segments (m)

Reach	1951	2015	Difference	Change
Upper Sheep River[1]	35,950	30,146	5,804	-16.1%
Lower Sheep River[1]	49,325	41,193	8,132	-16.5%
Threepoint Creek	43,244	42,341	903	-2.1%

[1] Division between upper and lower Sheep River reaches is at confluence with Threepoint Creek.

As indicated above, channel length reductions on Sheep River between Turner Valley and Black Diamond are dominantly suspected to be a direct and indirect response to construction of Highway 22. Road construction excluded some older channel segments on the north side of the valley, while consequent steepening of the river below may have led to abandonment of a bend downstream on the south side of the valley. The small-radius entry to the bend may have required lower velocities than had become normal after road construction.

Regarding the apparent change from the multi-channel pattern of the 1951 Sheep River immediately above and below the confluence with Threepoint Creek to dominantly a single channel extending through these zones, some of this apparent change may be related to higher water levels in 1951 while some surely relates to real abandonment of old channel segments and an inferred steepening of the river prior to 1990. If indeed, the Sheep River had steepened between 1951 and 1990 through causes in addition to construction of Highway 22, one possible additional cause for some of the steepening is that the river was sufficiently charged with sediment during flood events that the excess

sediment could not be carried and was deposited at the entrance of channel segments, which thereby cut those segments off from all but the highest of subsequent flows. This would imply that peak flows during one or more floods prior to 1990 were insufficient to carry the calibre or quantity of sediment contained within the channel during those events.

In terms of the geographic distribution of large and continuous channel movements from 1951 to 2015 (red channel segments on Map 1), the dominant pattern involved the uppermost parts of Sheep River and Threepoint Creek showing the smallest changes whereas larger changes appear essentially downstream of what can be thought of as the east edge of the foothills (Map 1, inset). Above this boundary, the streams are to a greater extent hemmed in within narrow bedrock-controlled valleys, while below, the valleys open up with larger floodplains where the channels are afforded greater opportunity to migrate. Should there be an innate need for channel form adjustment caused by variations in headwater flow conditions or sediment supply, within the first several kilometres below this boundary is where one might expect to see those changes most strongly manifested. If the parts of the streams between their confluence and the downstream edge of the foothills are isolated, the indicated changes in channel length are closer to a 20% reduction for Sheep River and about a 5% reduction for Threepoint Creek from 1951 to 2015.

Although the most dramatic channel changes have occurred downstream of the foothills, Sheep River and Threepoint Creek have shown dynamic behaviour throughout the study area. Relatively stable segments are present locally where the channels have remained remarkably stationary from 1951 to 2015, as shown in yellow on Map 1 and on detailed maps (Maps 2-21). In some of those relatively stable locations, there may be engineering or geological controls preventing the channel from migrating. System wide, 38% of the 2015 channel segments can be thought of as having been relatively stable, with no deviations exceeding 30 m from the 1951 channel centreline. Stable channel segment percentages found along the upper and lower Sheep River reaches and along Threepoint Creek are 44, 39 and 30%, respectively.

3.2 CROSS SECTION COMPARISON

JDMA used the cross sections created by the previous consultant (Appendix A) to classify changes in channel morphology at cross section locations. Data used for the cross section comparison are described in Section 2.2. Based on the analysis, changes in channel morphology were classified into 5 classes defined by JDMA. Table 5 is a description of the 5 channel classes. Locations of the classified cross sections are shown on Maps 4-7 and 12-13.

Table 5: Channel classifications

Classification	Description
Class 1A[1]	Wide/shallow floodplain; changes include widening of existing channel and downcutting to form new and wider channels within existing floodplain; may be accompanied by deposition adjacent to new downcut channel.
Class 1B[1]	Moderate floodplain width to depth ratio; changes dominated by lateral migration of the channel due to downcutting over an area of low to moderate width; may be accompanied by deposition adjacent to new downcut channel.
Class 1C[1]	Relatively narrow/deep floodplain; changes dominated by lateral migration of the channel with moderate to high channel depth and low to moderate width; may be accompanied by deposition adjacent to new downcut channel
Class 2	Changes dominated by lateral migration of high bank; with or without channel downcutting
Class 3	Changes dominated by downcutting of channel with or without minor lateral migration.

[1] Channel classes 1A-C are defined as floodplains of various widths where the major morphological change tends to be the lateral migration of the channel within the floodplain.

Cross sections in Appendix A only show the main channel from the 2015/2016 survey. For select locations, new cross sections were generated using data provided by Hatch (Appendix B). These cross sections, which represent a range of channel classifications and locations across the river reach, form the basis of the quantitative analysis.

The surveyed cross sections show a range of channel classification types. Most cross section locations in the Black Diamond-Turner Valley region (BDTV) are of Class 1 (A-C) (see Table 5). Within the communities of BDTV, most of the Class 1 channels are located towards the upstream end of the reach. Towards the downstream end (cross sections 2-7), the channel type is dominated by Class 3 channel types. The main morphological change observed at these locations is downcutting of the main channel (Maps 4-6).

The cross sections located in the Okotoks reach show different trends in morphological change as compared to the BDTV reach. At Okotoks the main channel classification is Class 3, dominated by downcutting. There are some locations where Class 1 channel classes are present, but these are not the dominant class (Maps 16-18).

As expected, Class 1 cross sections in the Okotoks and BDTV reaches tend to be in areas that display larger historical changes in channel position as mapped from historical imagery (Section 3.1).

In both reaches, a few examples of Class 2 channel types exist, and in each case these channel types are adjacent to bridges. The channel changes observed could be a result of engineered channel alterations at these locations.

At the Okotoks and BDTV reaches a range of channel migration and channel downcutting rates were measured by comparing the thalweg elevation from recent and historical cross-section data. Table 6 describes the range of those quantitative changes over the two reaches.

Table 6: Qualitative cross section changes

Calculated Change in Parameter	Sheep River in Okotoks	Sheep River in BDTV
Range of thalweg downcutting	0.13 to 1.5 m	-0.47 to 1.9 m
Range of lateral migration of thalweg	1 to 250 m	1 to 290 m
Range of changes in bankfull area	-186 to 87 m^2	-42 to 240 m^2
Range of changes in bankfull width	-47 to 34 m	-21 to 55 m

Changes in the elevation of the thalweg in cross sections indicate a general trend of channel downcutting. In the most extreme cases, the channel appears to have downcut 1.5-1.9 m in both reaches, while at other locations little (several cm) to no downcutting was observed. At several locations in the BDTV reach the thalweg appears to have aggraded up to 0.5 m.

Changes in channel bankfull width and cross-sectional area are more difficult to quantify. A reference water level position at each cross section location was chosen to calculate the bankfull area. In the Okotoks reach, bankfull area tended to decrease across most cross sections while bankfull width mainly increased, indicating a shallowing of the channel even though downcutting was general observed as well. The cross section at Okotoks that showed the largest decrease in bankfull area was classified as a Class 2 channel. Because of its location near a bridge, it seems likely that the geometry of the channel at this location has been modified by engineered works. In the BDTV reach, bankfull area and bankfull width mainly increased, although some cross sections showed a decrease in area and width. These latter exceptions could be the result of aggradation and infilling of the channel at these locations. Because only two cross section dates are available for both the Okotoks and BDTV reaches, it is not possible to say whether this trend has been long term and linear or whether the channels are constantly changing geometry, increasing and decreasing in area, width, and depth. The rating curve comparison presented in Section 3.4 provides additional information on this issue.

3.3 THALWEG PROFILE COMPARISON

The thalweg profiles created by the previous consultant were used for this study component. One change was noted in the thalweg profiles at Station 43.04 (BDTV). At this location, updated geometry data from the HEC-RAS 5.0.5 geometry file, *SheepRiverHazard.g24* model was obtained from Hatch.

Thalweg profiles are compared both qualitatively and quantitatively to assess changes in the vertical channel position. Changes in thalweg position and changes to the thalweg slope are compared.

Thalweg profiles for the Okotoks reach and BDTV reach are shown in Figure 2 and Figure 3. The horizontal axis of the figures shows the Sheep River station numbers. Station numbers start downstream and increase upstream through the reach.

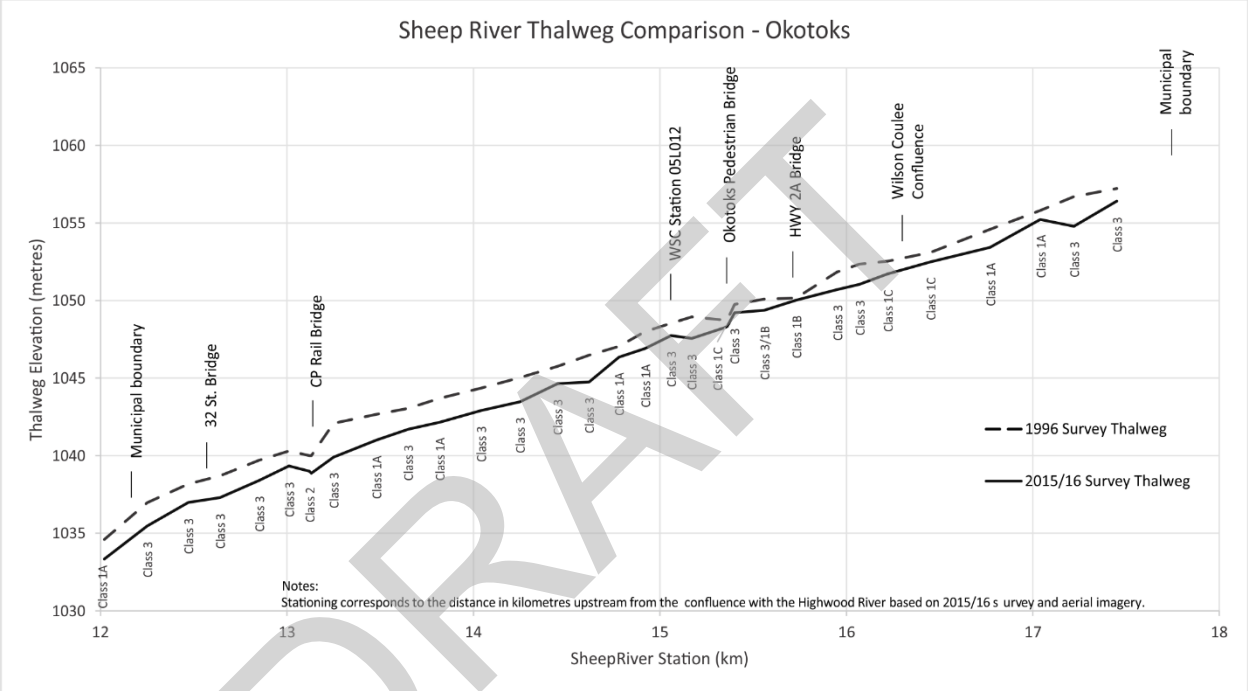

Figure 2: Sheep River Thalweg Comparison – Okotoks

The thalweg profile of Sheep River at Okotoks shows a general trend of downcutting, with more downcutting having occurred between River Station 12.02-14.62 than the stations upstream of those points. From Station 13.01 to 13.12 there is an increase in thalweg elevation shown in both the historical survey and 2015/16 survey creating a reverse gradient at the CP Rail Bridge. This reverse gradient could be a result of channel improvements or other engineered works at this location.

A Sheep River thalweg comparison at Okotoks is presented in Table 7, listing the elevations of the river thalweg from the 1996 survey and the 2015/16 survey as well as changes in slope. The Sheep River, at this location increases in slope throughout this entire reach. The change in slope is slight, increasing from 0.00417 to 0.00425 m/m (rise/run). This change in the overall slope can be attributed to either increases in channel downcutting or a shortening of the channel length (see Section 3.1).

Between cross sections, individual changes in channel slope are more variable with some locations showing an increase in channel slope and others a decrease in slope. The differences in slope changes appear to be spatially heterogeneous with no apparent pattern.

The thalweg of Sheep River at BDTV experienced much less downcutting than at Okotoks. In several locations channel aggradation is evident as indicated by an increase in thalweg elevation between the 2015/16 survey and the 1992 survey. At the upper end of the profile, there is very little change between the two surveyed thalwegs. Lower on this reach, larger changes in channel downcutting and aggradation are observed between stations 43.67-44.78. The largest changes are observed at the lowest end of the profile between stations 39.85 and 41.13.

Table 8 is the Sheep River thalweg comparison for BDTV. It presents the elevations of the river thalweg from the 1992 survey and the 2015/16 survey as well as changes in slope. Overall, the Sheep River at this location increases in slope throughout this entire reach. The change in slope is slight, increasing from 0.00583 to 0.00589 m/m (rise/run). This change in the overall slope can be attributed to either increases in channel downcutting or a shortening of the channel length, or both. Between cross sections, individual changes in channel slope are more variable with some locations showing an increase in channel slope and others a decrease in the channel slope. The variability of slope changes appears to be spatially heterogeneous with no significant patterns. Changes in slope tend to be greater downstream in the community of Black Diamond and the rural area and less upstream at Turner Valley.

Table 7: Sheep River Thalweg Comparison Table – Okotoks

1996 Cross Section Number	2015/2016 River Station	1996 Survey Thalweg Elevation (m)	2015/2016 Survey Thalweg Elevation (m)	Change in Slope Between Stations (m/m)	Overall Change in Slope (m/m)
1	12.02	1034.6	1033.338		
2	12.25	1036.97	1035.474	-0.00102	
3	12.47	1038.18	1036.981	0.00135	
4.1	12.64	1038.7	1037.301	-0.00118	
5.1	12.85	1039.7	1038.406	0.00050	
5.2	13.01	1040.3	1039.334	0.00205	
6	13.12	1040	1038.99	-0.00040	
6.1	13.13	1040	1038.865	-0.01250	
6.2	13.25	1042.08	1039.905	-0.00867	
7.1	13.48	1042.66	1041.007	0.00227	
7.2	13.65	1043.05	1041.702	0.00179	
8.1	13.82	1043.7	1042.161	-0.00112	
8.2	14.04	1044.36	1042.901	0.00036	
9	14.25	1045.03	1043.48	-0.00043	
10.1	14.45	1045.75	1044.633	0.00216	
10.2	14.62	1046.48	1044.752	-0.00359	
11	14.78	1047.05	1046.355	0.00646	0.00008
12.1	14.92	1048	1046.908	-0.00284	
12.2	15.06	1048.54	1047.734	0.00204	
12.3	15.17	1048.95	1047.56	-0.00531	
13.22	15.35	1048.733	1048.268	0.00514	
13.23	15.36	1048.733	1048.321	0.00530	
13.3	15.4	1049.75	1049.221	-0.00292	
14.1	15.56	1050.1	1049.368	-0.00127	
14.2	15.73	1050.16	1050.026	0.00352	
15.2	15.95	1051.84	1050.708	-0.00454	
16	16.07	1052.34	1051.041	-0.00139	
17	16.22	1052.53	1051.715	0.00323	
18	16.45	1053.1	1052.482	0.00086	
19	16.77	1054.59	1053.417	-0.00173	
20.1	17.04	1055.8	1055.227	0.00222	
20.2	17.22	1056.7	1054.783	-0.00747	
21	17.45	1057.22	1056.406	0.00480	

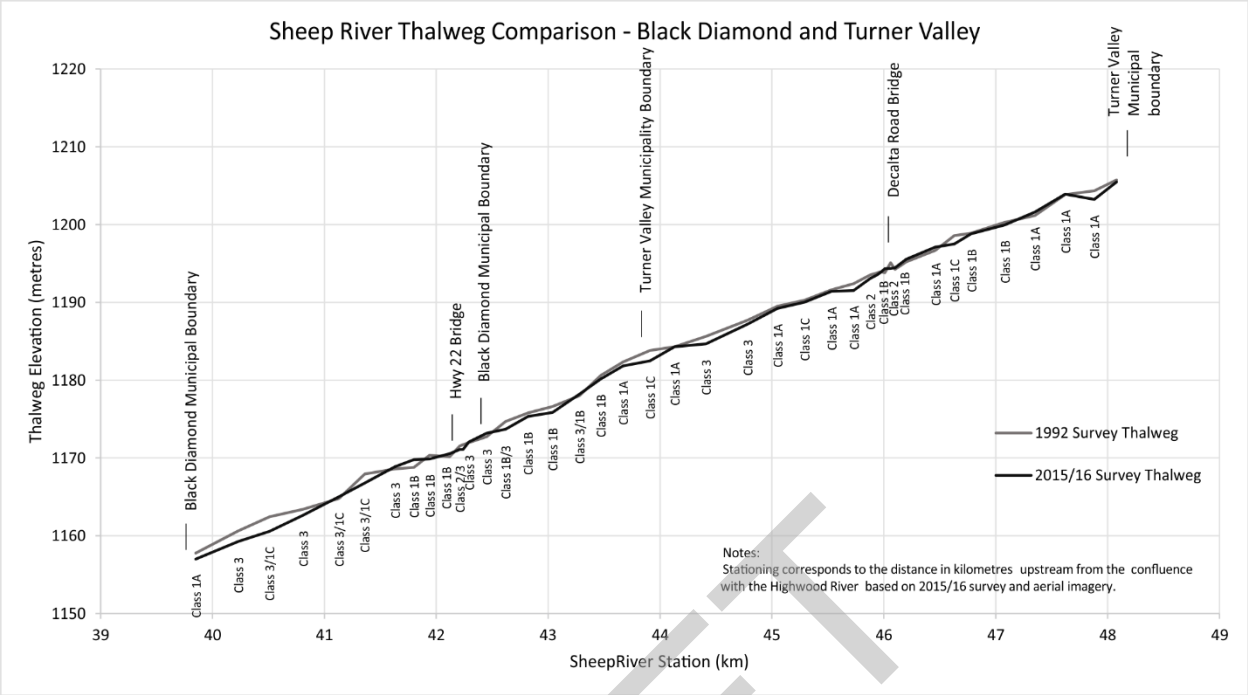

Figure 3: Sheep River cross section comparison – BDTV

Table 8: Sheep River Thalweg Comparison Table – BDTV

1992 Cross Section Number	2015/2016 River Station	1992 Survey Thalweg Elevation (m)	2015/2016 Survey Thalweg Elevation (m)	Change in Slope Between Stations (m/m)	Change in Slope within Municipal Boundaries (m/m)	Overall Change in Slope (m/m)
1	39.85	1157.77	1156.997		0.00047 (BD)	0.00006
2	40.23	1160.63	1159.266	-0.00156		
3	40.51	1162.45	1160.571	-0.00184		
4	40.81	1163.4	1162.65	0.00376		
5	41.13	1164.8	1165.006	0.00299		
6	41.36	1167.93	1166.771	-0.00593		
7	41.63	1168.59	1168.868	0.00532		
8	41.8	1168.8	1169.791	0.00419		
9	41.94	1170.34	1169.87	-0.01044		
10	42.12	1170.14	1170.551	0.00489		
11.1	42.21	1171.54	1171.091	-0.00956		
11.2	42.24	1171.7	1171.087	-0.00547		
12	42.29	1171.97	1172.063	0.01412		
13	42.45	1172.72	1173.173	0.00225		
14	42.62	1174.68	1173.685	-0.00852	0.00047 (Rural area)	
15	42.82	1175.8	1175.342	0.00269		
16	43.04	1176.6	1175.85	-0.00133		
17	43.28	1178	1178.206	0.00398		
18	43.47	1180.6	1180.169	-0.00335		
19	43.67	1182.33	1181.83	-0.00035		
20	43.91	1183.8	1182.474	-0.00344	0.00026 (TV)	
21	44.13	1184.3	1184.283	0.00595		
22	44.41	1185.62	1184.678	-0.00330		
23	44.78	1187.7	1187.187	0.00116		
24	45.05	1189.51	1189.223	0.00084		
25	45.29	1190.28	1190.008	0.00006		
26	45.53	1191.6	1191.4	0.00030		
27	45.73	1192.39	1191.511	-0.00340		
28	45.88	1193.54	1193.088	0.00285		
29.1	45.94	1193.79	1193.524	0.00310		
29.2	45.97	1193.92	1193.861	0.00690		

30	46.01	1193.83	1194.332	0.01403		
31.1	46.06	1195.1	1194.352	-0.02500		
31.2	46.1	1194.25	1194.442	0.02350		
32	46.2	1195.2	1195.538	0.00146		
33	46.46	1196.68	1197.113	0.00037		
34	46.63	1198.59	1197.504	-0.00894		
35	46.78	1198.9	1198.812	0.00665		
36	47.08	1200.28	1199.953	-0.00080		
37	47.35	1201.15	1201.623	0.00296		
38	47.62	1203.86	1203.905	-0.00159		
39	47.88	1204.35	1203.222	-0.00451		
40	48.08	1205.74	1205.479	0.00433		

3.4 RATING CURVE COMPARISON

Three rating curves were analysed in this study. These rating curves were taken from WSC hydrometric data at gauge locations on the Sheep River and Threepoint Creek. The three gauges that were used are shown in Map 1. These gauges are:

- Sheep River at Okotoks (05BL012)
- Threepoint Creek near Millarville (05BL013)
- Sheep River at Black Diamond (05BL014)

The rating curve data were obtained from AEP and initially collected by a previous consultant. Rating curves were compiled and changes and trends through time were examined. Where large changes occurred in the ratings curves these changes were related to recent hydrologic events (see next paragraph) to help understand why the curves changed. Water Survey of Canada (WSC) technologists also collect station observations which were provided in Station Analysis documents, which help explain variability observed between the rating curves.

The hydrographs for these gauges show that several floods of note occurred in this record. Significant changes tend to occur in rating curves after high-water events. These changes may be due to erosion/scour or deposition/aggradation of the channel and banks. Floods of note that occurred in the rating curves were 1995 (Sheep River at Black Diamond), 2005 (Threepoint Creek & Sheep River at Black Diamond), 2011 (Threepoint Creek, Sheep River at Okotoks), and 2013 (all three gauges).

Table 9 demonstrates the year to year changes observed at these gauges. The changes observed in the curve are based on the comparison of that rating curve to the previous rating curve.

Table 9: Rating Curve Comparison

Sheep River at Okotoks (05BL012)			
	Aggradation/deposition	Stable	Erosion/scour
Curve 2 (2007)[1]	(No Curve 1)	(No Curve 1)	(No Curve 1)
Curve 3 (2008)			
Curve 4 (2010)			
Curve 5 (2011-2013)			
Curve 6 (2013-2014)			
Curve 7 (2014+)			
Threepoint Creek near Millarville (05BL013)			
	Aggradation/deposition	Stable	Erosion/scour
Curve 6 (1973-1995)[1]	(No Curve 5)	(No Curve 5)	(No Curve 5)
Curve 7 (1996-1997)			
Curve 8 (1998)			
Curve 9 (1999-2003)			
Curve 10 (2004-2005)			
Curve 11 (2005-2006)			
Curve 12 (2007)			
Curve 13 (2008)			
Curve 14 (2009+)			
Sheep River at Black Diamond (05BL014)			
	Aggradation/deposition	Stable	Erosion/scour
Curve 9 (1990-1995)[1]	(No Curve 8)	(No Curve 8)	(No Curve 8)
Curve 10 (1995-1996)[2]			
Curve 11 (1997)[3]			
Curve 12 (1998)			
Curve 13 (1999-2002)			
Curve 14 (2003-2005)			
Curve 15 (2005-2008)			
Curve 16 (2009-2013)			

[1] The first curve available for each station is left blank as there is no previous curve to base a comparison on.
[2] Curve 10 for Station 05BL014 showed erosion at low stage and deposition at higher stage. Overall it appears to trend more towards deposition at this location.
[3] Curve 11 for Station 05BL014 showed deposition at low stage and erosion at high stage. Overall it appears to trend more towards erosion at this location.

3.4.1 SHEEP RIVER AT OKOTOKS (05BL012)

For the hydrometric gauge on Sheep River at Okotoks (05BL012) there are 6 rating curves available (curves 2-7). The hydrometric gauge was moved in 2007 and therefore rating curve 1 cannot be compared to more recent rating curves. This gauge is located adjacent to South Railway Avenue in Okotoks. Figure 4 shows the rating curve comparison.

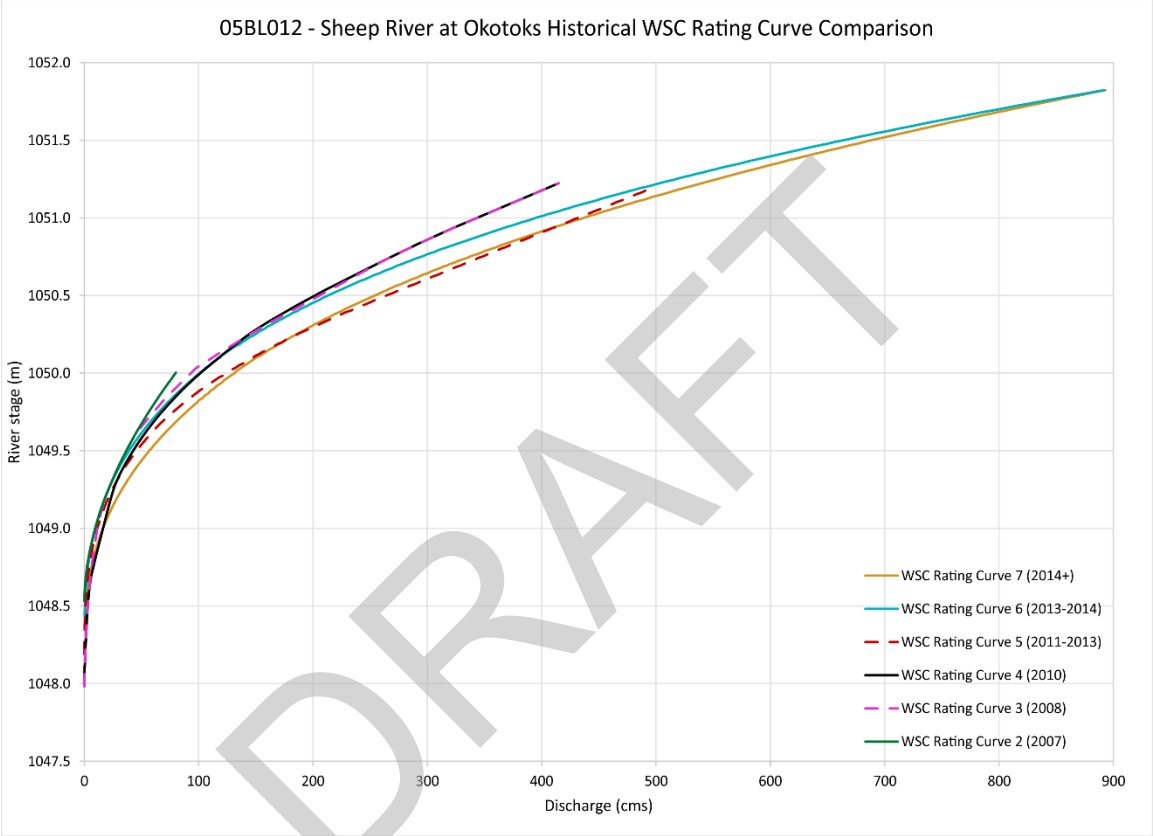

Figure 4: Rating Curve for Sheep River at Okotoks

The lower parts of the curves are all generally quite similar, indicating that bed scour is not significant throughout the record. At the upper end there is divergence of the curves, which is indicative of the upper banks and flood plain changing through time.

Rating curves 3 and 4 (2008/2010) follow the same trend as curve 2 (2007) to 1,050 m. At this elevation there is a break point observed and curves 3 and 4 continue to 1,051.22 m. Curves 3 and 4 are dissimilar at the higher elevations compared to curves 5-7 (2011-onwards). In early 2011 there was a large flood event (daily average discharge >400 cms) which may have been responsible for eroding the channel. After 2010 the rating curves reflect a noticeably different profile. Curve 6 shifts

left from curve 5 indicating that deposition may have occurred between the construction of these two curves. Rating curve 7 is right-shifted again, indicating erosion compared to the previous curve.

Notes in the Station Analysis documents indicated that a channel bar at this location shifts laterally and is suspected to be largely responsible for the changes in the rating curve through time.

3.4.2 THREEPOINT CREEK NEAR MILLARVILLE (05BL013)

There are 9 rating curves for the hydrometric gauge on Threepoint Creek near Millarville (05BL013) (curves 6-14). All years since 2009 have used curve 14. Notes in Station Analysis say that ongoing bank stabilization is the reason WSC has not updated the rating curve even though several large flood events have occurred since that likely impacted the shape of the cross section. This gauge is located adjacent to Range Road 30. Figure 5 shows the rating curve comparison.

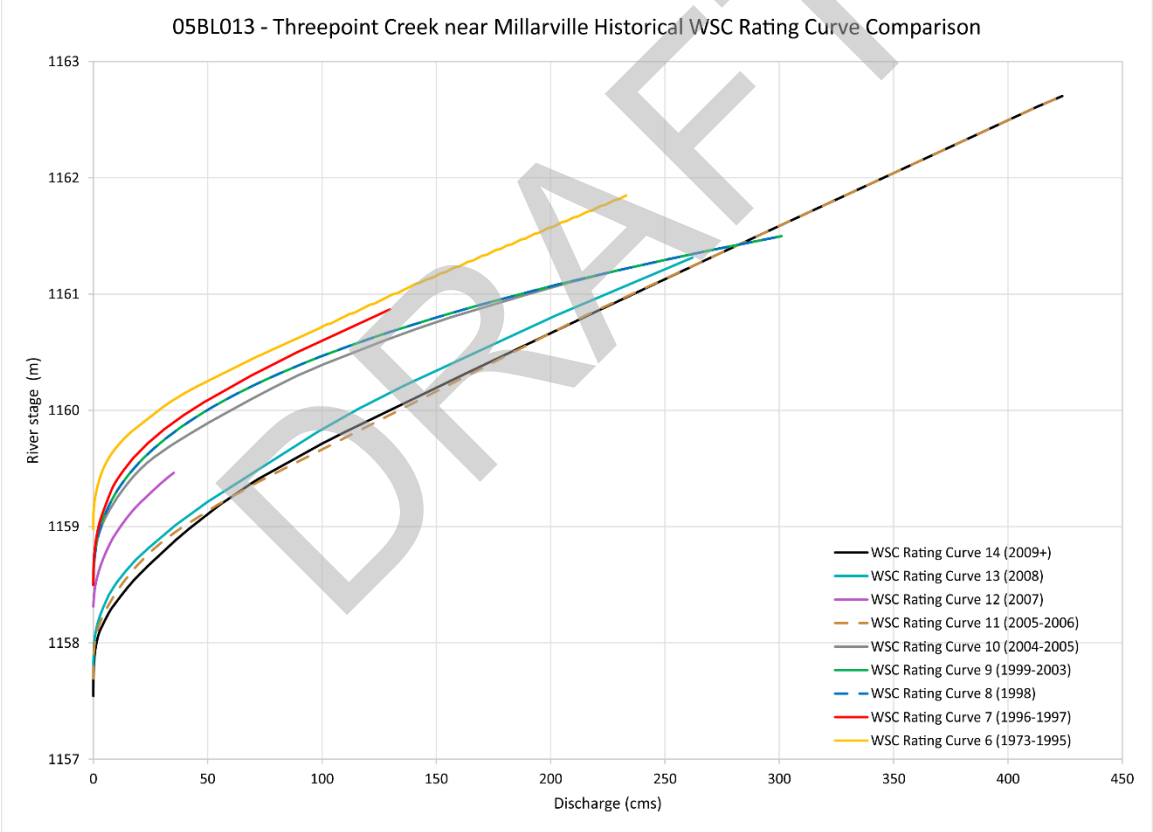

Figure 5: Rating Curve for Threepoint Creek near Millarville

The rating curves form two distinct clusters as seen in Figure 5. Curves 11-14 are shifted to the right of curves 6-10. The distinct change between curves 10-11 (2004/05 to 2005/06) occurred due to a record flow on Threepoint Creek in spring 2005. The change that is seen is due to massive bed scour

and erosion of the channel bottom attributed to three flood events that occurred in June 2005. The WSC Station Analysis documents state that the gauge orifice was above the water level after the last flooding event, which resulted in negative water levels being reported. To mitigate this, WSC technicians reinstalled the orifice back in the channel bed and modified the datum of the station by lowering the benchmark by 2.185 m (from 1157.185 to 1155.000 m) to accommodate the new, lower, position of the river within its banks.

Prior to the 2005 flood event rating curves 6-10 were relatively consistent while curves 7-8 differ slightly. Curve 8 is shifted right from 7, especially at higher elevations. This may be due to erosion, especially near the top of bank.

Rating curve 12 is left-shifted from curve 11. This shift is caused by aggradation of sediment at this location. The WSC Station Analysis documents show that the orifice line was buried in the sediment and had to be replaced at this time.

Rating curves 13 and 14 are right shifted again across the entire profile. This is indicative of bed scour and channel erosion. The profile shapes of the curves are like curve 11, indicating that the material that aggraded in 2007 (curve 12) was eroded away. It appears that the state of the channel represented by curve 11 (2005-2006) is very similar to that of curve 13 (2008-2009).

3.4.3 SHEEP RIVER AT BLACK DIAMOND (05BL014)

There are 8 rating curves for the hydrometric gauge on Sheep River at Black Diamond (05BL014) (curves 9-16). The gauge was destroyed by flooding in 2013 and moved downstream. As a result, the post-2013 gauges cannot be directly compared to earlier gauges. This gauge is in Lion's Centennial Park 40 m upstream of the bridge. Figure 6 shows the rating curve comparison.

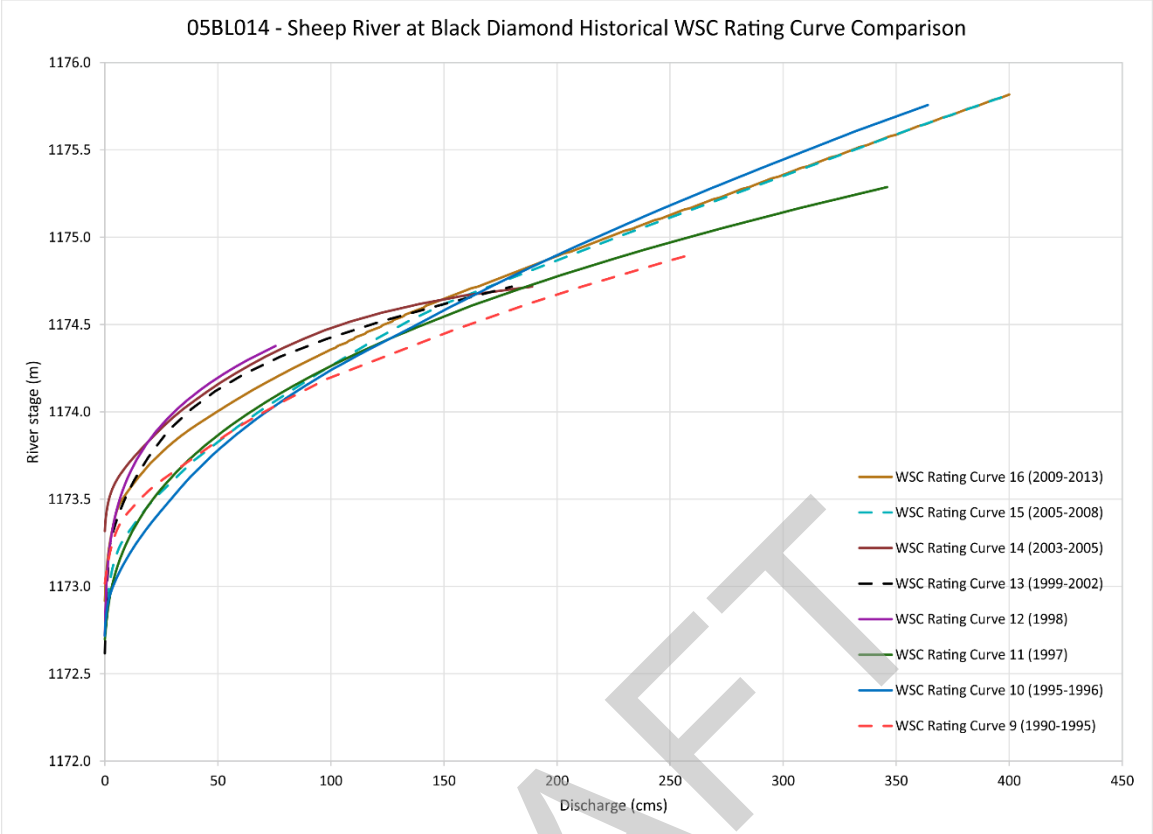

Figure 6: Rating Curve for Sheep River at Black Diamond

The rating curves from 1990 to 2013 show that the channel at this location is highly dynamic. It shows a combination of erosion and aggradation at this location throughout time.

The change from curve 9 (1990-1995) to curve 10 (1995-1996) shows aggradation at this location. After the 1995 high flow event sediment appears to have been deposited at this location, as the curve is shifted left.

The changes from curve 10 to 11 indicate erosion at this site. The curve shifts right especially at the higher end which is an indication of the change in shape of the upper banks and less so of the lower banks.

Curve 12 shifts left in relation to curve 11 and the shape of curve 12 is very different than curve 11. This shows that the channel morphology is very different across the entire profile. The curve shows aggradation of material between these time periods.

Curves 12, 13, and 14 indicate very similar channel geometry with small shifts between each year. The shift from left (Curve 12) to right (Curve 13) and back left again (Curve 14) from curve 13 to 14 is indicative of slight erosion followed by deposition.

The change from curve 14 to 15 indicates erosion near the bottom and middle of the channel but possible deposition above approximately 1174.7 m where the two rating curves cross. The slope of curve 15 is straighter than that of curve 14.

At lower stage elevations (<1174.25 m) curve 16 is left of curve 15. This indicates a narrower channel, and possibly deposition of material at this location. At higher elevations the curves continue along the same path and line up quite well, indicating that the upper banks of the channel were quite similar.

There are no curves after curve 16 as the gauge at this location was washed away by the flood in 2013.

In summary, the gauge at Sheep River at Okotoks shows minimal divergence throughout its record, though there are signs of erosion and deposition between years. The gauges at Threepoint Creek and Sheep River at Black Diamond show a larger amount of variation throughout the years with some years indicating erosion and others indicating deposition. The variability in the rating curves was more pronounced for these two gauges than it was for the gauge at Sheep River at Okotoks.

4 CONCLUSIONS

The dominant pattern of planform channel changes from 1951 to 2015 involves the uppermost parts of Sheep River and Threepoint Creek showing the smallest changes whereas larger changes appear below the downstream boundary of the foothills. Above this boundary, the streams are to a greater extent hemmed in within narrow bedrock-controlled valleys, while below, the valleys open up with larger floodplains where the channels are afforded greater opportunity to migrate. If the parts of these streams between their confluence and the downstream edge of the foothills are isolated, reductions in channel length of about 20% for Sheep River and 5% for Threepoint Creek are indicated from 1951 to 2015, and a Landsat image revealed that most of these length changes had already occurred by July 1990. Although the most dramatic channel changes have occurred downstream of the foothills, dynamic behaviour is observed throughout the study area. Relatively stable segments are present locally, where in some cases engineering or geological controls may have restricted migration. System wide, 38% of the 2015 channel segments can be thought of as having been relatively stable, with no deviations exceeding 30 m from the 1951 centreline. Stable channel segment percentages found along the upper and lower Sheep River reaches and along Threepoint Creek are 44, 39 and 30%, respectively.

The comparison of historical cross sections near Okotoks and BDTV show that channel morphology can be classified into several distinct classes. Changes observed in each reach tend to be different and reflective of different channel conditions at these locations. At the most upstream reach, near Turner Valley, the main cross section classification shows changes dominated by lateral migration of the channel across the floodplain (Class 1). The cross sections showed both increases and decreases in bankfull area and width, illustrating that the channel is highly variable. Further downstream at Black Diamond, the main trend was for the cross sections to show increases in bankfull area and the main channel class tending to be dominated by downcutting of the thalweg (Class 3). At Okotoks, the cross sections tended to be mainly Class 3, and the main trend was for bankfull areas and widths to decrease throughout this reach despite downcutting of the channel.

The thalweg comparison showed that the thalweg has undergone downcutting on the Sheep River at Okotoks and BDTV. The largest rates of downcutting occurred near Okotoks and Black Diamond, with the river in Turner Valley showing the least amount of downcutting and some aggradation in places. The overall trend at both Okotoks and BDTV is for both channel reaches to have increased in slope, which is consistent with channel morphology mapping from historical imagery. However, at a larger scale changes in slope tend to be more variable.

The rating curve analysis shows that the channel at both Okotoks and BDTV aggrades and degrades over time. The most variable locations were Sheep River at Black Diamond and Threepoint Creek near Millarville with these hydrometric gauges showing the most dynamic channel morphological changes. The gauge at Okotoks on Sheep River showed significantly less change, but the period of record extends only from 2007-2014, a much smaller period than at the other two gauges.

5 CLOSURE

It is anticipated that the results on river morphological changes presented in this report will be useful for interpreting results obtained from other components of the Sheep River Hazard Study. The results are also expected to be of value for regional planning purposes. However, the high-level nature of the results precludes them from being suitable for use in site-specific evaluation of hazards and risks associated with flooding, erosion or slope instability.

Shayne MacDonald, B.Sc. David van Zeyl, M.Sc.

Lynden Penner, M.Sc., P.Eng., P.Geo.

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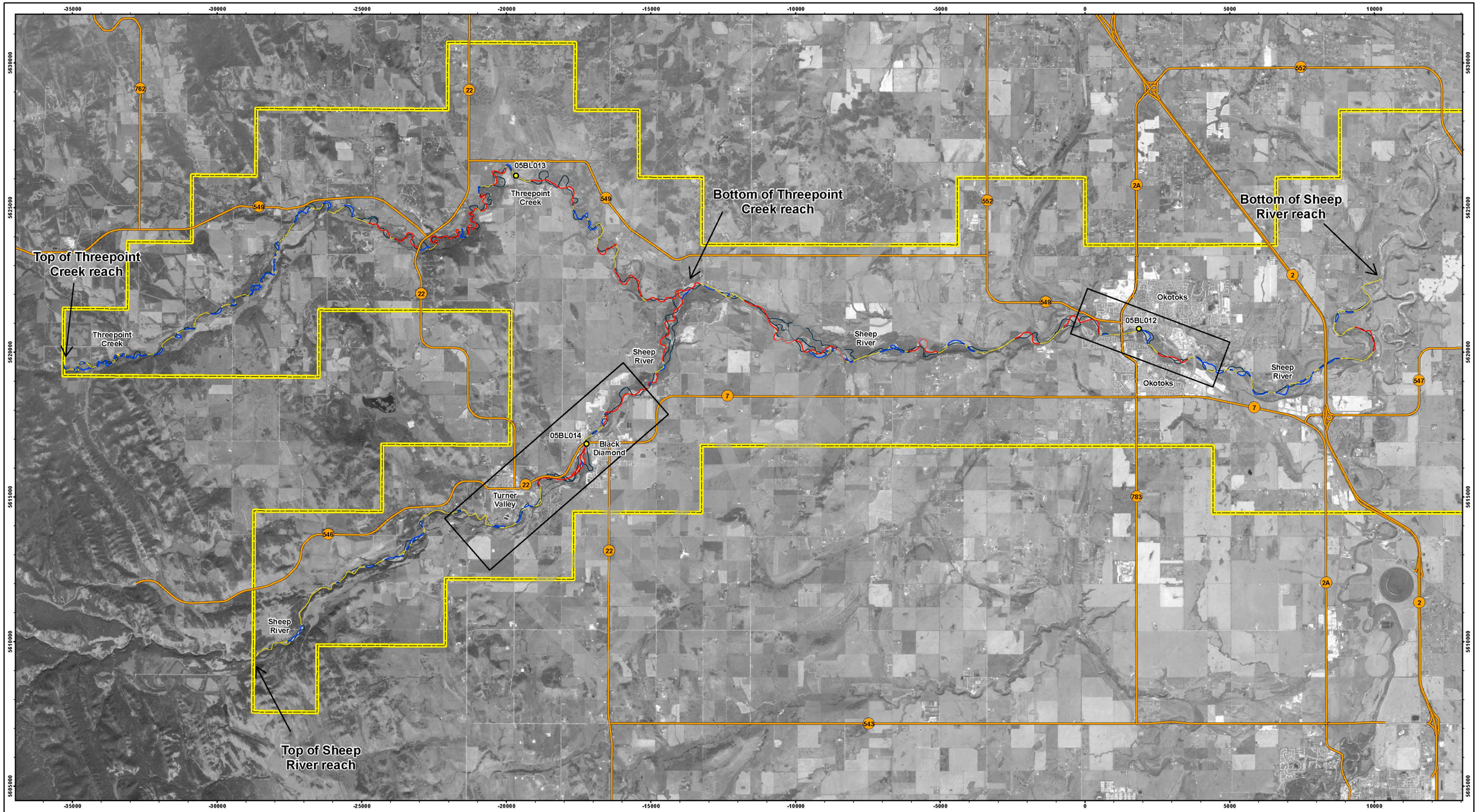
AMEC Foster Wheeler, *Channel Stability Investigation – Interim Deliverable Cross Section and Thalweg Profile Comparison.* Report Prepared for Alberta Environment and Parks (April 18, 2017).

AMEC Foster Wheeler, *Sheep River Hazard Study Survey and Base Collection Report.* Report prepared for Alberta Environment and Parks (February 2017).

MAPS



LEGEND

- Hydrometric station
- Extent of LiDAR survey
- Historical cross section survey coverage
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

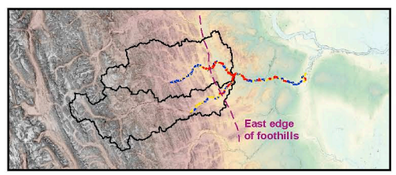
- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Background imagery: 22 Aug 2018 Landsat

N W E S

500 0 1,500 m

500 0 2,000 m



J.D. MOLLARD AND ASSOCIATES LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Location map and key plan

DRAWN	DVZ	09 FEB 2019	MAP 1	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:125,000

Classification: Public

LEGEND

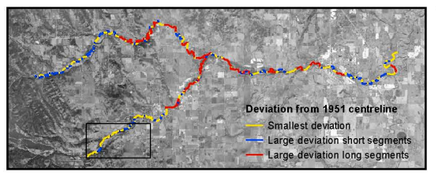
- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m



J.D. MOLLARD AND ASSOCIATES (2007) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

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REVIEW	LAP	11 FEB 2019		1:20,000

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5613500 5613000 5612500 5612000 5611500 5611000 5610500 5610000 5609500

SEC-32 TWP-019
RGE-03 MER-5

SEC-33 TWP-019
RGE-03 MER-5

SEC-34 TWP-019
RGE-03 MER-5

SEC-35 TWP-019
RGE-03 MER-5

546

SEC-29 TWP-019
RGE-03 MER-5

SEC-28 TWP-019
RGE-03 MER-5

SEC-27 TWP-019
RGE-03 MER-5

SEC-20 TWP-019
RGE-03 MER-5

LEGEND

- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments

Elevation (m)
Value
High : 1474.05
Low : 1226.61

- Road
- Highway

Background imagery: 2016 LiDAR

N W E S

50 0 200 m

100 0 300 m

Deviation from 1951 centreline
- Smallest deviation
- Large deviation short segments
- Large deviation long segments

J.D. MOLLARD AND ASSOCIATES (2007) LIMITED

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

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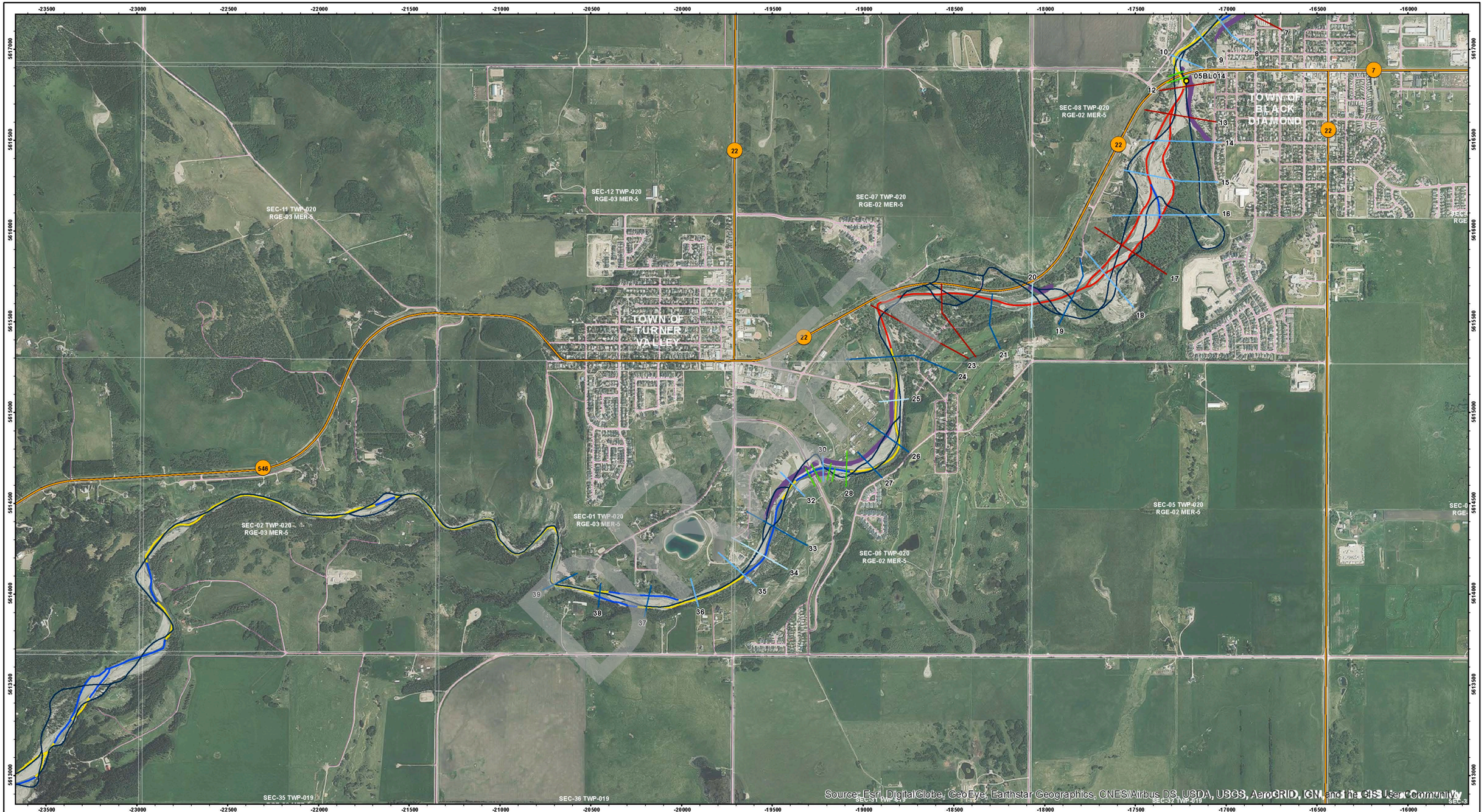
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Cross section classification

- Class 1A
- Class 1B
- Class 1C
- Class 2
- Class 3

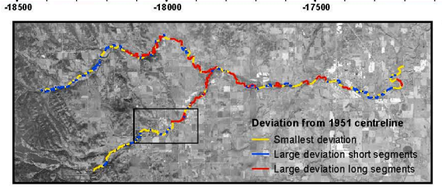
- Road
- Highway
- Control structure

Background imagery: 2015 ESRI ortho

N W E S

50 0 200 m

100 0 300 m



J.D MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

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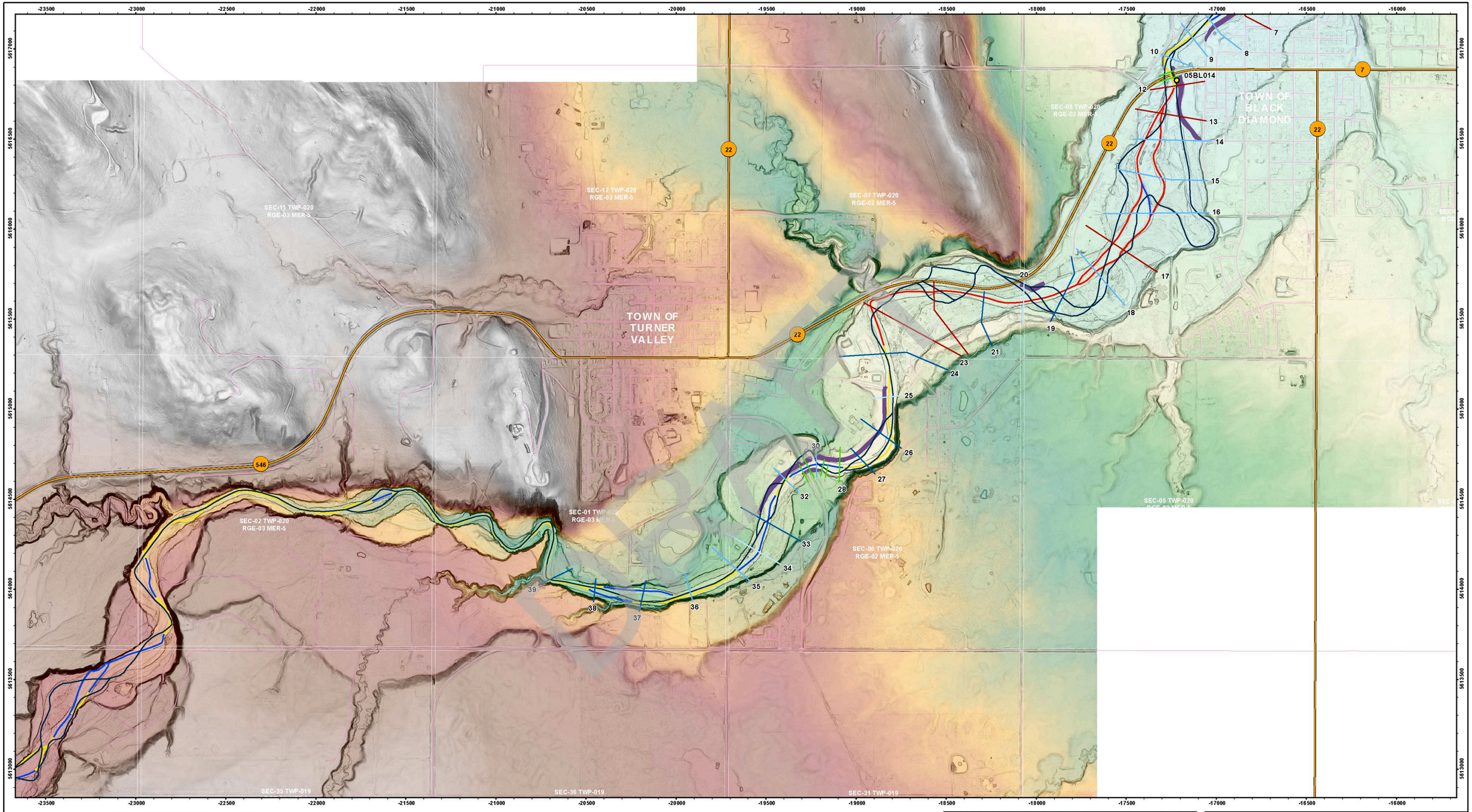
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Elevation (m)
Value
High : 1410.31
Low : 1169.45

Cross section classification

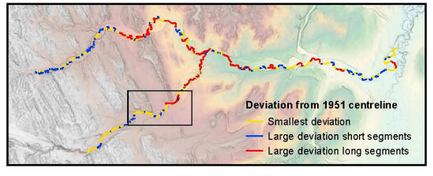
- Class 1A
- Class 1B
- Class 1C
- Class 2
- Class 3

- Road
- Highway
- Control structure

Background imagery: 2016 LiDAR

N W E S

50 0 200 m
100 0 300 m



J.D MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

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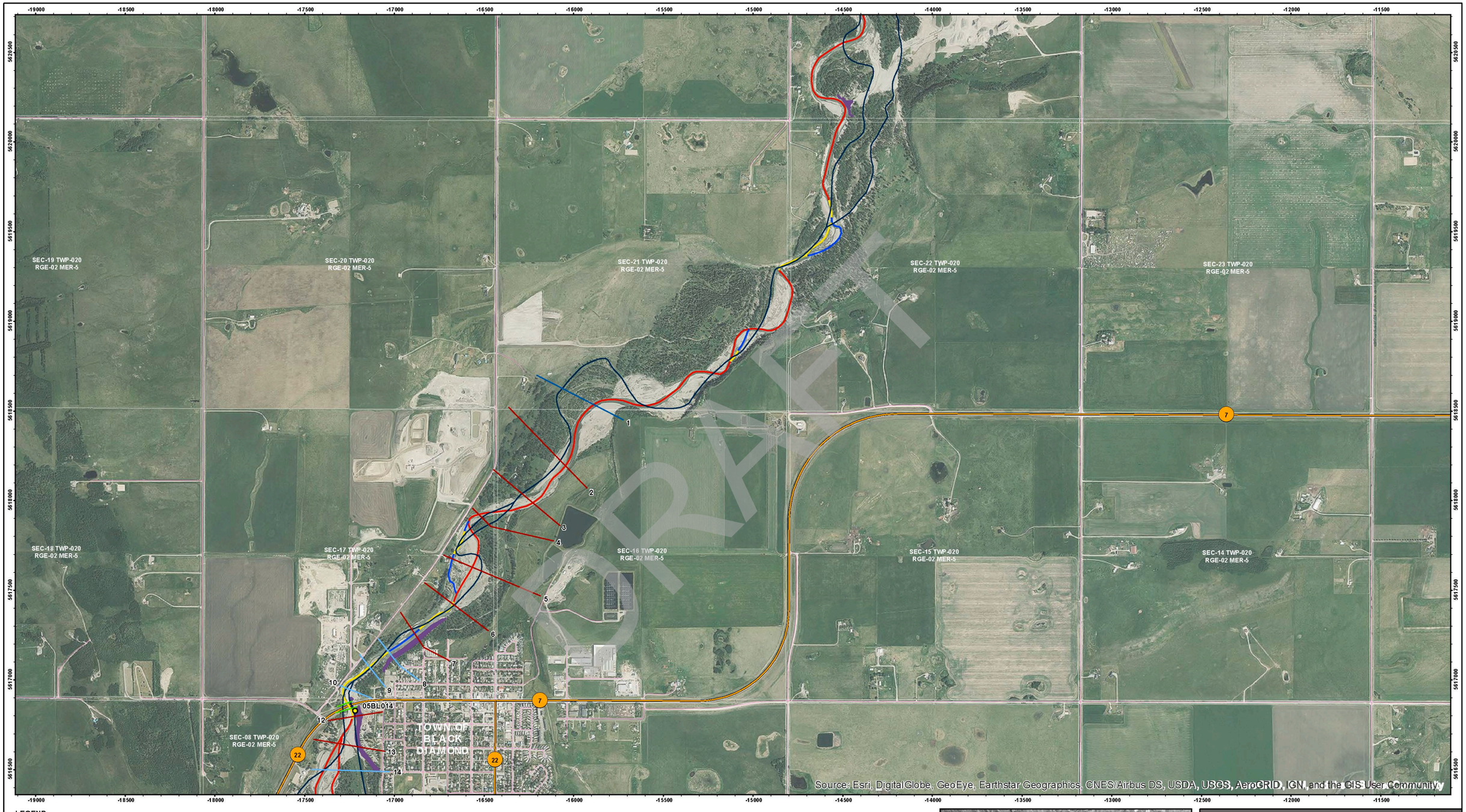
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Cross section classification

- Class 1A
- Class 1B
- Class 2
- Class 3

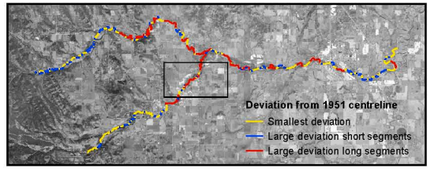
- Road
- Highway
- Control structure

Background imagery: 2015 ESRI ortho

N W E S

50 0 200 m

100 0 300 m



J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

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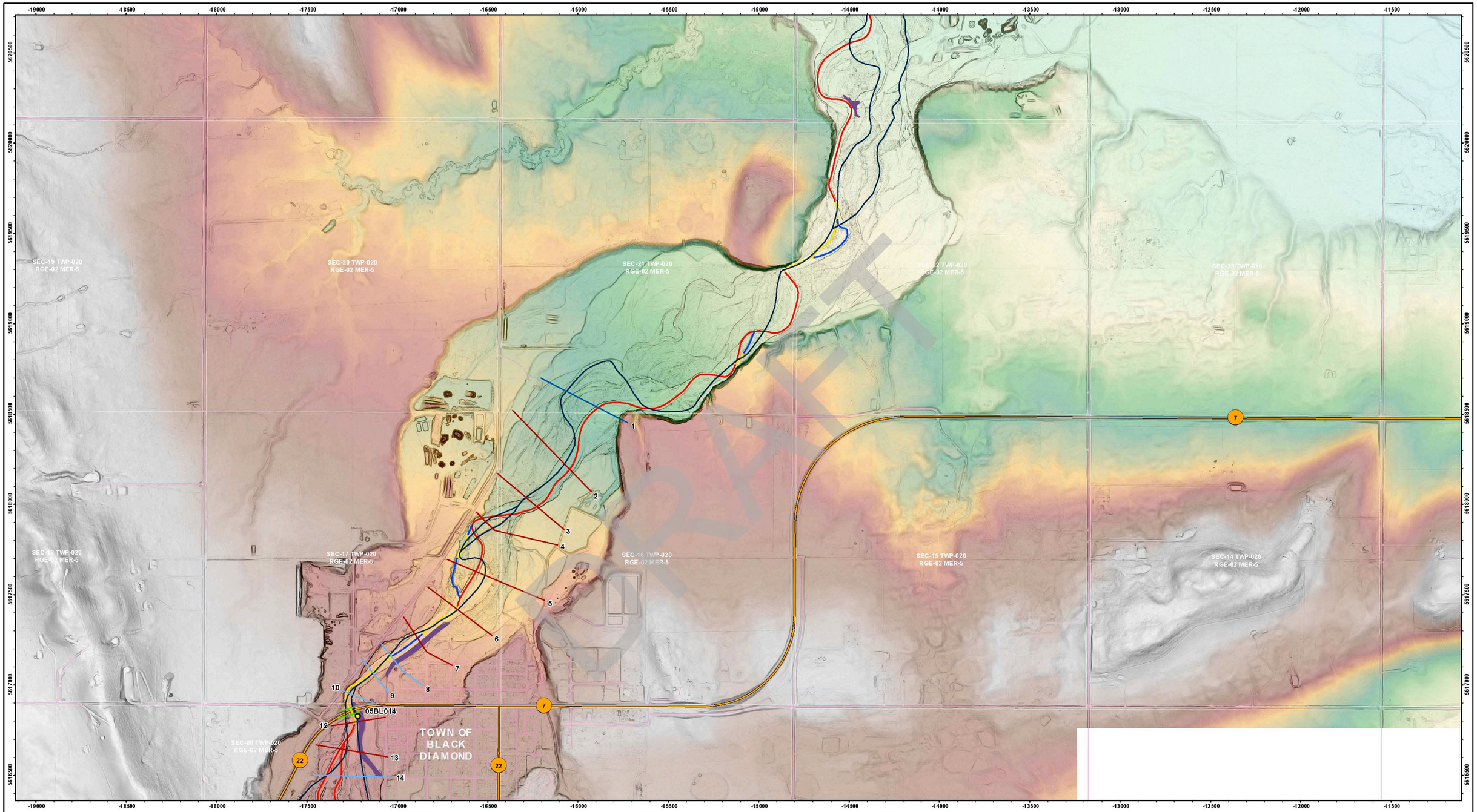


LEGEND

- Hydrometric station
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Elevation (m)
Value
High : 1315.96
Low : 1115.18

Cross section classification

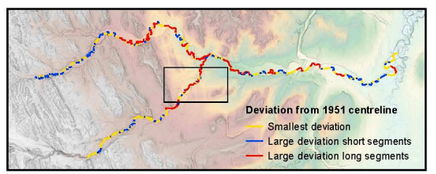
- Class 1A
- Class 1B
- Class 2
- Class 3

- Road
- Highway
- Control structure

Background imagery: 2016 LiDAR

N W E S

50 0 200 m
100 0 300 m

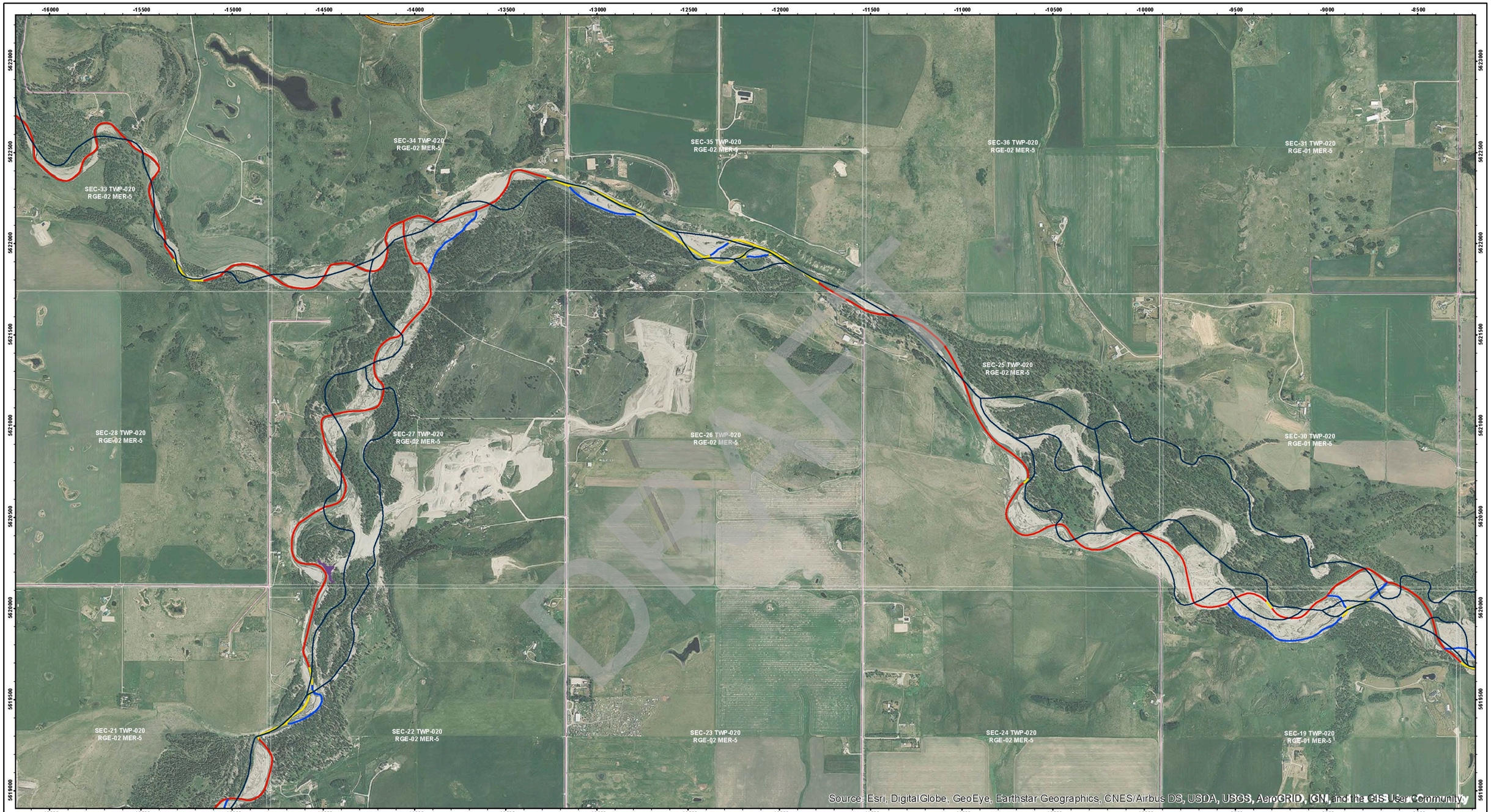


J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 7	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

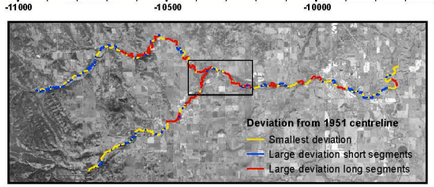
- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments
  - Large deviation long segments
- Road
- Highway
- Control structure

Background imagery: 2015 ESRI ortho

N W E S

50 0 200 m

100 0 300 m

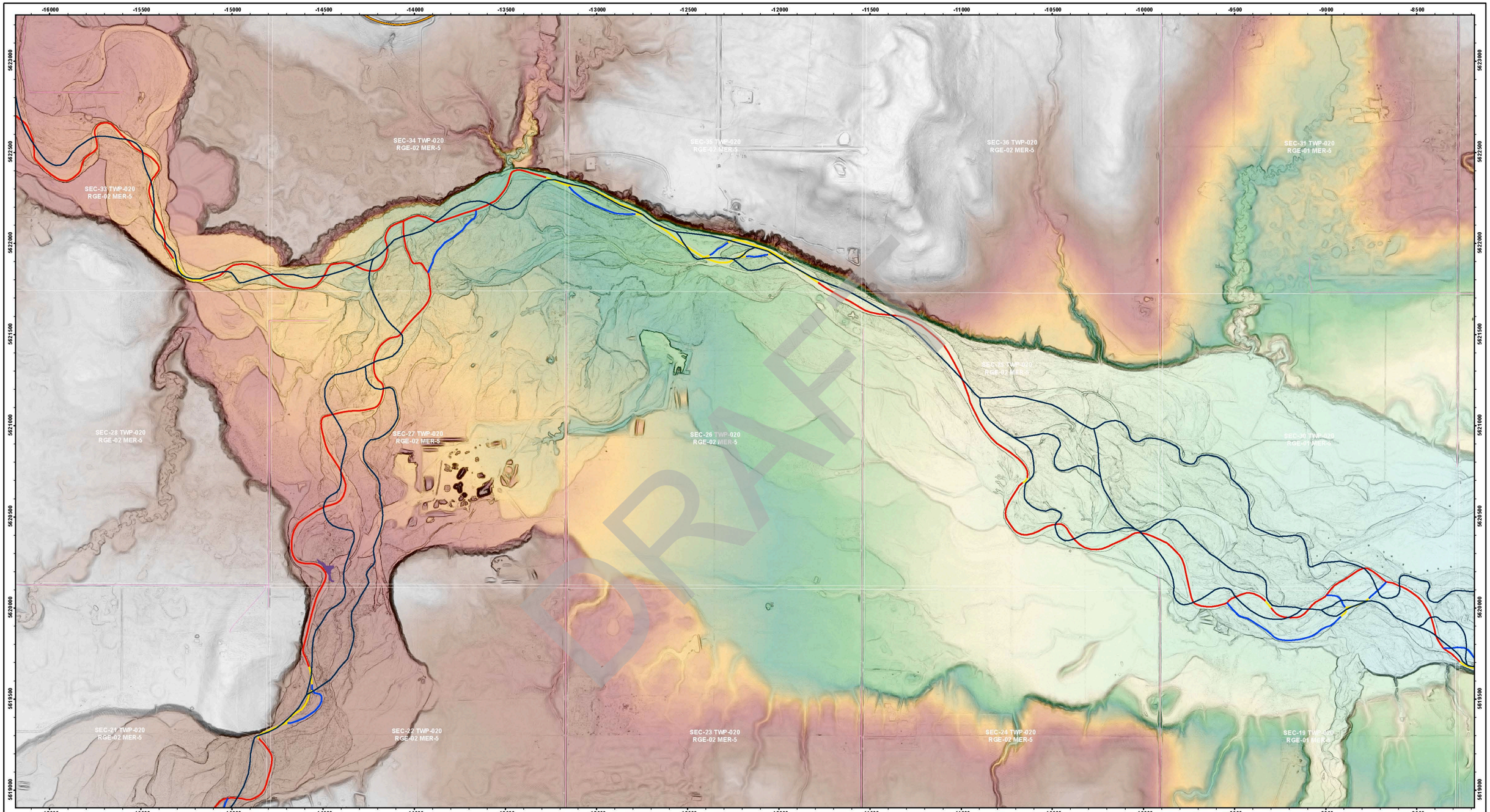


J.D. MOLLARD AND ASSOCIATES (2007) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 8	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

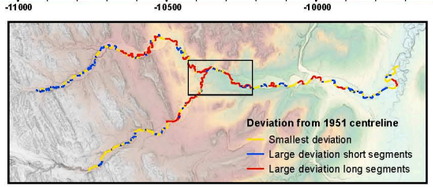
- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Elevation (m)
Value
High : 1237.92
Low : 1097.25

- Road
- Highway
- Control structure

N
W E
S

50 0 200 m
100 0 300 m



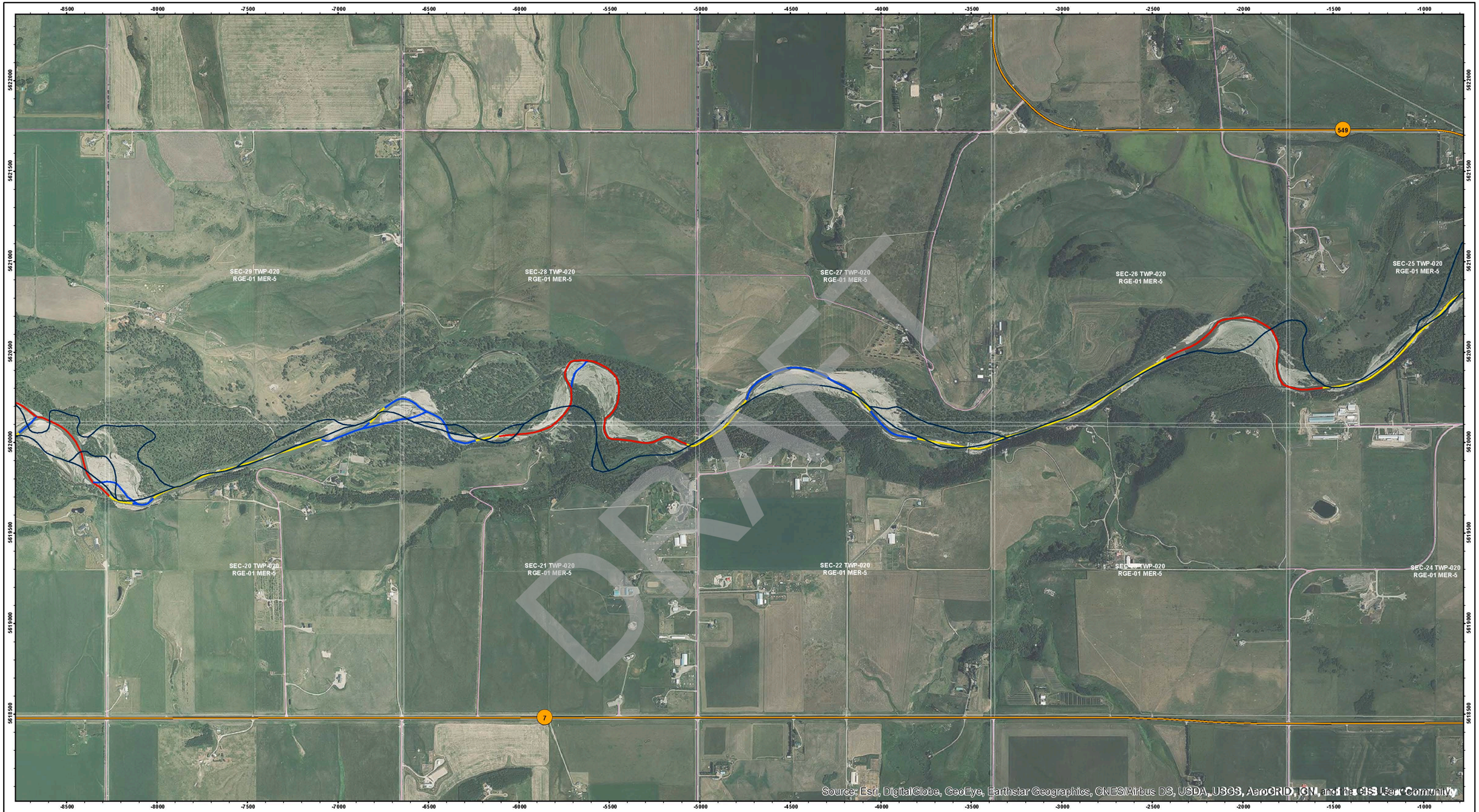
Background imagery: 2016 LiDAR

J.D. MOLLARD AND ASSOCIATES (2007) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 9	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

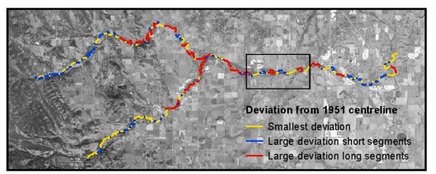
- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments
  - Large deviation long segments
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m

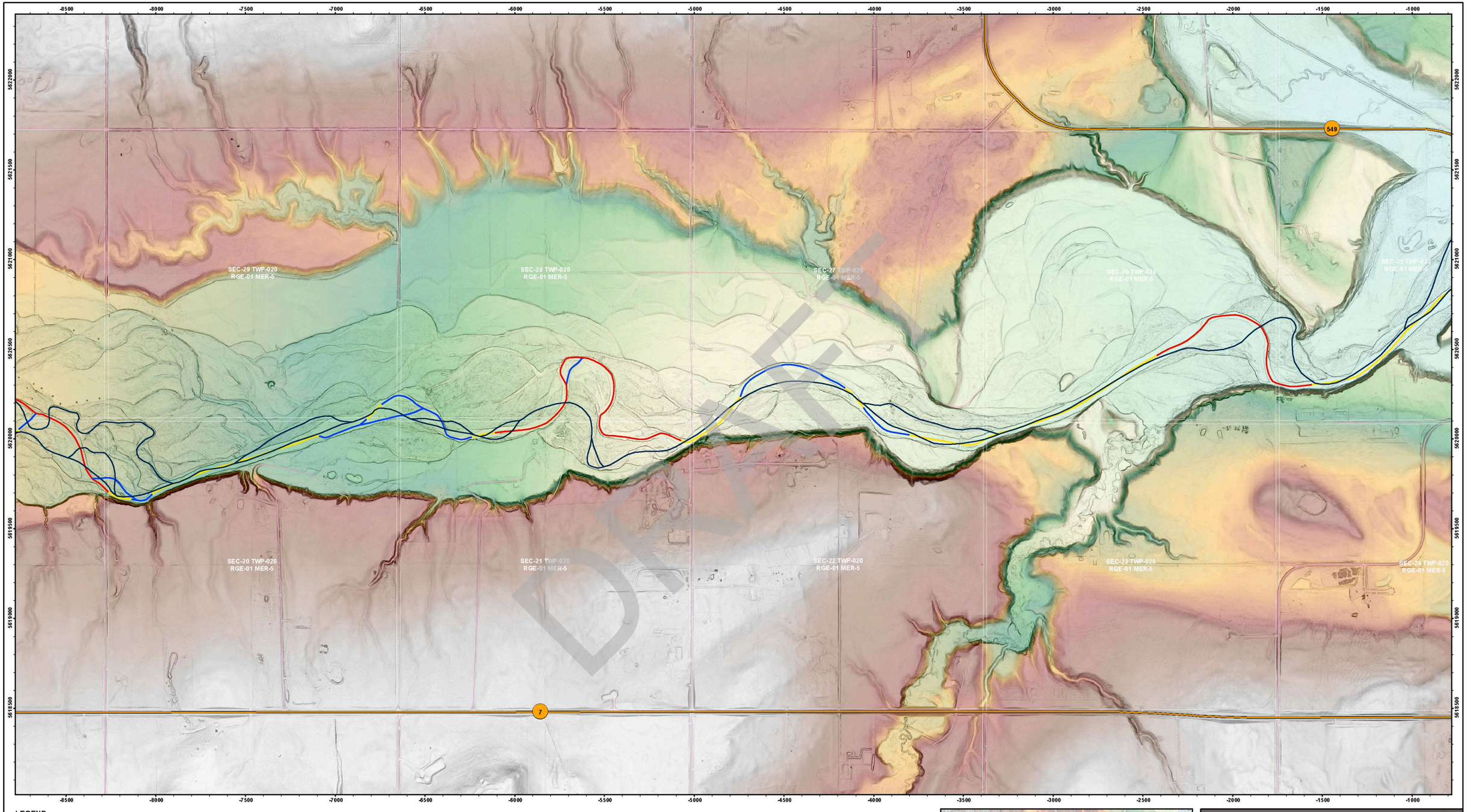


J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 10	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

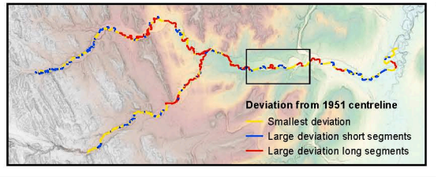
Elevation (m)
Value
High : 1198.78
Low : 1061.59

- Road
- Highway

Background imagery: 2016 LiDAR

N
W E
S

50 0 200 m
100 0 300 m

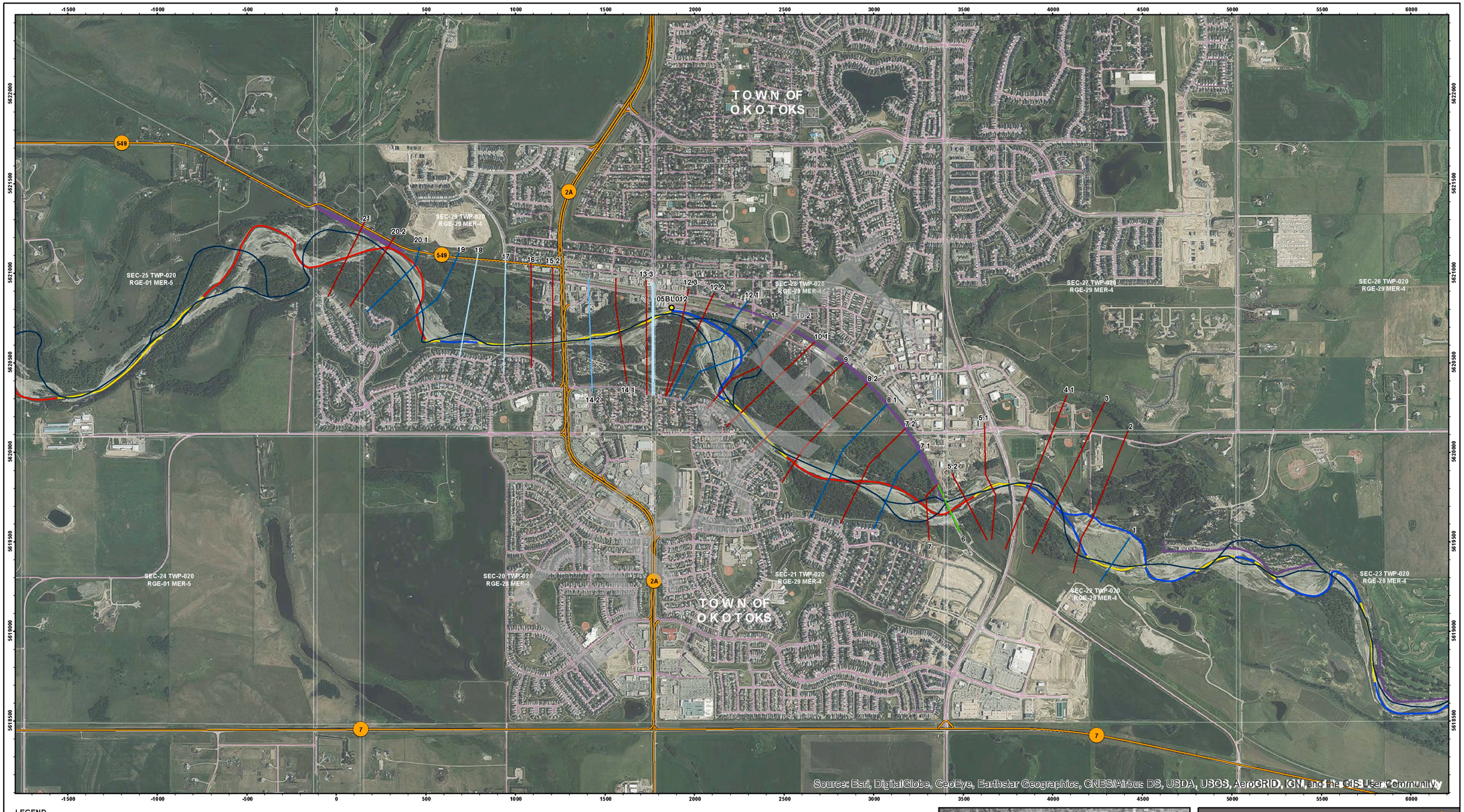


J.D. MOLLARD
AND ASSOCIATES - DESIGN WITH THE LAND

PROJECT: SHEEP RIVER HAZARD STUDY,
CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 11	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Cross section classification

- Class 1A
- Class 1B
- Class 1C
- Class 2
- Class 3

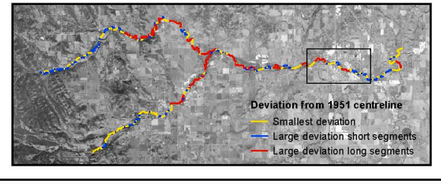
- Road
- Highway
- Control structure

Background imagery: 2015 ESRI ortho

N W E S

50 0 200 m

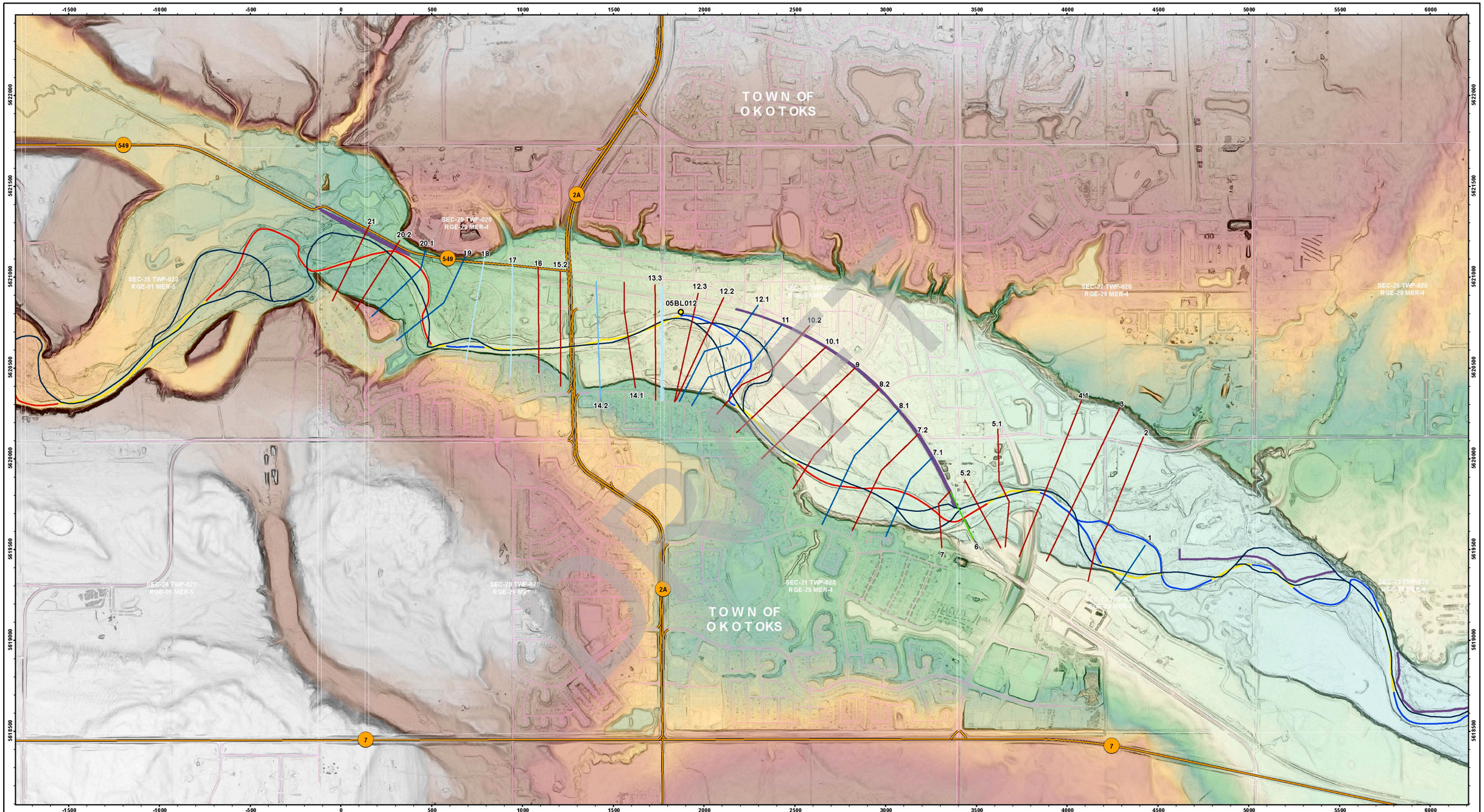
100 0 300 m



J D MOLLARD AND ASSOCIATES

PROJECT	SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION
TITLE	River centrelines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 12	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Elevation (m)
Value
High : 1148.51
Low : 1023.87

Cross section classification

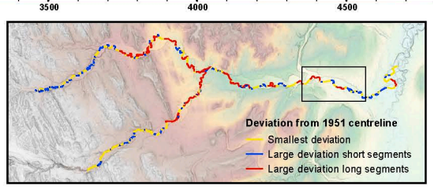
- Class 1A
- Class 1B
- Class 1C
- Class 2
- Class 3

- Road
- Highway
- Control structure

Background imagery: 2016 LiDAR

N W E S

50 0 200 m
100 0 300 m

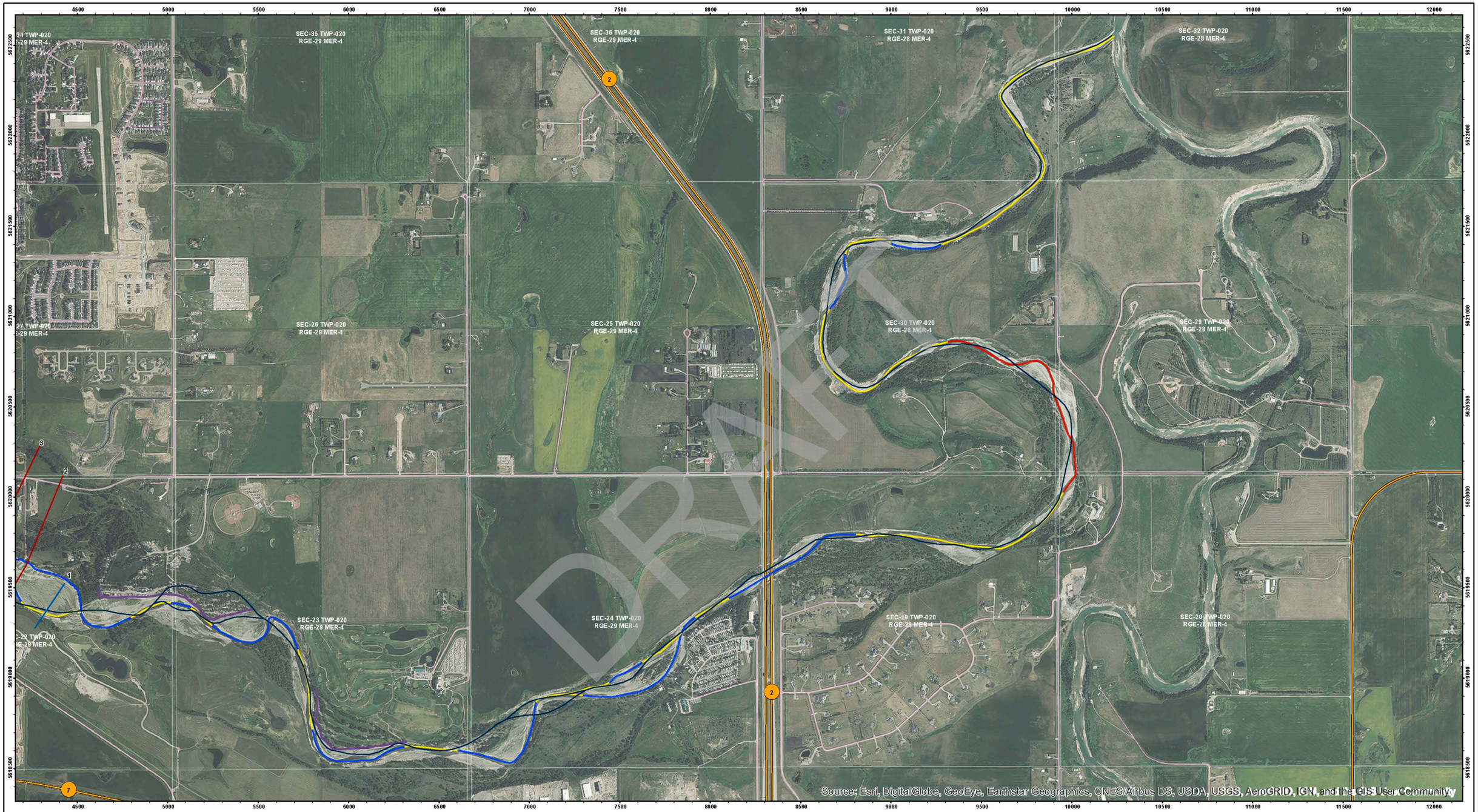


J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 13	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- 1951 channel centreline
- **2015 channel centreline**
  Deviation from 1951 centreline
  - Smallest deviation
  - Large deviation short segments
  - Large deviation long segments

Cross section classification

- Class 1A
- Class 3

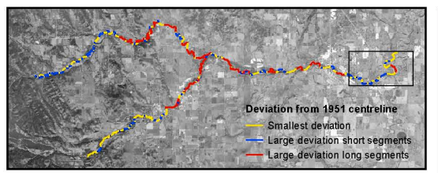
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m

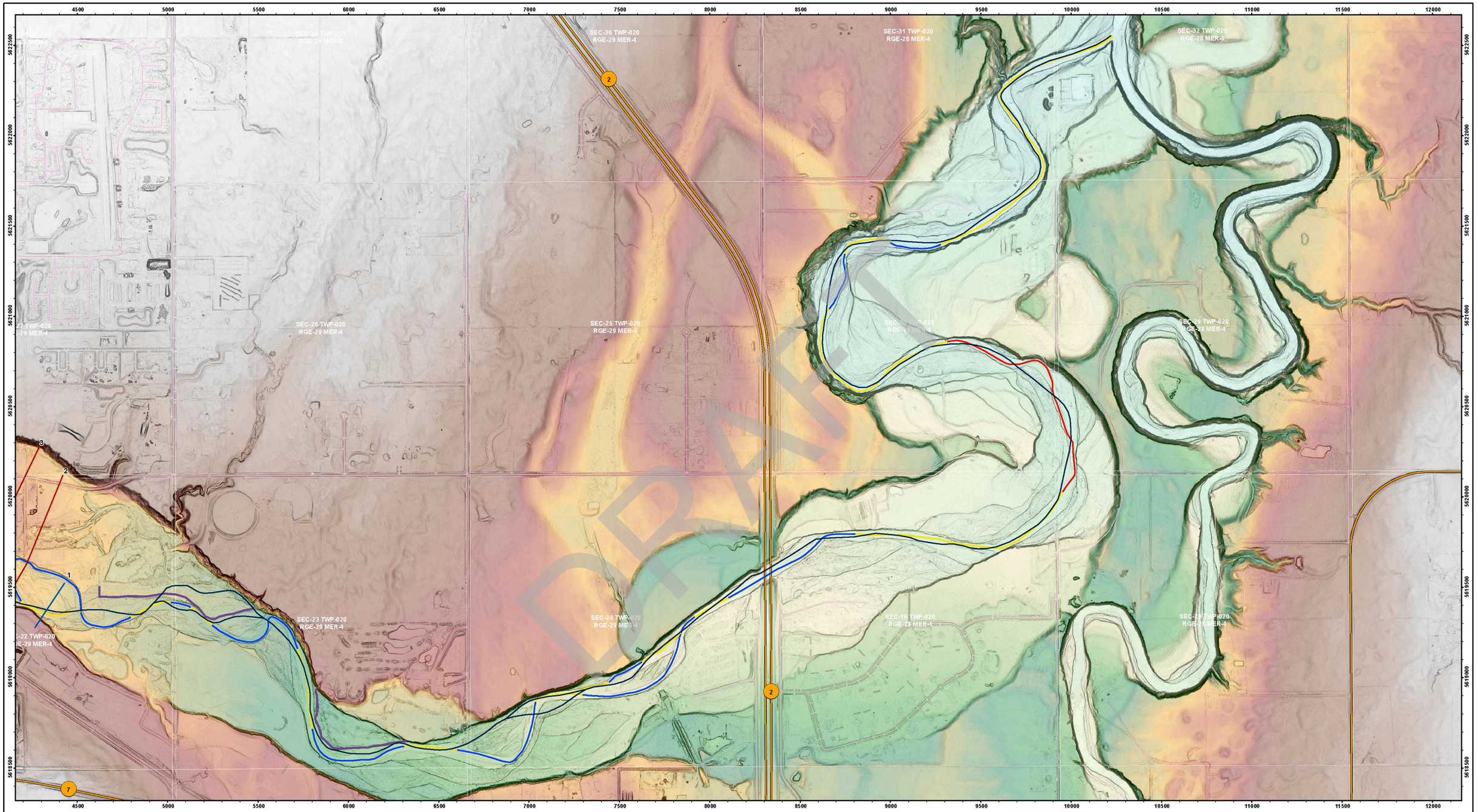


J.D. MOLLARD AND ASSOCIATES (2010) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY,
CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 14	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments
  - Large deviation long segments

Elevation (m)
Value
High : 1103.16
Low : 983.28

Cross section classification
- Class 1A
- Class 3

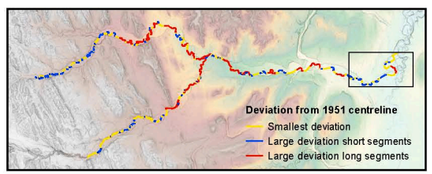
- Road
- Highway

Background imagery: 2016 LiDAR

N
W E
S

50 0 200 m

100 0 300 m

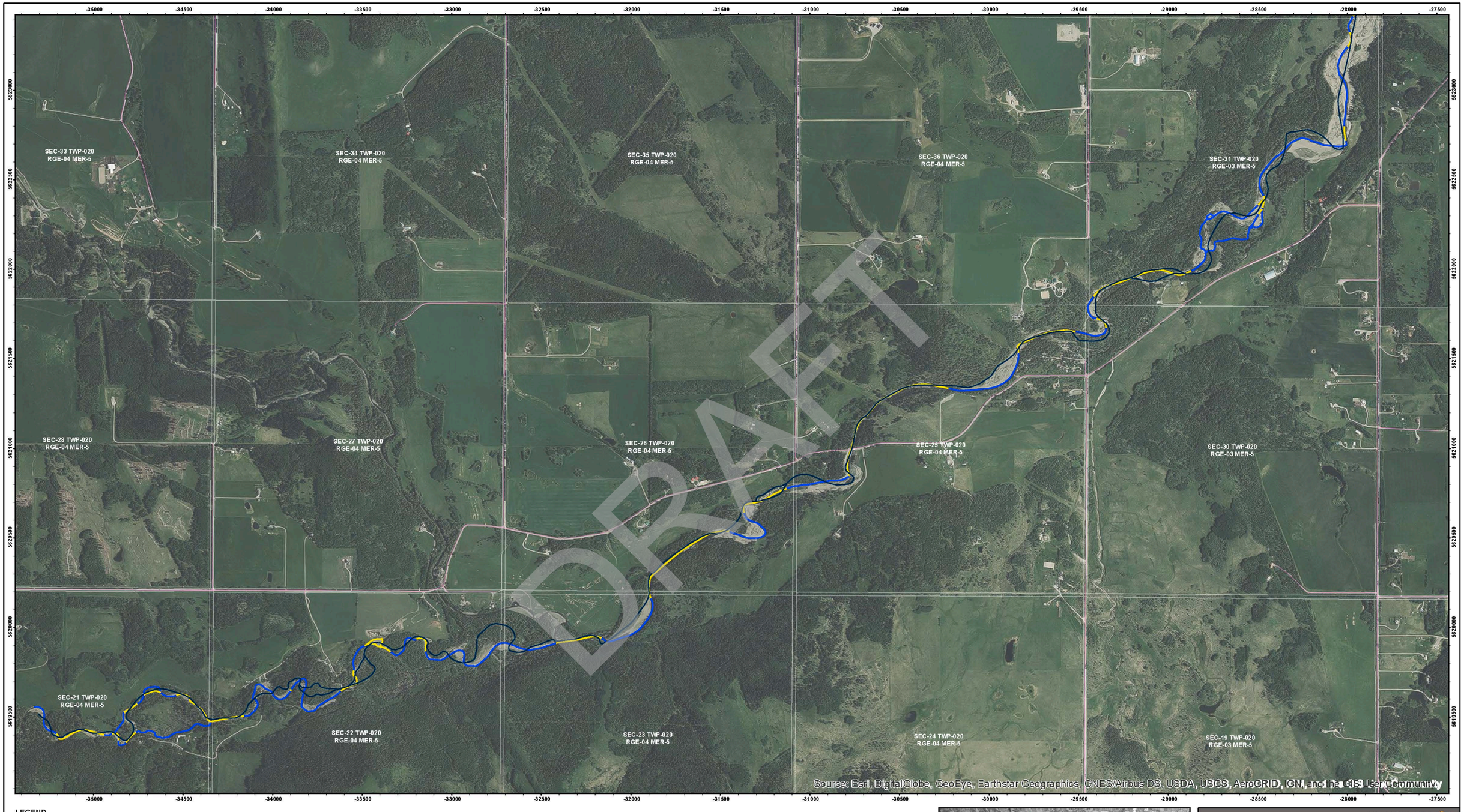


J.D. MOLLARD AND ASSOCIATES (2010) LIMITED

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 15	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- 1951 channel centreline
- Road

2015 channel centreline

Deviation from 1951 centreline

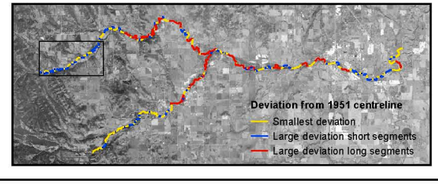
- Smallest deviation
- Large deviation short segments

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m

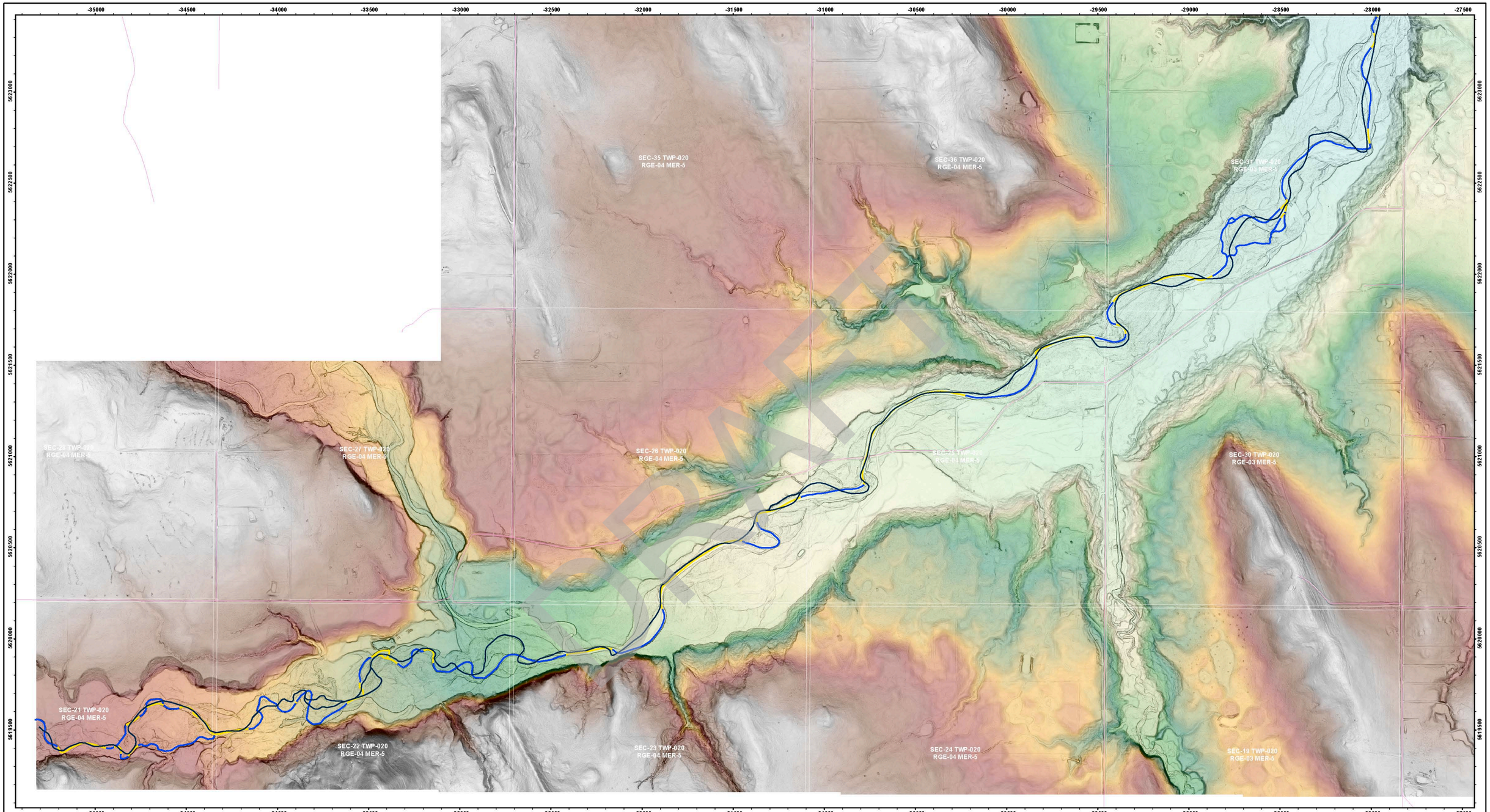


J.D. MOLLARD AND ASSOCIATES LIMITED

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 16	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments

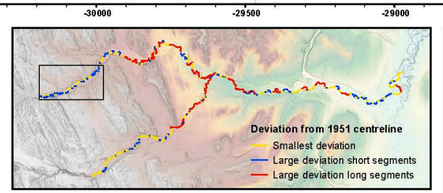
Elevation (m)
Value
High : 1462.87
Low : 1220.48

- Road

Background imagery: 2016 LiDAR

N
W E
S

50 0 200 m
100 0 300 m

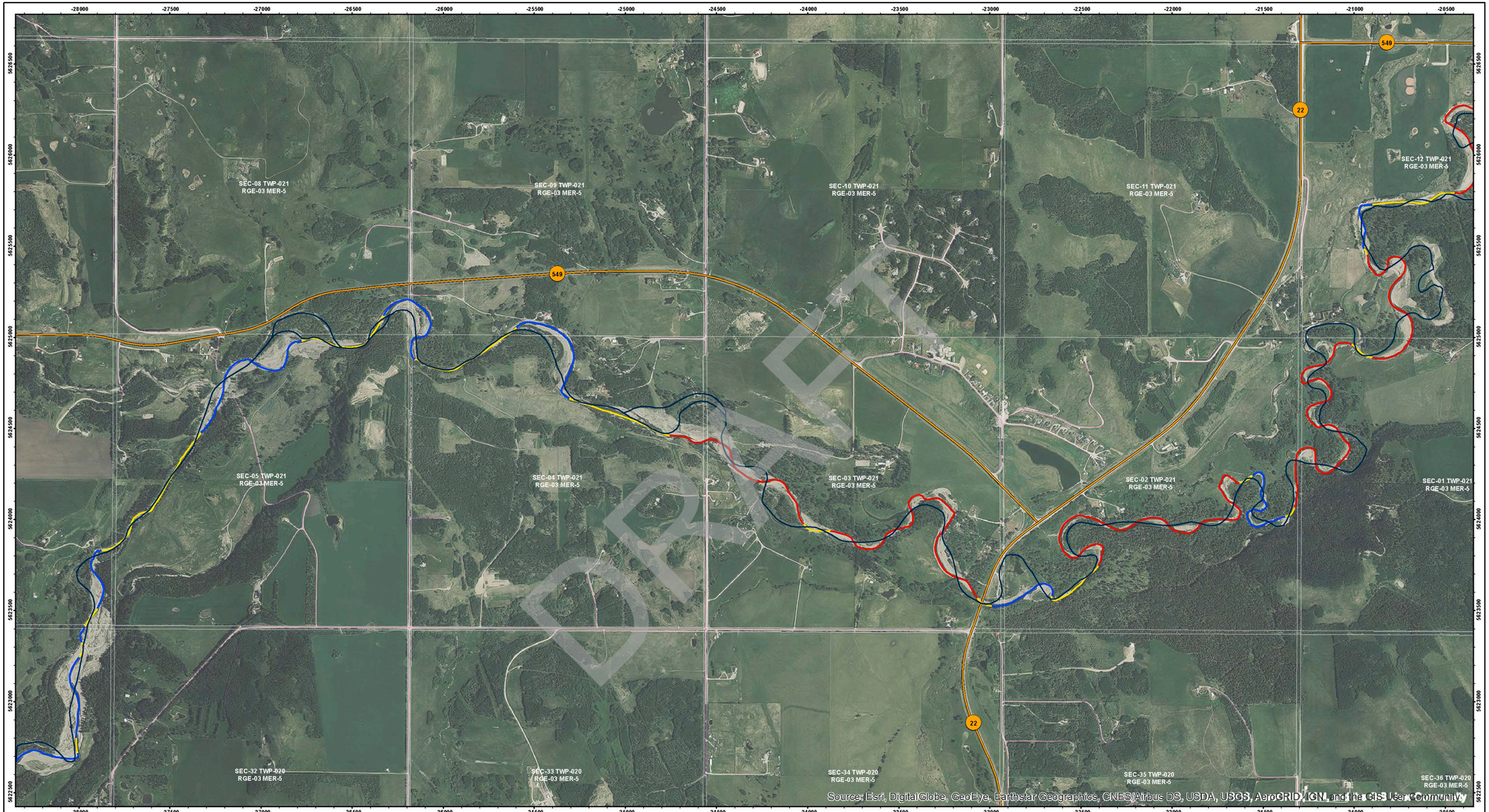


J.D. MOLLARD AND ASSOCIATES 2010 LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 17	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

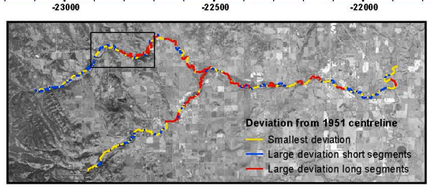
- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments
  - Large deviation long segments
- Road
- Highway

Background imagery: 2015 ESRI ortho

N W E S

50 0 200 m

100 0 300 m

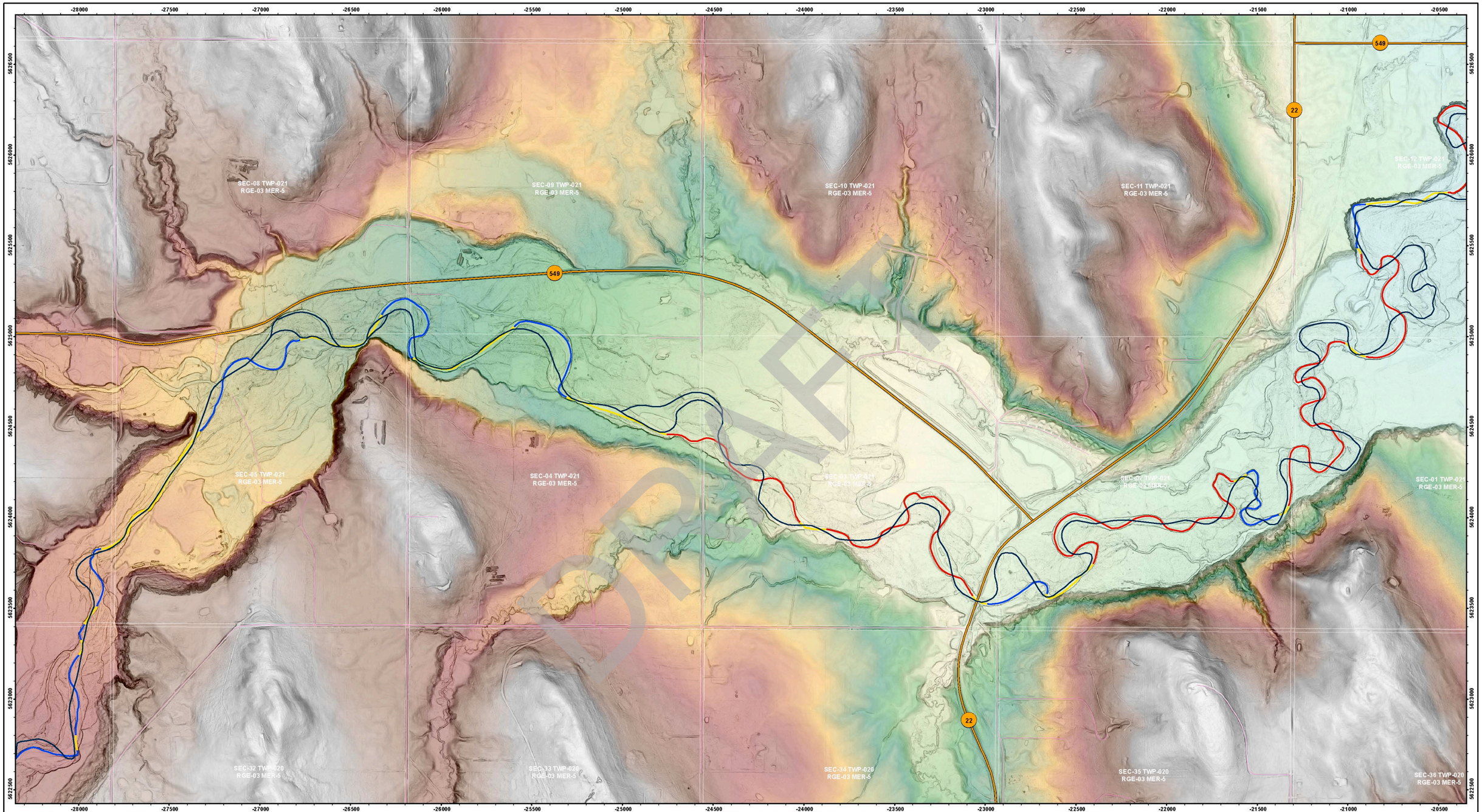


J.D. MOLLARD AND ASSOCIATES (2015) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 18	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

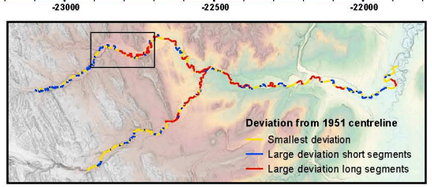
- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments
  - Large deviation long segments

Elevation (m)
Value
High : 1359.21
Low : 1161.5

- Road
- Highway

N
W E
S

50 0 200 m
100 0 300 m



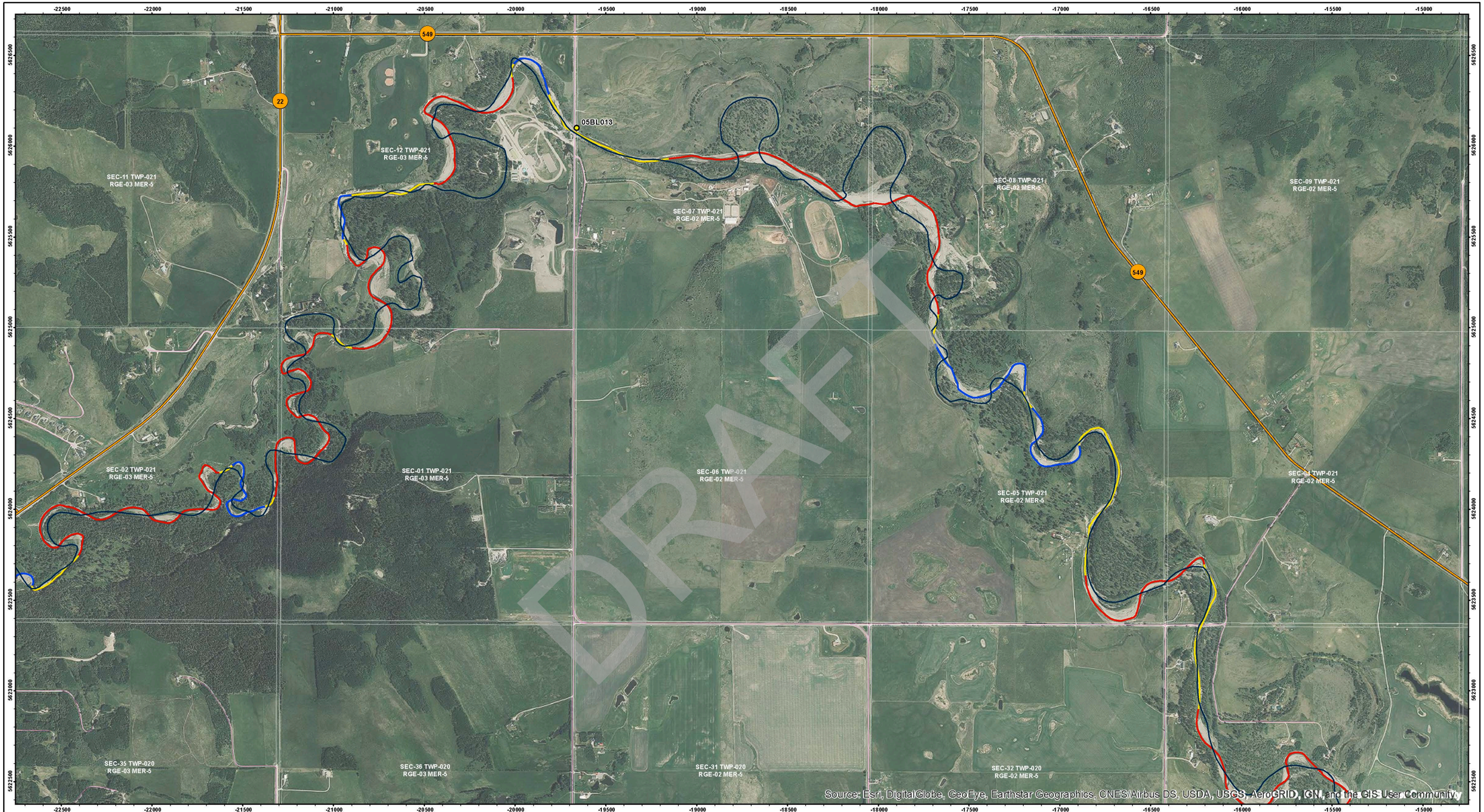
Background imagery: 2016 LiDAR

J.D. MOLLARD

PROJECT
SHEEP RIVER HAZARD STUDY,
CHANNEL STABILITY INVESTIGATION

TITLE
River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 19	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

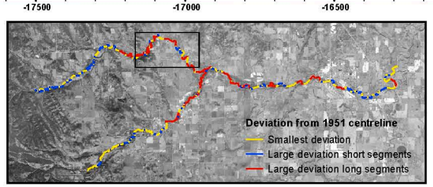
- Hydrometric station
- 1951 channel centreline
- **2015 channel centreline**
- **Deviation from 1951 centreline**
  - Smallest deviation
  - Large deviation short segments
  - Large deviation long segments
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m

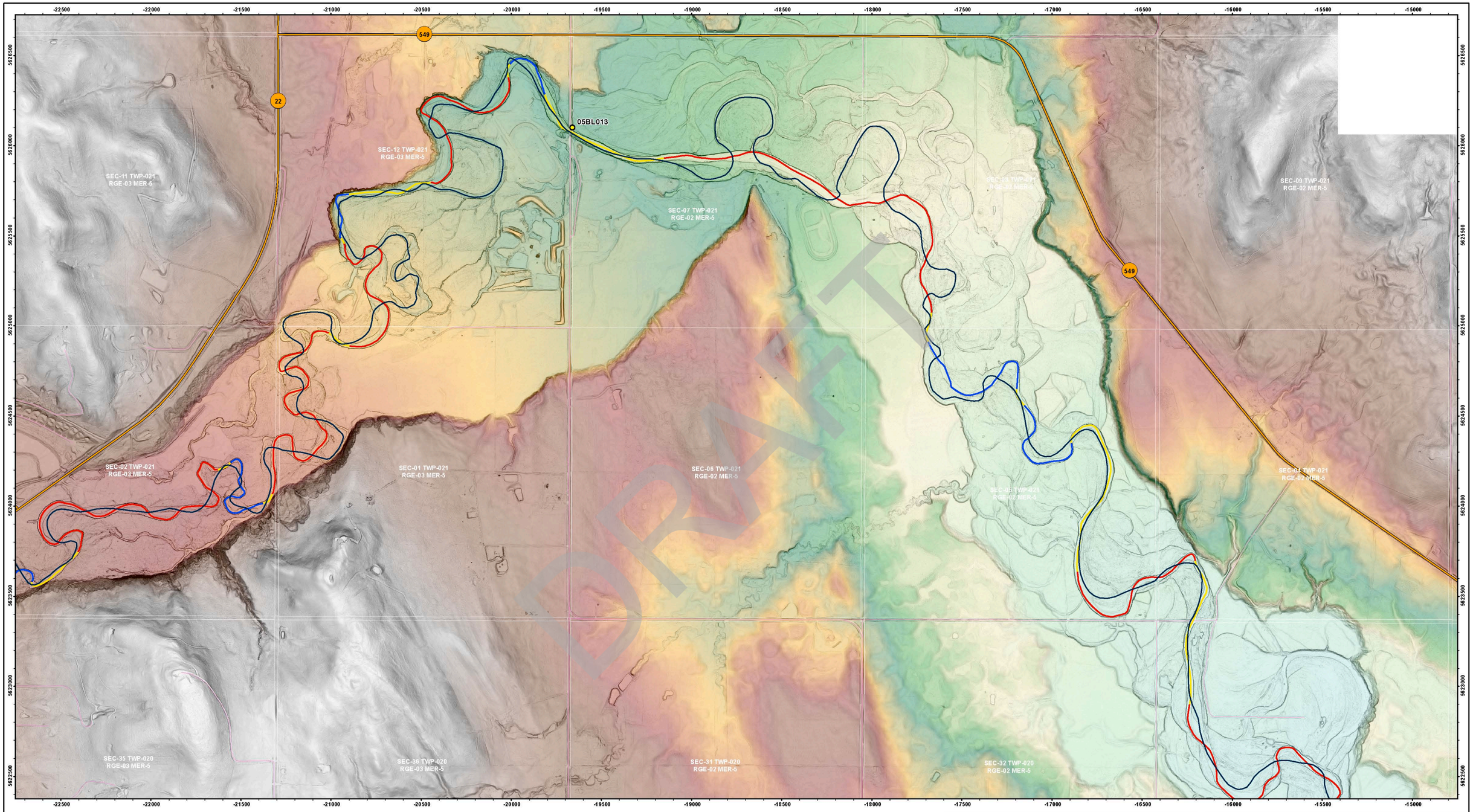


J.D. MOLLARD AND ASSOCIATES CONSULTANTS LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 20	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- 1951 channel centreline

2015 channel centreline
Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

Elevation (m)
Value
High : 1324.76
Low : 1134.43

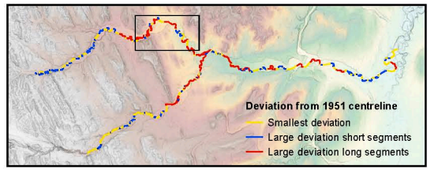
- Road
- Highway

Background imagery: 2016 LiDAR

N W E S

50 0 200 m

100 0 300 m



J.D. MOLLARD AND ASSOCIATES (2007) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: River centrelines, 2016 LiDAR

DRAWN	DVZ	09 FEB 2019	MAP 21	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000

LEGEND

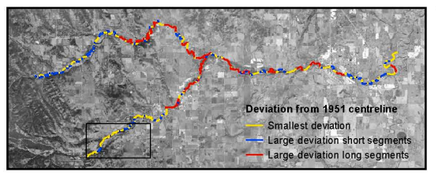
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m

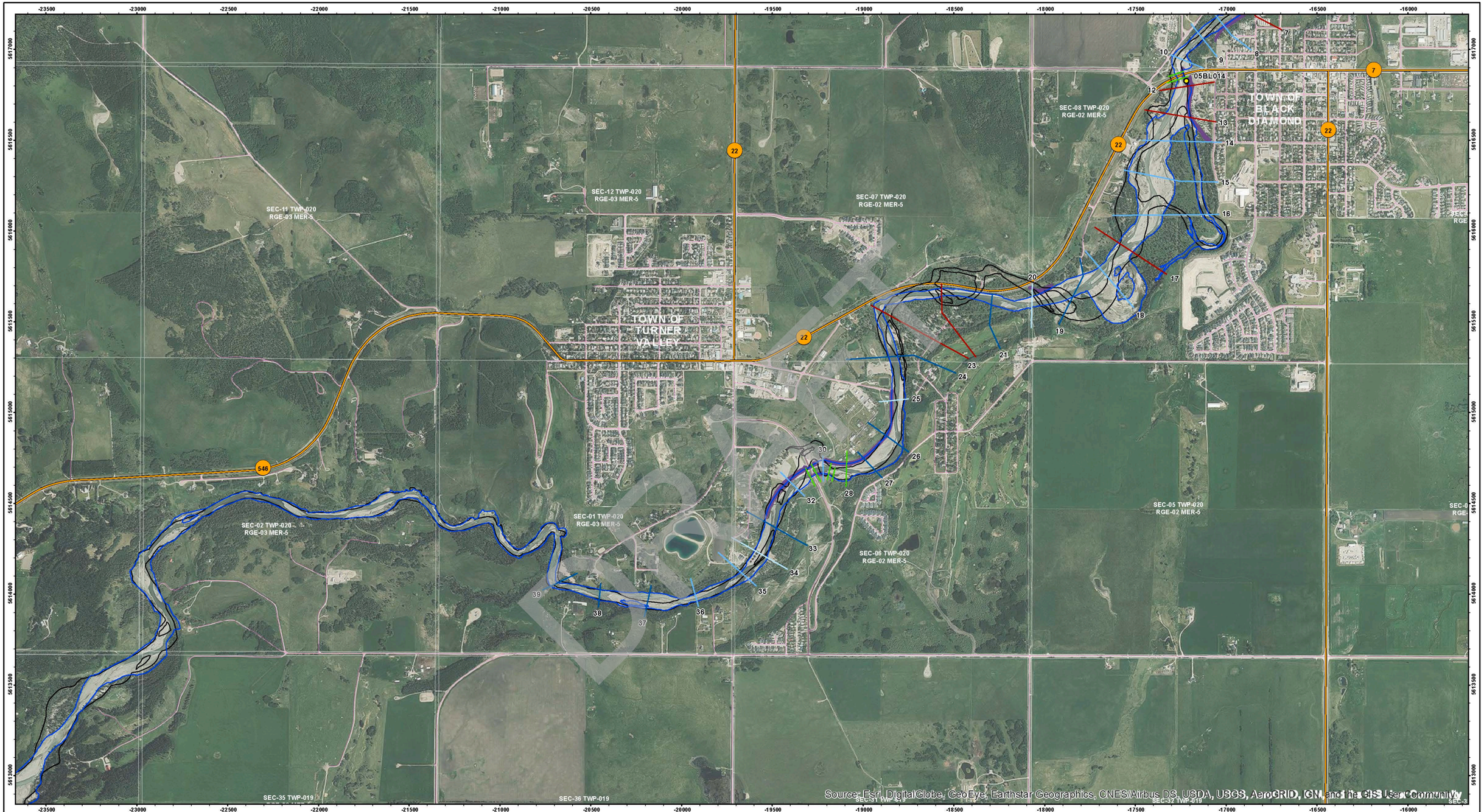


J.D. MOLLARD AND ASSOCIATES (2010) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 22	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway
- Control structure

Cross section classification

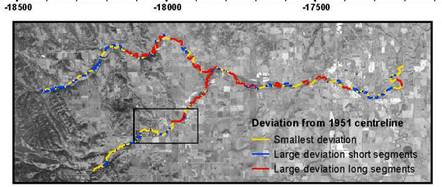
- Class 1A
- Class 1B
- Class 1C
- Class 2
- Class 3

Background imagery: 2015 ESRI ortho

N W E S

50 0 200 m

100 0 300 m

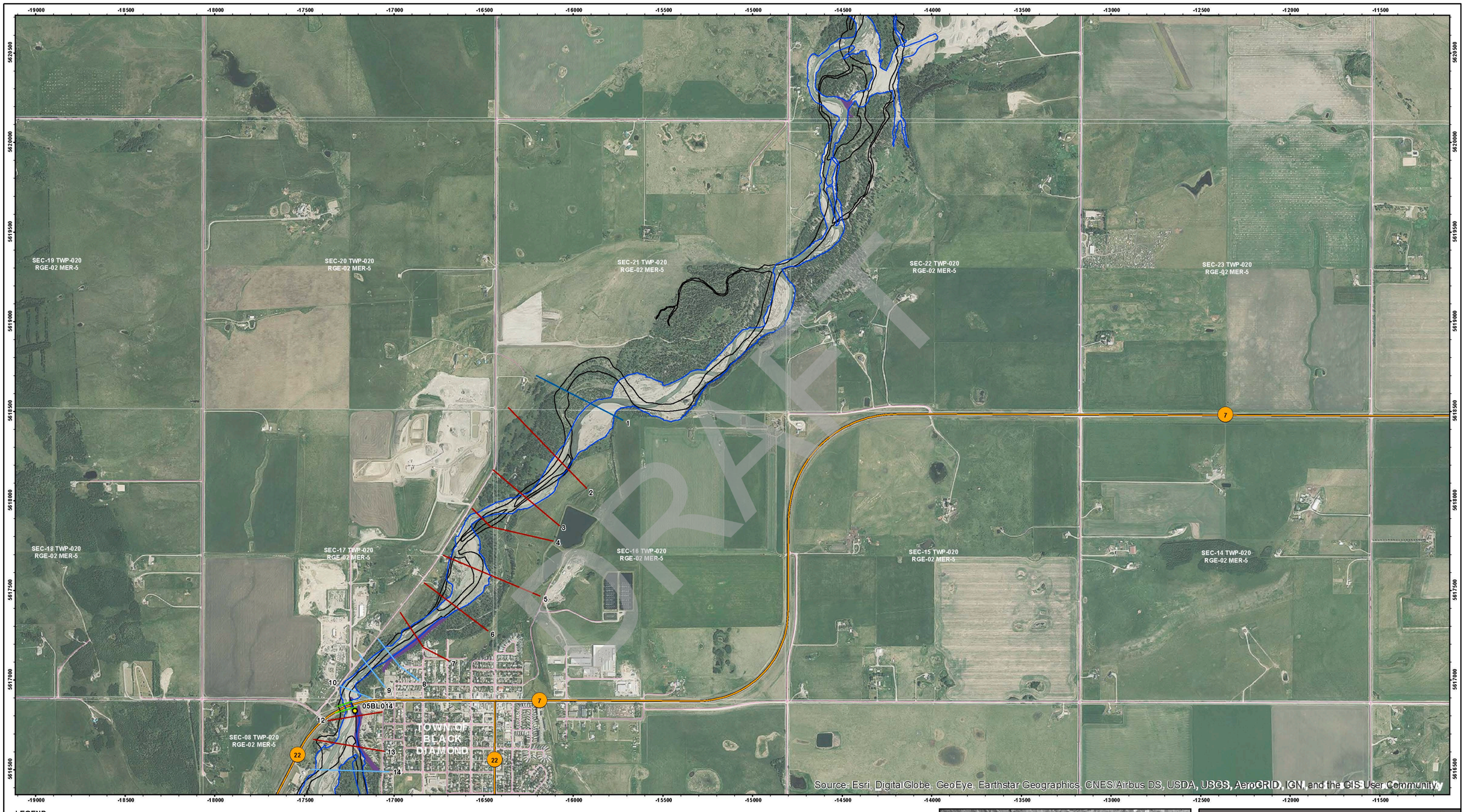


J D MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 23	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway
- Control structure

Cross section classification

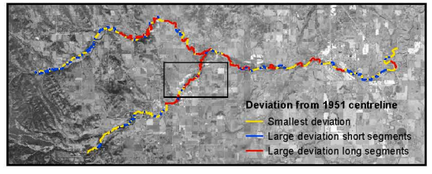
- Class 1A
- Class 1B
- Class 2
- Class 3

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m



J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY,
CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 24	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000

SEC-34 TWP-020 RGE-02 MER-5
SEC-35 TWP-020 RGE-02 MER-5
SEC-36 TWP-020 RGE-02 MER-5
SEC-31 TWP-020 RGE-01 MER-5
SEC-33 TWP-020 RGE-02 MER-5
SEC-25 TWP-020 RGE-02 MER-5
SEC-28 TWP-020 RGE-02 MER-5
SEC-27 TWP-020 RGE-02 MER-5
SEC-26 TWP-020 RGE-02 MER-5
SEC-30 TWP-020 RGE-01 MER-5
SEC-21 TWP-020 RGE-02 MER-5
SEC-22 TWP-020 RGE-02 MER-5
SEC-23 TWP-020 RGE-02 MER-5
SEC-24 TWP-020 RGE-02 MER-5
SEC-19 TWP-020 RGE-01 MER-5

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

LEGEND

- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway
- Control structure

Background imagery: 2015 ESRI ortho

50 0 200 m

100 0 300 m

Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

J D MOLLARD AND ASSOCIATES (2007) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 25	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000

LEGEND

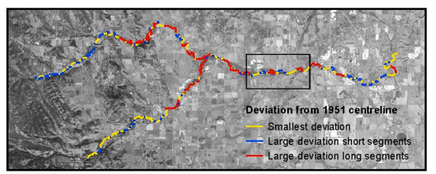
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m



J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

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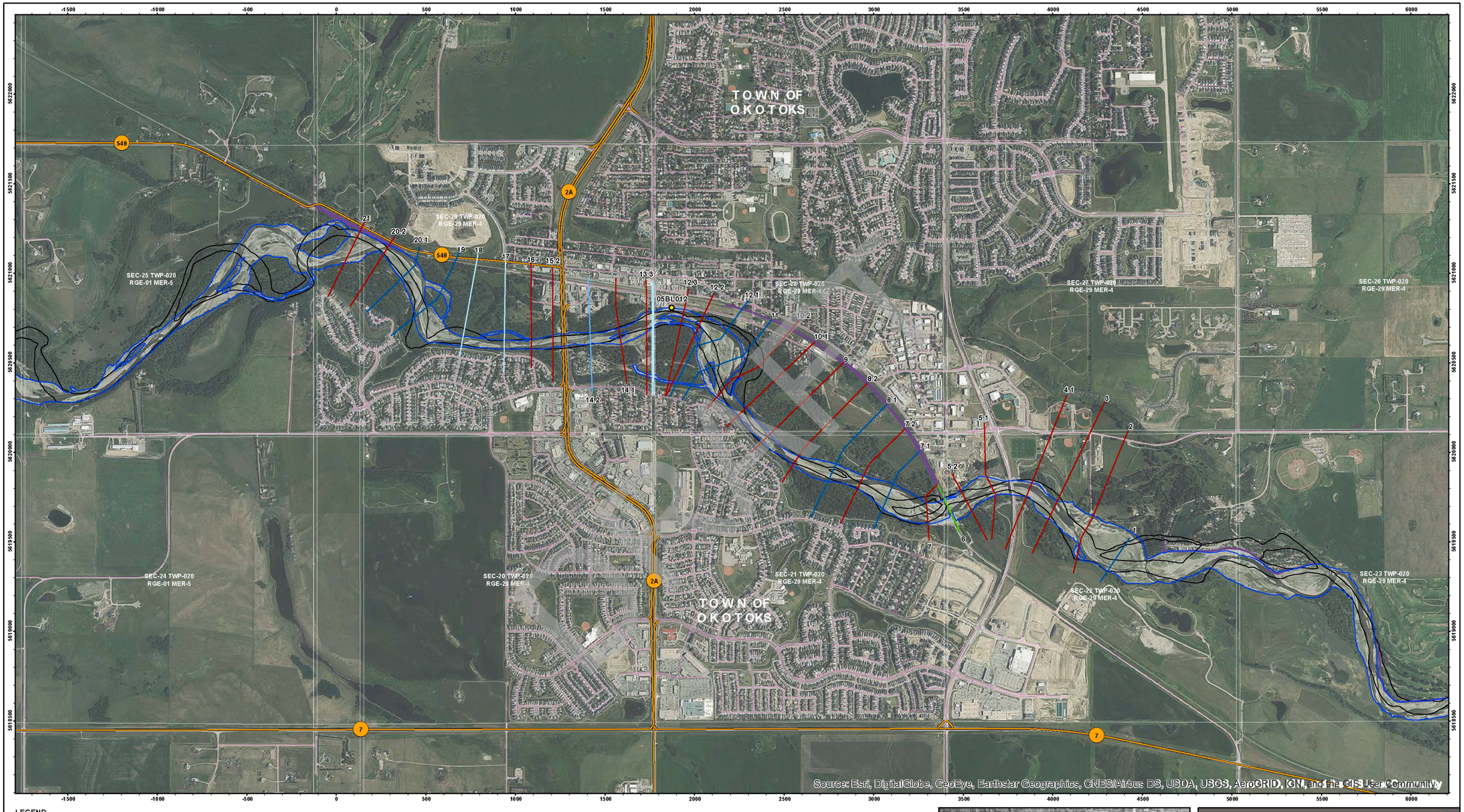
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Hydrometric station
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway
- Control structure

Cross section classification

- Class 1A
- Class 1B
- Class 1C
- Class 2
- Class 3

Background imagery: 2015 ESRI ortho

50 0 200 m

100 0 300 m

Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

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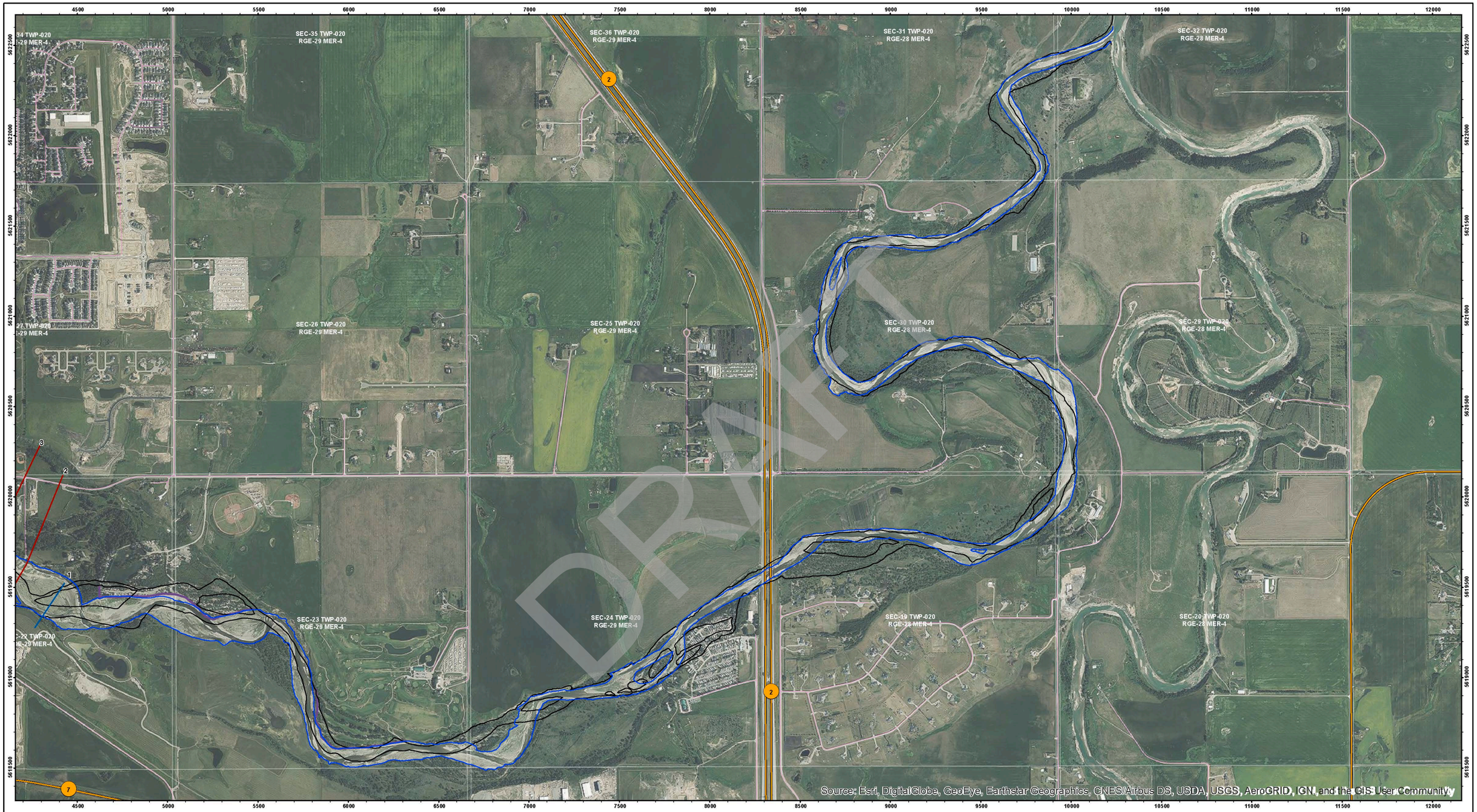
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway

Cross section classification

- Class 1A
- Class 3

Background imagery: 2015 ESRI ortho

50 0 200 m

100 0 300 m

Deviation from 1951 centreline

- Smallest deviation
- Large deviation short segments
- Large deviation long segments

J.D. MOLLARD

PROJECT: SHEEP RIVER HAZARD STUDY,
CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

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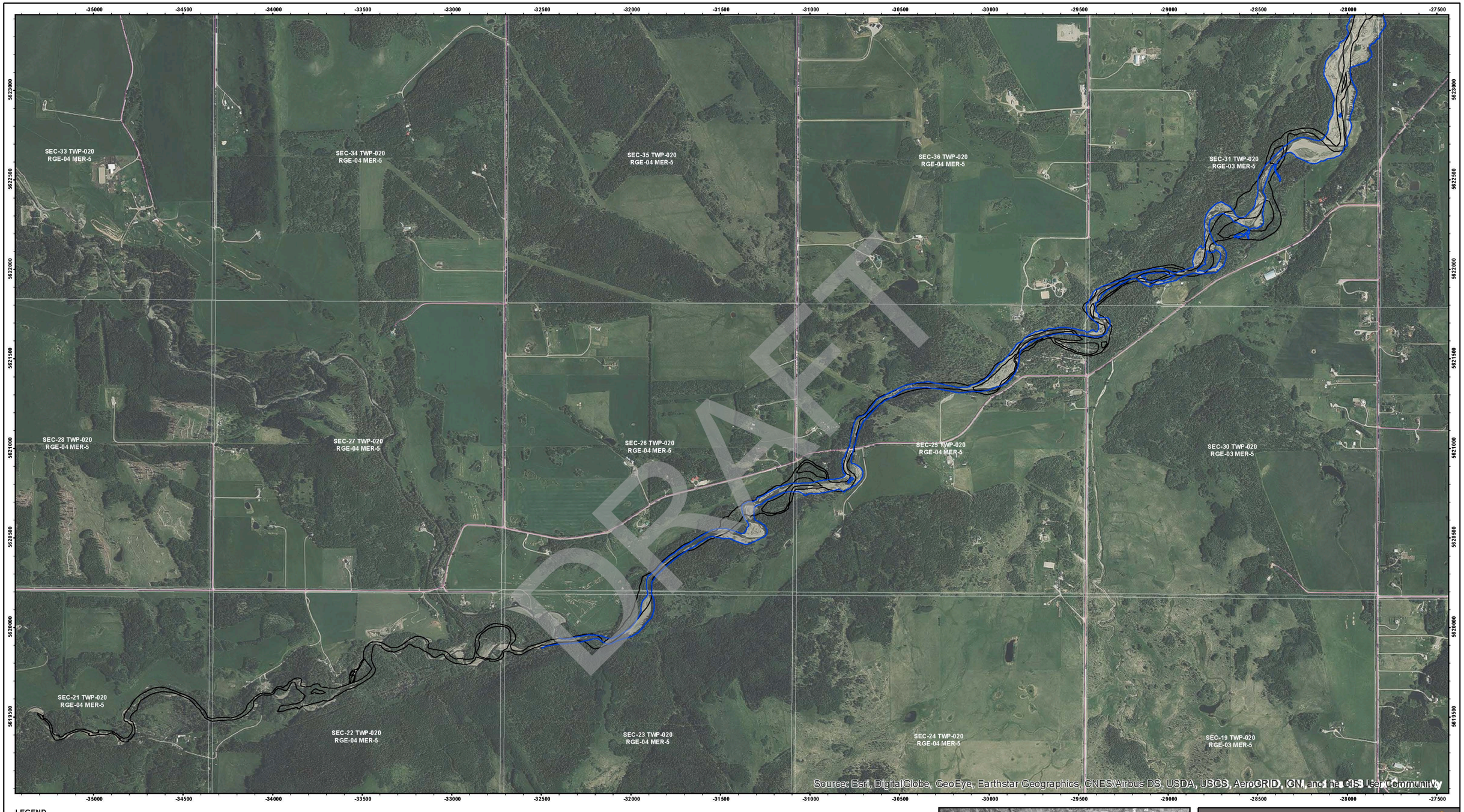
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

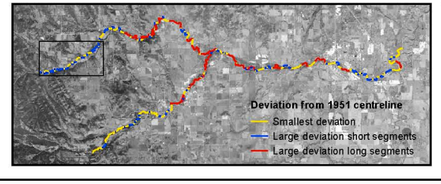
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m



J.D. MOLLARD AND ASSOCIATES LIMITED

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

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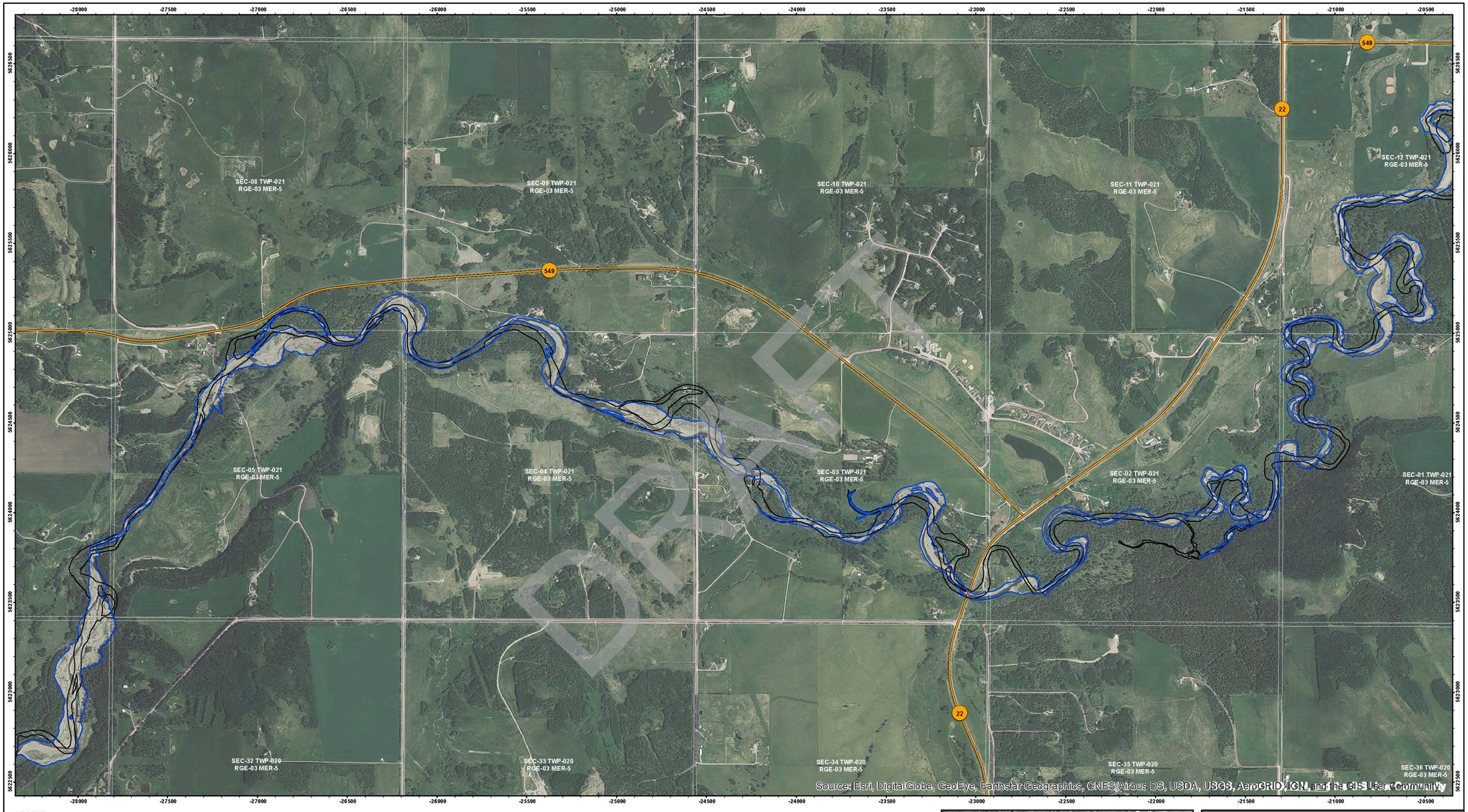
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

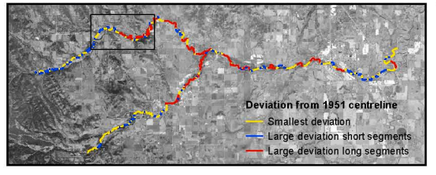
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m



J.D. MOLLARD AND ASSOCIATES (2007) LTD.

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

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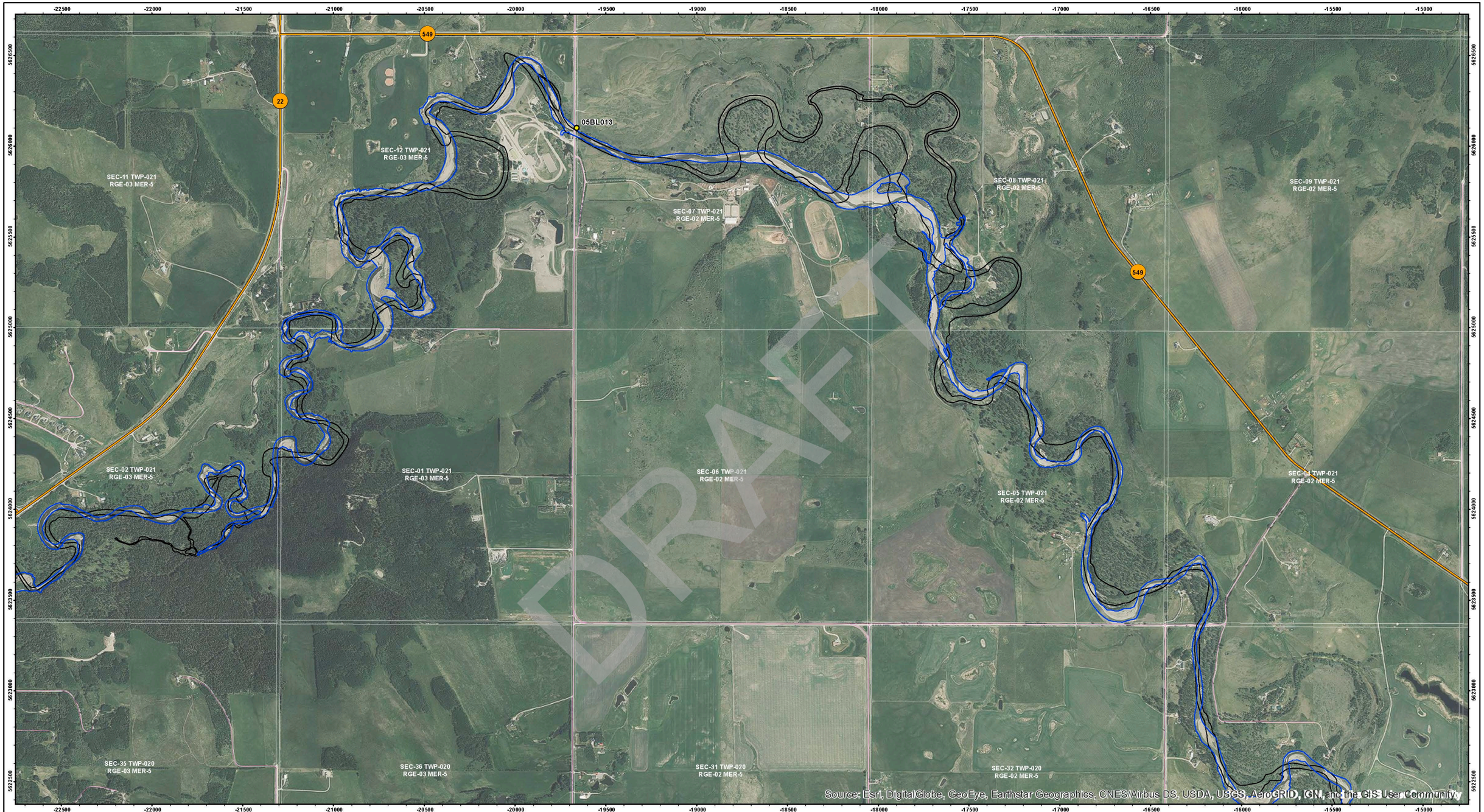
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000



LEGEND

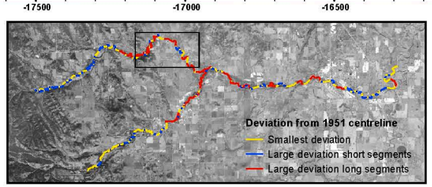
- Hydrometric station
- Previously mapped 'riverline' 1951
- Previously mapped 'bankline' 2016
- Road
- Highway

Background imagery: 2015 ESRI ortho

N
W E
S

50 0 200 m

100 0 300 m



J.D. MOLLARD AND ASSOCIATES - ENGINEERED

PROJECT: SHEEP RIVER HAZARD STUDY, CHANNEL STABILITY INVESTIGATION

TITLE: Previously mapped banklines, 2015 orthoimagery

DRAWN	DVZ	09 FEB 2019	MAP 31	3TM 114
CHECK	DSM	11 FEB 2019		NAD 1983
REVIEW	LAP	11 FEB 2019		1:20,000

APPENDIX A – PREVIOUSLY PREPARED CROSS SECTION COMPARISON

Memo

To:	Peter Bezeau, Project Manager Sheep Hazard Study	**Date:**	18 April 2017
From:	L.S. Hundal, P.Eng.	**Email:**	liv.hundal@amecfw.com
c:	Pat Stevenson, AEP		
Ref:	CW2241.700		
Re:	Channel Stability Investigation – Interim Deliverable Cross Section and Thalweg Profile Comparison		

1.0 Introduction

This memo contains an overview description of the draft cross section and thalweg profile comparison of the channel stability investigation component of the Sheep River Hazard Study. The methodology and graphical results are provided herein. The interpretation and quantitative analysis of results will be provided in future documents. This is an interim deliverable and is only one component of the Channel Stability Investigation.

The 2015 and 2016 cross section survey of the main channel that was obtained by Amec Foster Wheeler for the Sheep Hazard Study was compared to historic cross section data obtained from the following previous studies:

- Black Diamond – Turner Valley Flood Risk Mapping Study (1992) – Cross Sections obtained from HEC-2 file SHEE_ENC_BD_TV.HC2; and
- Okotoks Flood Risk Mapping Study (1996) – Cross Sections obtained from HEC-2 file SHEE_EBD_OKOTOKS.HC2, which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross Sections 3.0, 4.2 and 5.1. These correspond to 2015/2016 cross sections 12.47, 12.64 and 12.85, respectively.

2.0 Methodology to Georeference Historic Cross Section Surveys

The alignment of the historic cross sections was contained in shapefiles obtained from AEP. These are the same shapefiles that show cross section locations on the AEP flood hazard mapping website. However, these shapefiles only contain cross section alignment and not the locations of individual survey points. The procedure for locating individual survey points on this alignment is detailed below.

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140 Quarry Park Boulevard SE
Calgary, Alberta T2C 3G3
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Fax +1 403 248-1590
amecfw.com

- These shapefiles were plotted on georeferenced aerial imagery. All cross sections are viewed looking downstream. The end points of the cross sections typically coincided with the toe of the valley wall.
- The HEC-2 model input files contain the following information for each survey point: (1) elevation; and (2) stationing along the cross section, as measured from the left (looking downstream) starting point of each cross section.
- For the majority of the cross sections, the lengths for the HEC-2 data and the shapefiles corresponded well (within 1 to 2 m). This allowed the end points of the cross section to be identified and georeferenced. Once these are known, all other points from the HEC-2 data can be georeferenced.
- For a few of the cross sections, the length of the cross sections obtained from the shapefiles was greater than the lengths obtained from the HEC-2 data (i.e. the shapefile cross section alignment extended well past the toe of the valley wall). In these instances, the georeferenced location of the toe of the valley wall was obtained from recent aerial imagery (this location was known not to have changed), this point was correlated to the toe of the valley wall identified from the HEC-2 data. In the HEC-2 data, the toe of the valley wall can be readily identified as it is the last point that has the same general elevation as the valley bottom, prior to the abrupt increase in elevation that occurs at the next survey point.Once this is known, all other points from the HEC-2 data can be georeferenced.

3.0 Cross Section Comparison

Attachments A and B contain the comparisons of historic and 2015/2016 cross sections for Okotoks and Black Diamond/Turner Valley, respectively. Both attachments contain the following information

- Map showing the location of the cross sections (**Figures A1 and B1**).
- Cross section comparison plots. Information for an individual cross section is shown separately on one page. The bottom half of the page contains the cross section comparison plot. The top half of the page is a plan view that shows the northings and eastings plotted for both historic (green) and 2015/2016 (red) survey points. A blue line is plotted as a visual aid to compare the location of the survey points with respect to this alignment. A close grouping to the line of both the 2015/2016 (red) and historic (green) points indicates the historic and 2015/2016 surveys are at a similar location. The majority of the historic and 2015/2016 survey points are located on or close to the line indicating that two sets of survey were taken at a similar cross section location.

The terms of reference require a comparison of historic and 2015/2016 main channel cross sections. The location of the historic thalweg has moved outside the 2015/2016 main channel at several cross sections. The entire cross section (main channel and floodplain) plot of the historic survey is shown, in order to see these areas, which are noted below:

- Okotoks
  - 13.12
  - 15.06
  - 15.17
  - 15.4
  - 17.45
- Black Diamond/Turner Valley
  - 41.36
  - 47.62

4.0 Thalweg Profile Comparison

Attachments C and D contain the thalweg profile comparisons, for Okotoks and Black Diamond/Turner Valley, respectively. The thalweg (minimum channel elevation) was obtained from the cross sections discussed above. Thalweg information is presented both as a plot of the profile and tabular data.

Yours truly,

Amec Foster Wheeler Environment & Infrastructure,

a Division of Amec Foster Wheeler Americas Limited

Review *ed by:*

L.S. Hundal, M.Eng., P.Eng.
Senior Associate Water Resources Engineer
T: (403) 387-1669
E: liv.hundal@amecfw.com

Gary R.E. Beckstead, M.Sc., P.Eng.
Principal Engineer Water Resources

LSH

Attach. A, B, C and D

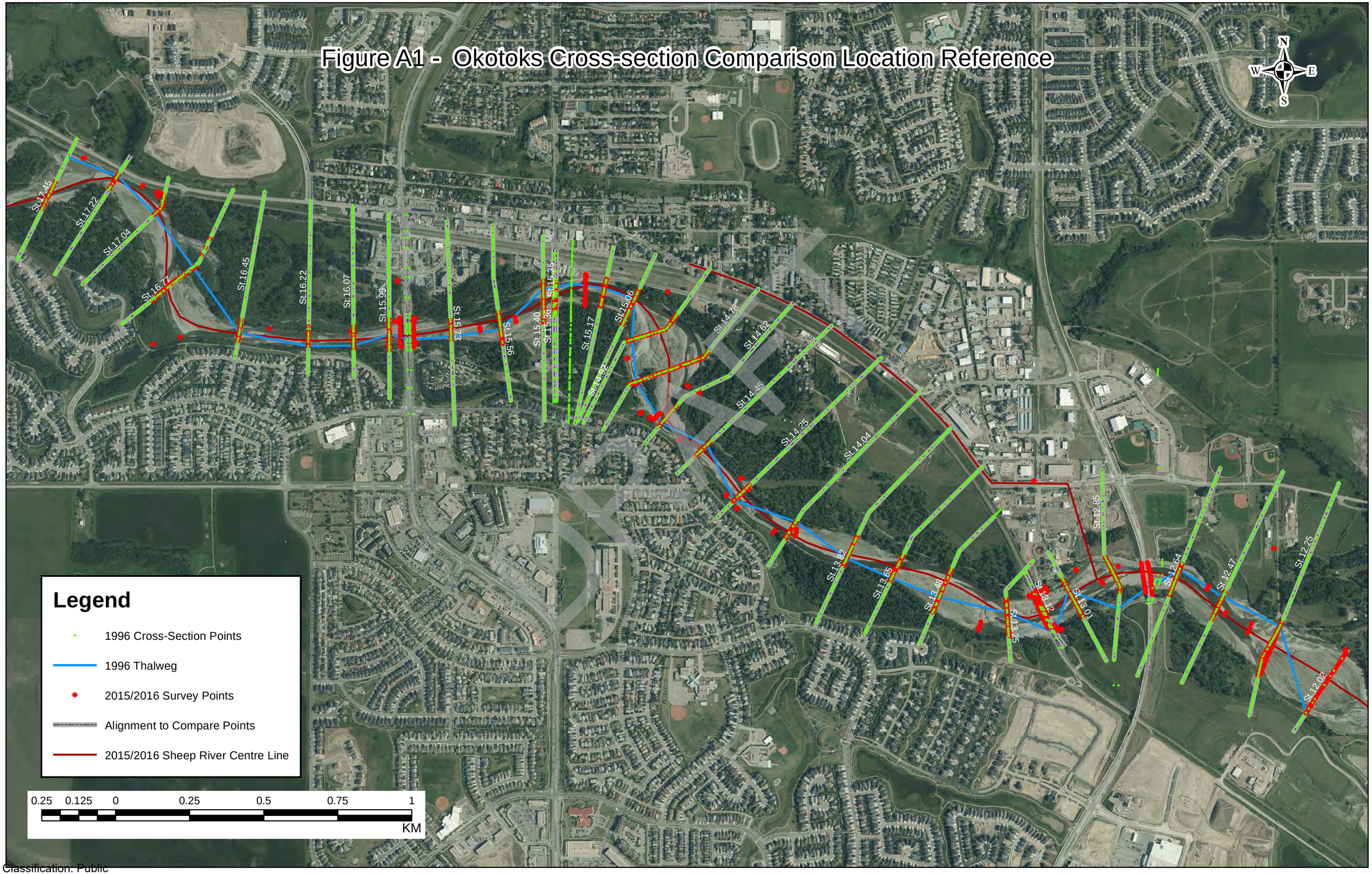
c: (Click here - enter copy(s) to)

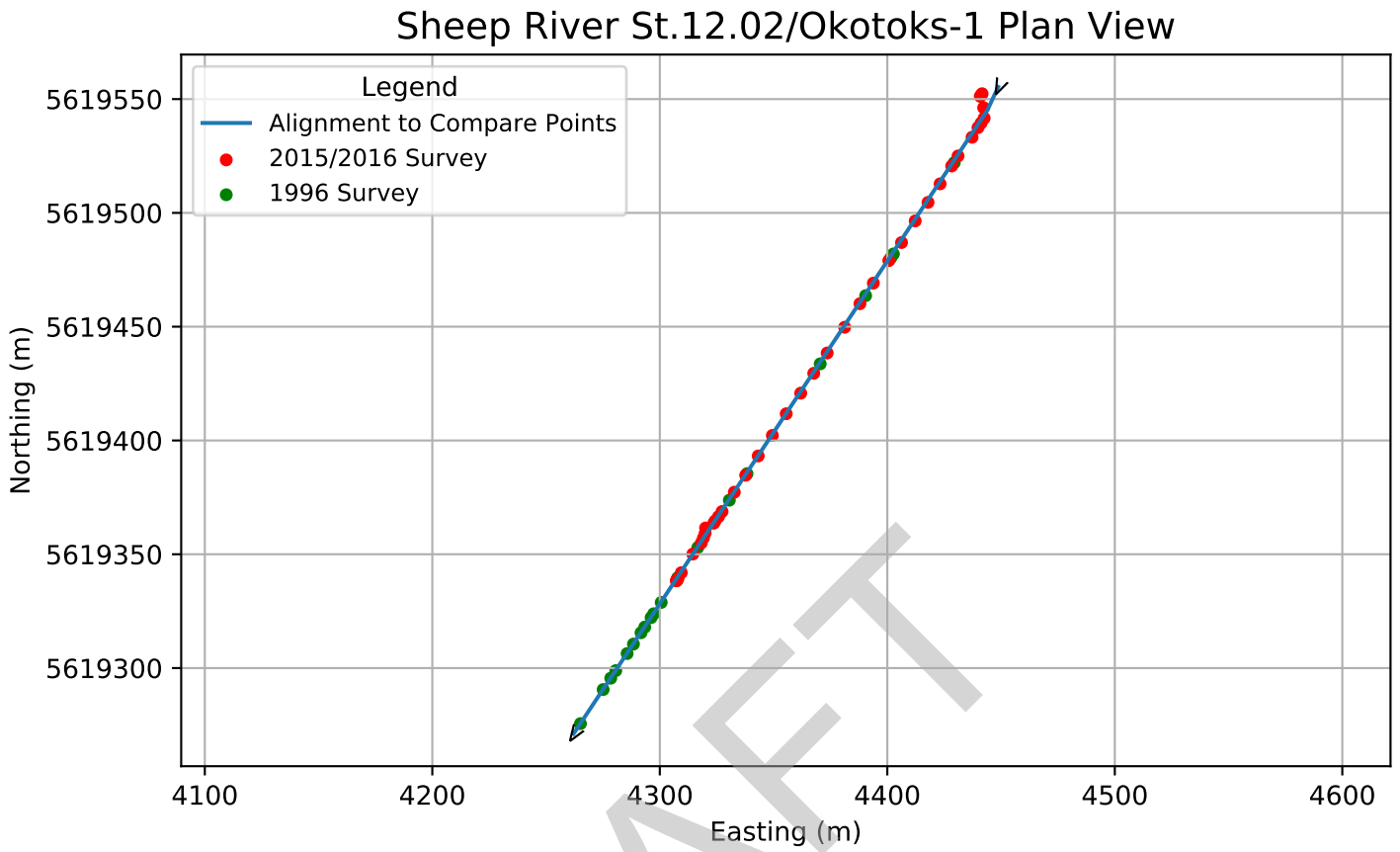
Permit to Practice No. P-4546

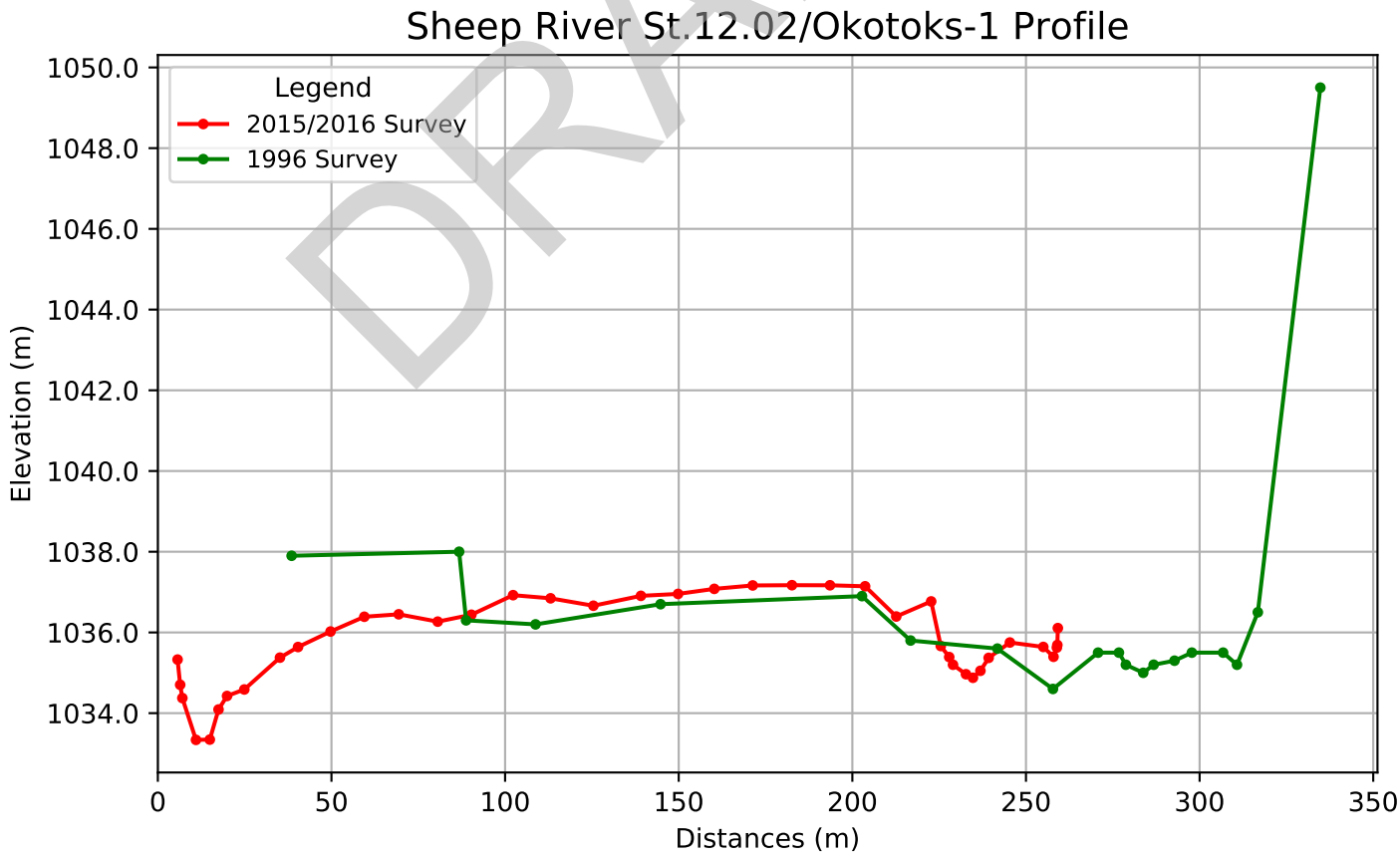
Attachment A

Okotoks Cross Section Comparison

Figure A1 - Okotoks Cross-section Comparison Location Reference

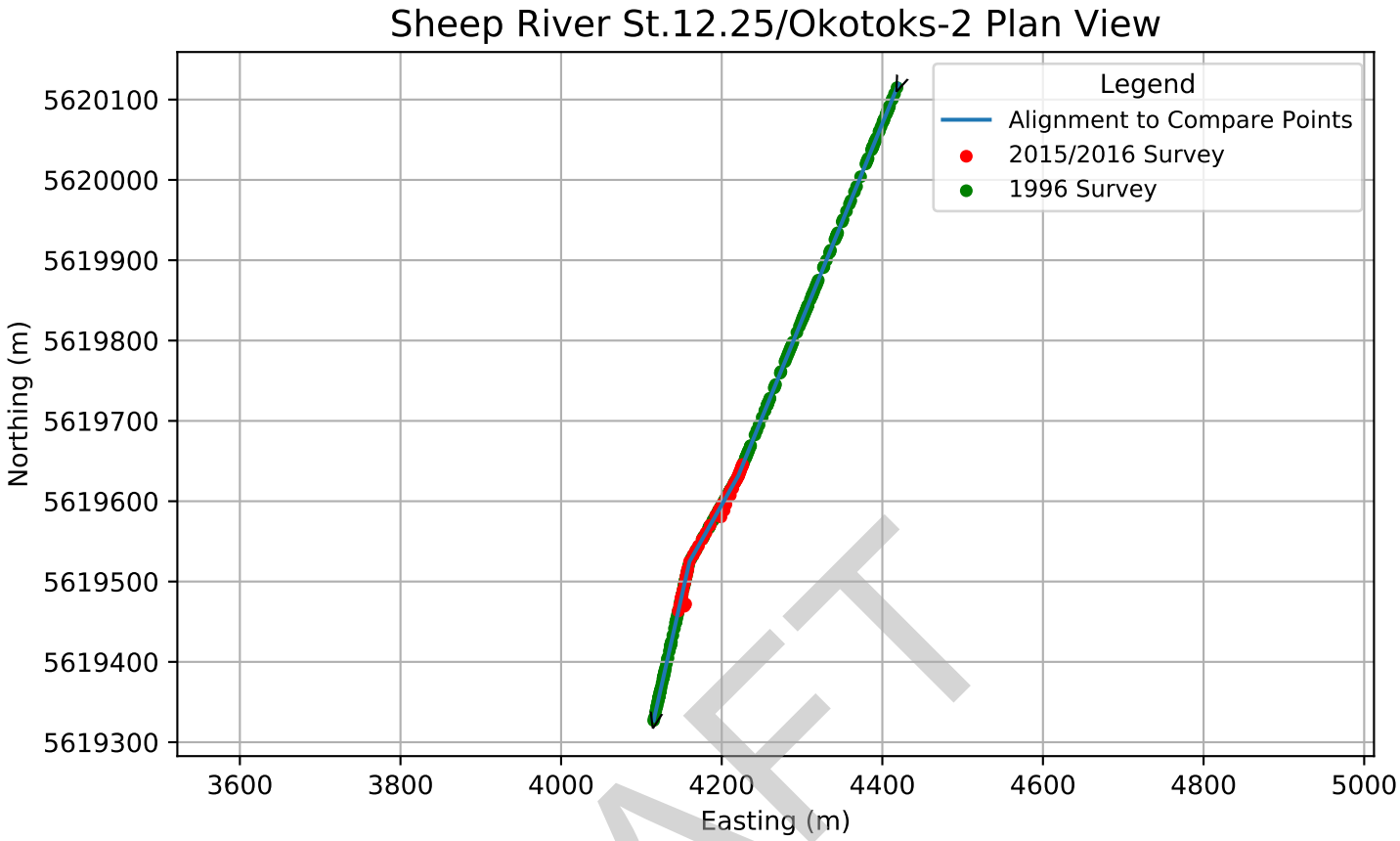


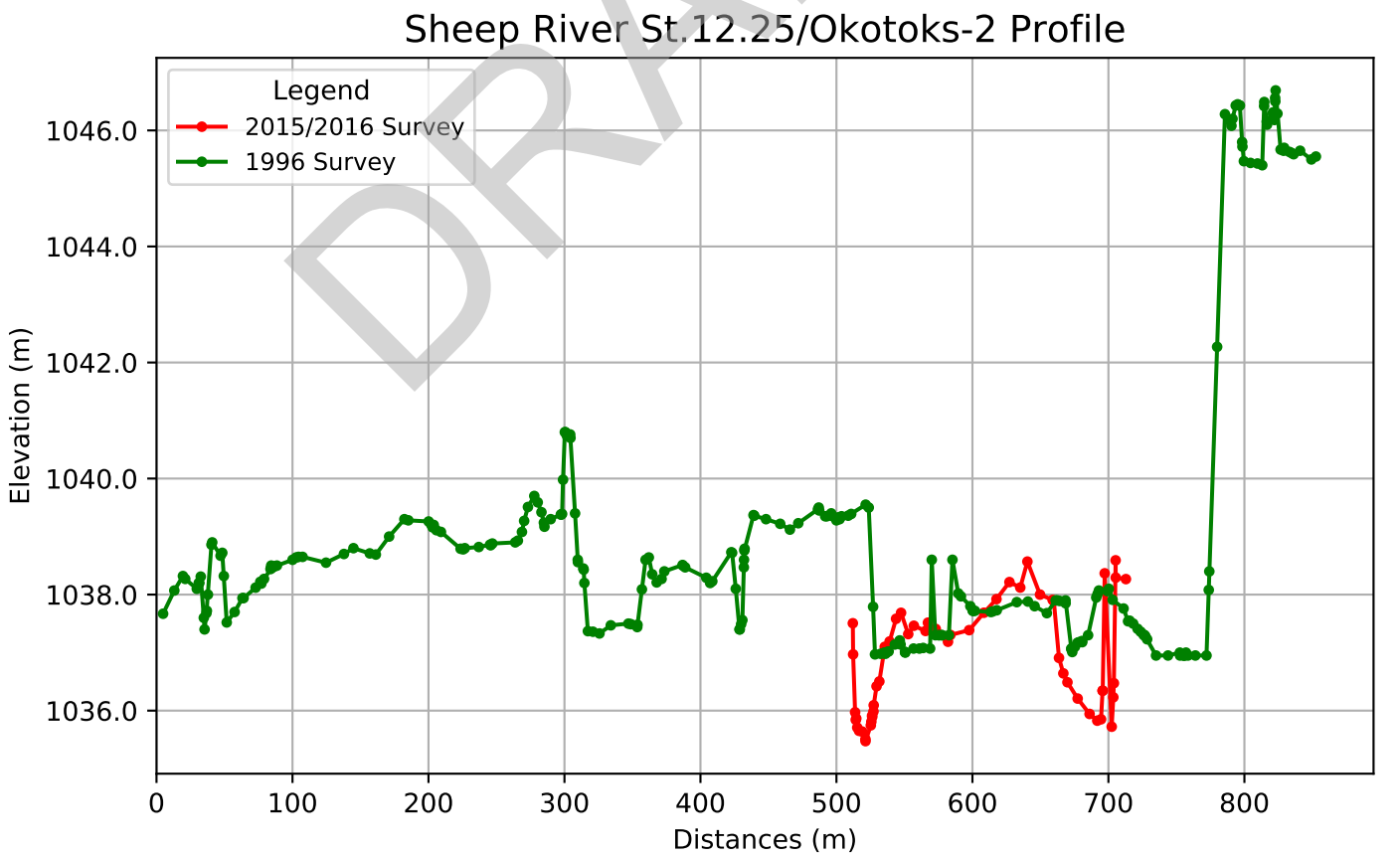




Note:

1.1996 Cross-Section data obtained from file SHEE-EBD.OKOTOKS.HC2 which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross-Sections 3.0,4.2, and 5.1. These correspond to 2015/2016 Cross-Sections 12.47,12.64 and 12.89, respectively.





Note:

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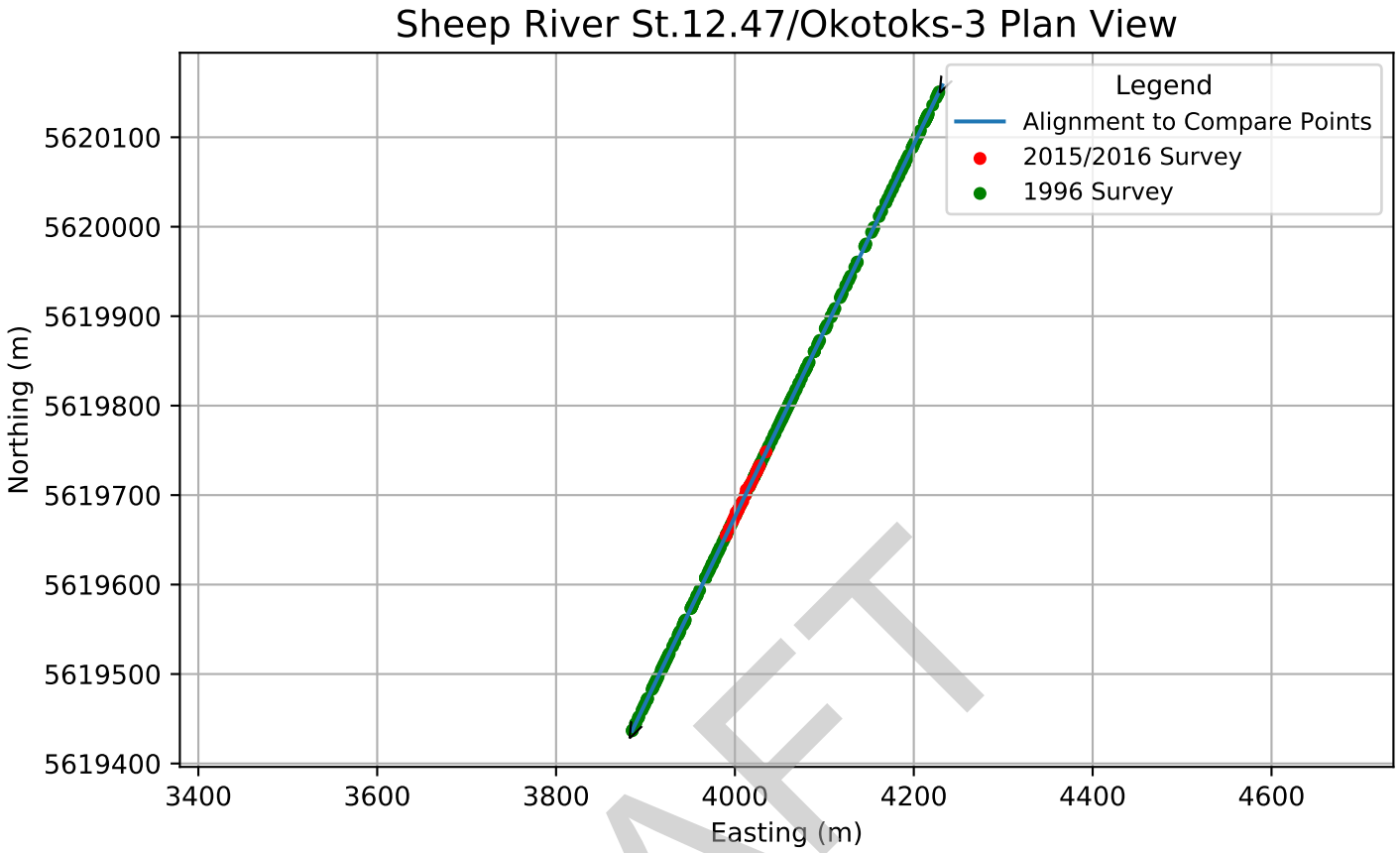

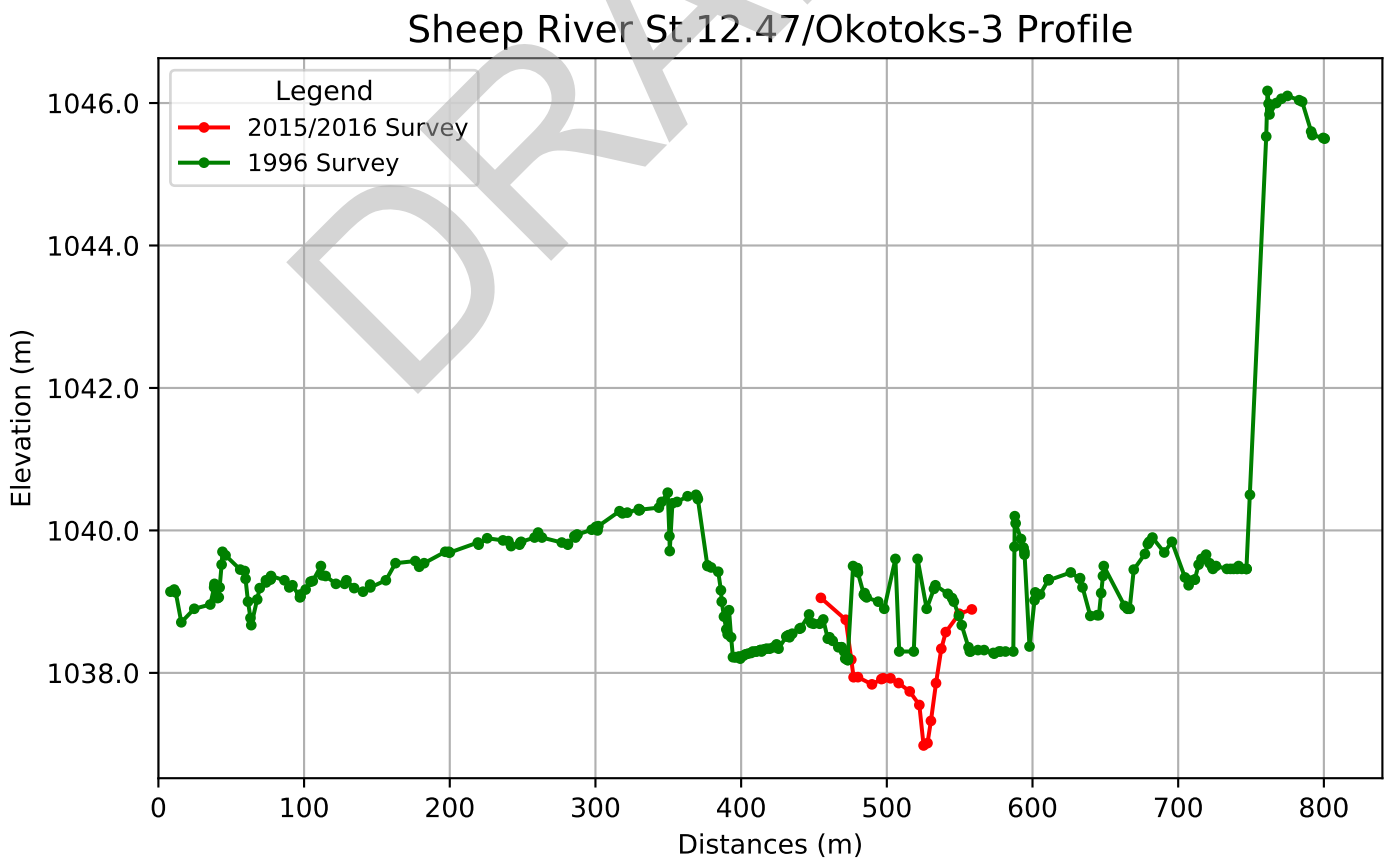

Note:

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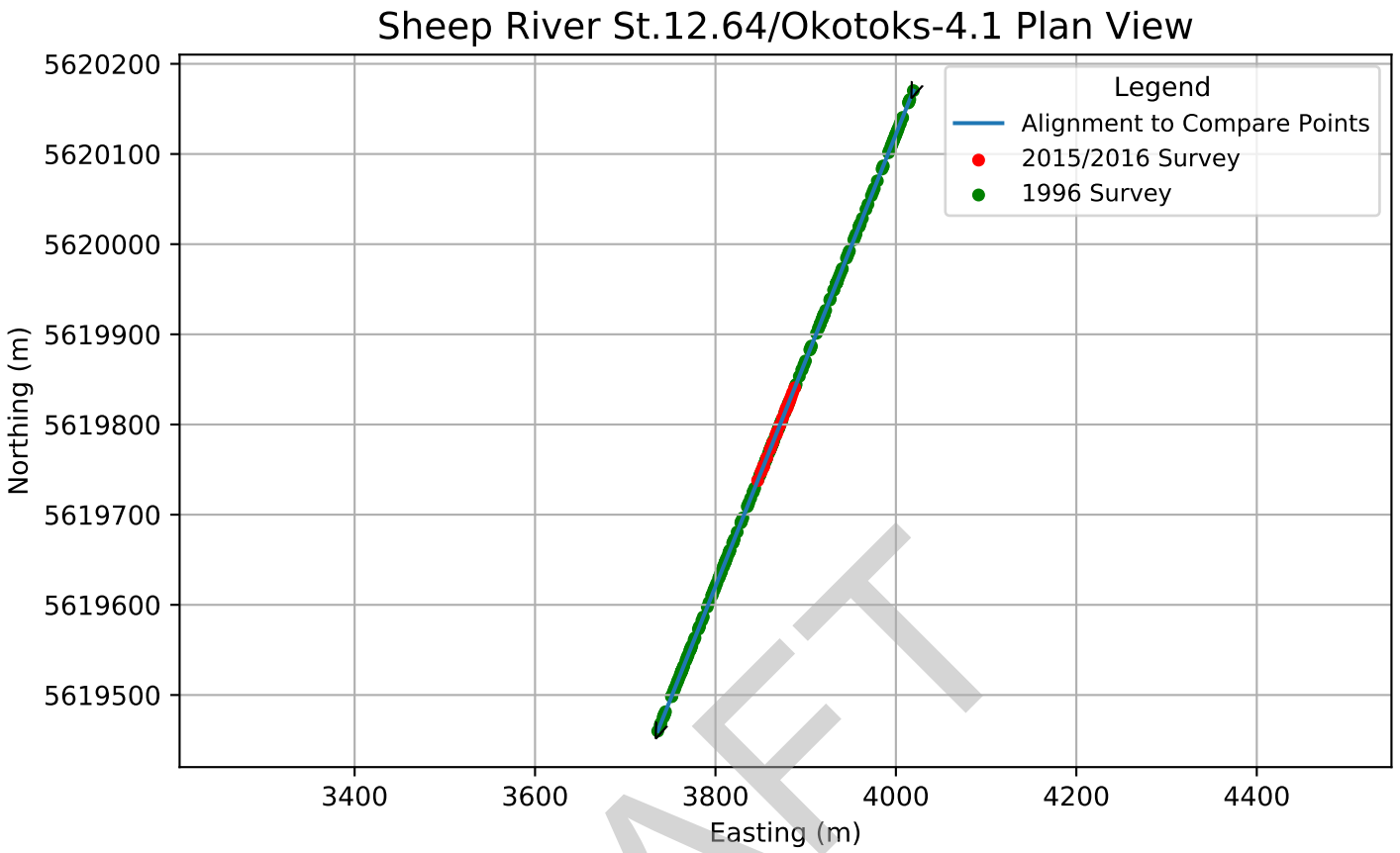

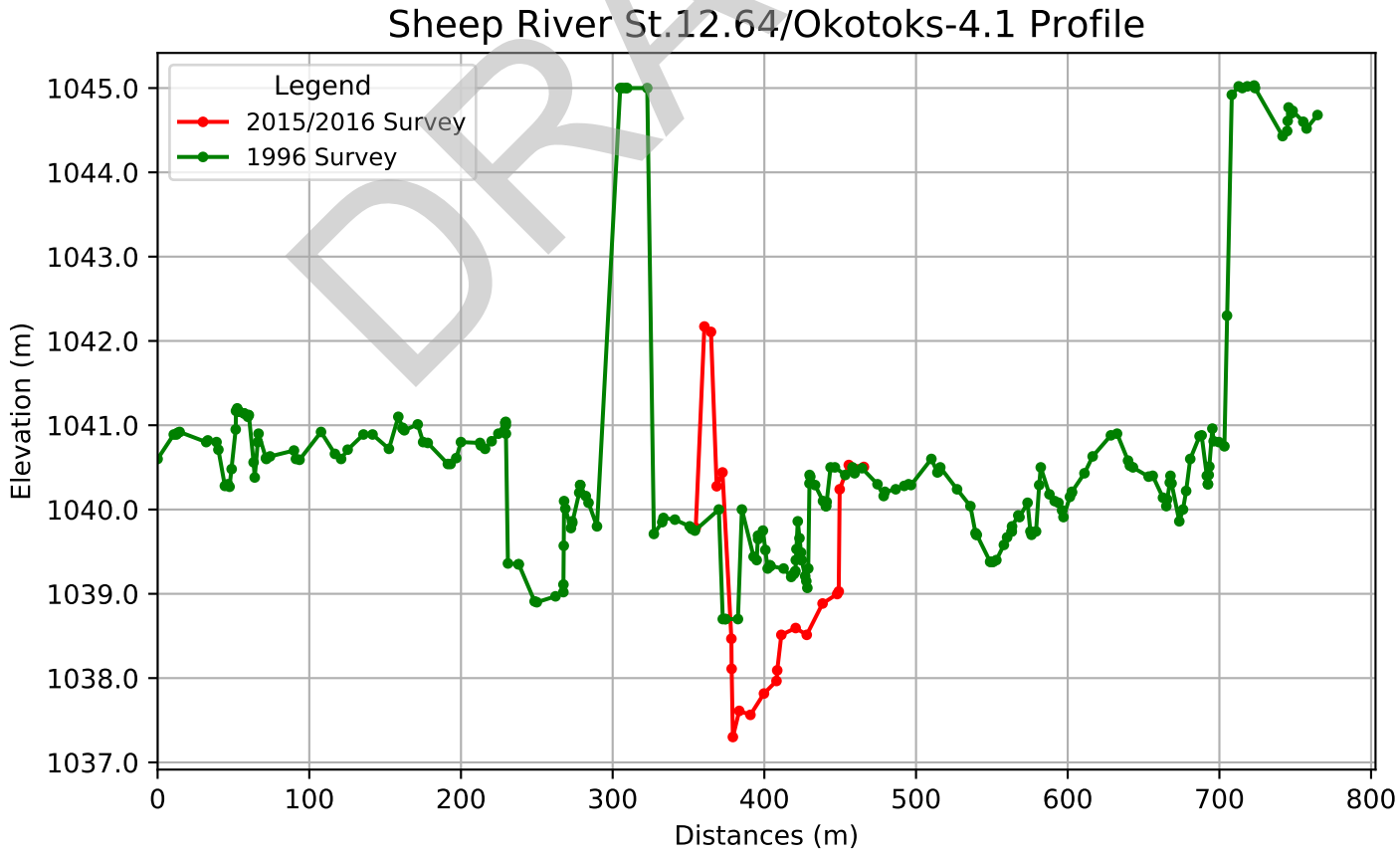

Note:

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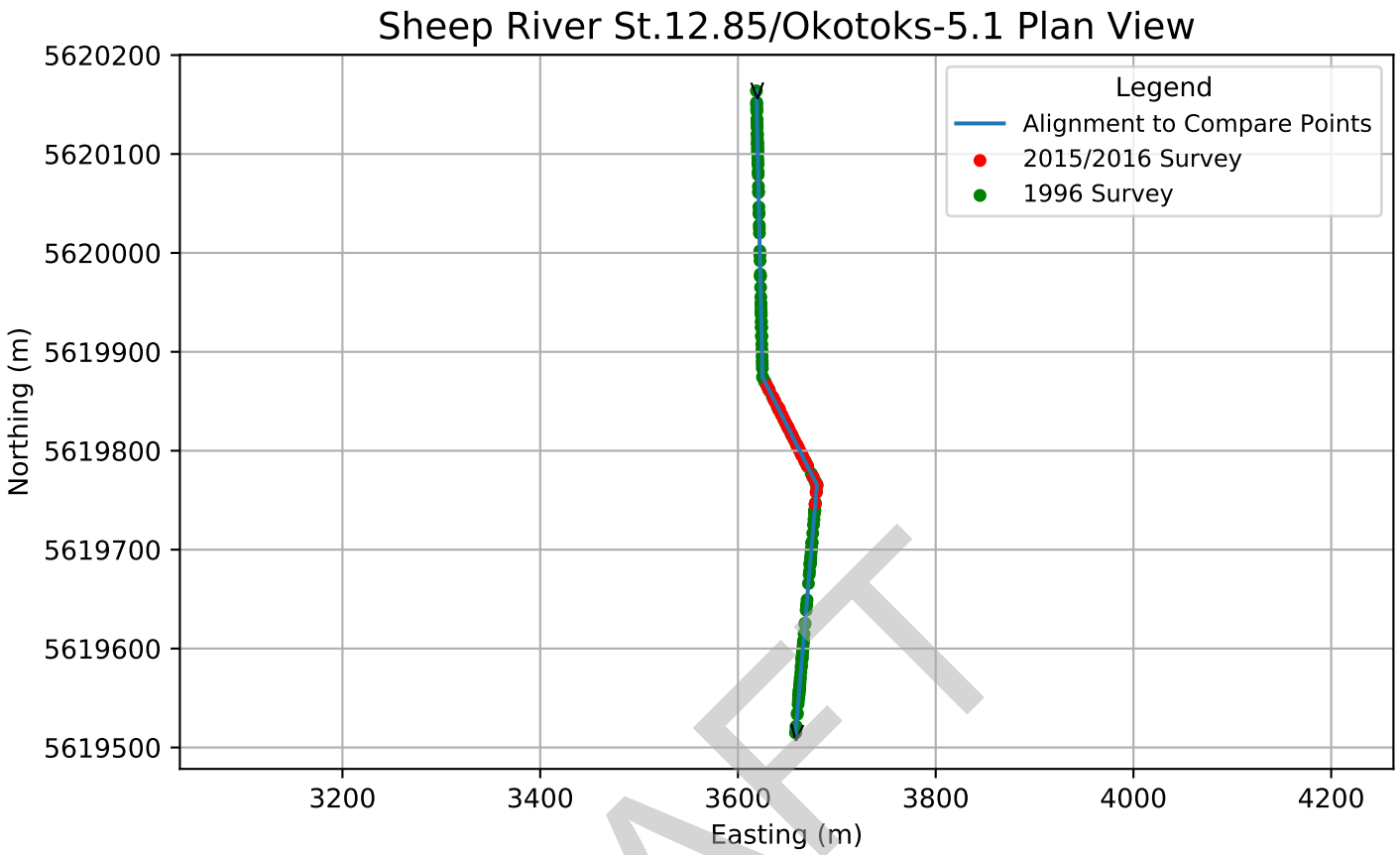

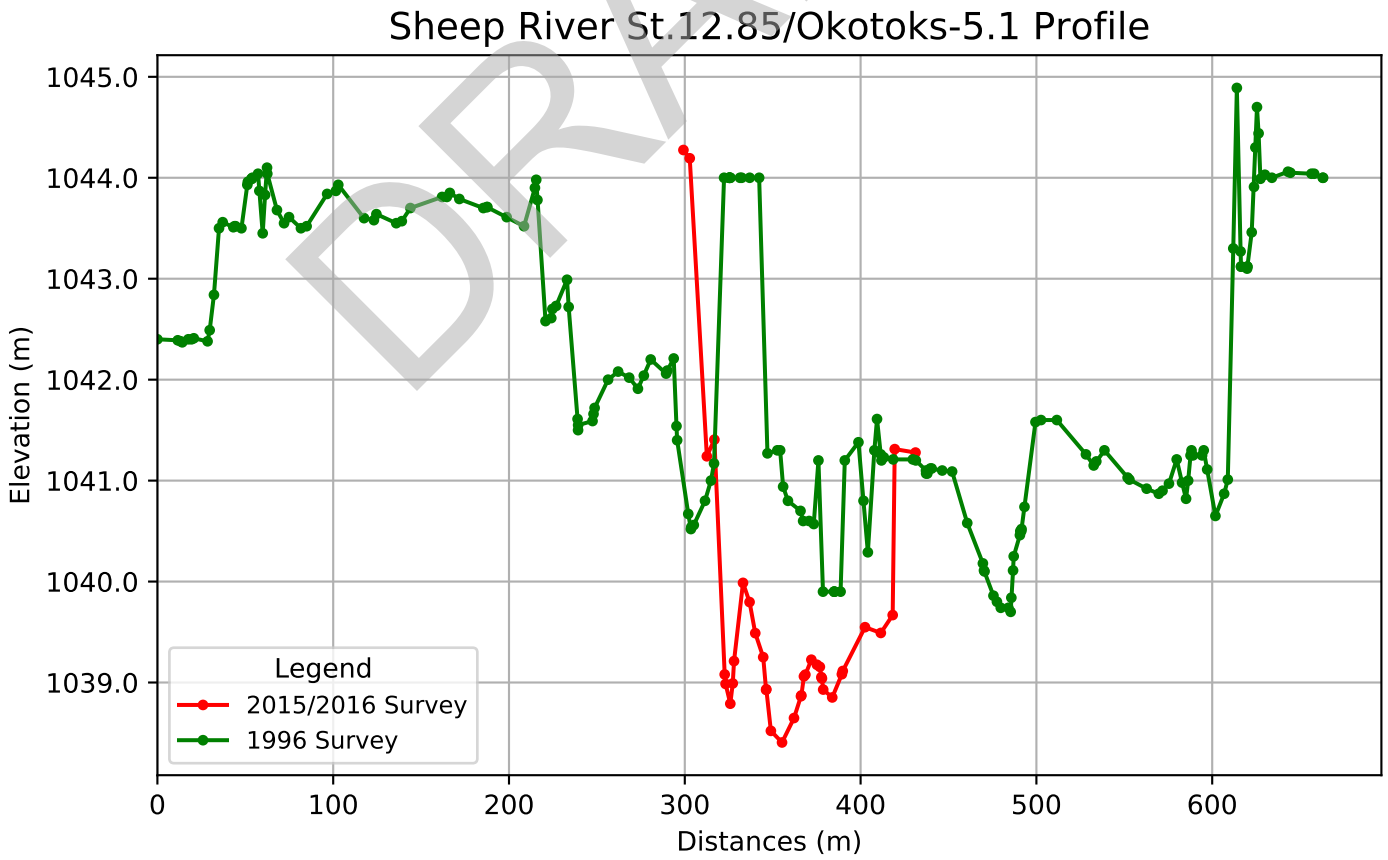

Note:

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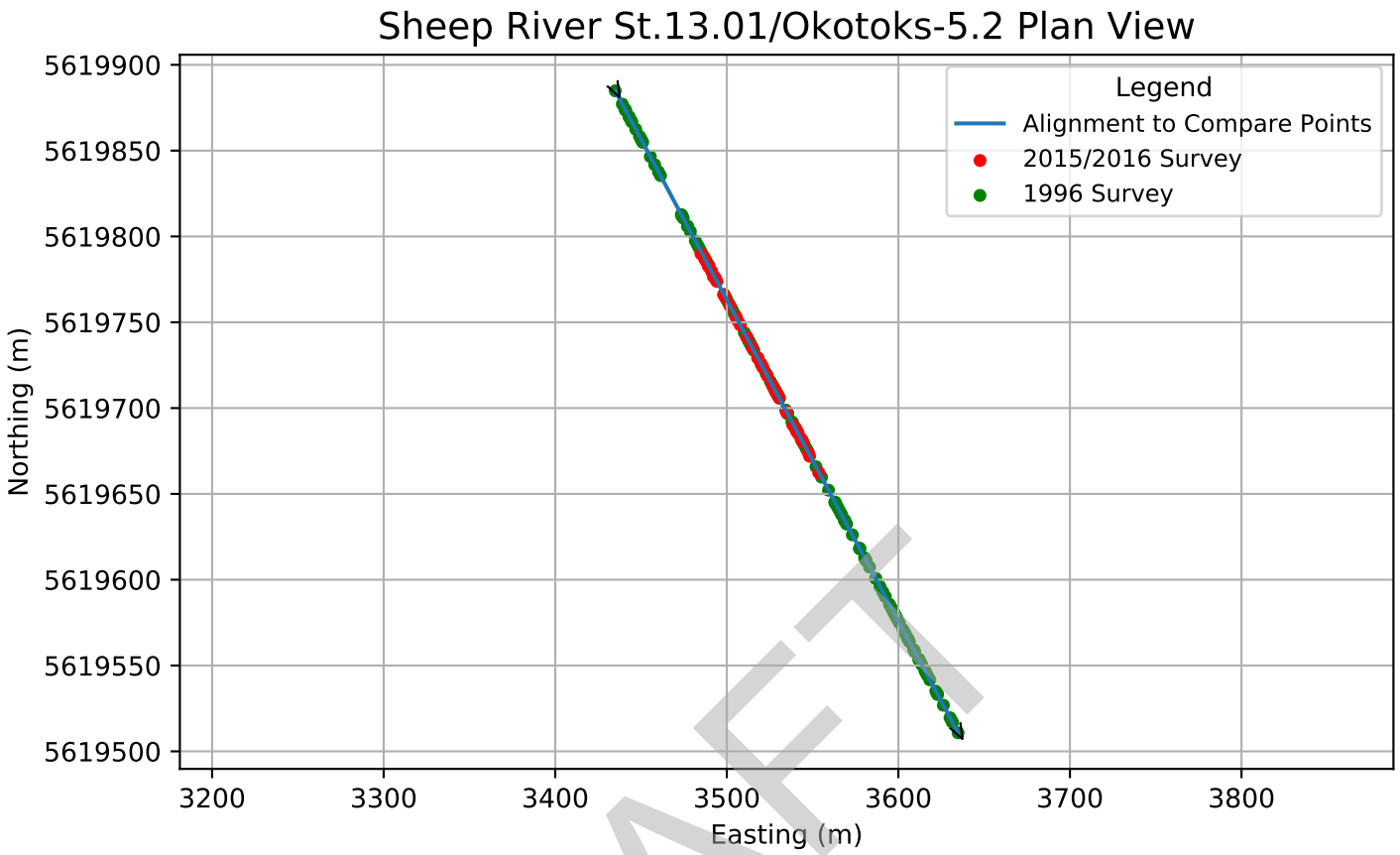

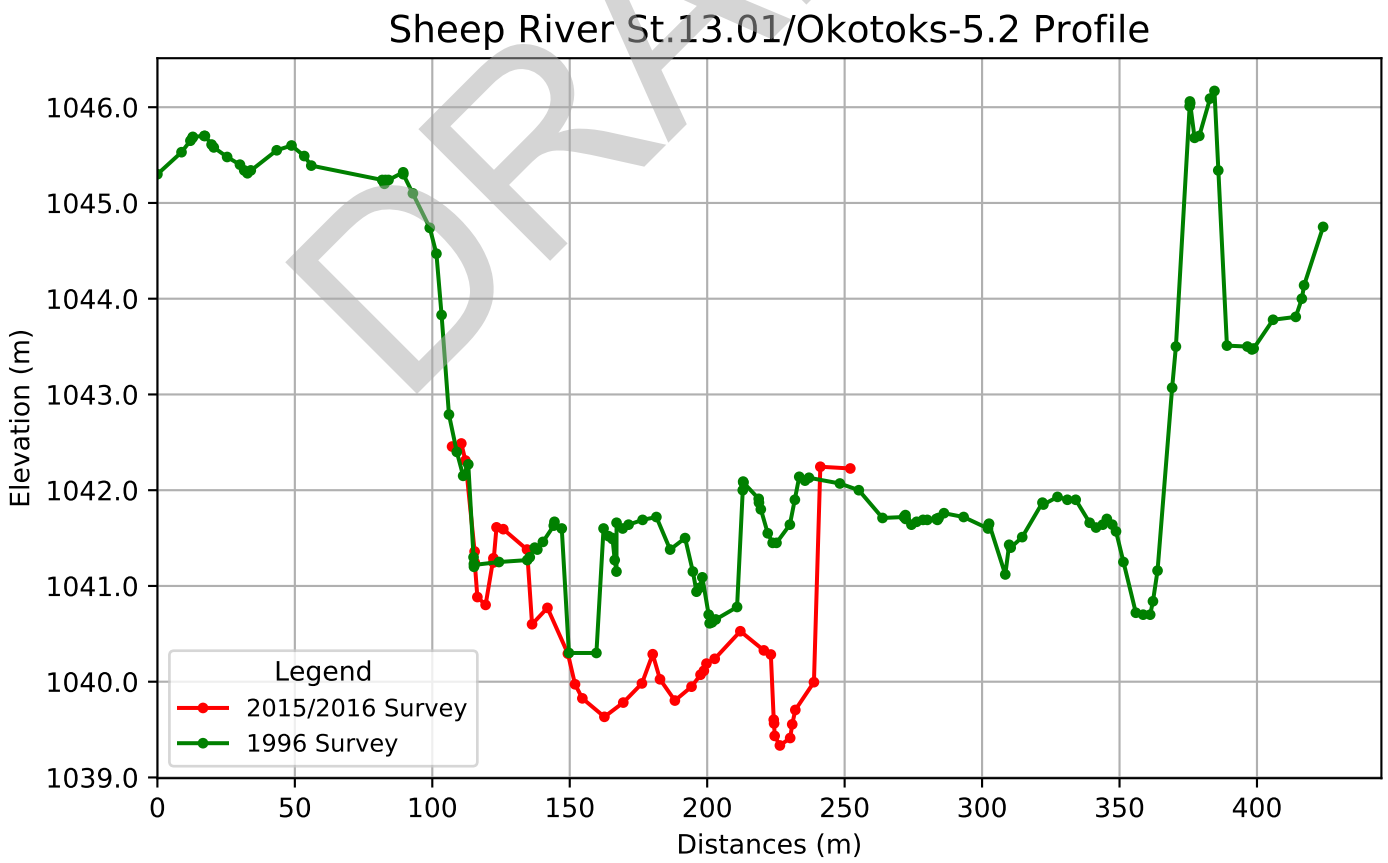

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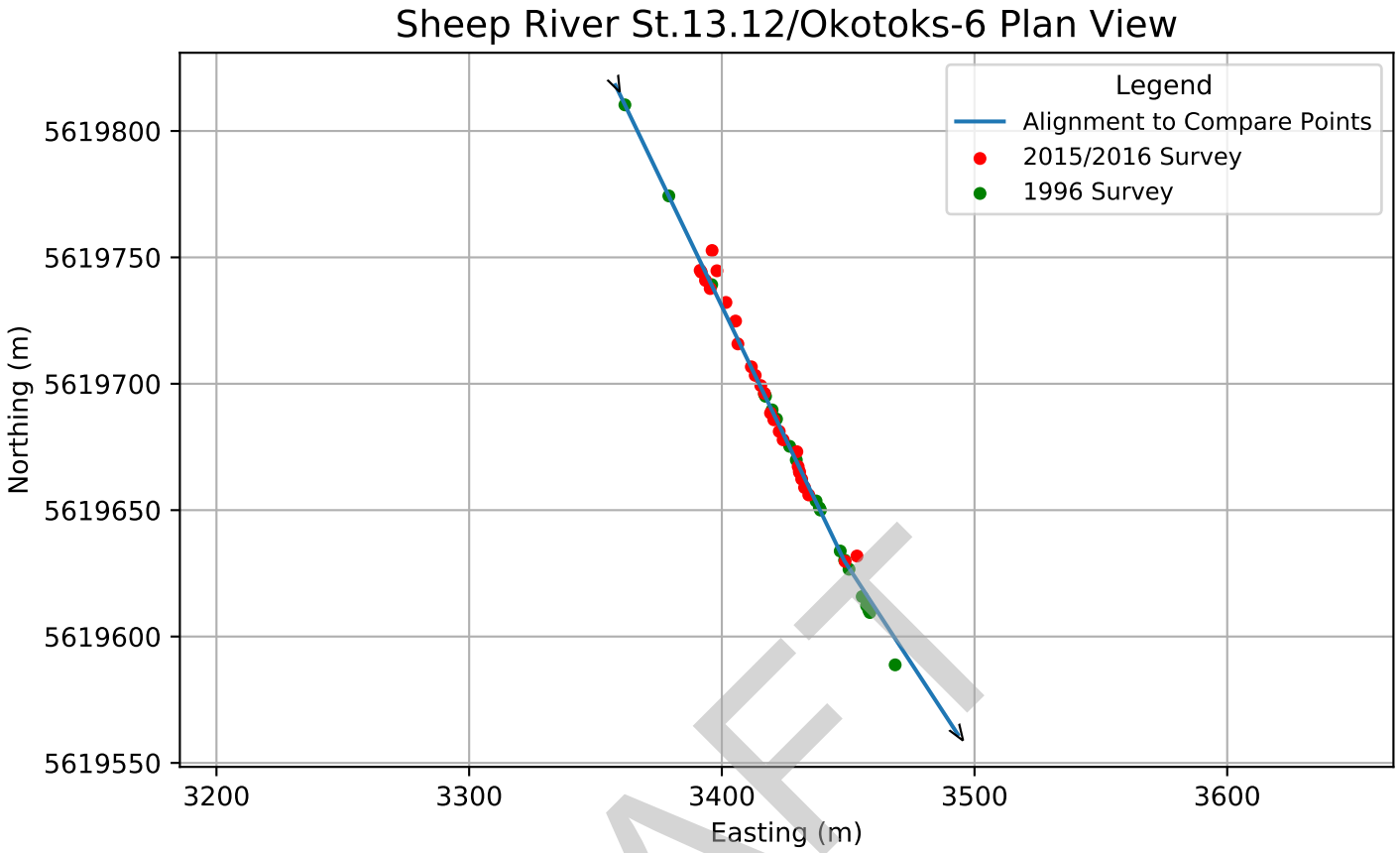

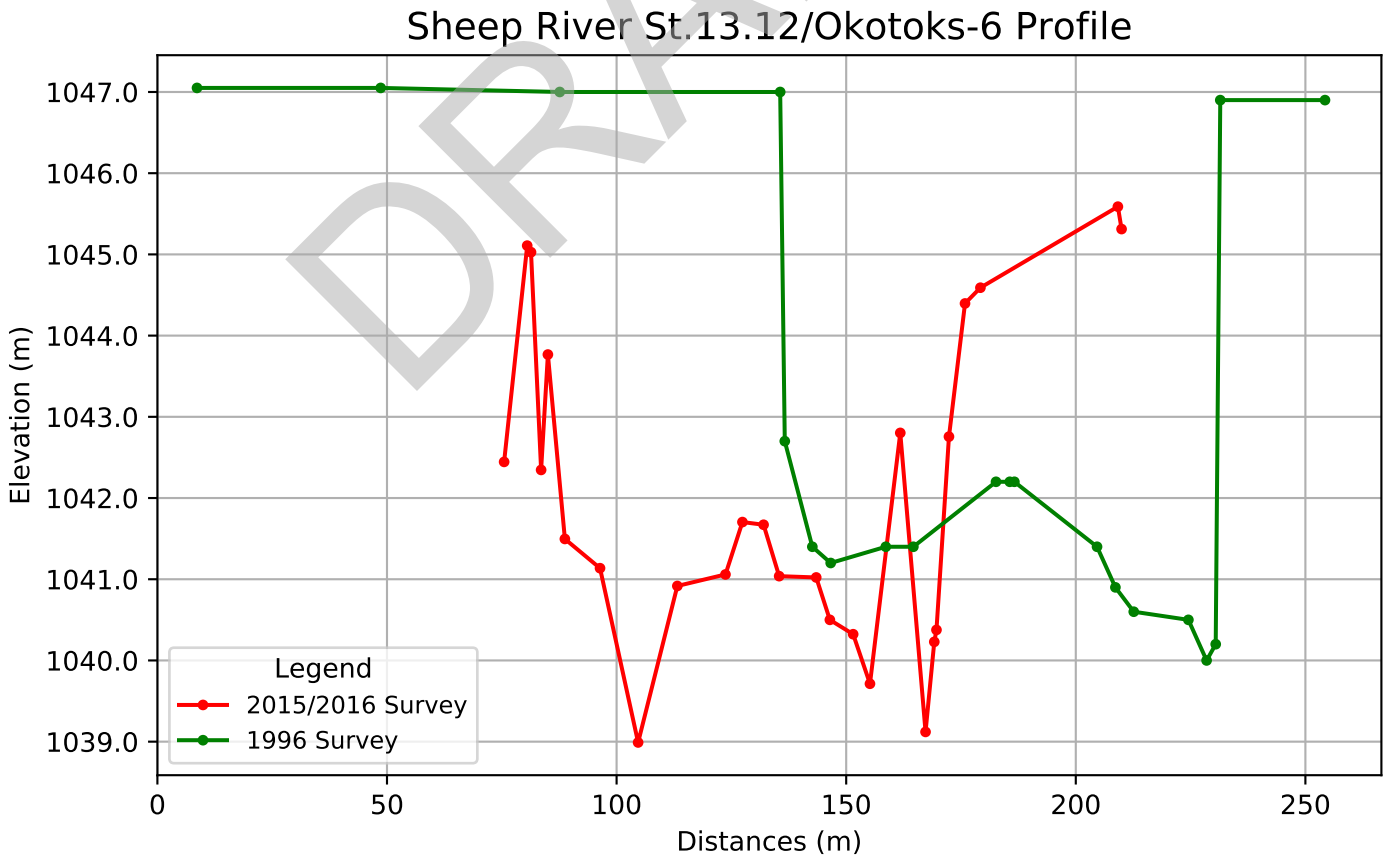

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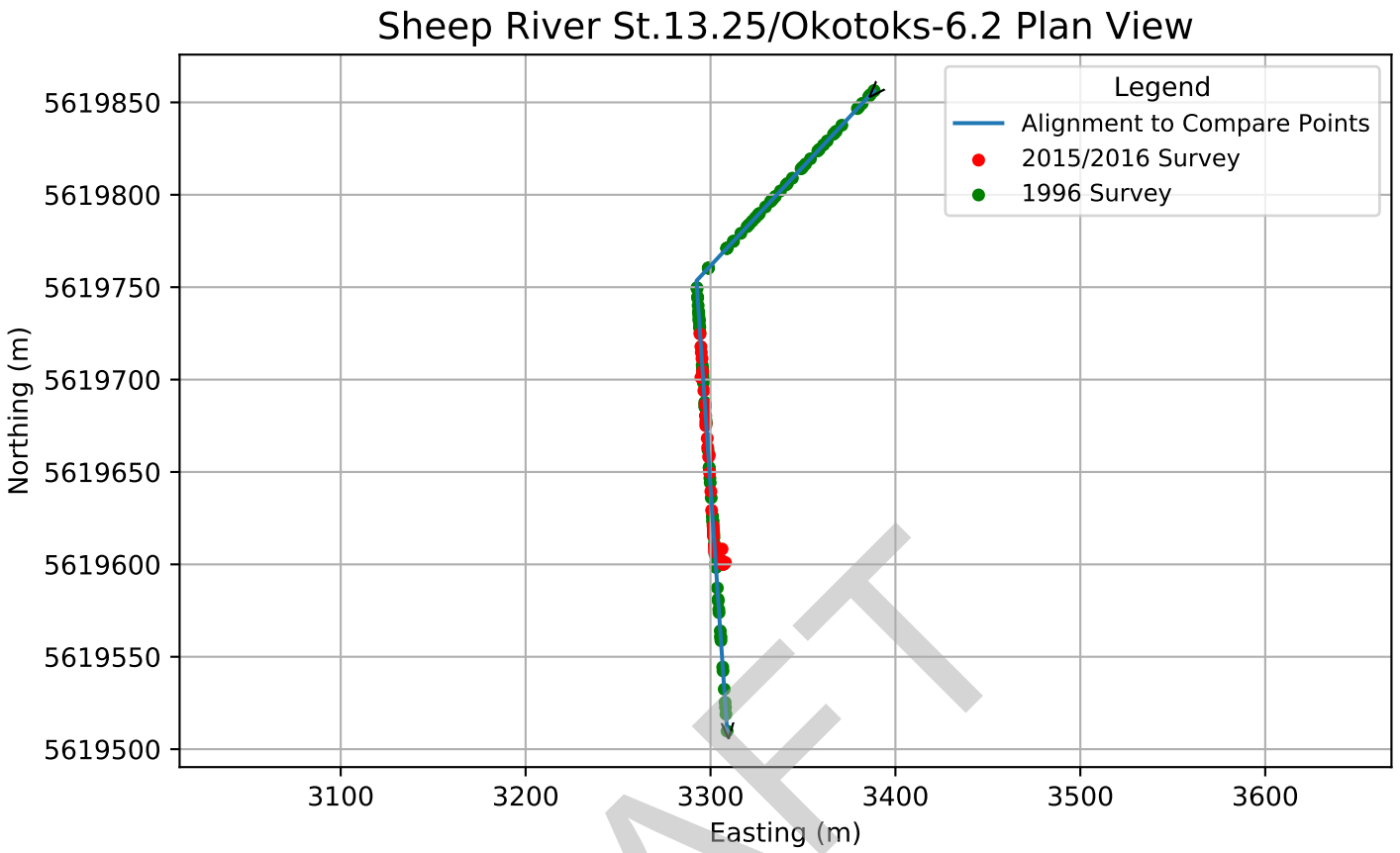

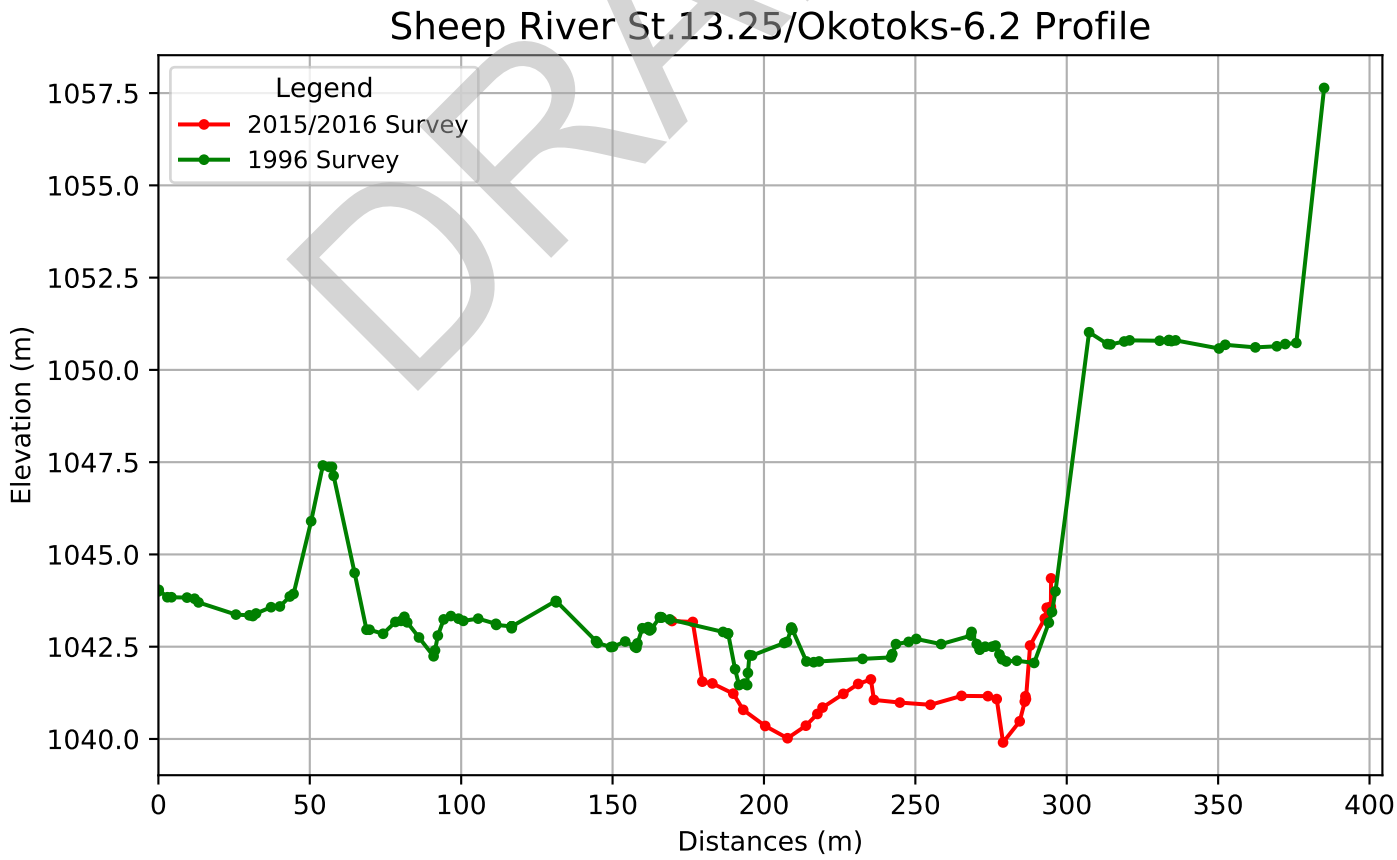

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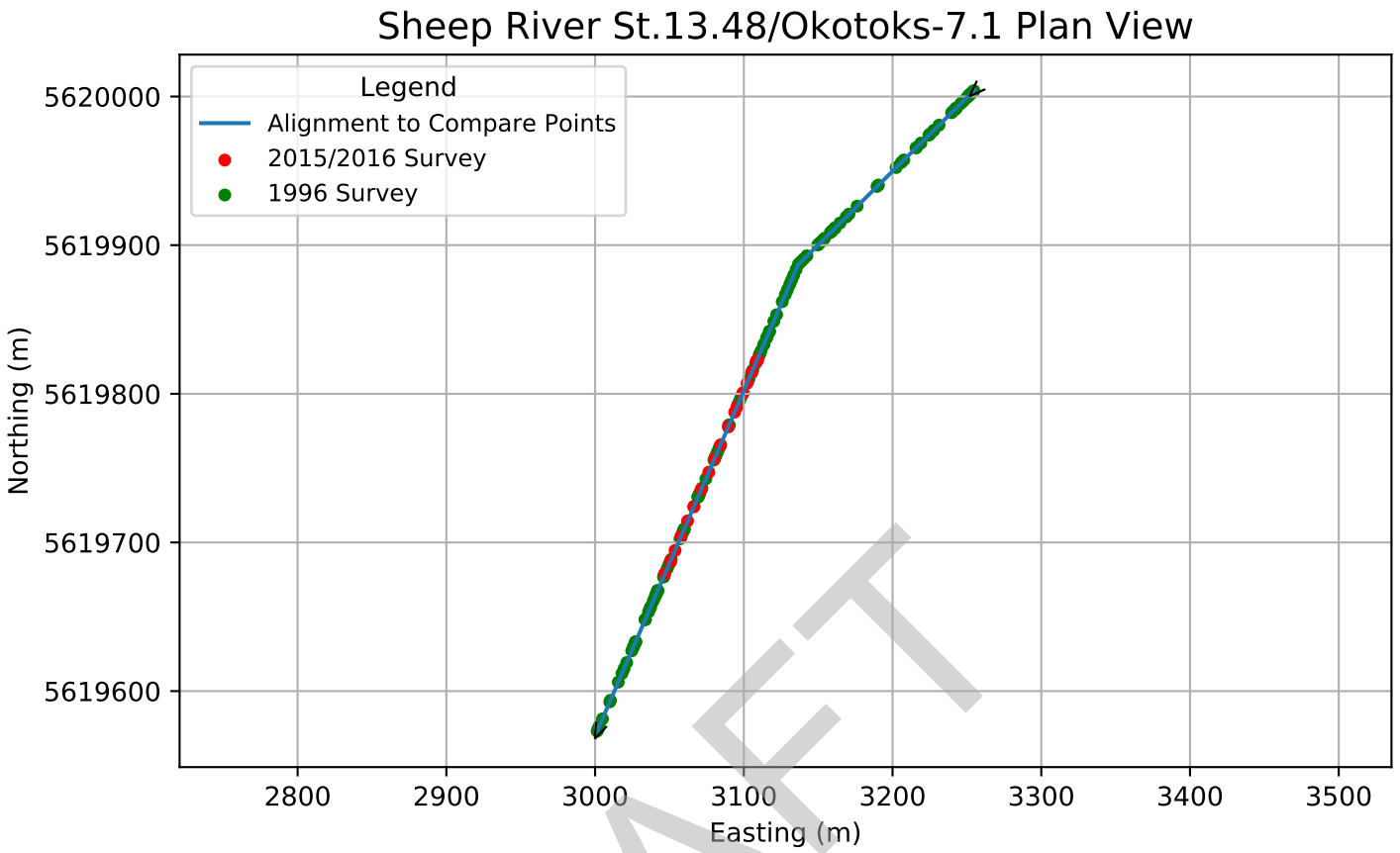

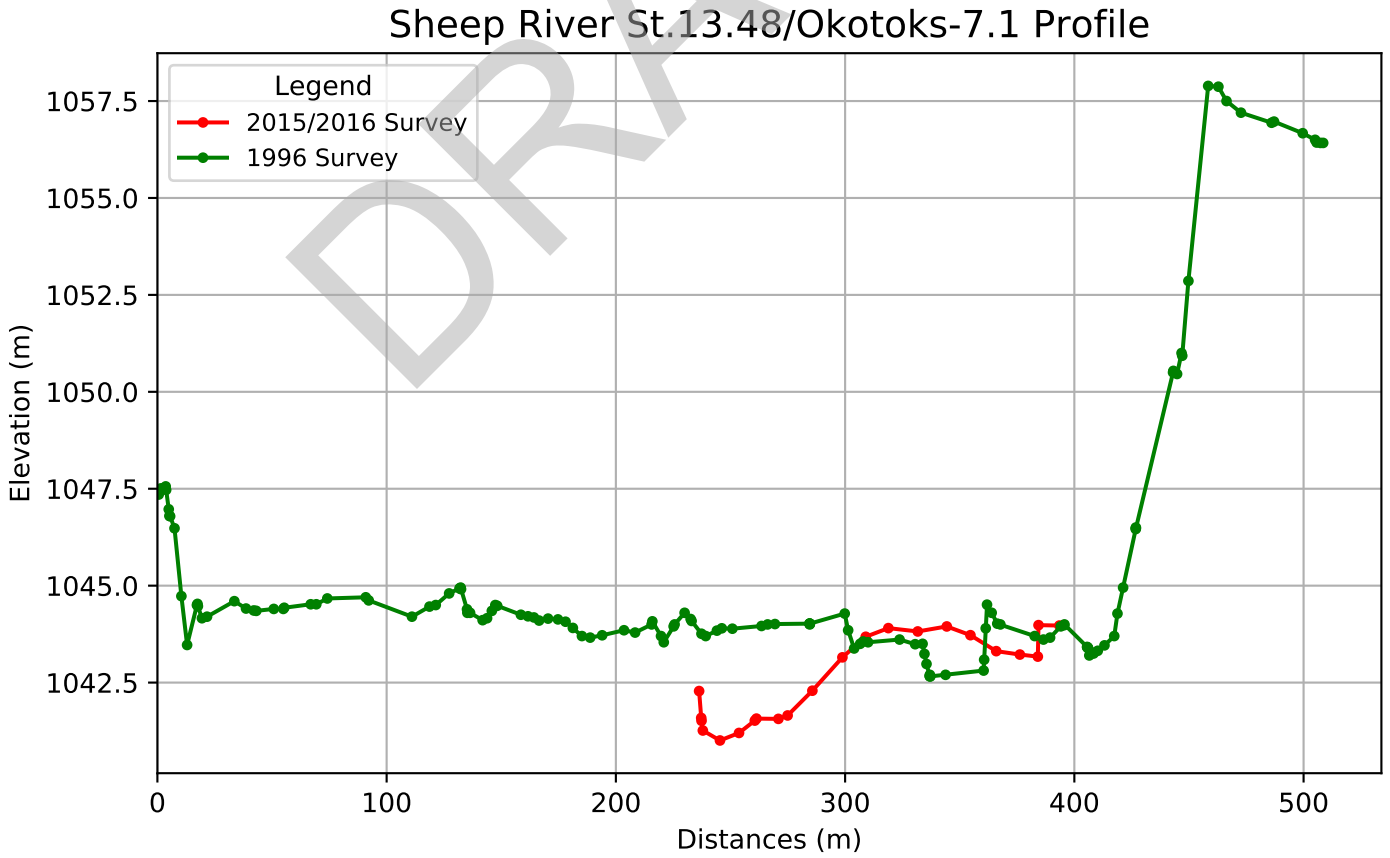

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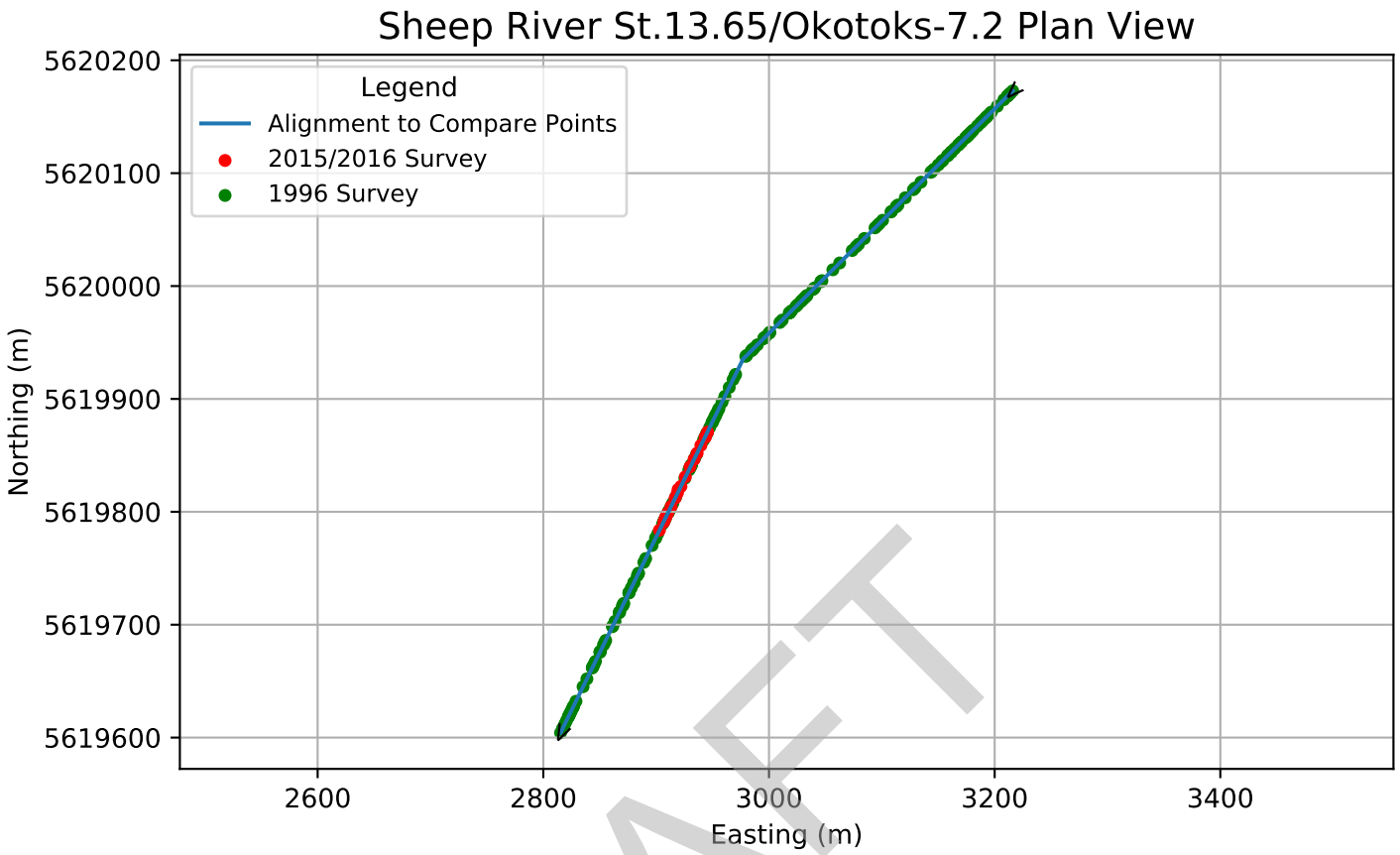

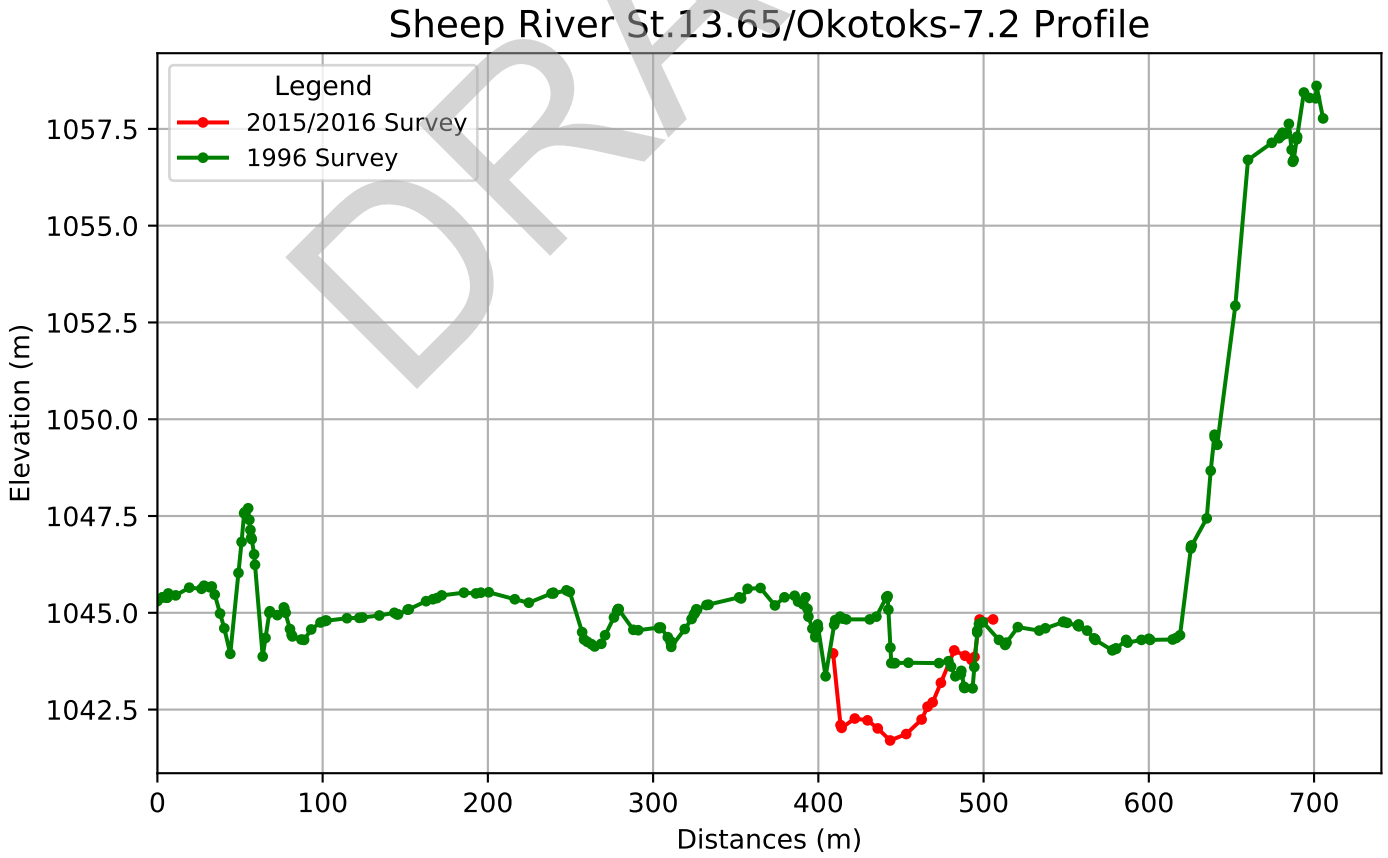

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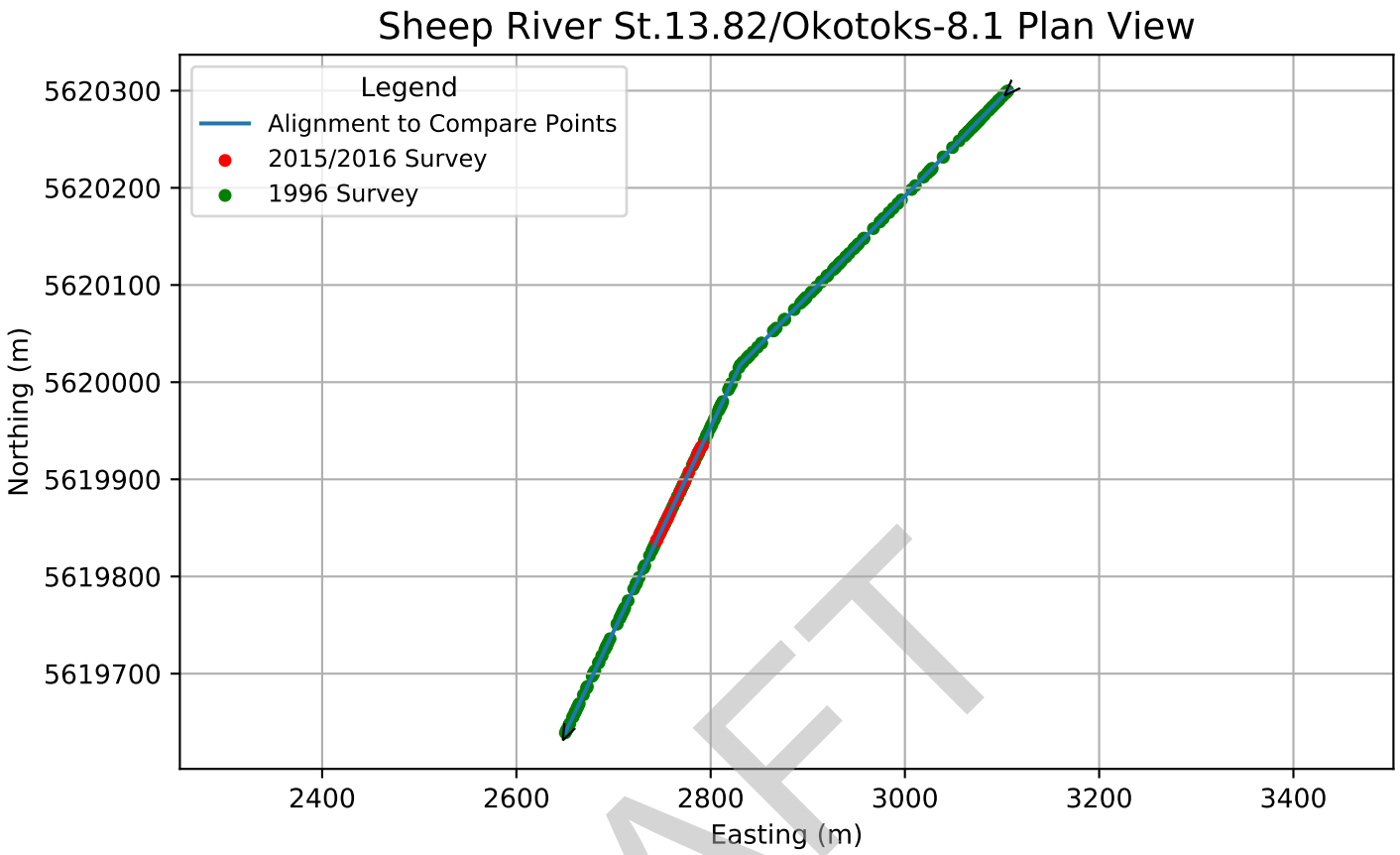
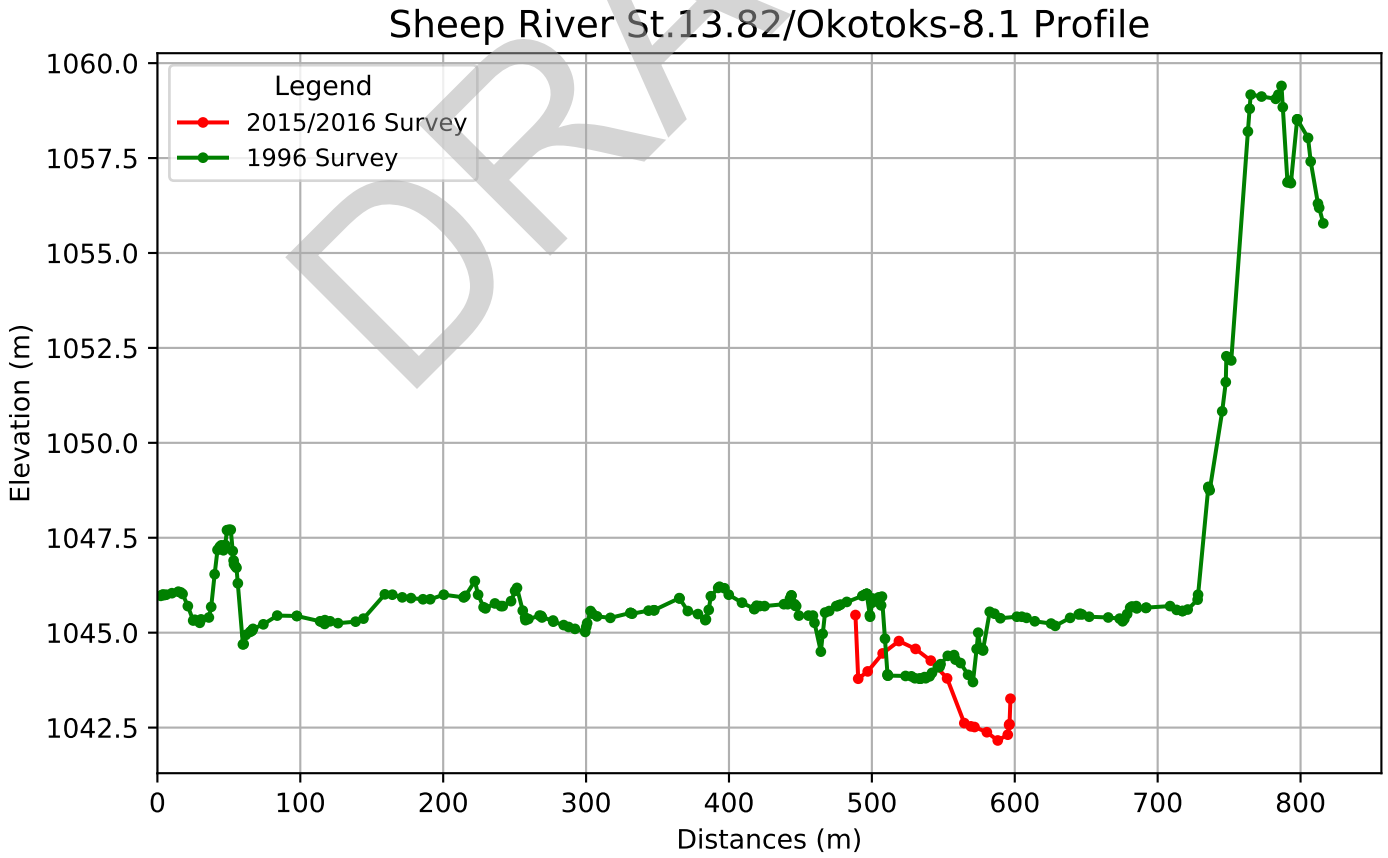
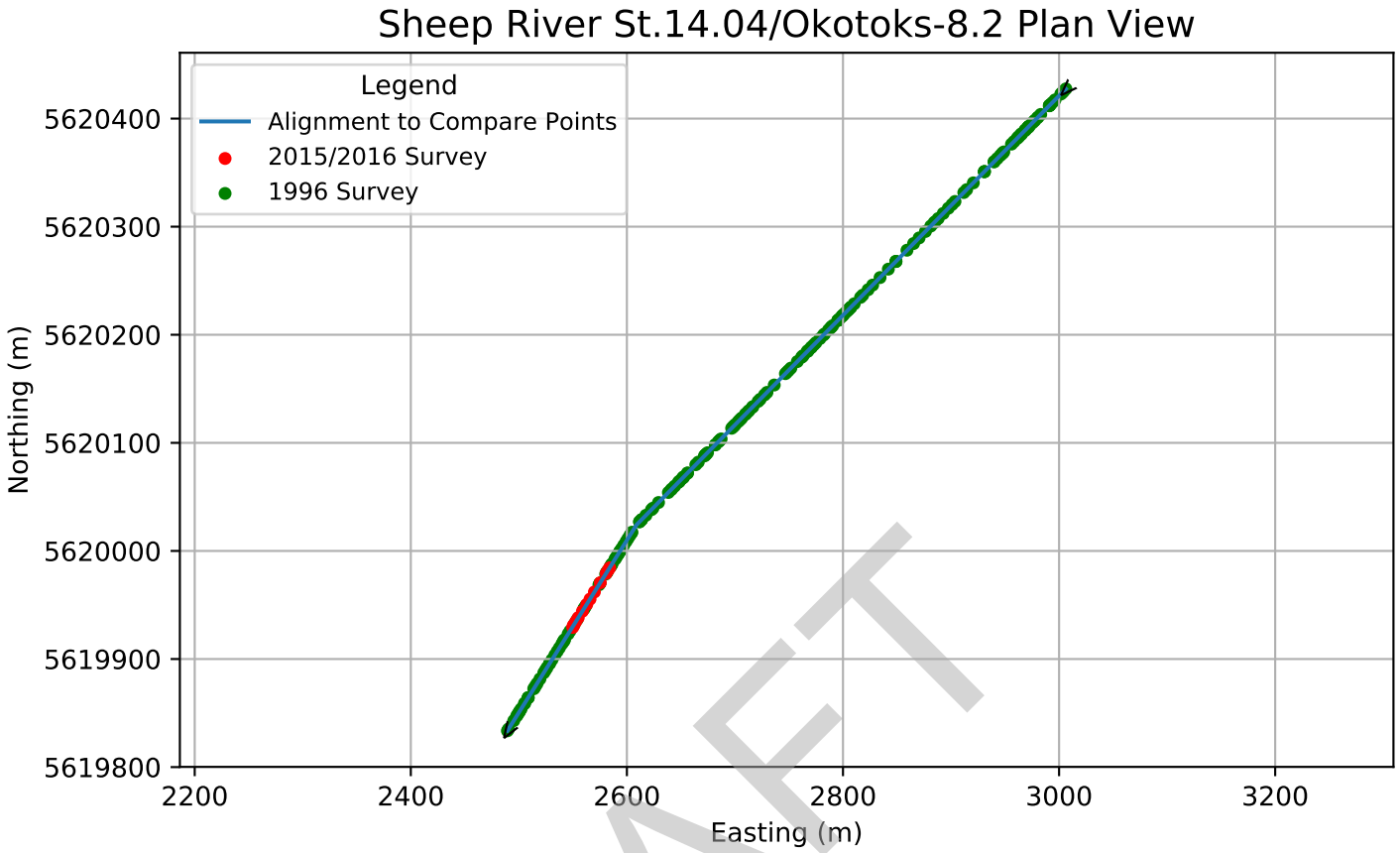
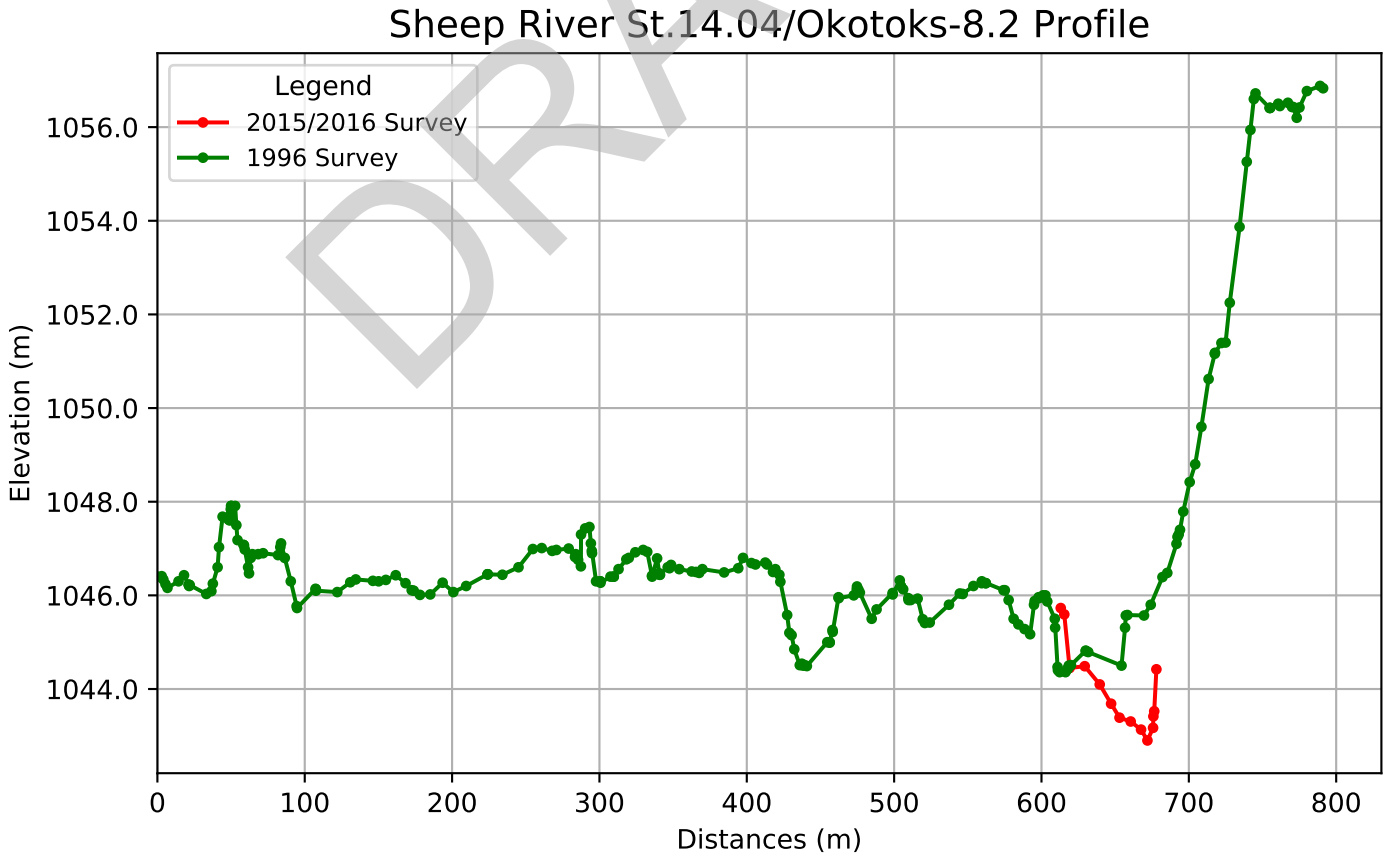




Note:

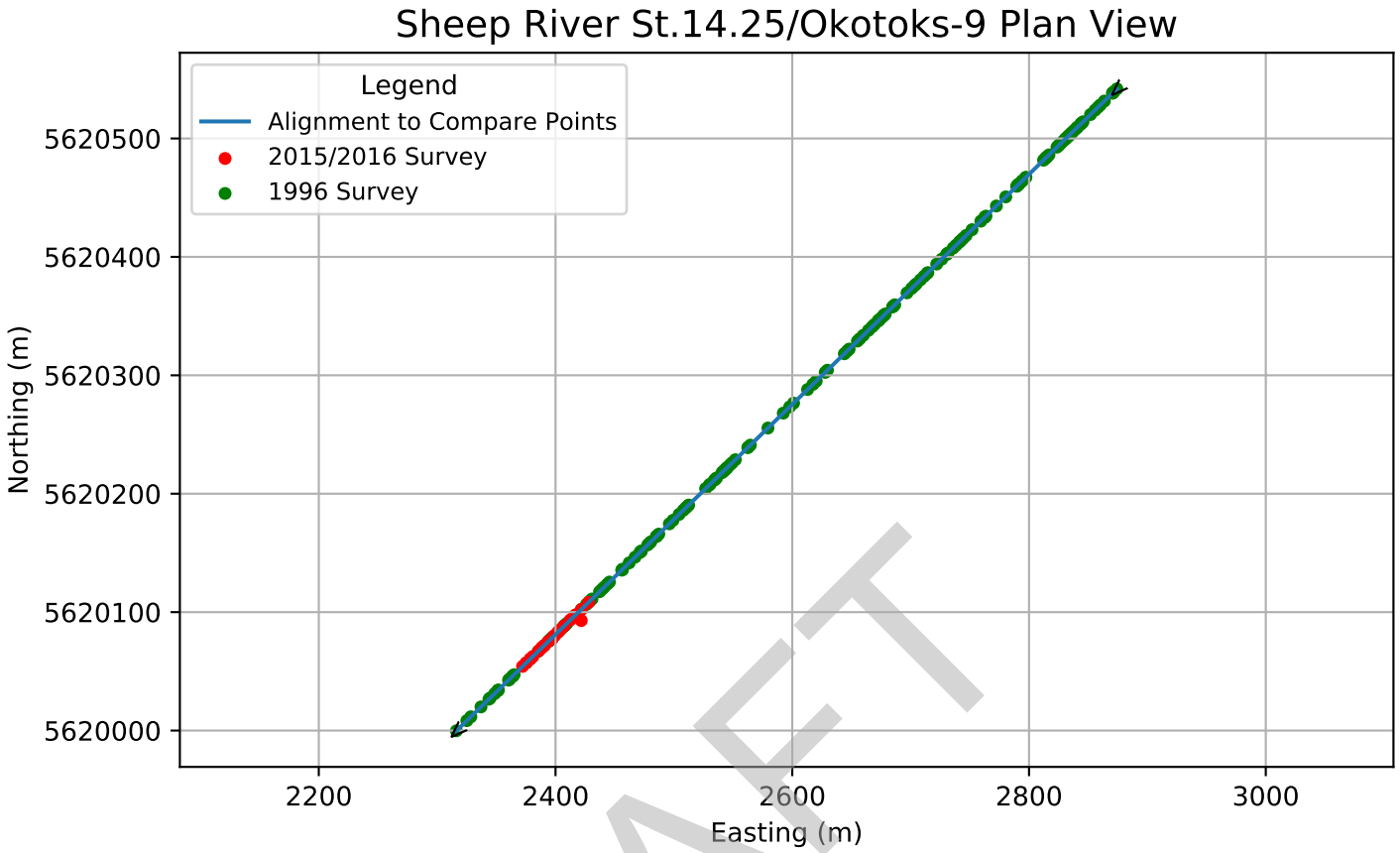
1.1996 Cross-Section data obtained from file SHEE-EBD.OKOTOKS.HC2 which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross-Sections 3.0,4.2, and 5.1. These correspond to 2015/2016 Cross-Sections 12.47,12.64 and 12.89, respectively.

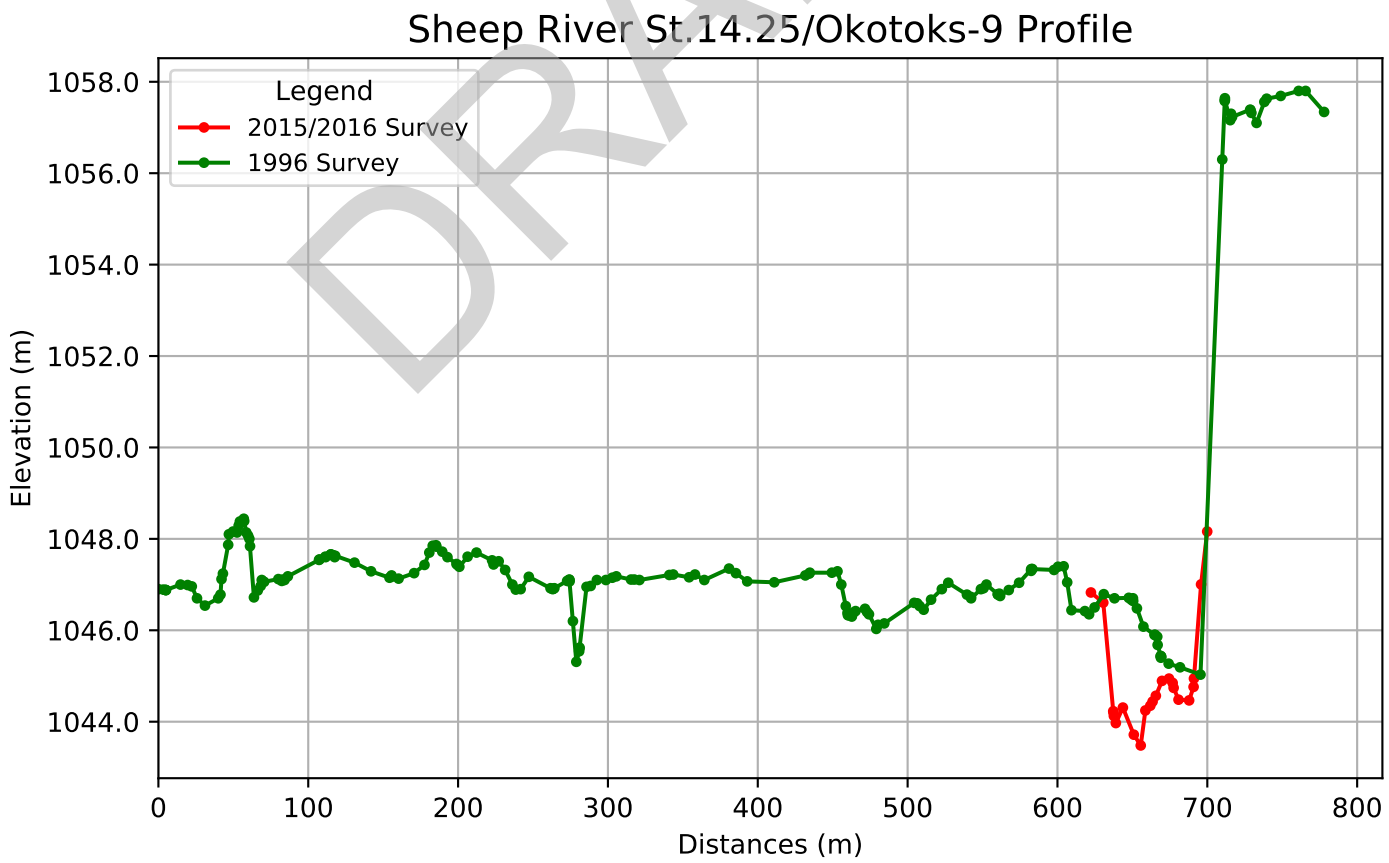




Note:

1.1996 Cross-Section data obtained from file SHEE-EBD.OKOTOKS.HC2 which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross-Sections 3.0,4.2, and 5.1. These correspond to 2015/2016 Cross-Sections 12.47,12.64 and 12.85, respectively.





Note:

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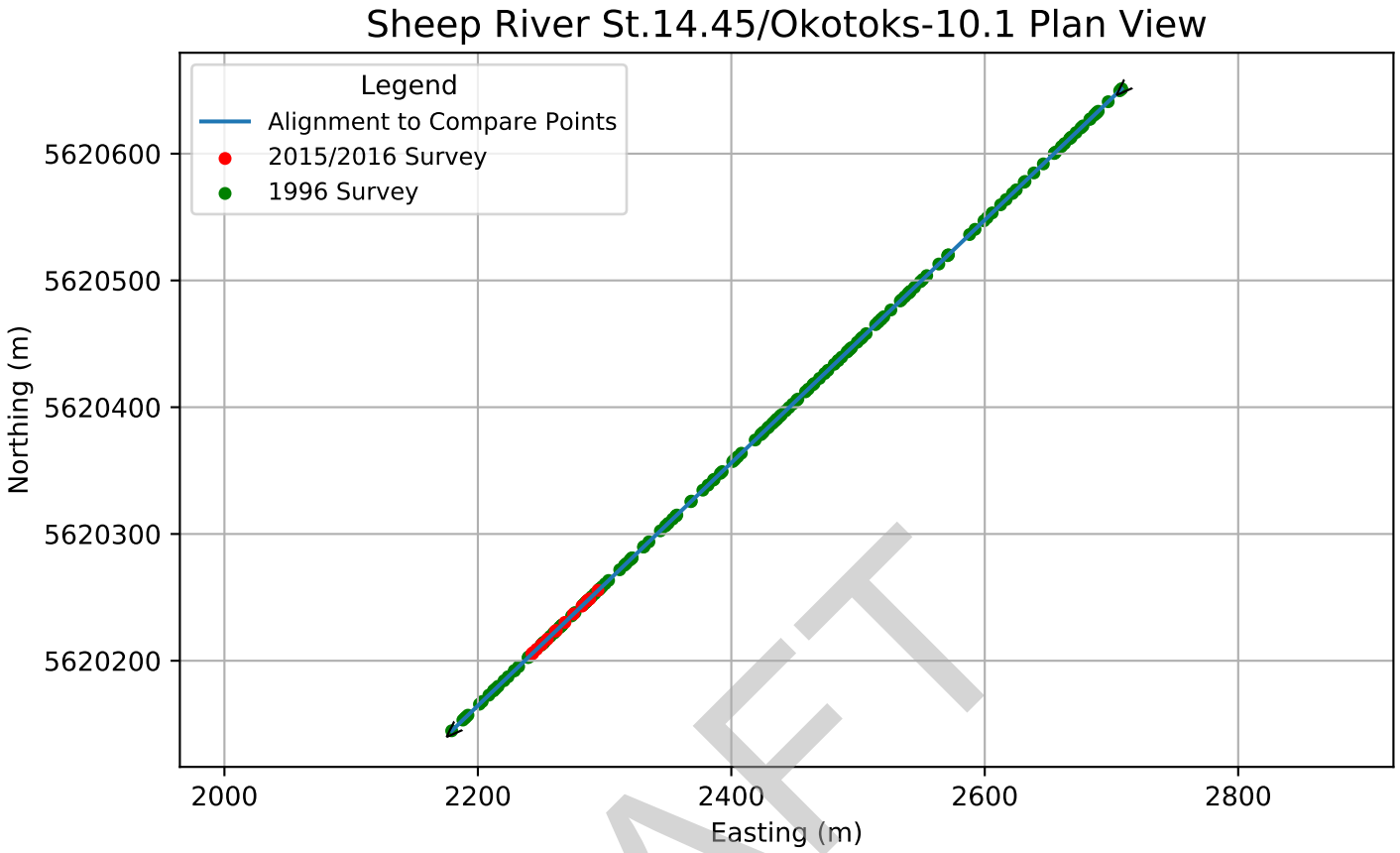

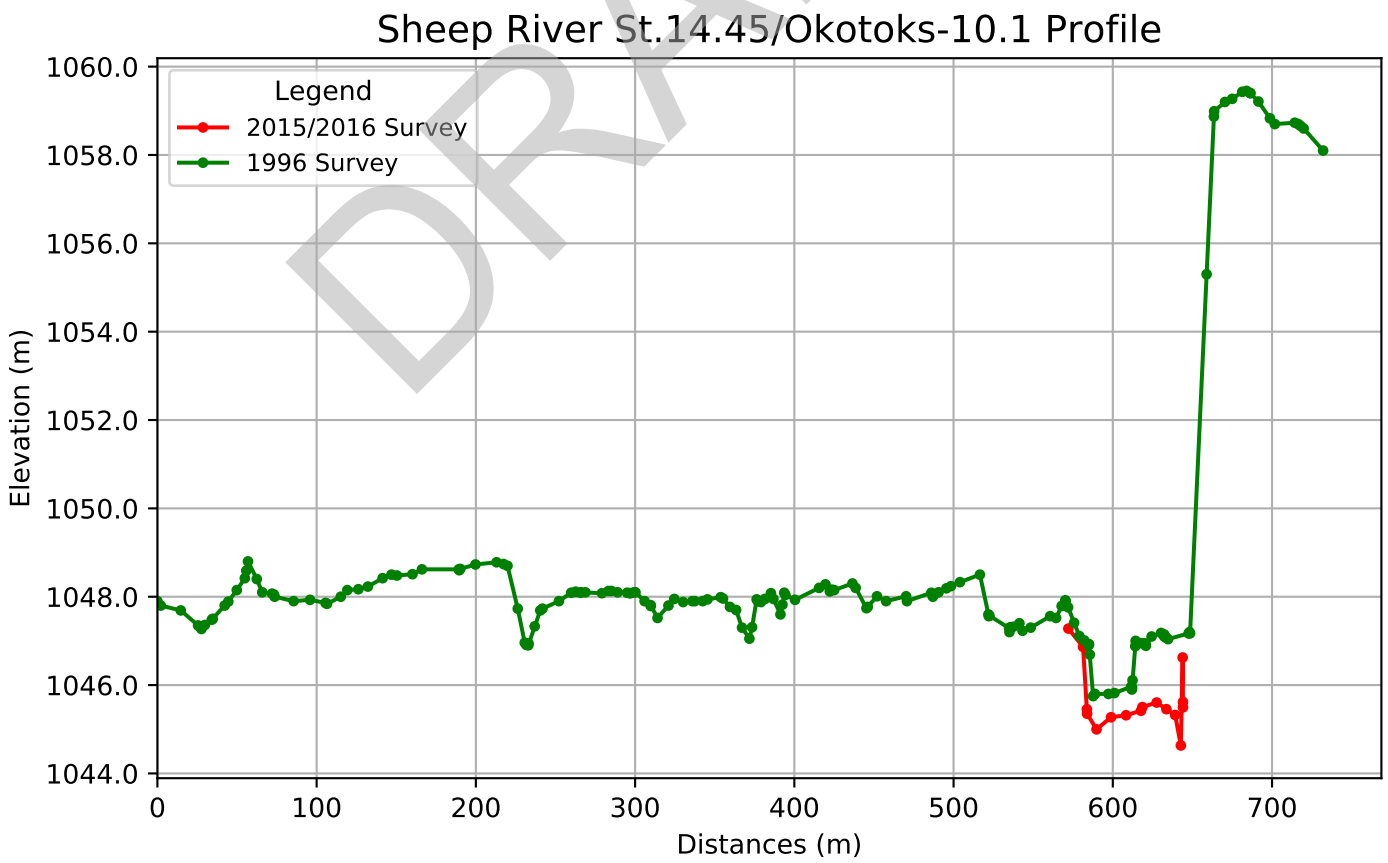

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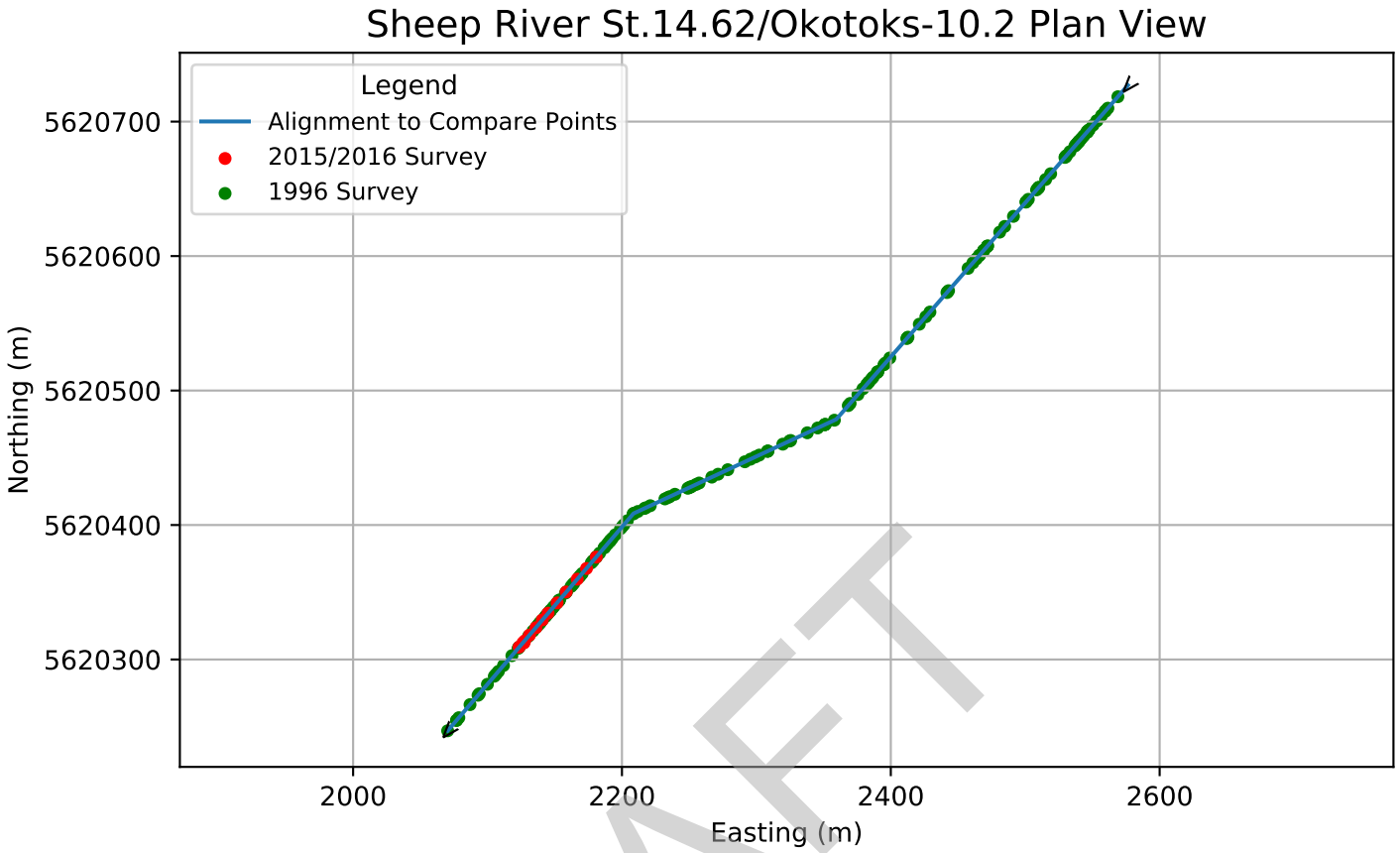
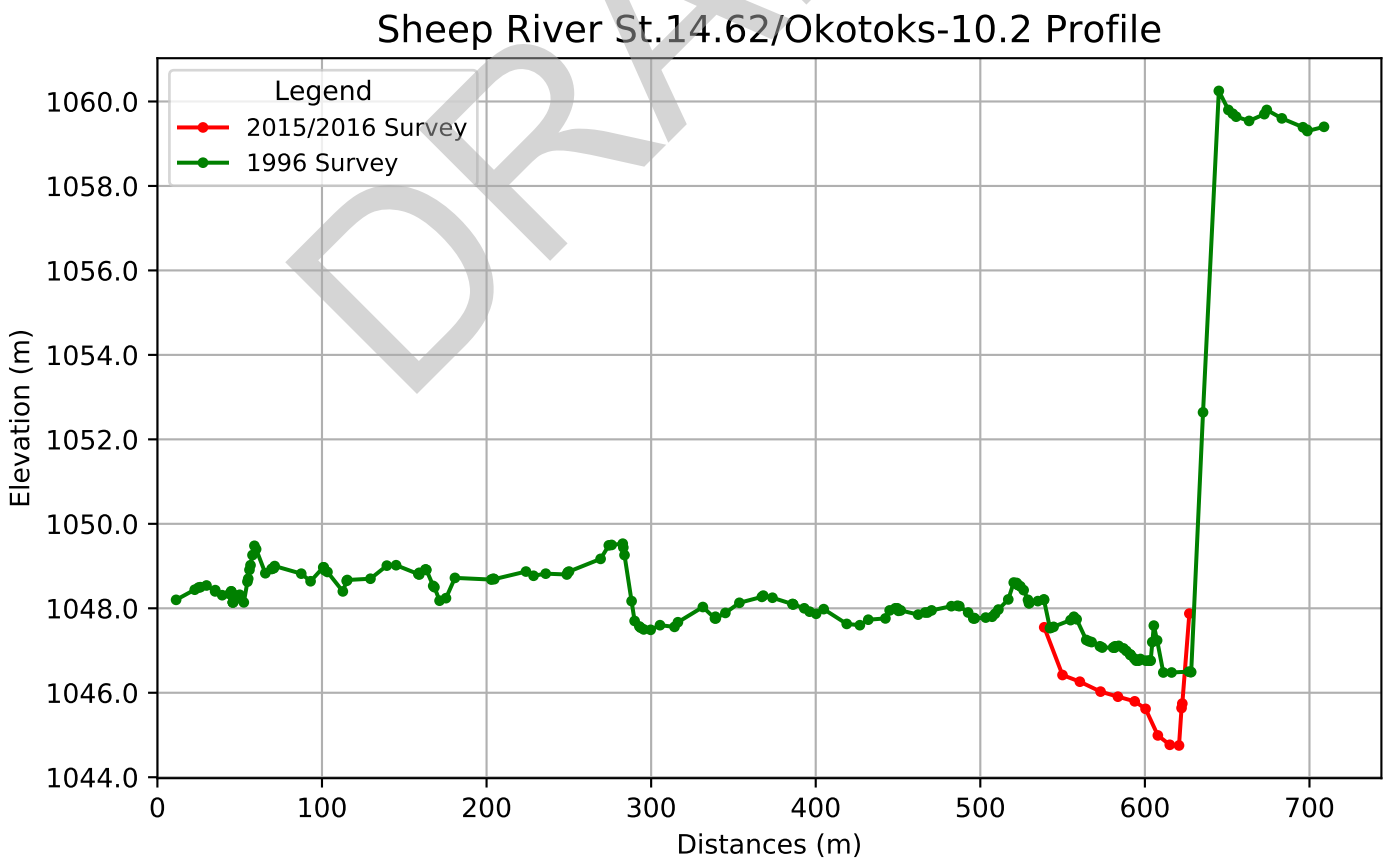
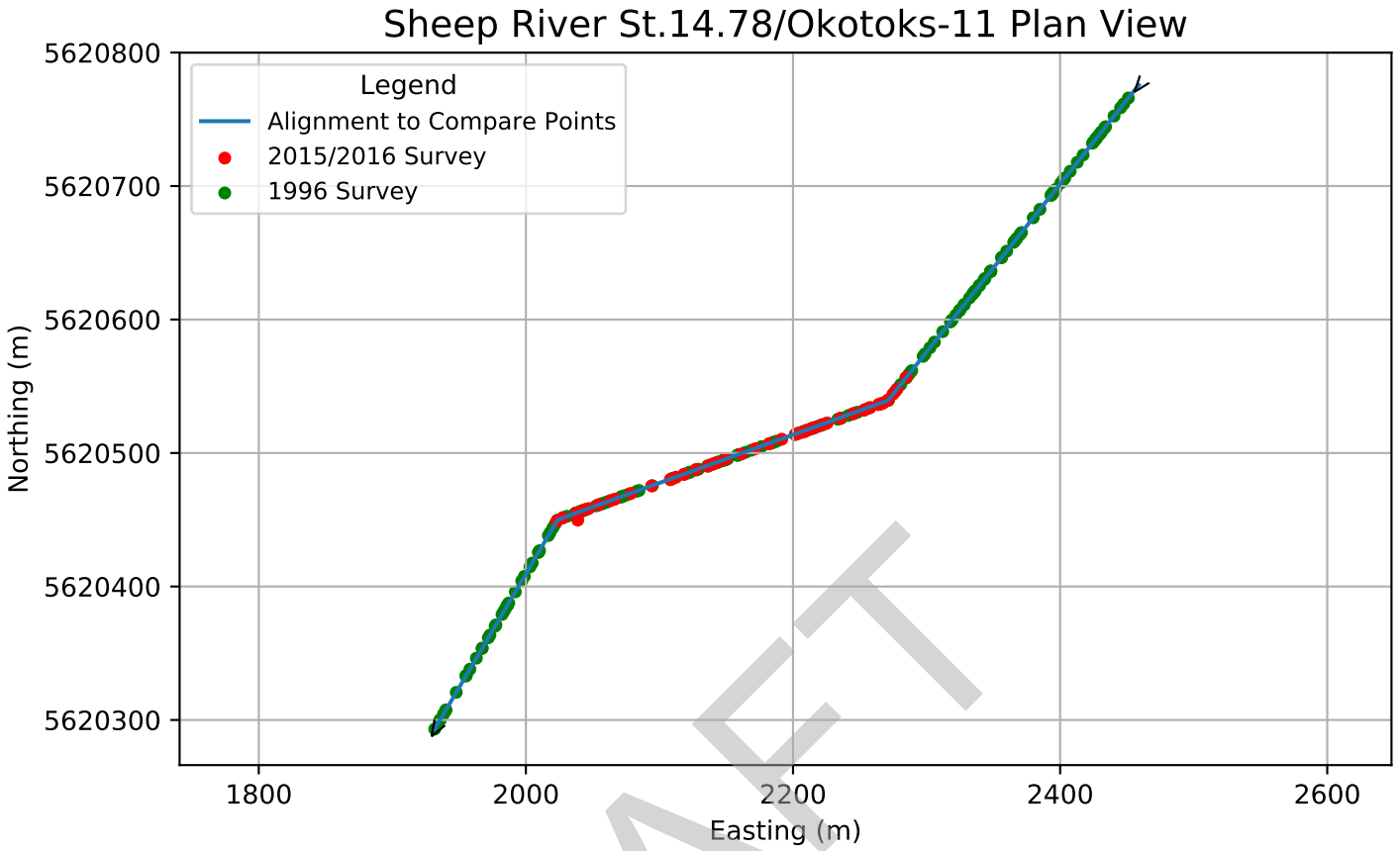
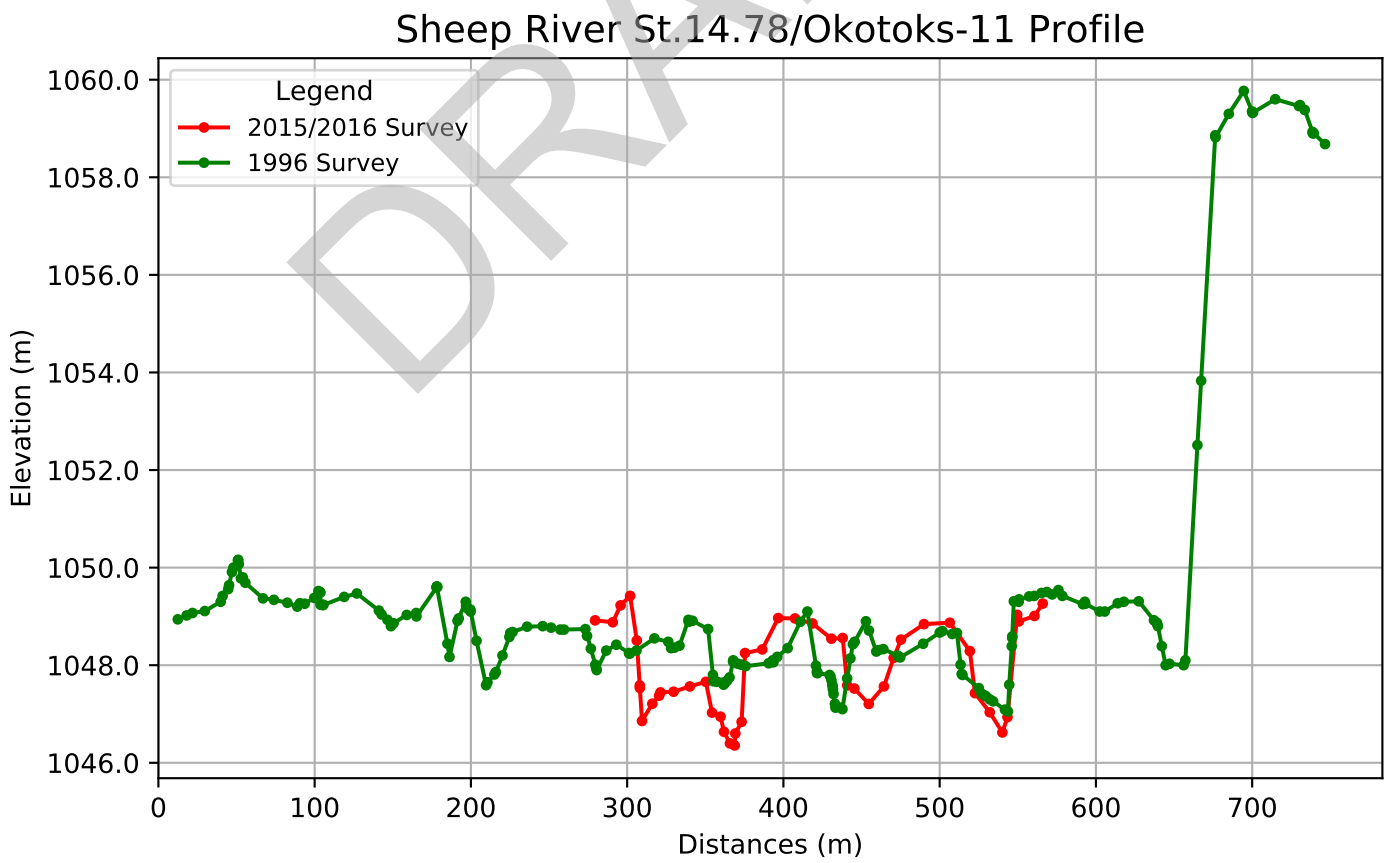




Note:

1.1996 Cross-Section data obtained from file SHEE-EBD.OKOTOKS.HC2 which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross-Sections 3.0,4.2, and 5.1. These correspond to 2015/2016 Cross-Sections 12.47,12.64 and 12.85, respectively.





Note:

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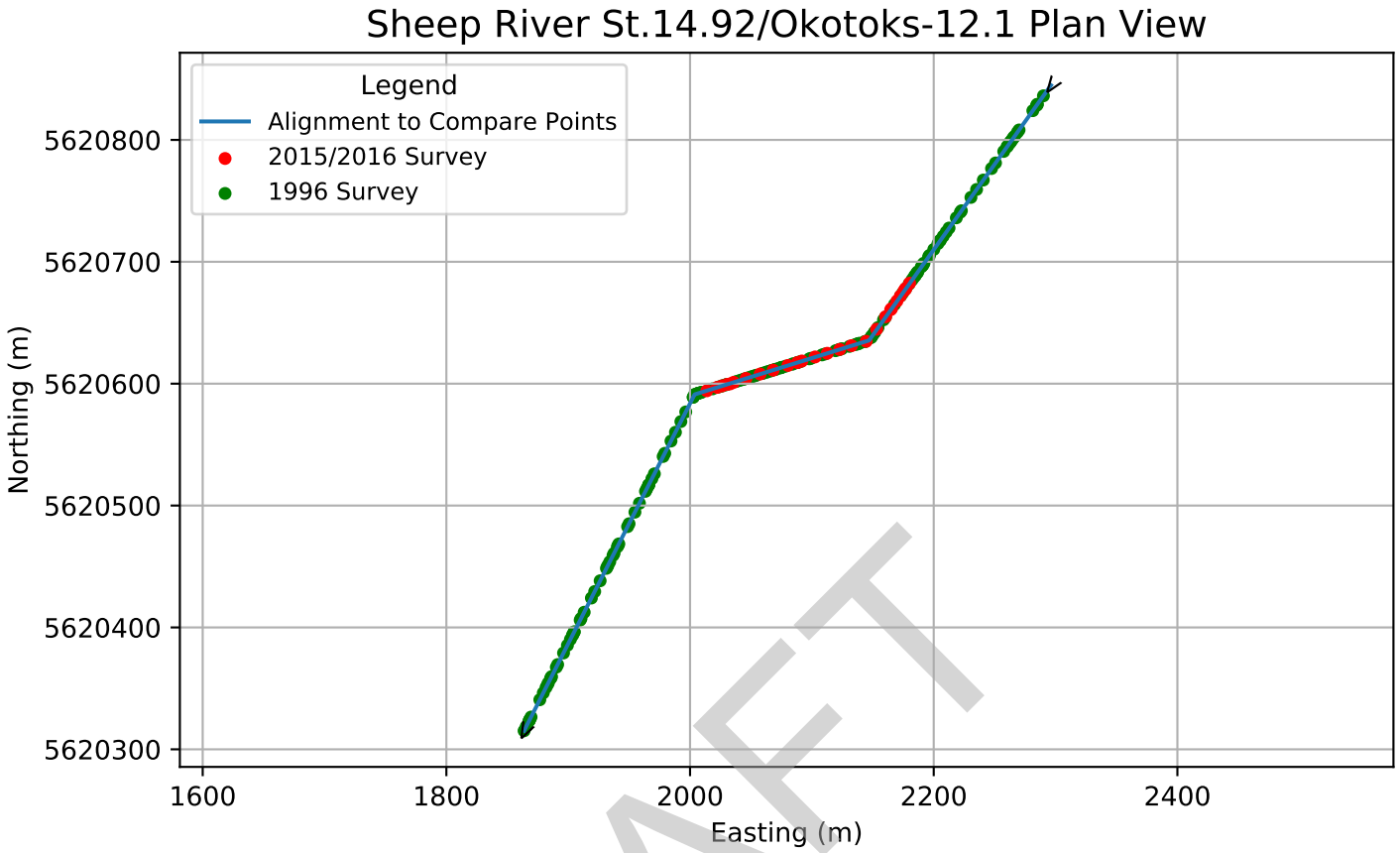

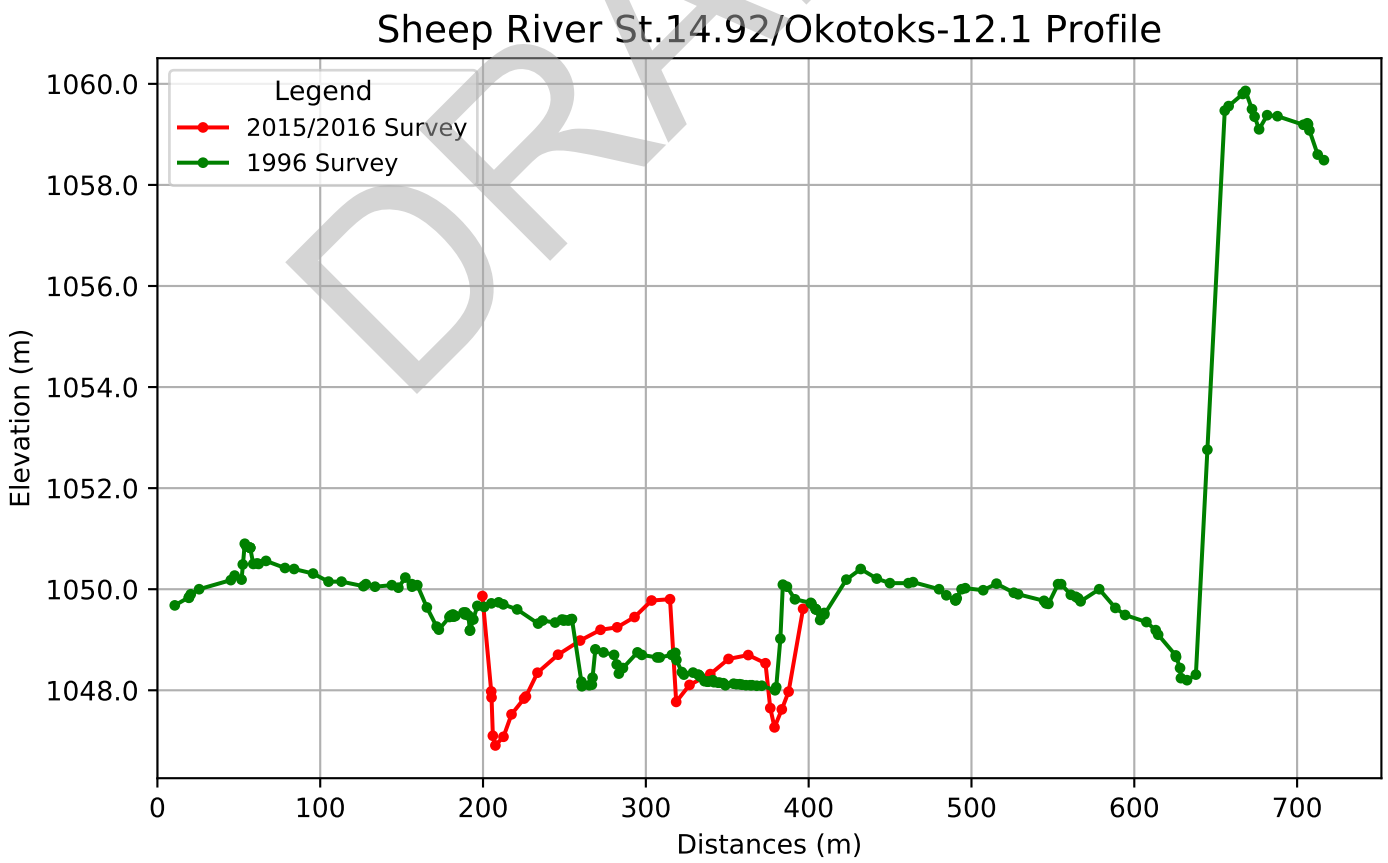

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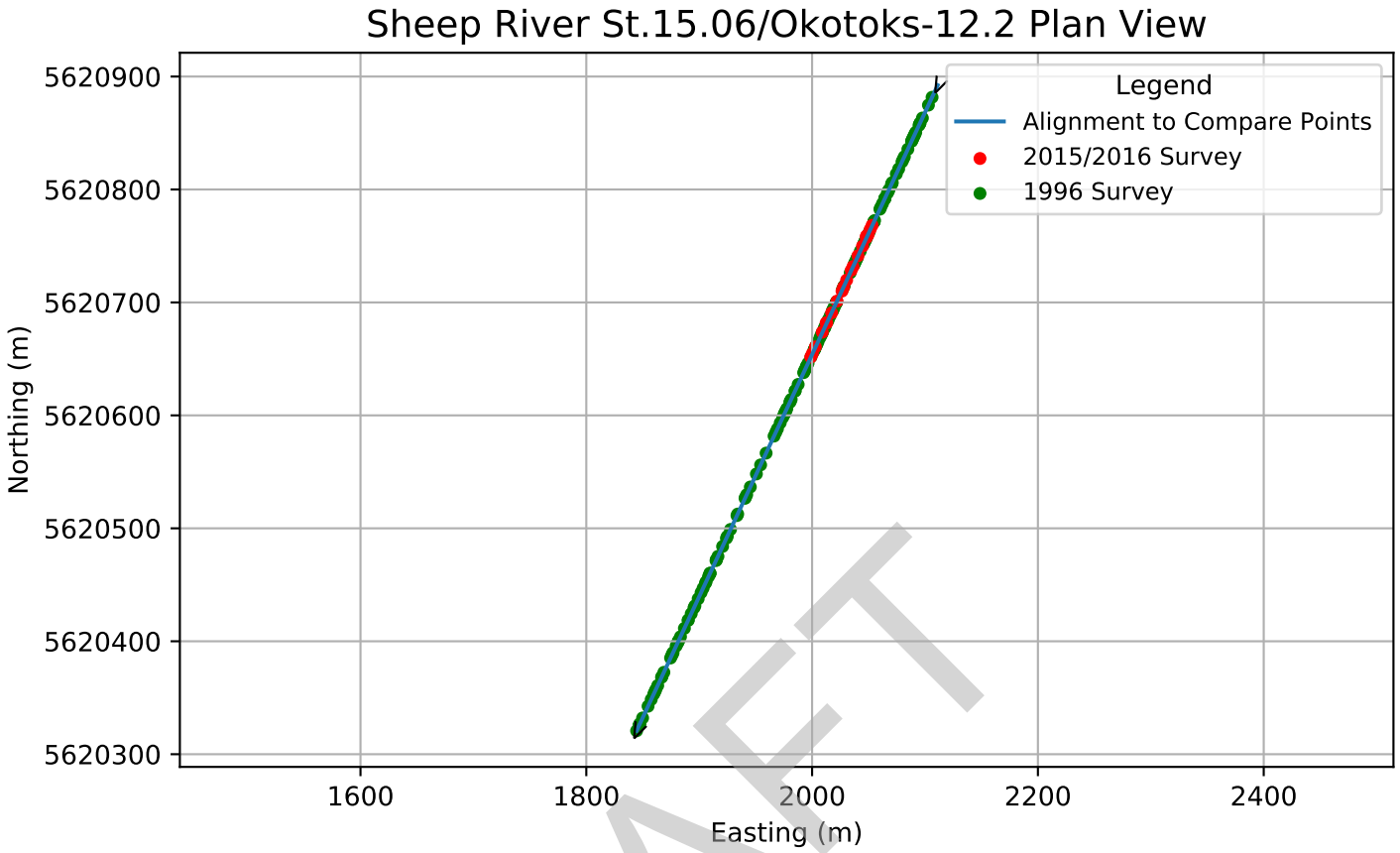
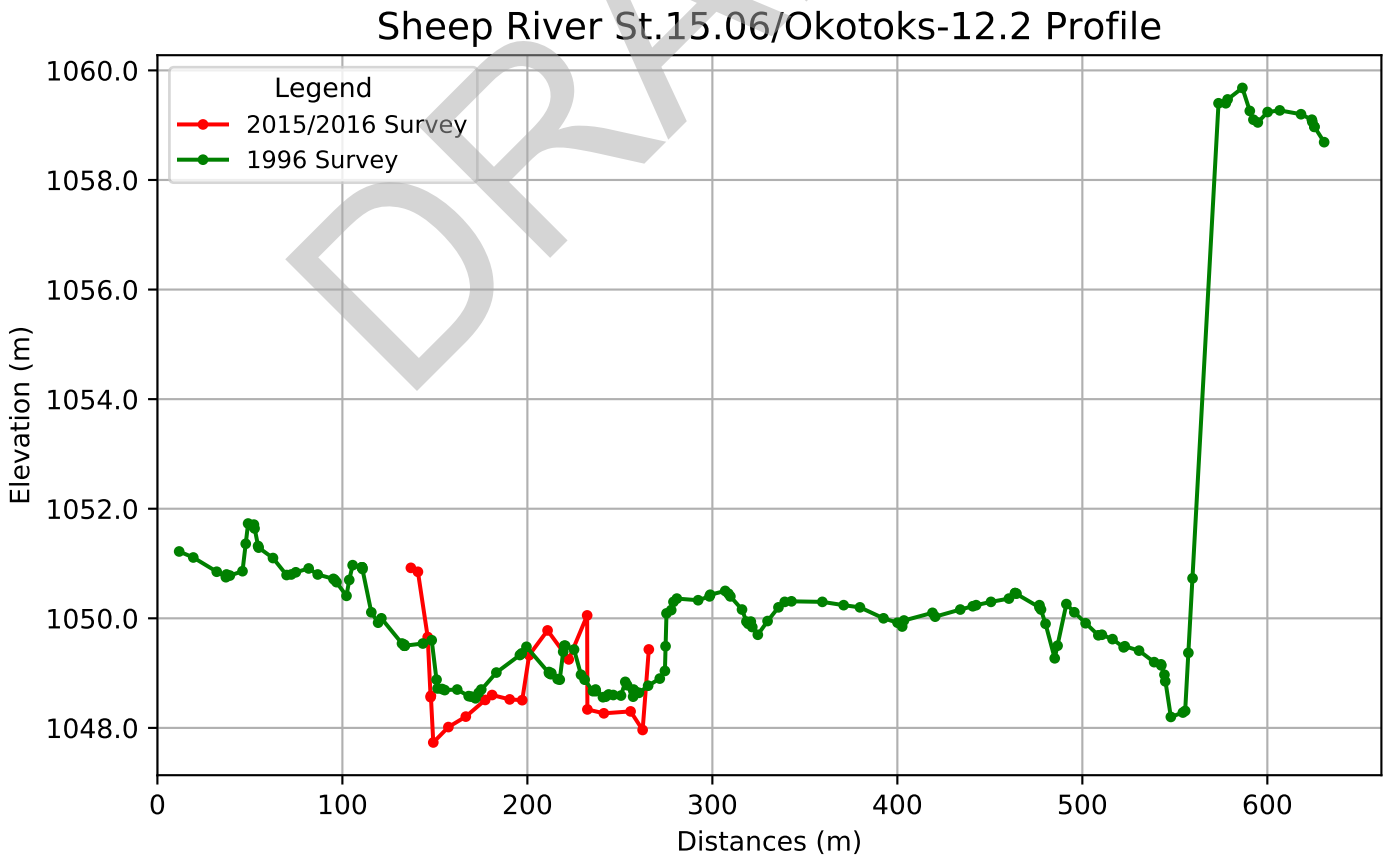
1.1996 Cross-Section data obtained from file SHEE-EBD.OKOTOKS.HC2 which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross-Sections 3.0,4.2, and 5.1. These correspond to 2015/2016 Cross-Sections 12.47,12.64 and 12.85, respectively.





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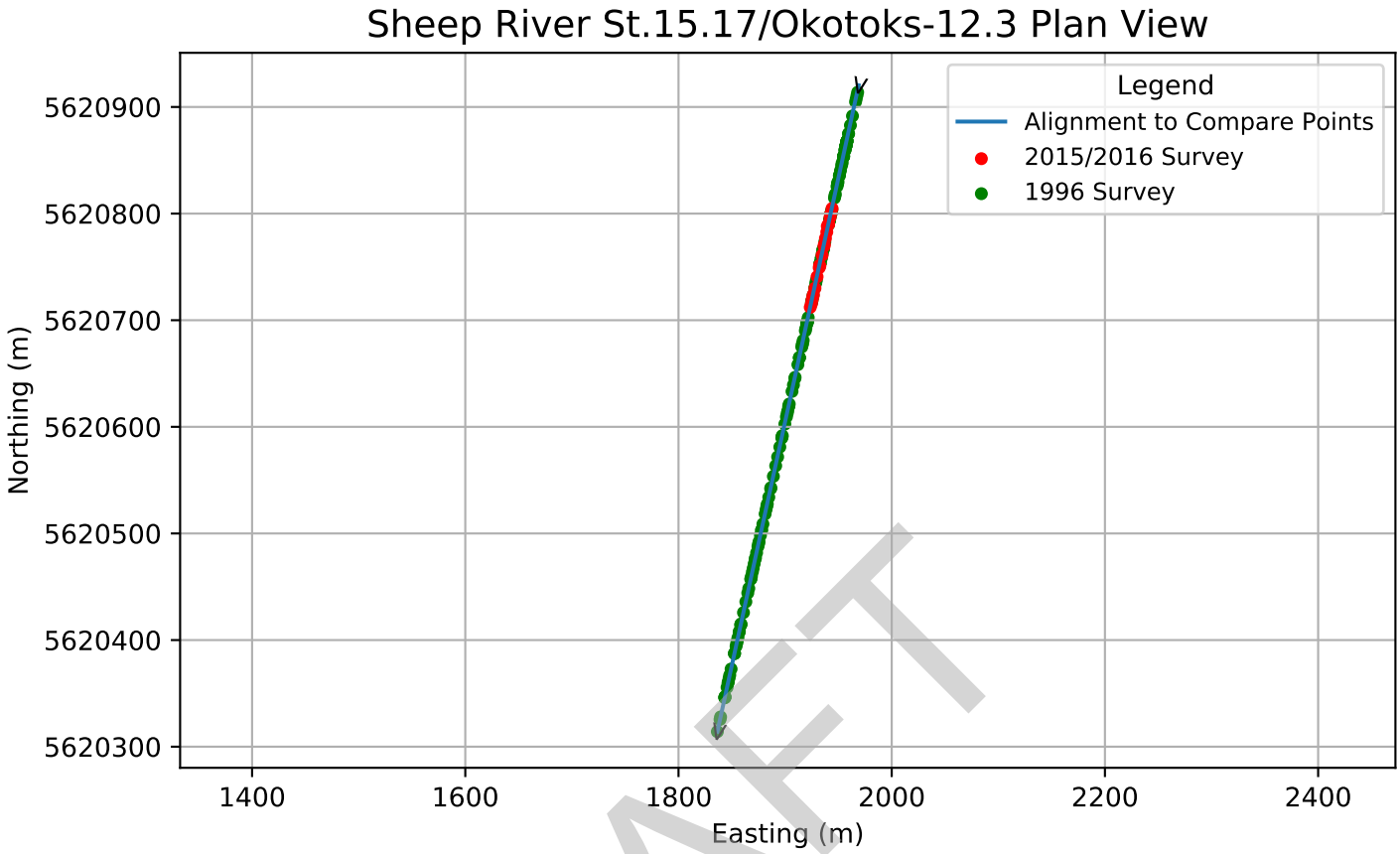

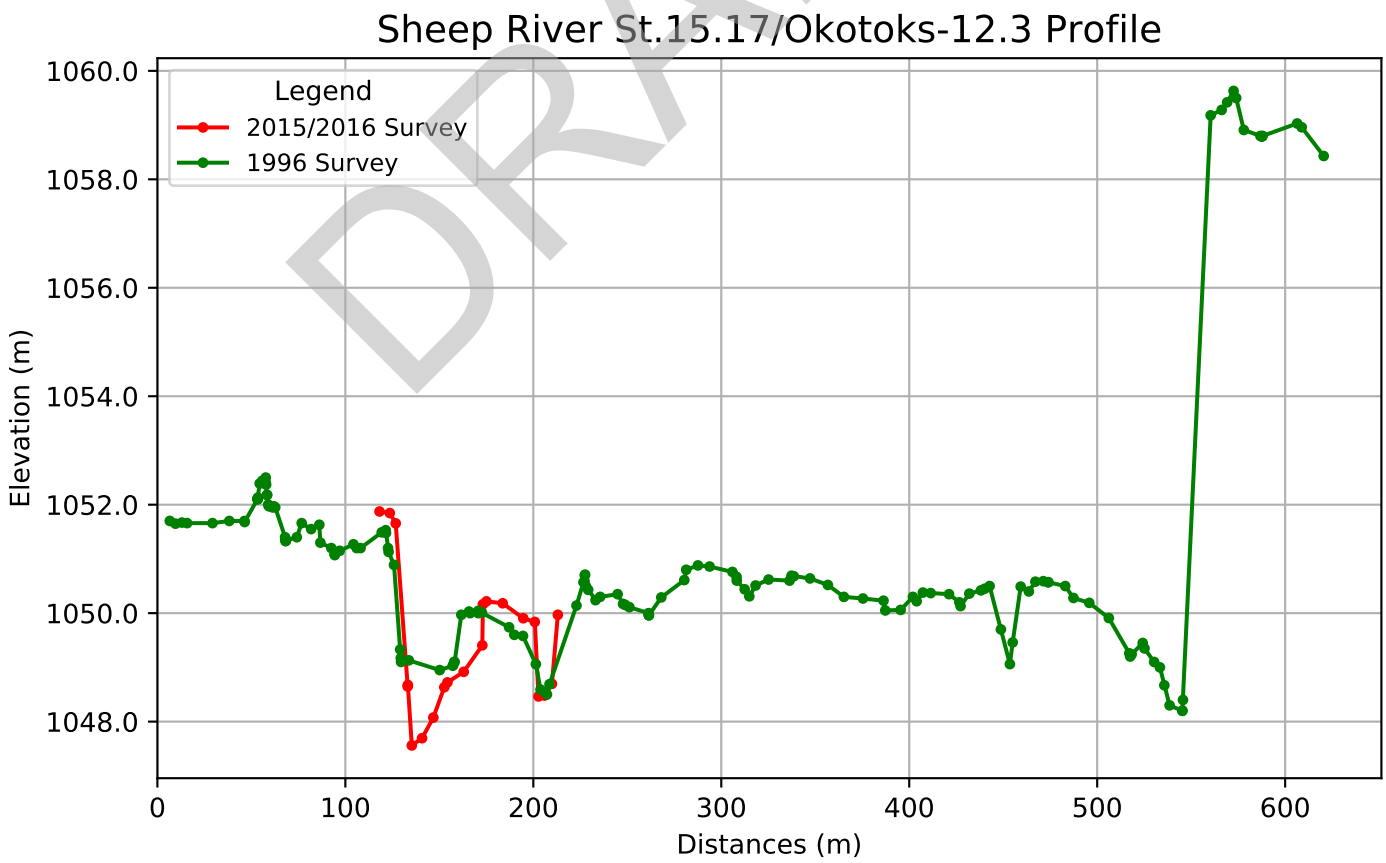

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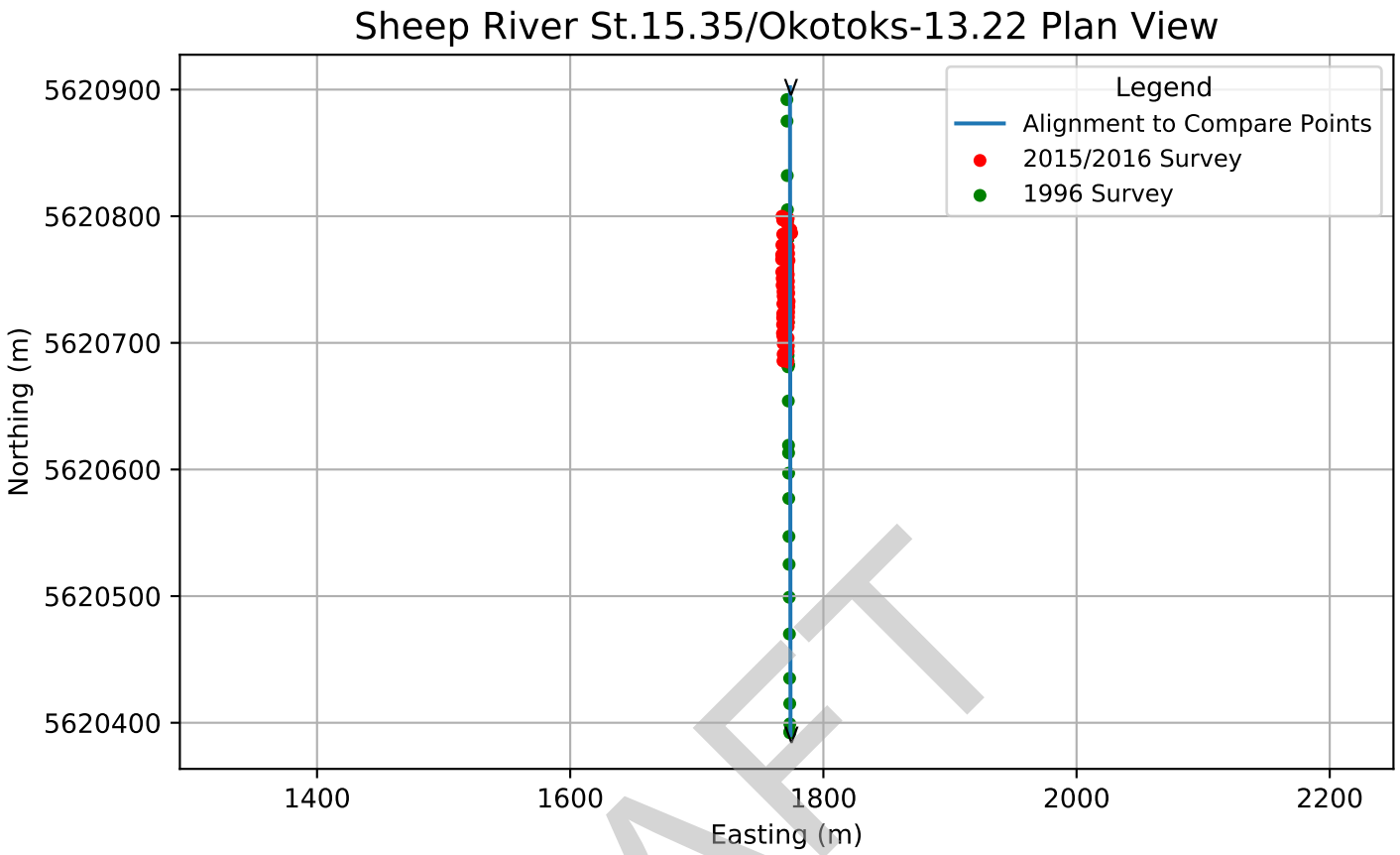

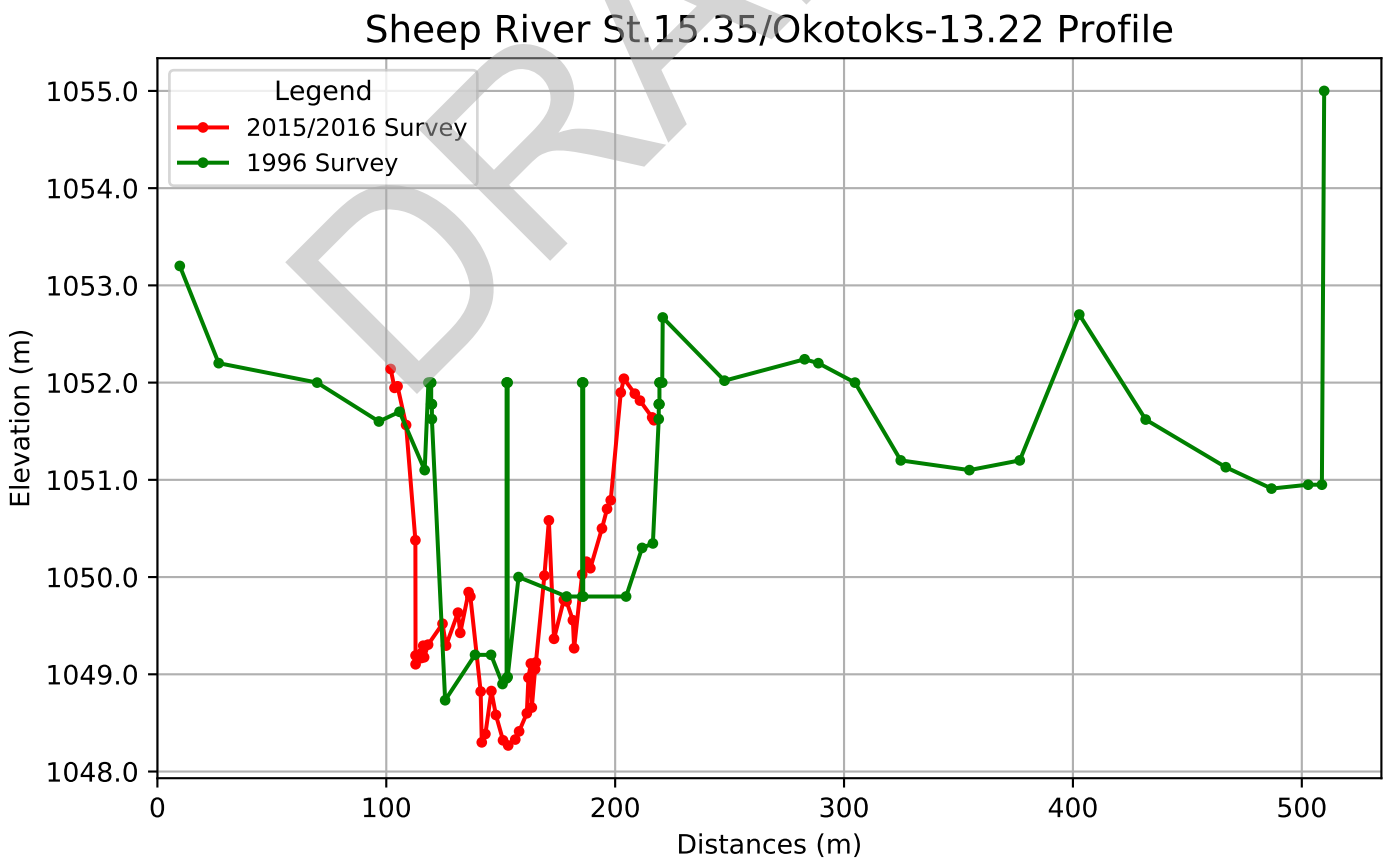

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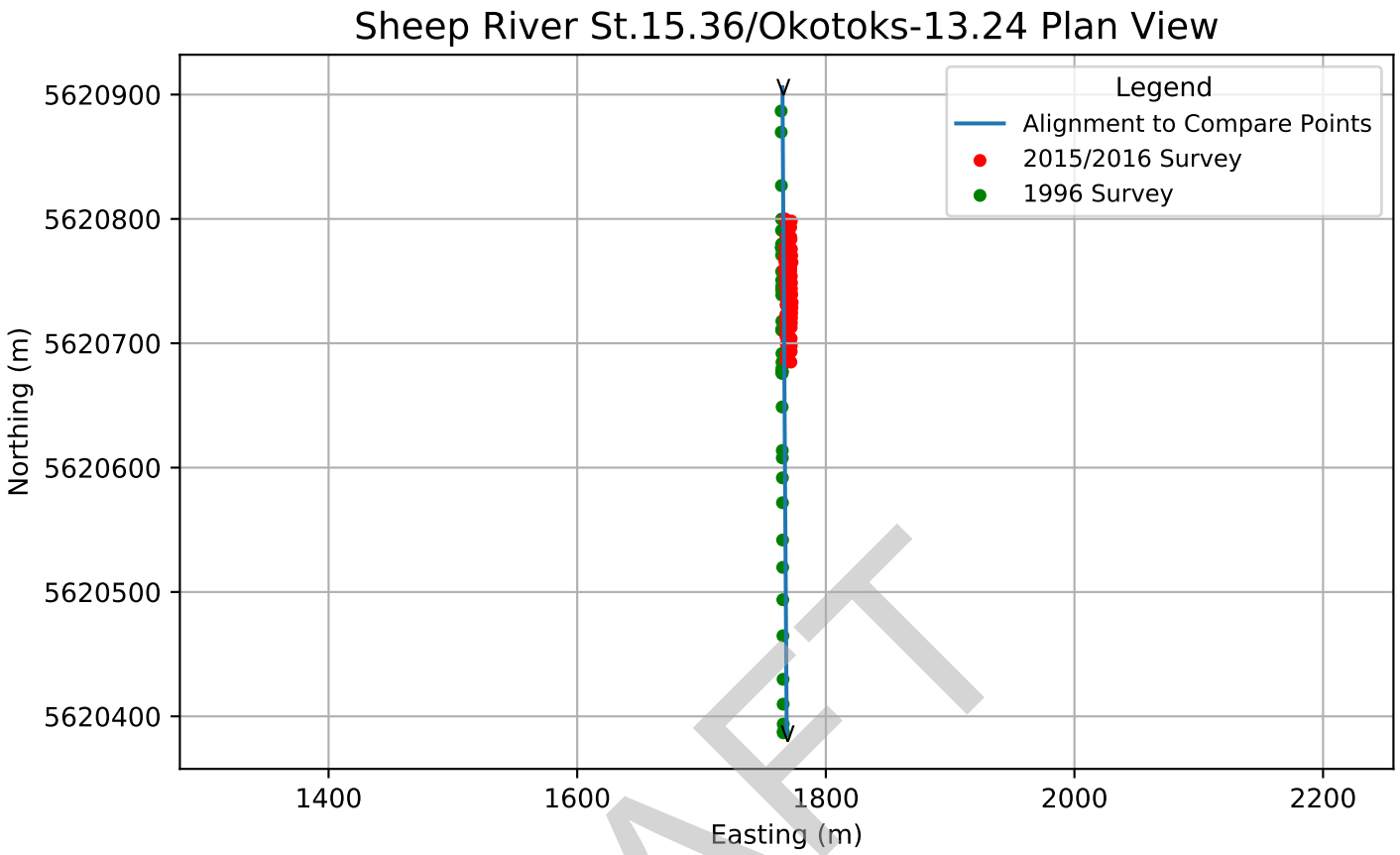

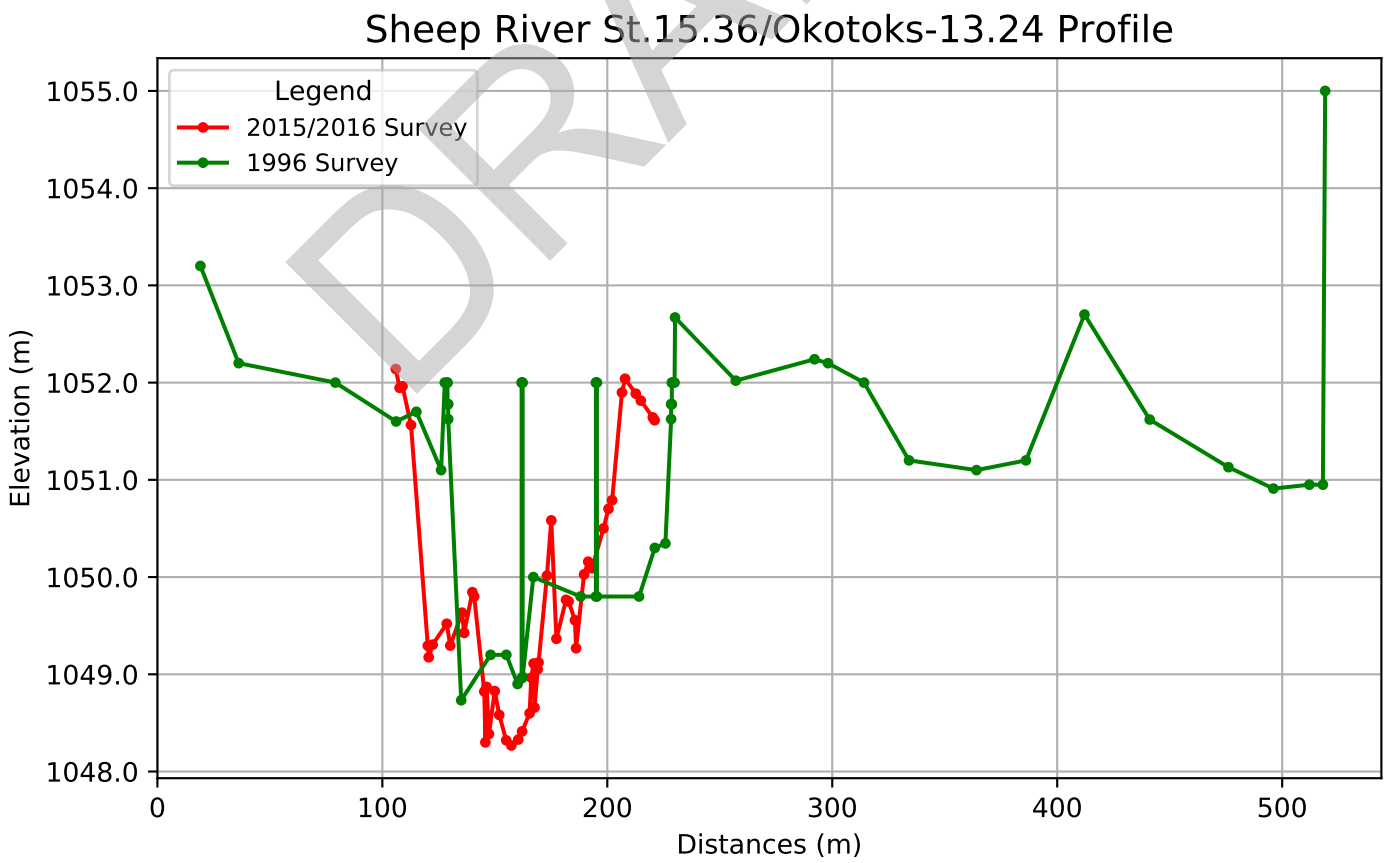

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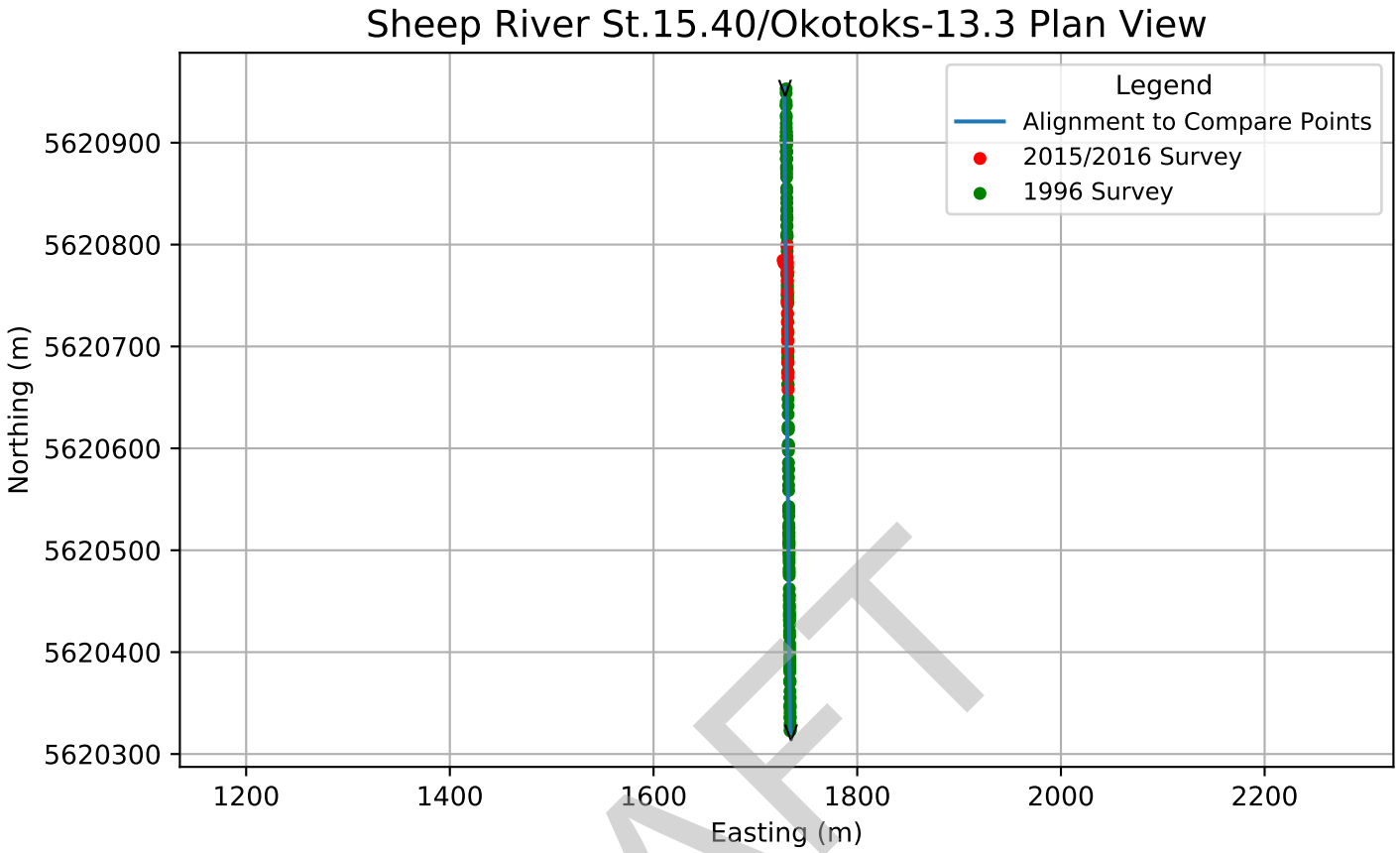

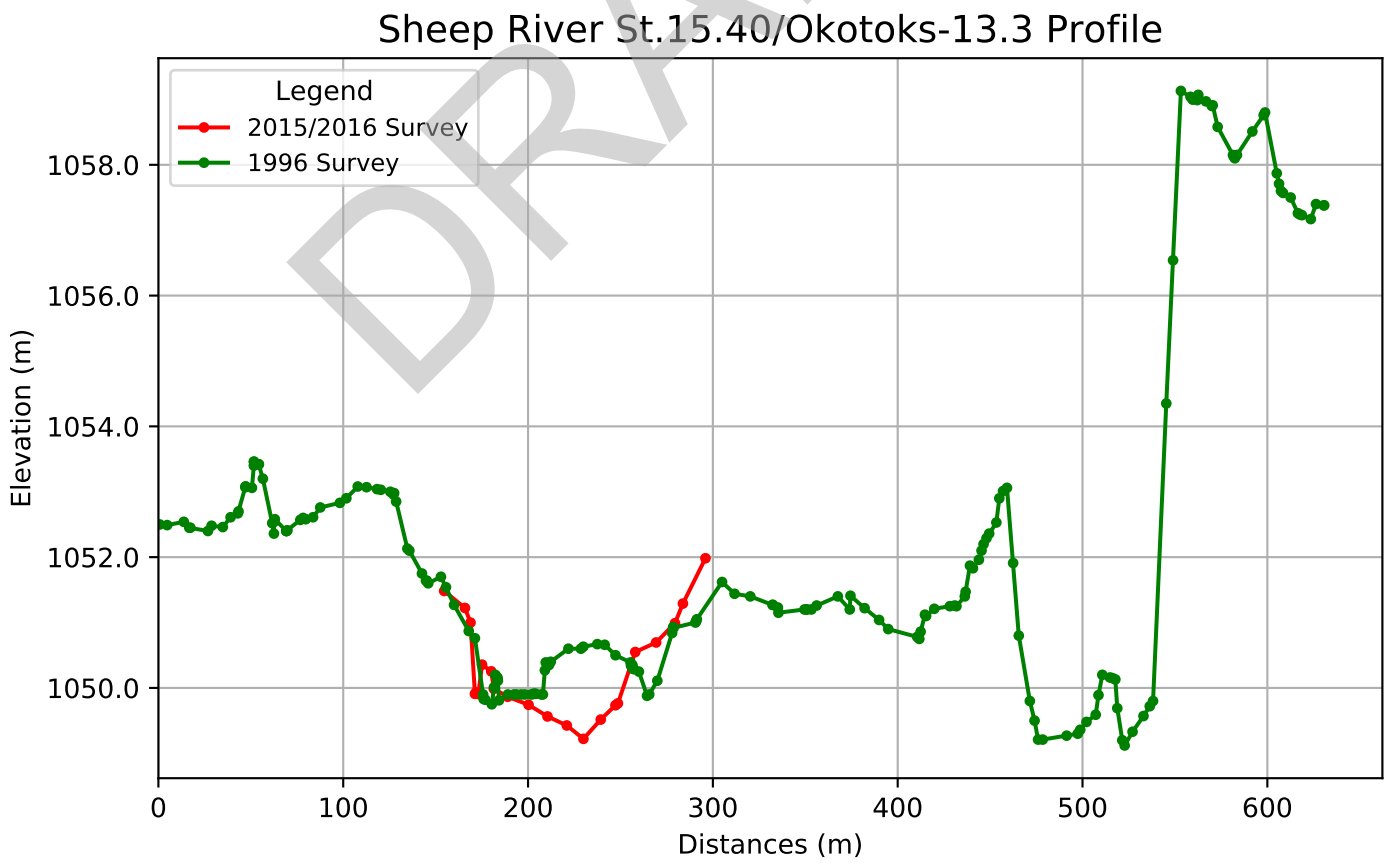

Note:

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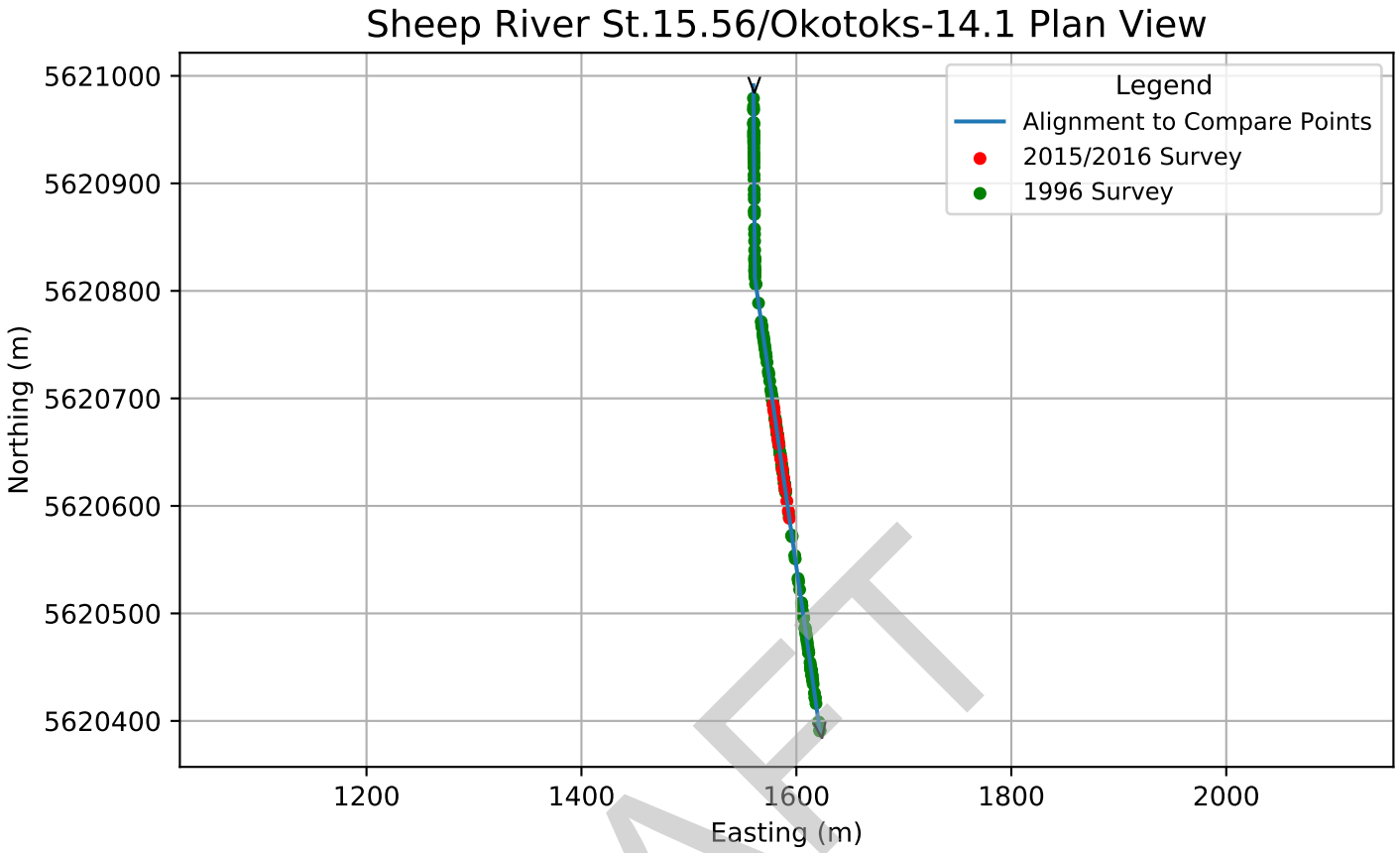

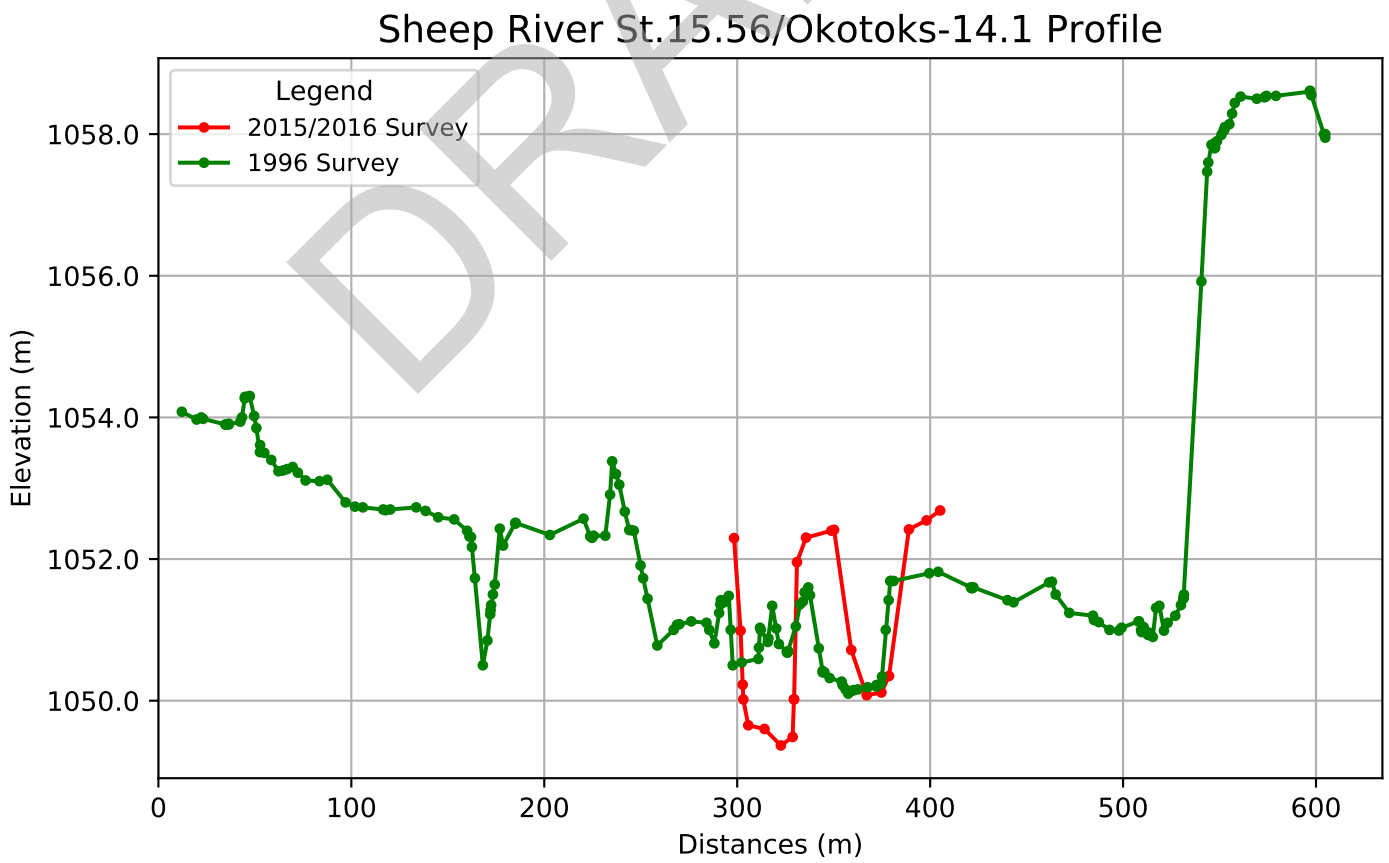

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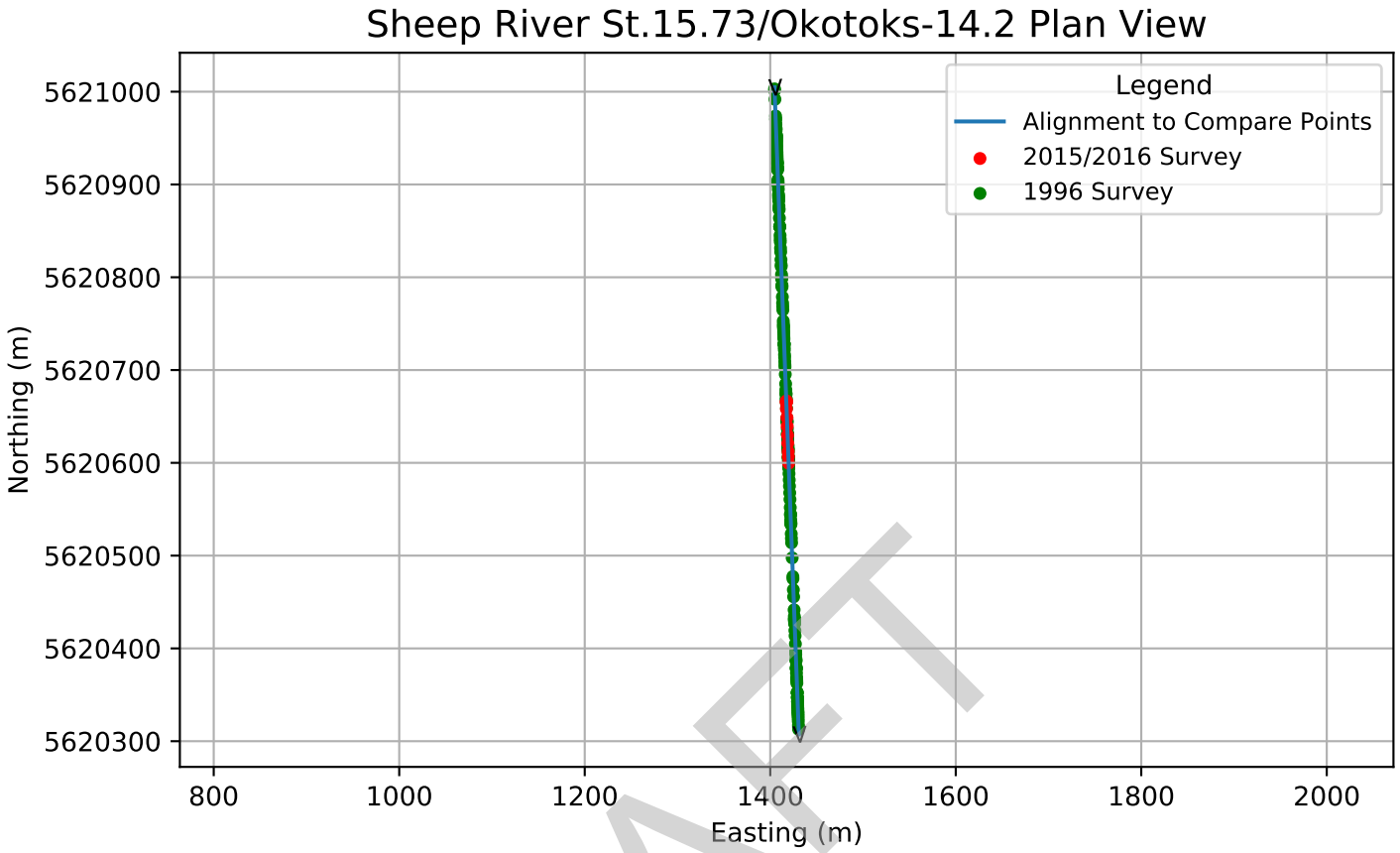

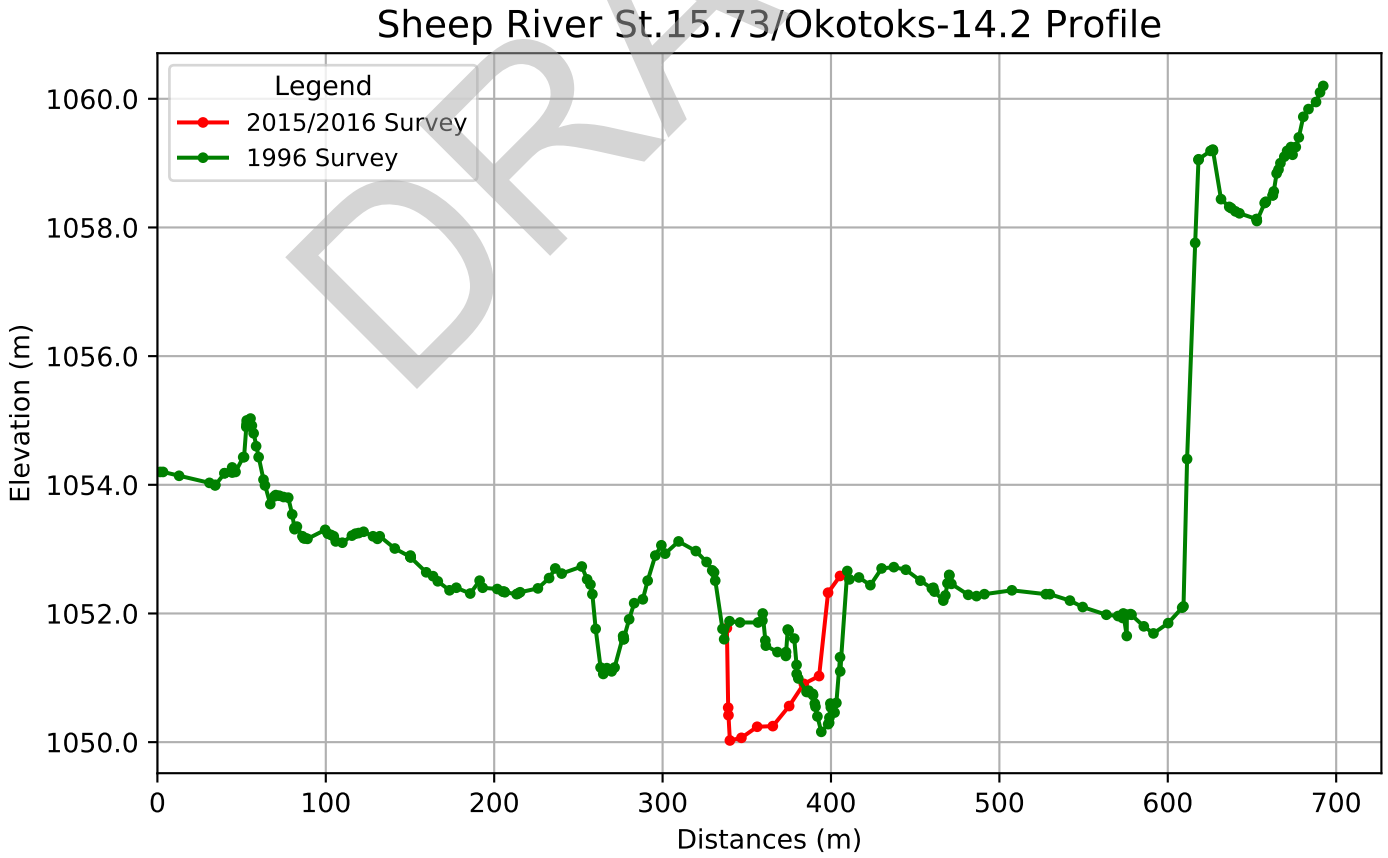

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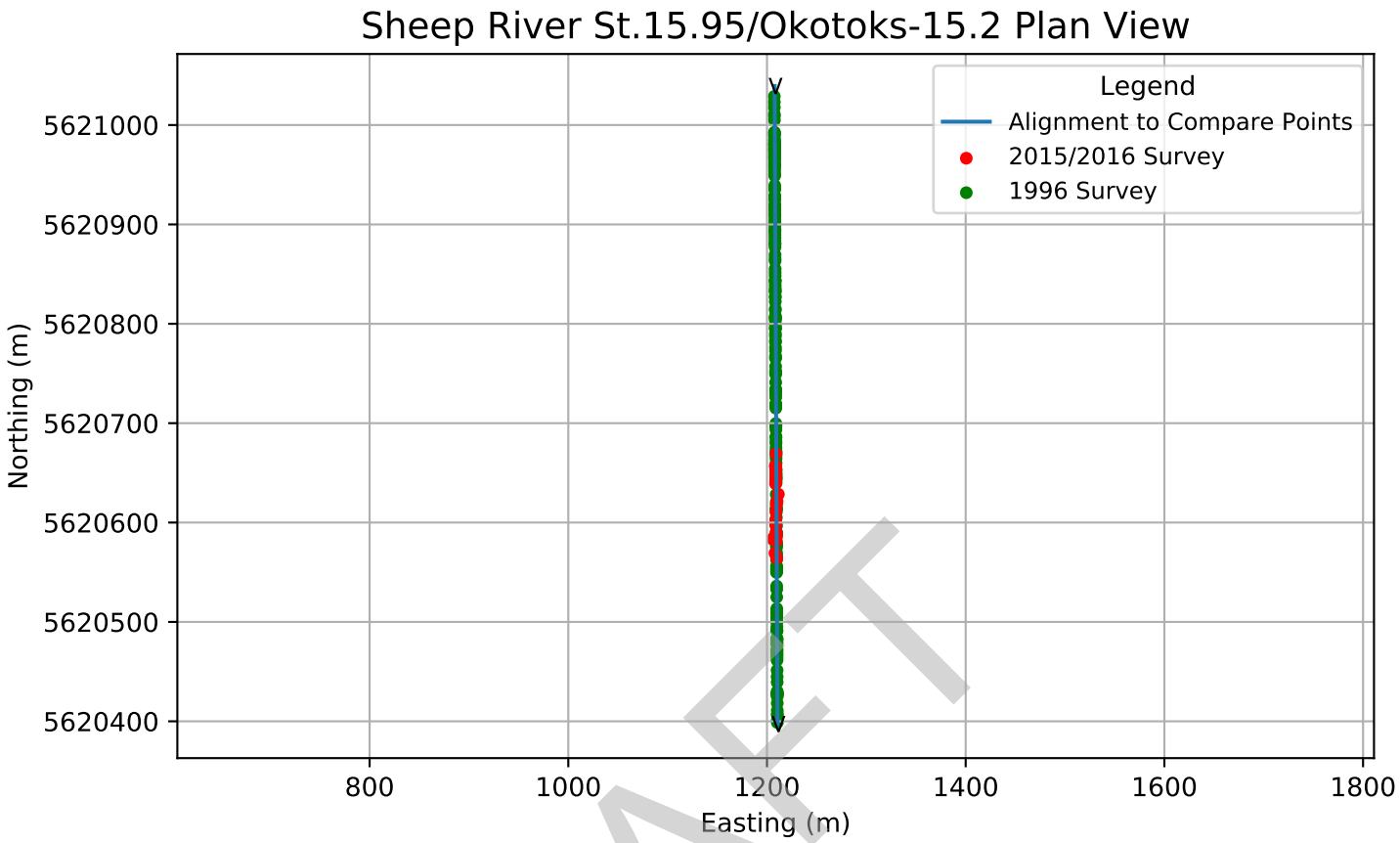

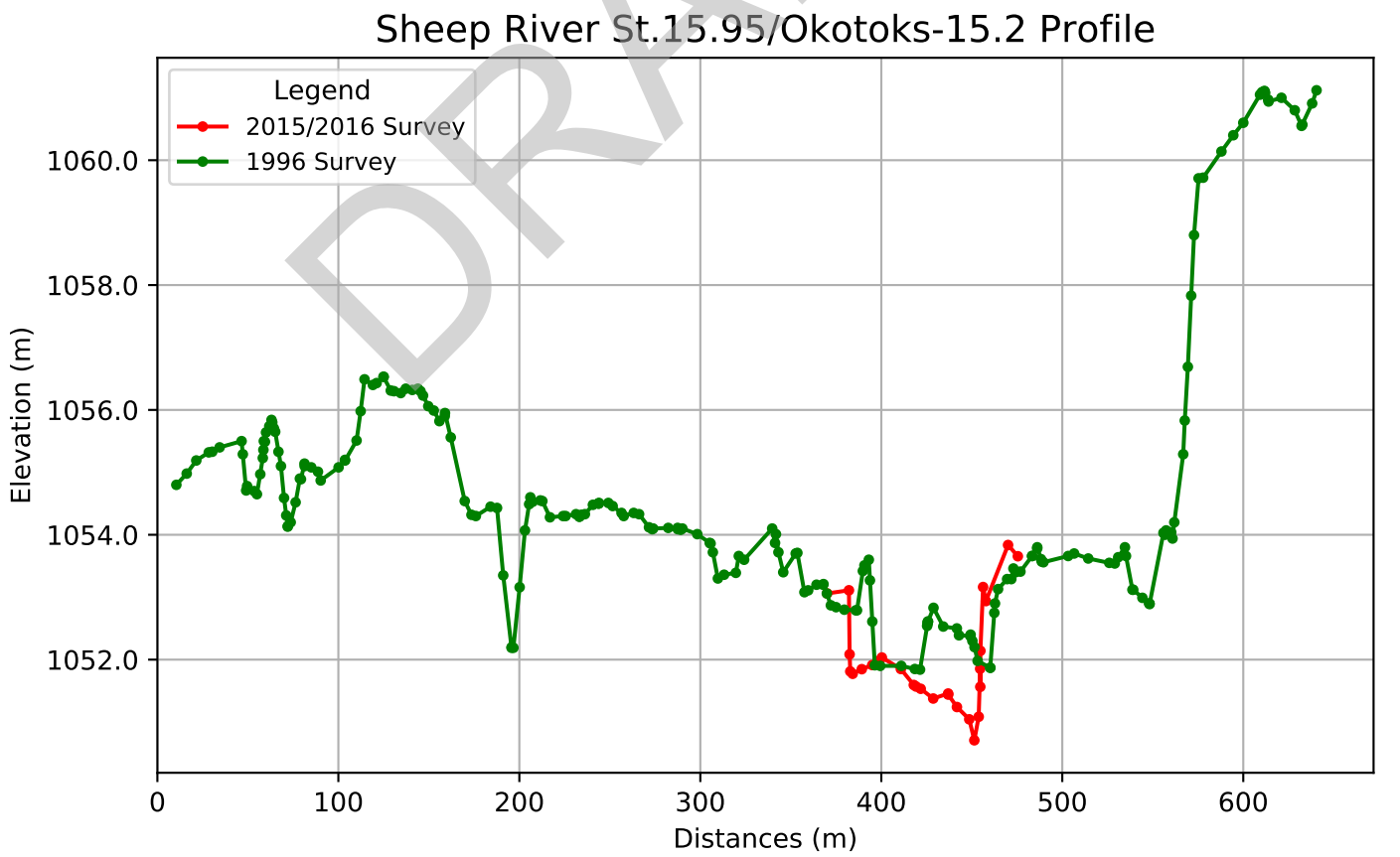

Note:

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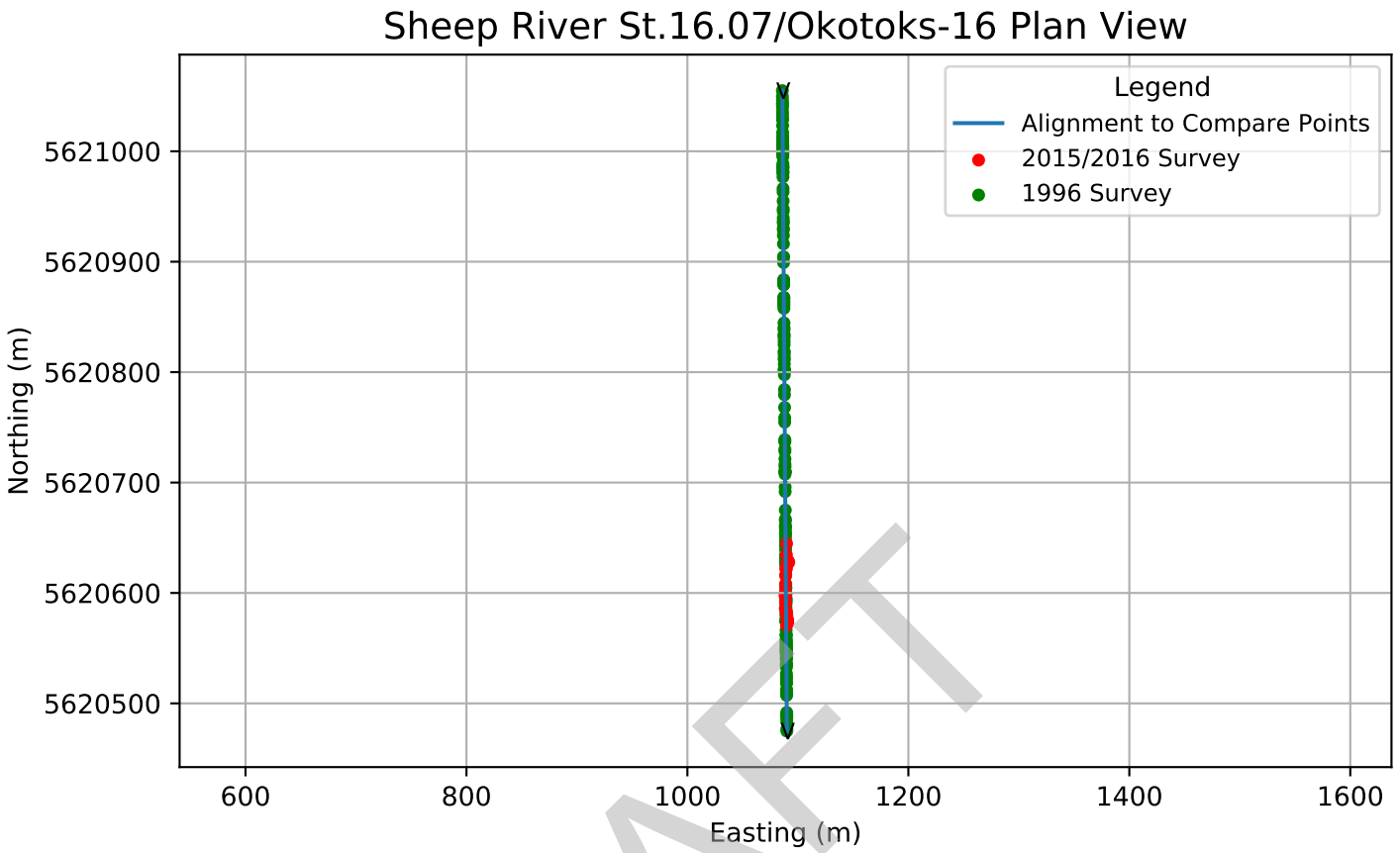

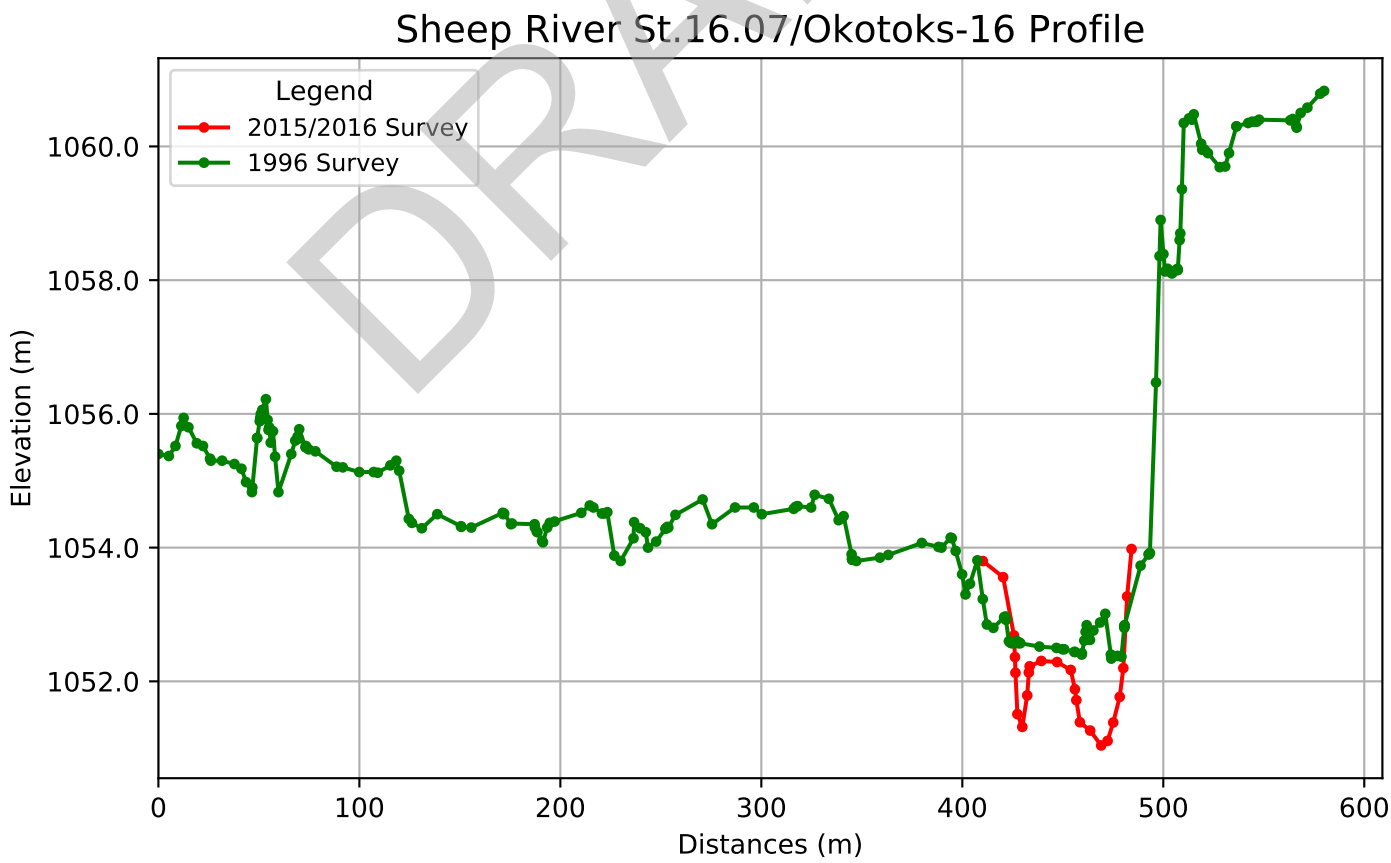

Note:

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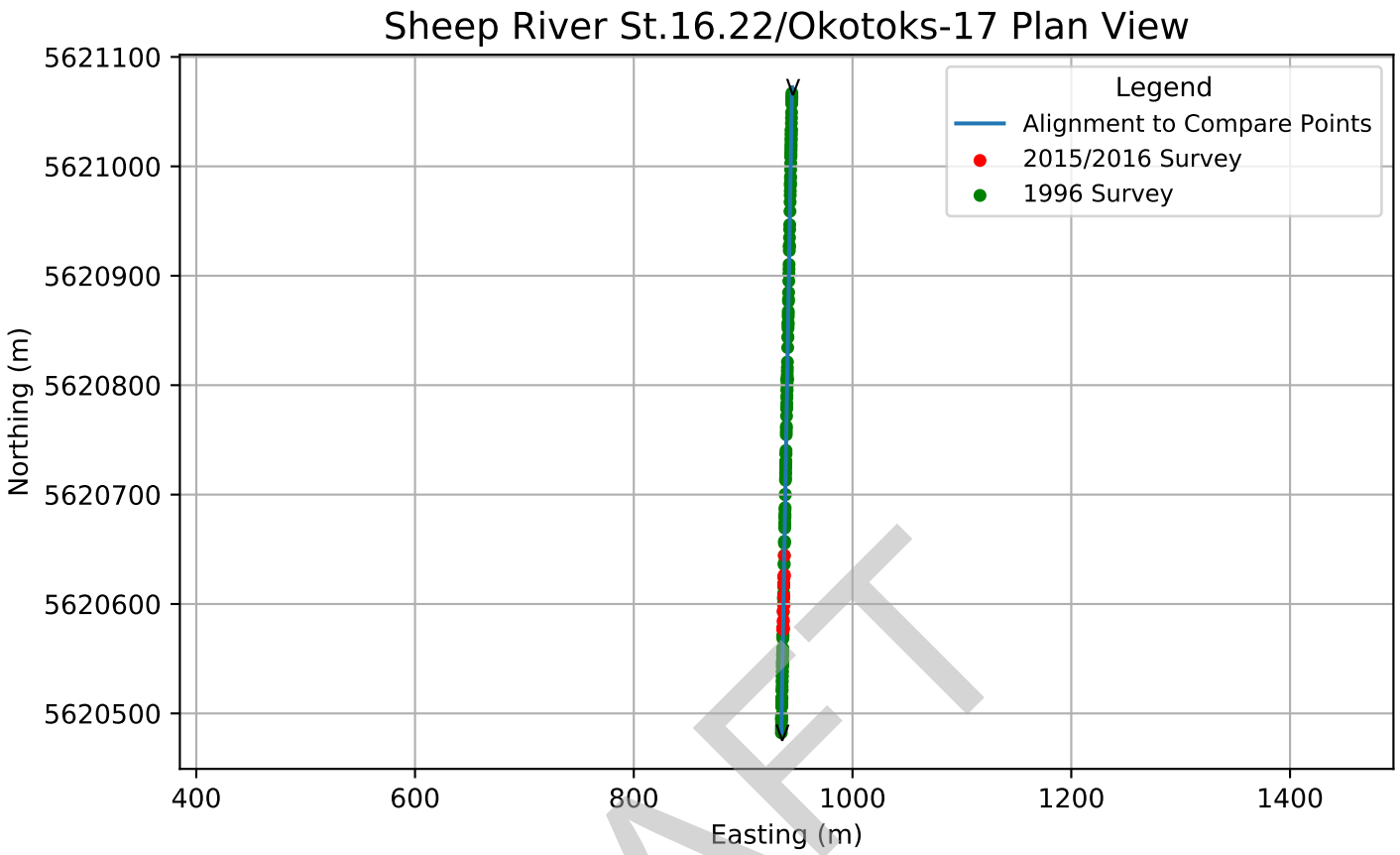

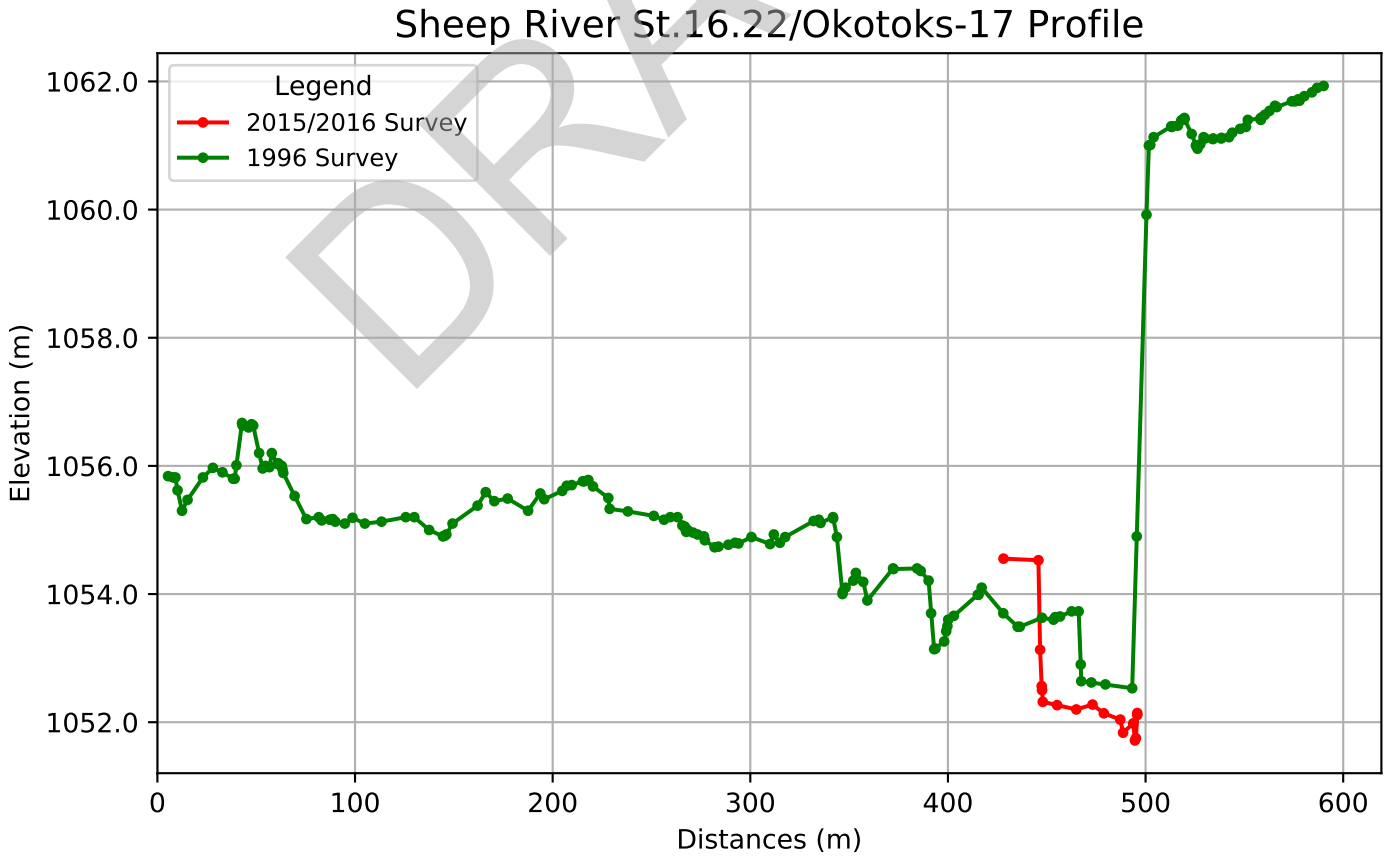

Note:

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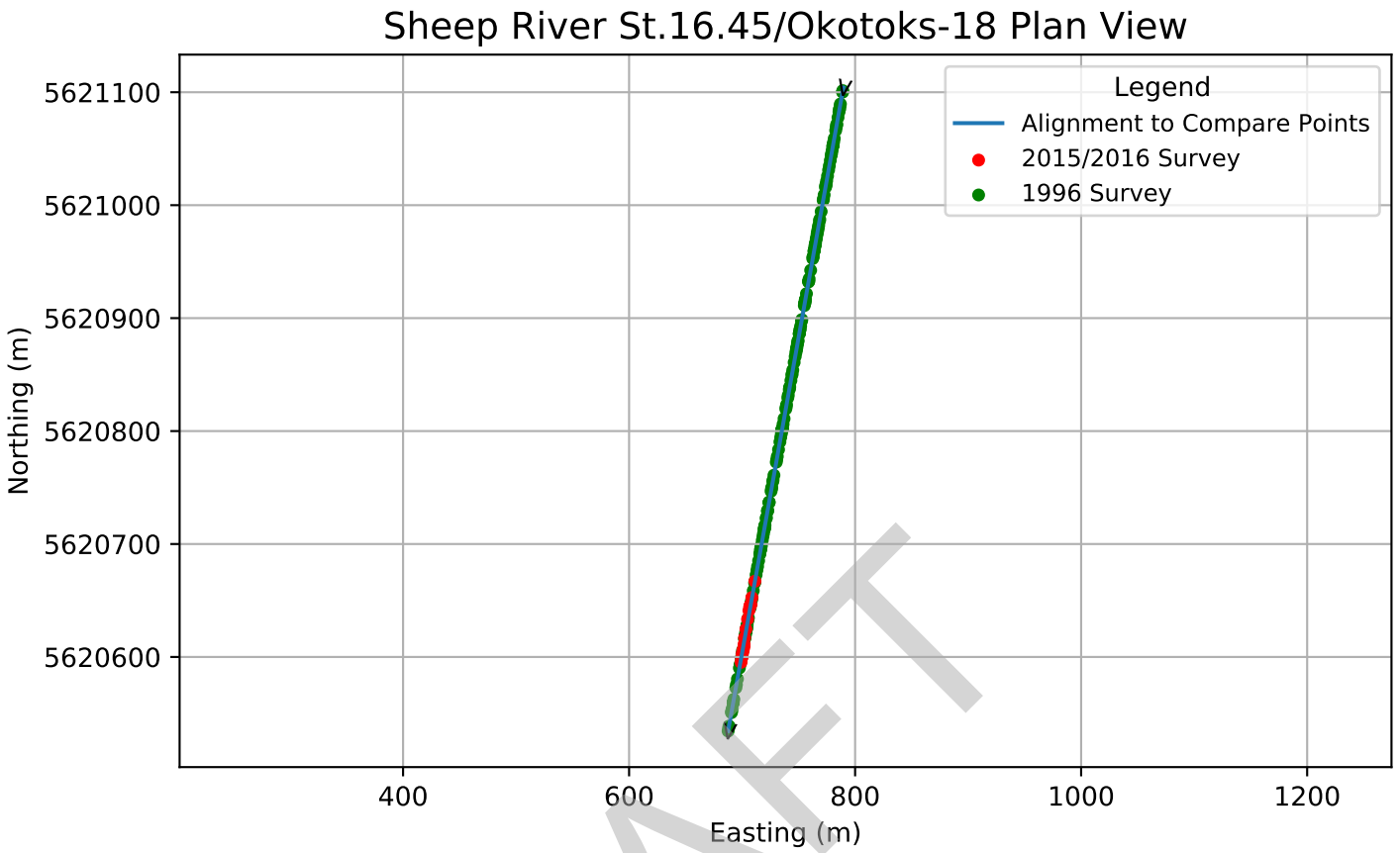

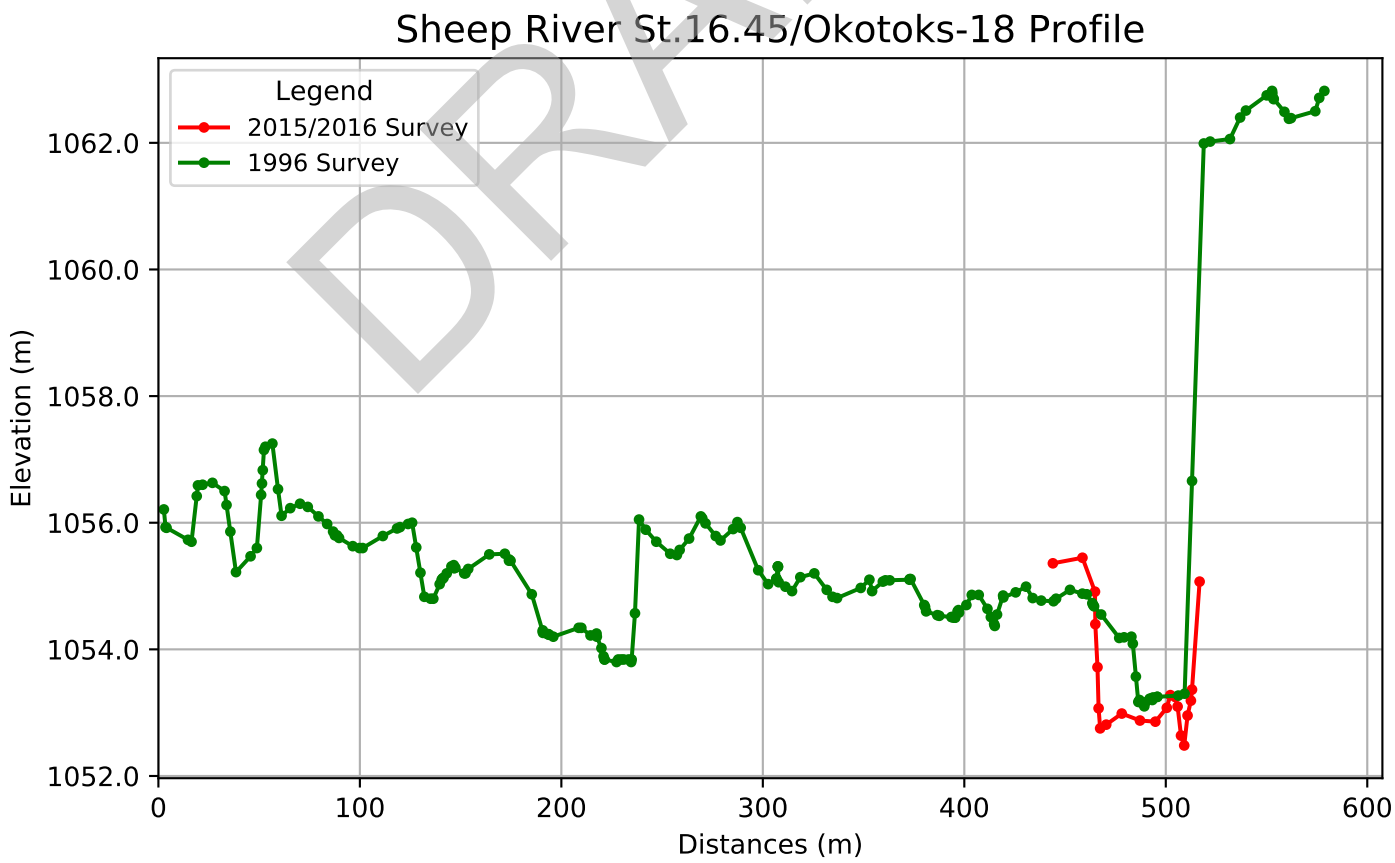

Note:

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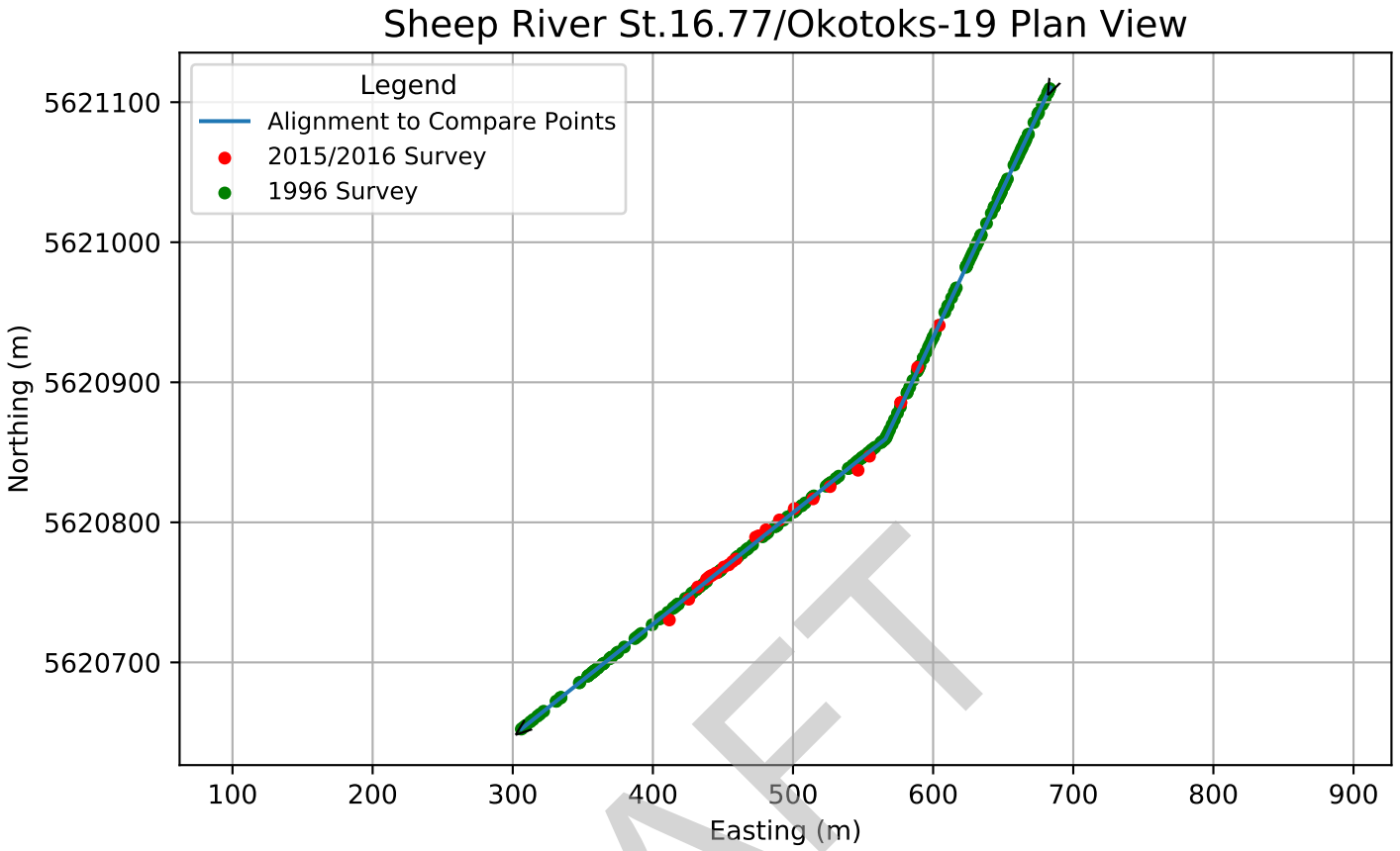

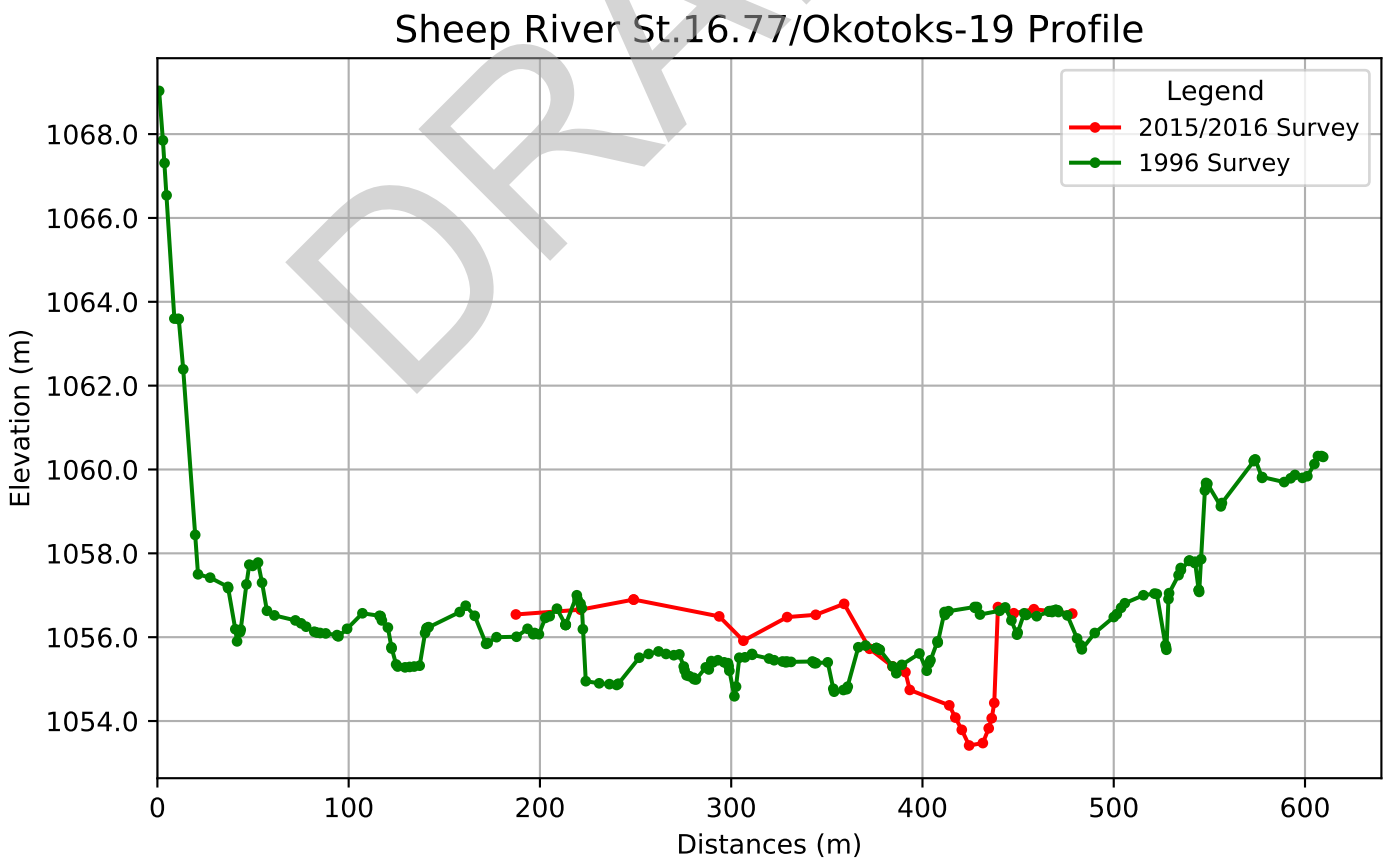

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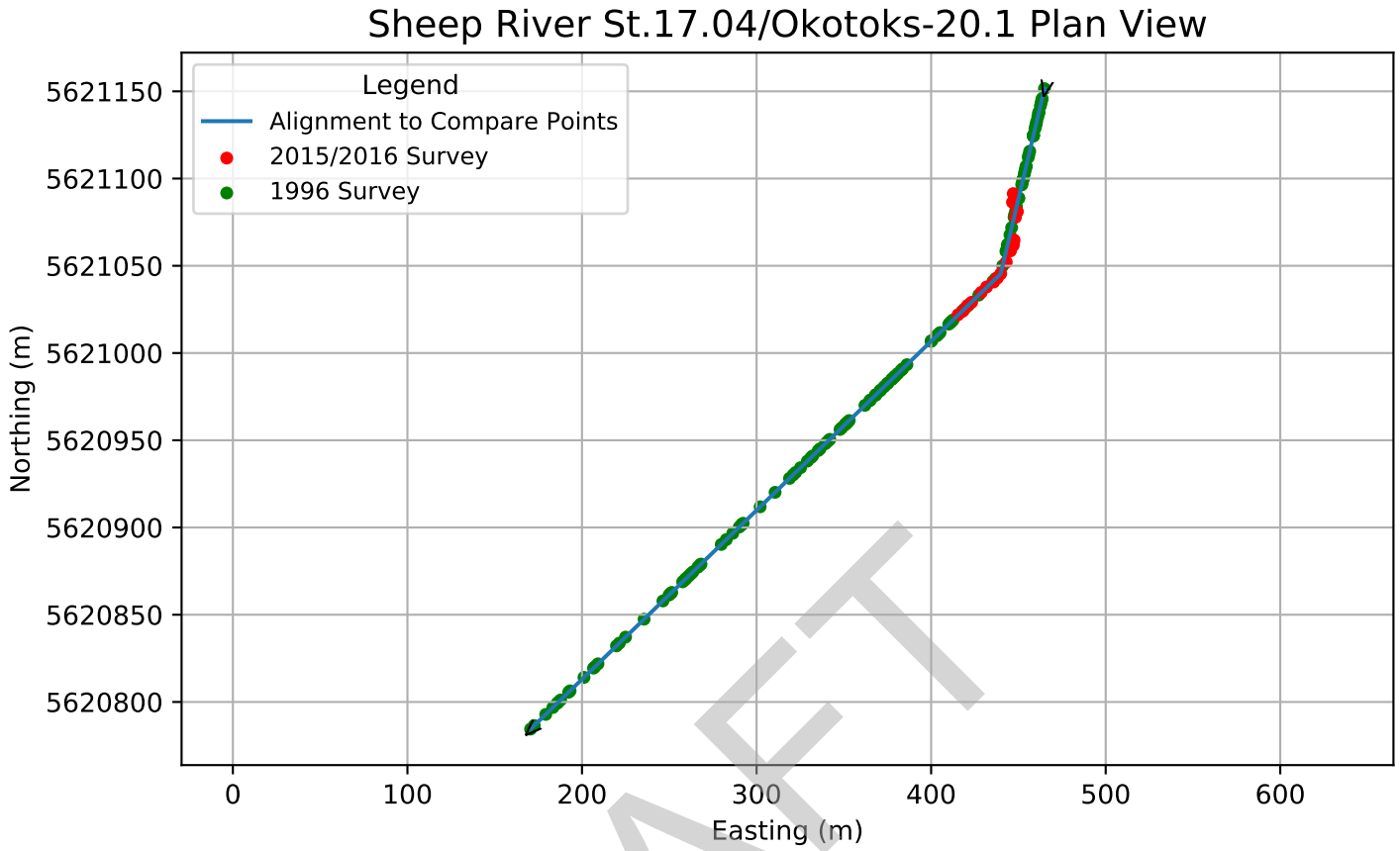

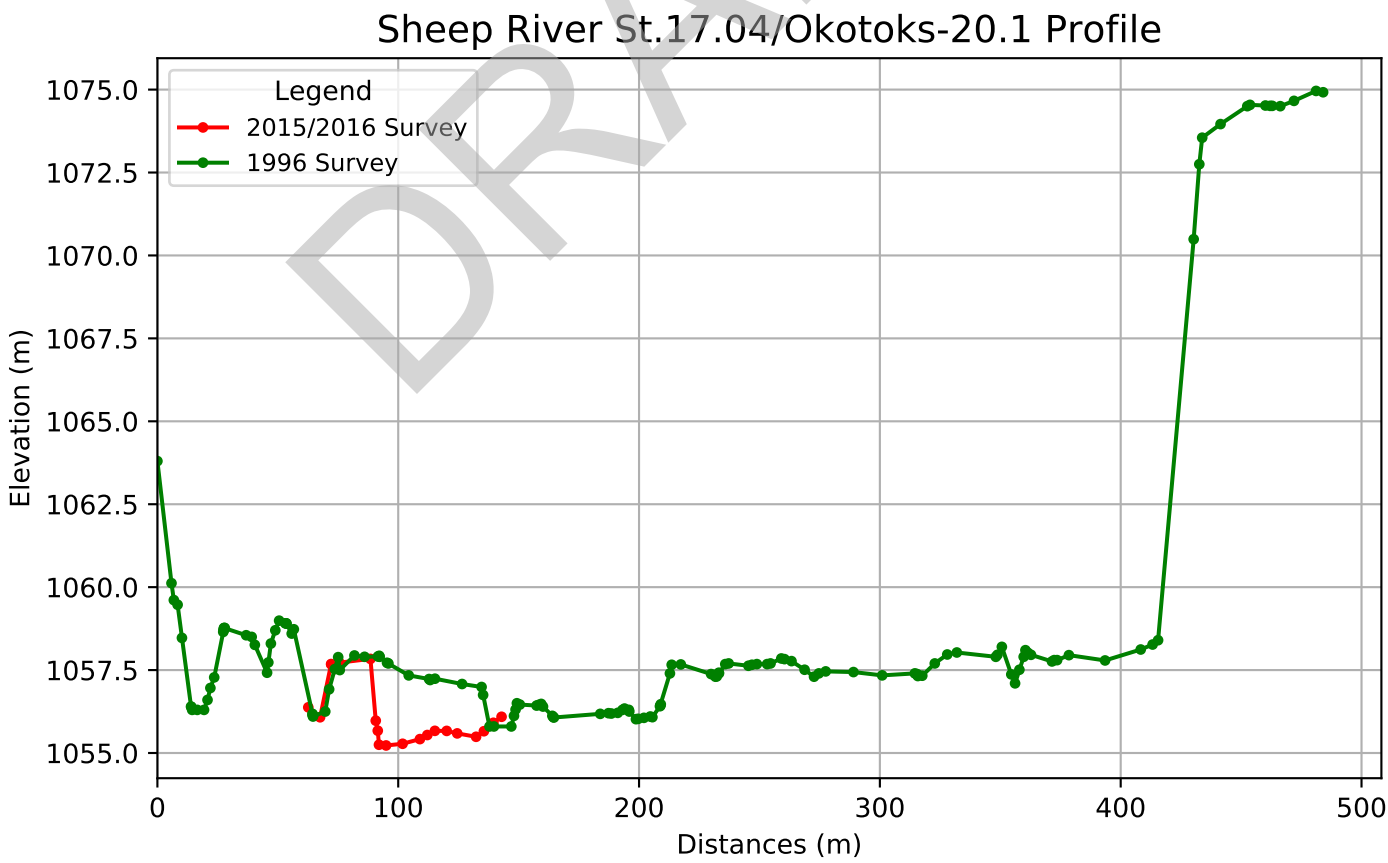

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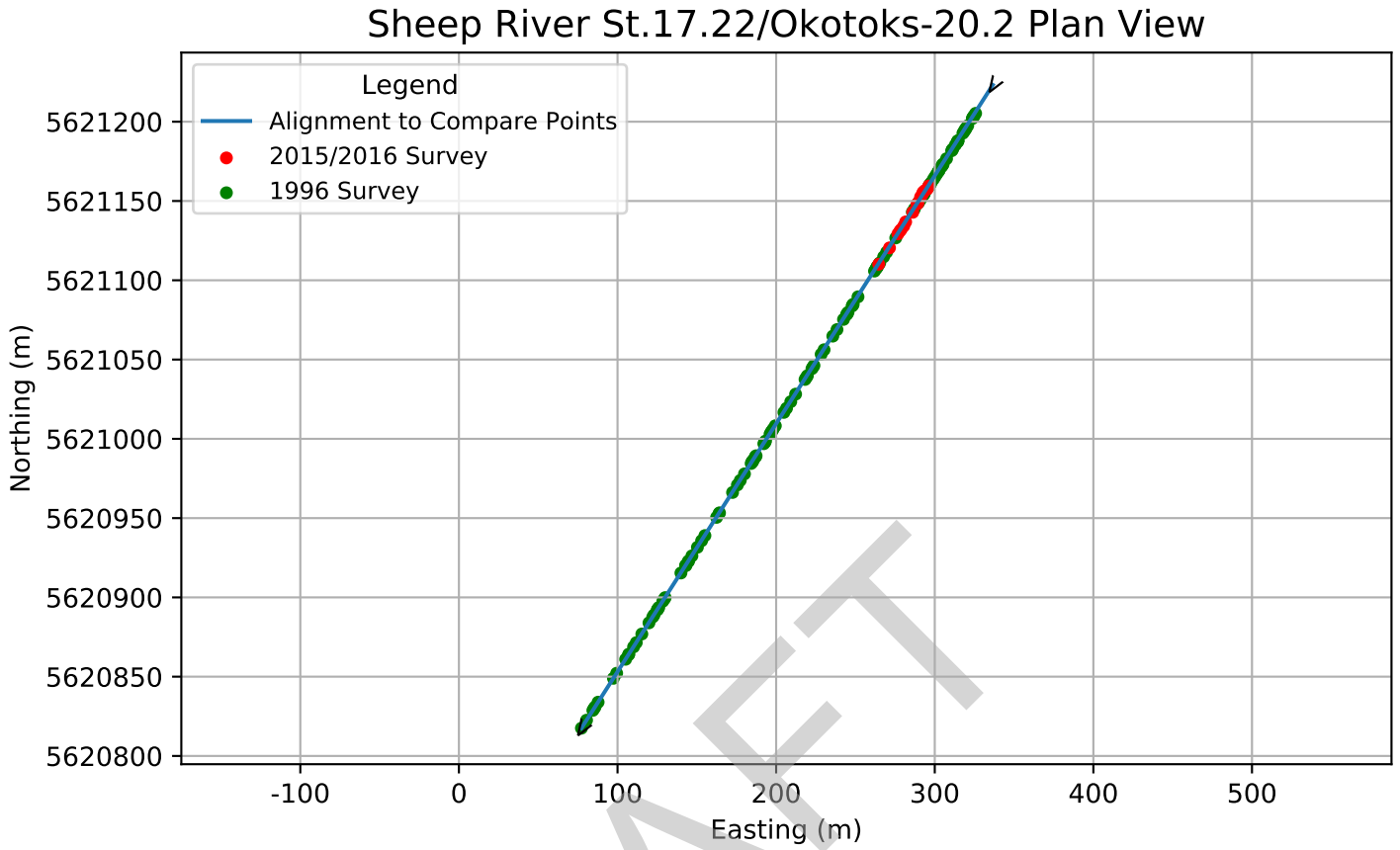
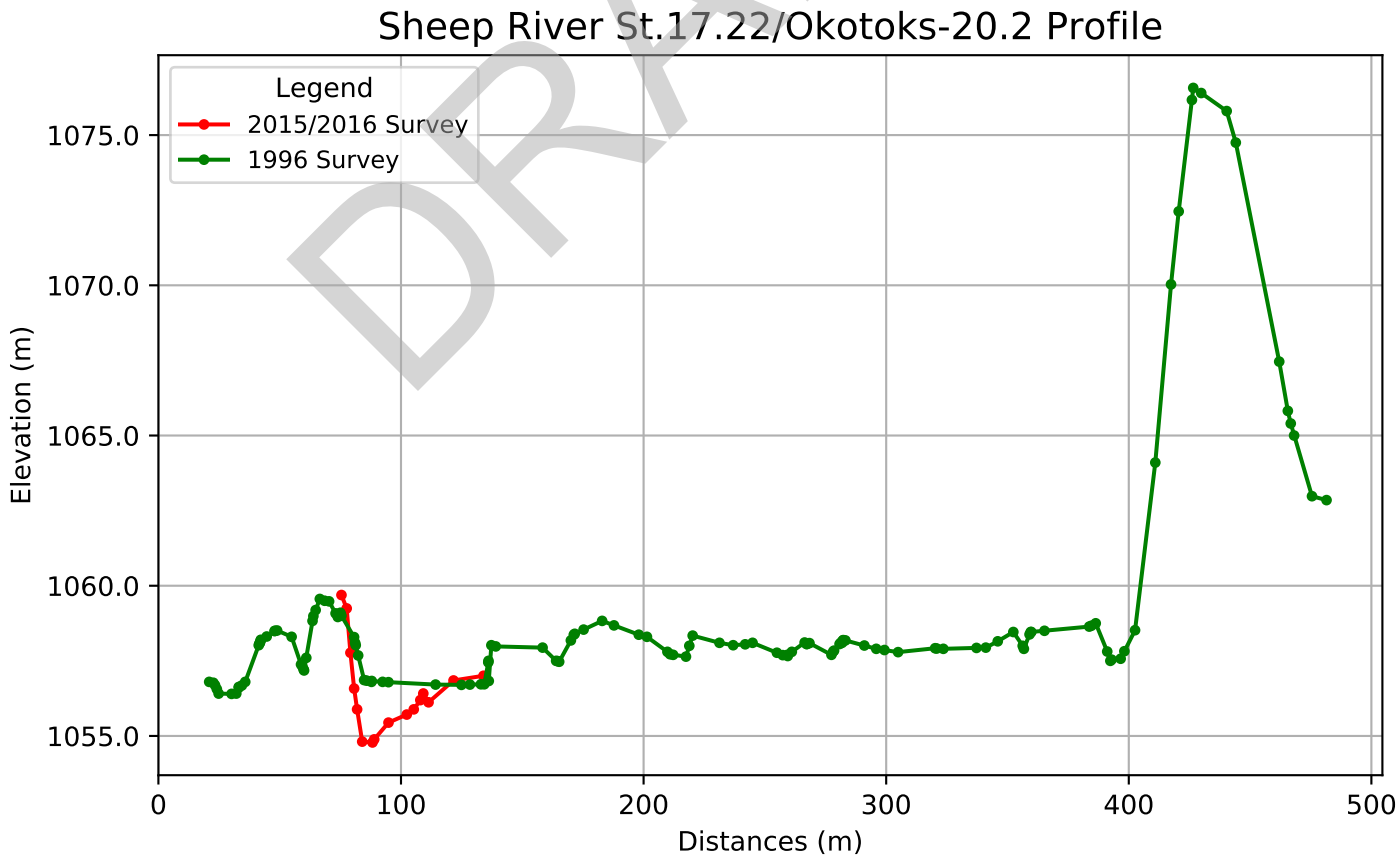
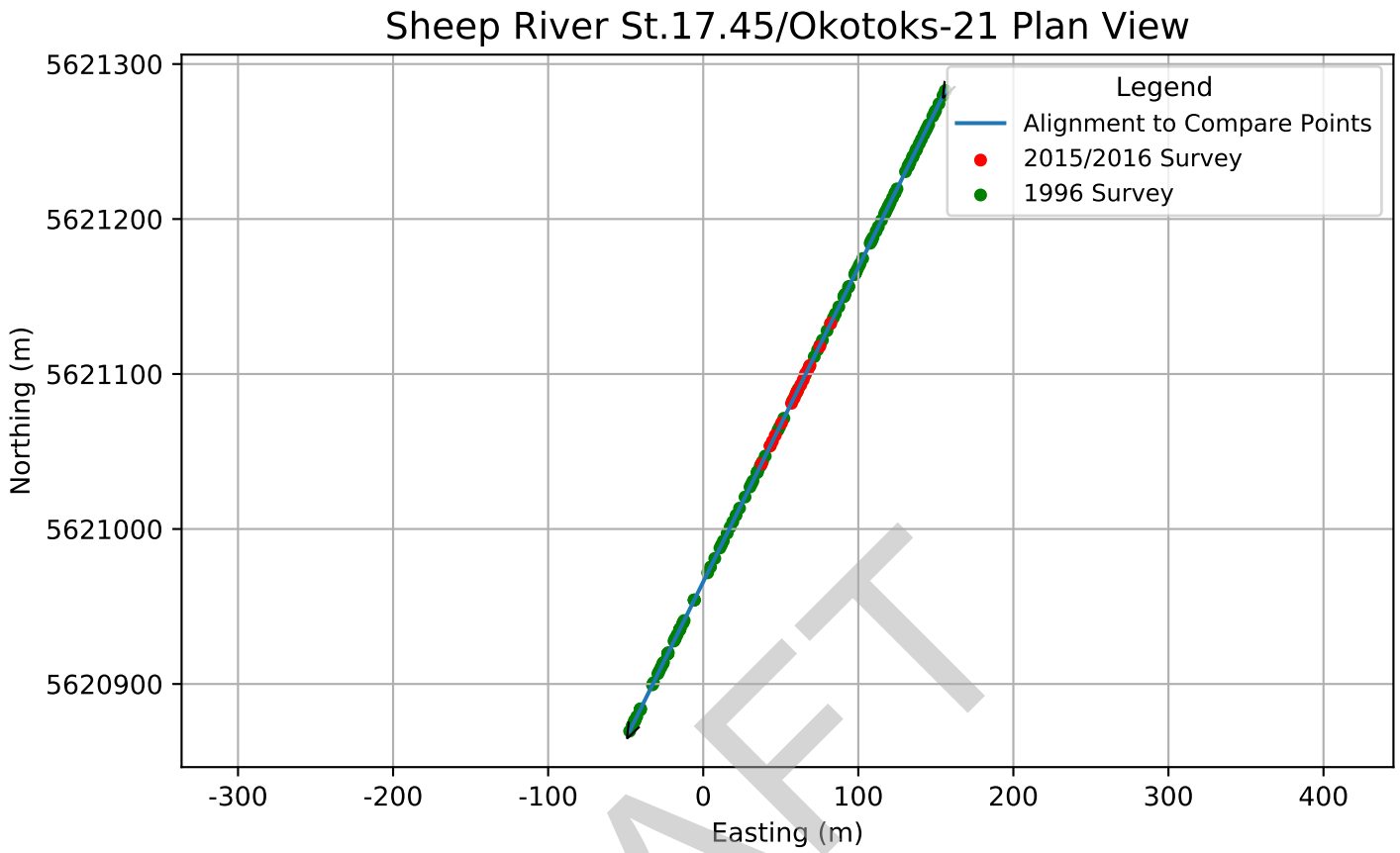
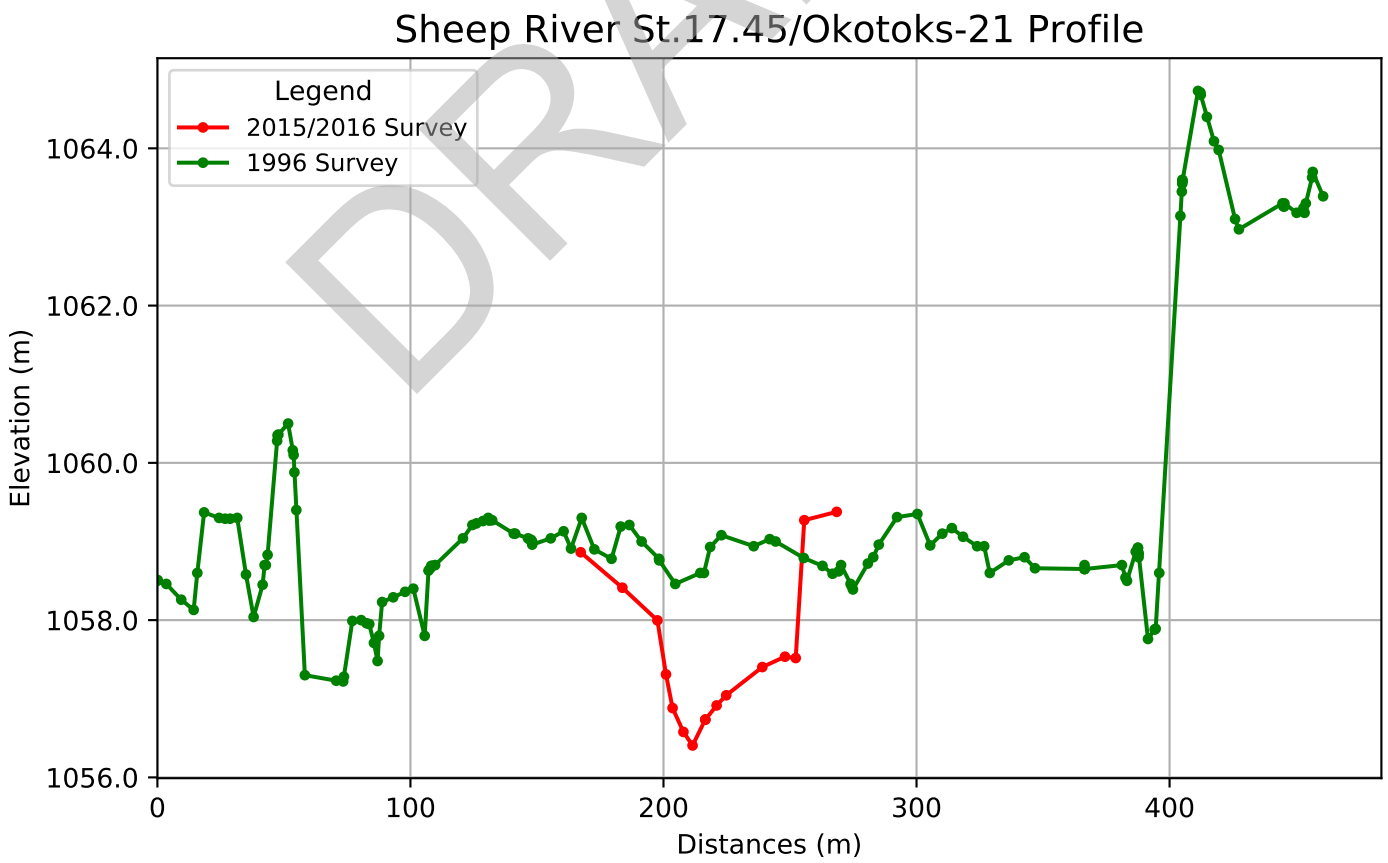




Note:

1.1996 Cross-Section data obtained from file SHEE-EBD.OKOTOKS.HC2 which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross-Sections 3.0,4.2, and 5.1. These correspond to 2015/2016 Cross-Sections 12.47,12.64 and 12.89, respectively.



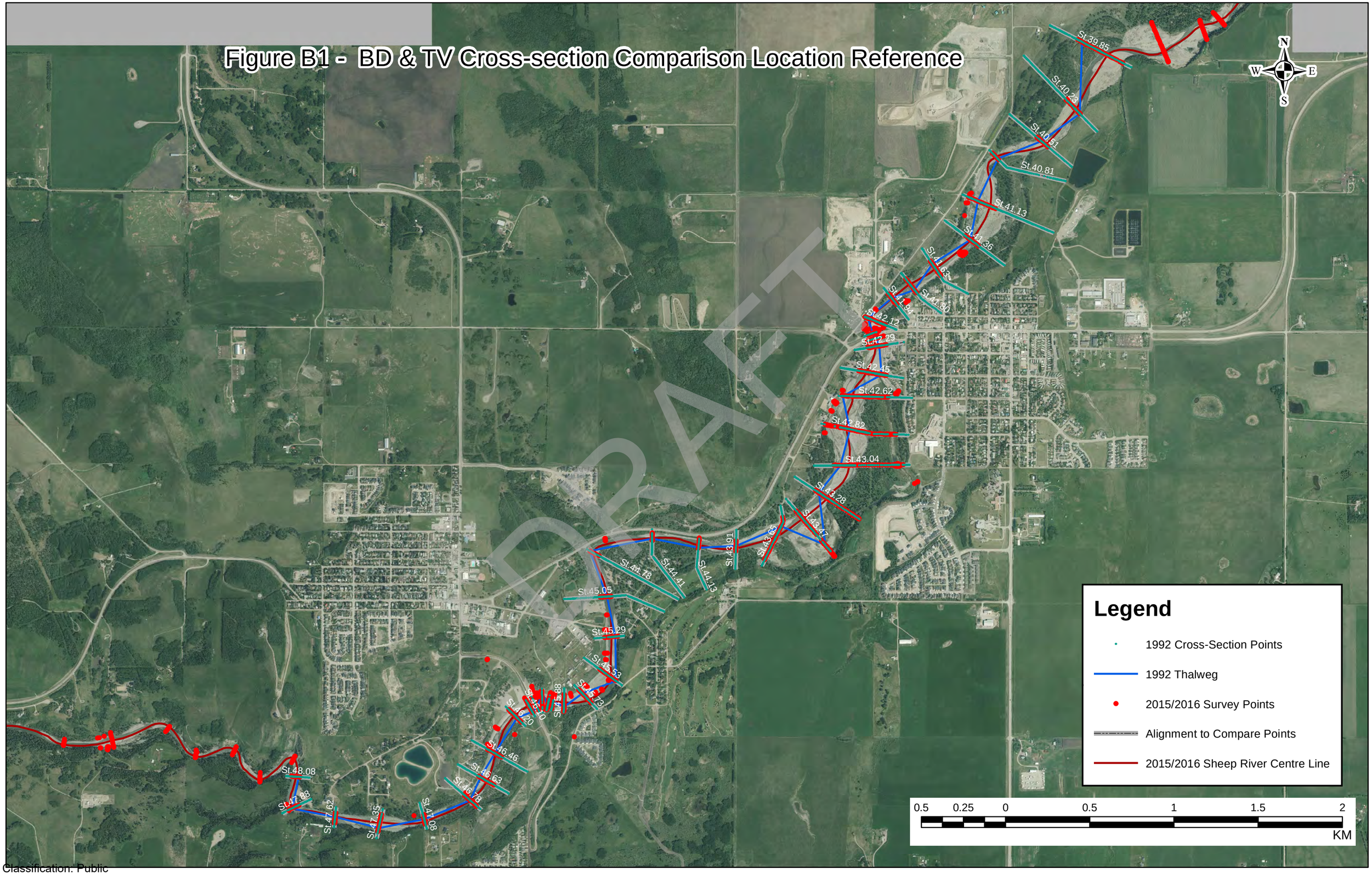


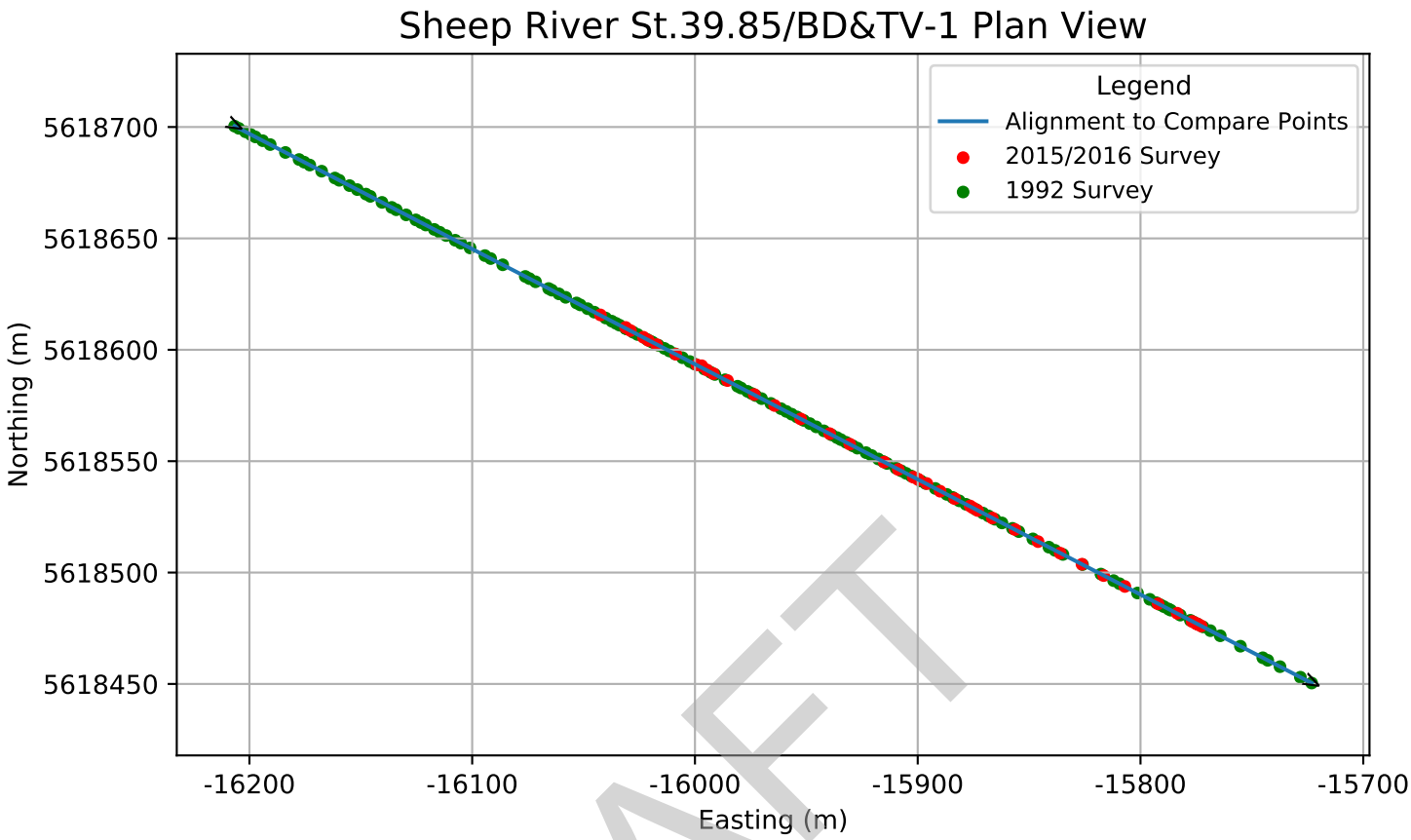
Note:

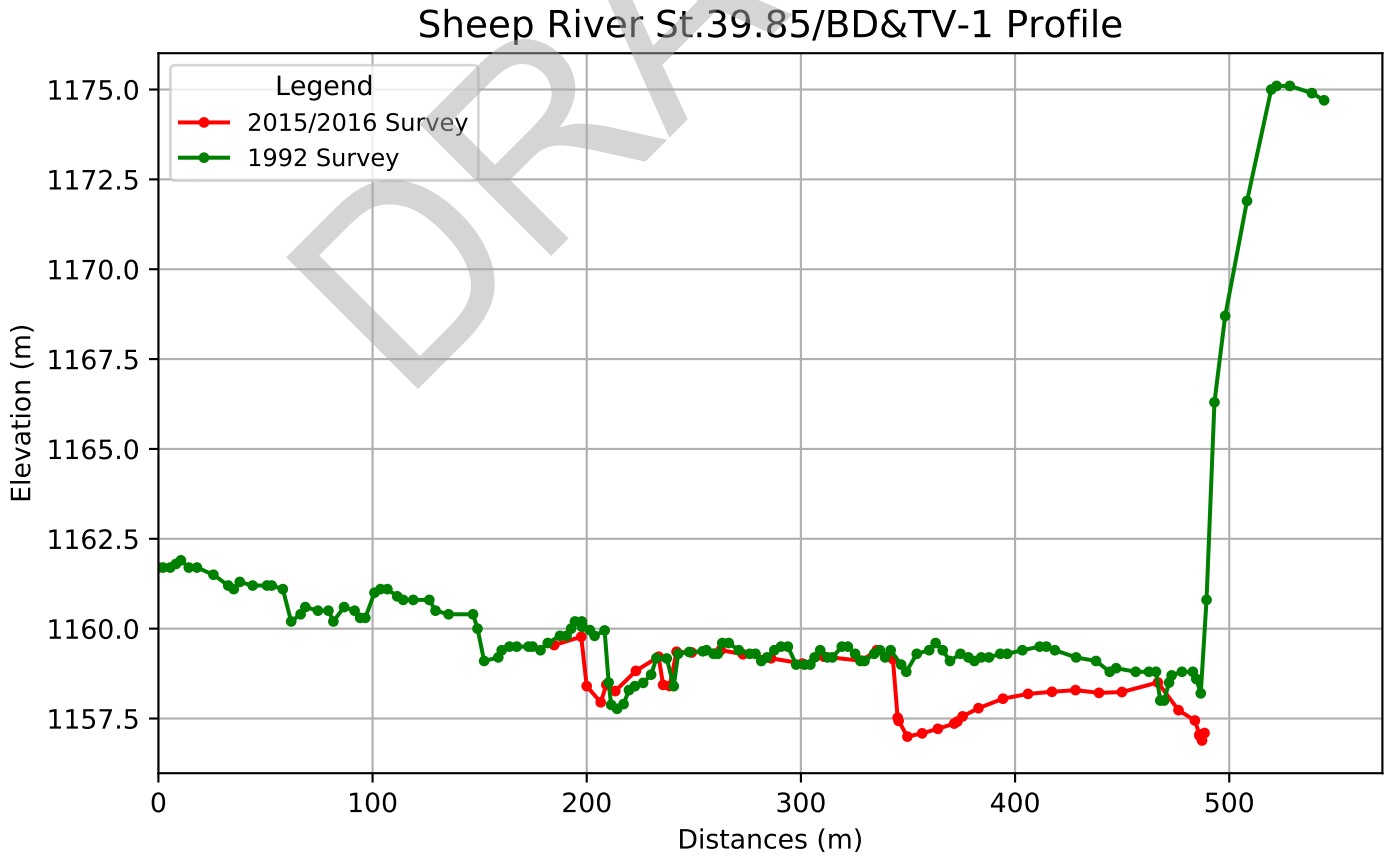
1.1996 Cross-Section data obtained from file SHEE-EBD.OKOTOKS.HC2 which was last modified in June 2009 to account for the 32nd Street Bridge and modified 1996 Cross-Sections 3.0,4.2, and 5.1. These correspond to 2015/2016 Cross-Sections 12.47,12.64 and 12.85, respectively.

Attachment B
Black Diamond/Turner Valley Cross Section Comparison

Figure B1 - BD & TV Cross-section Comparison Location Reference







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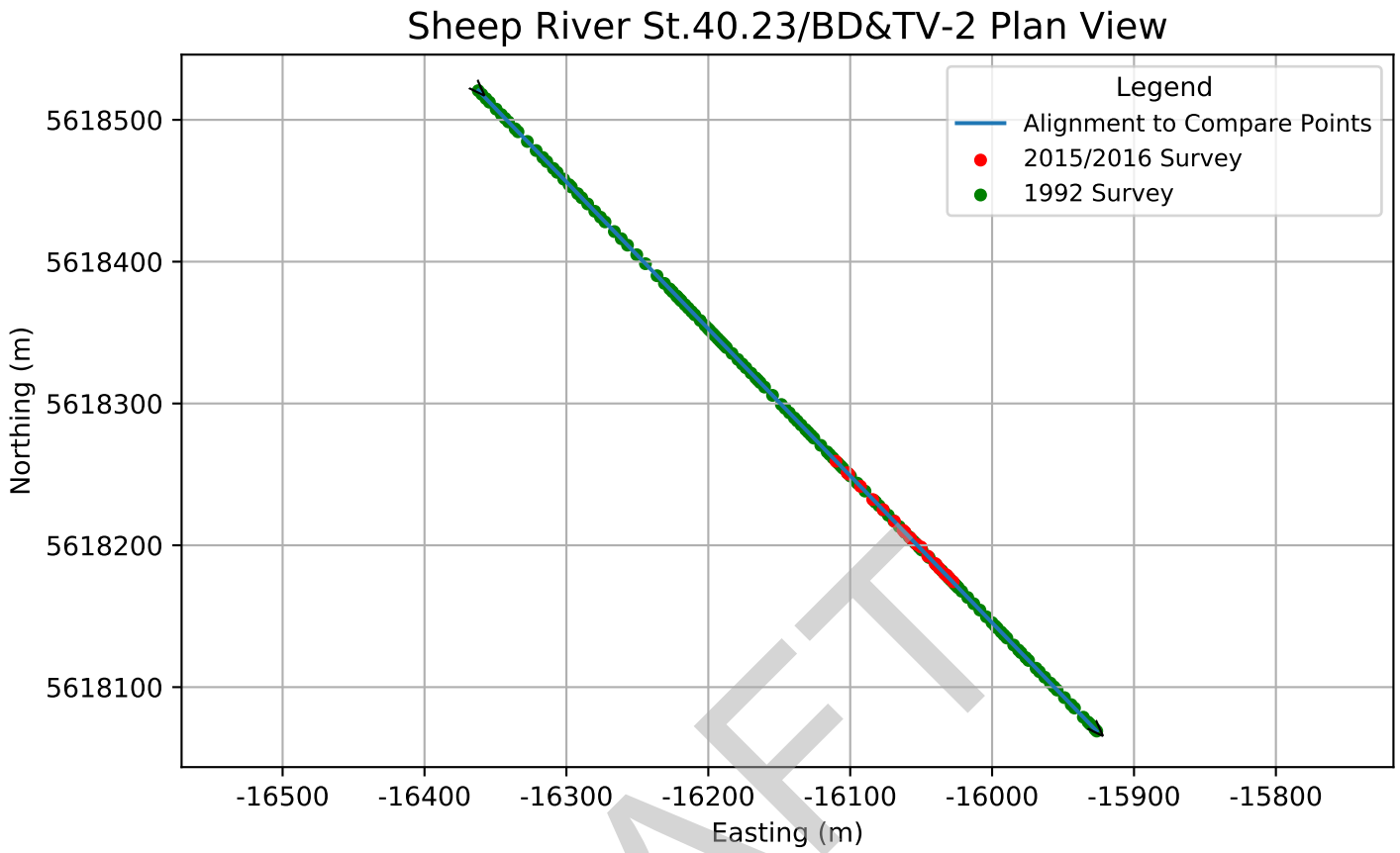
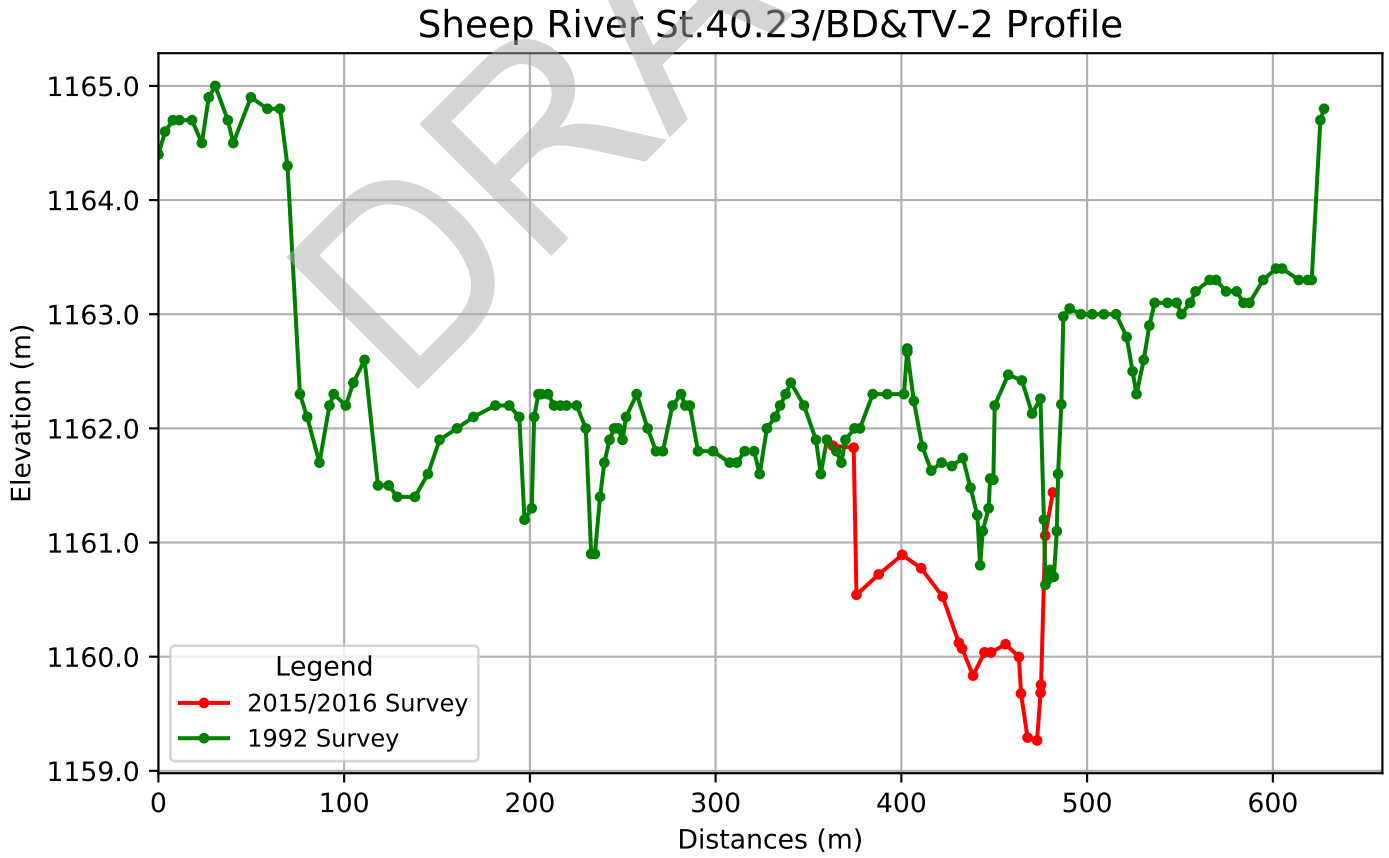
1.1992 Cross-Section data obtained from file SHEE_ENC_BD_TV.HC2.





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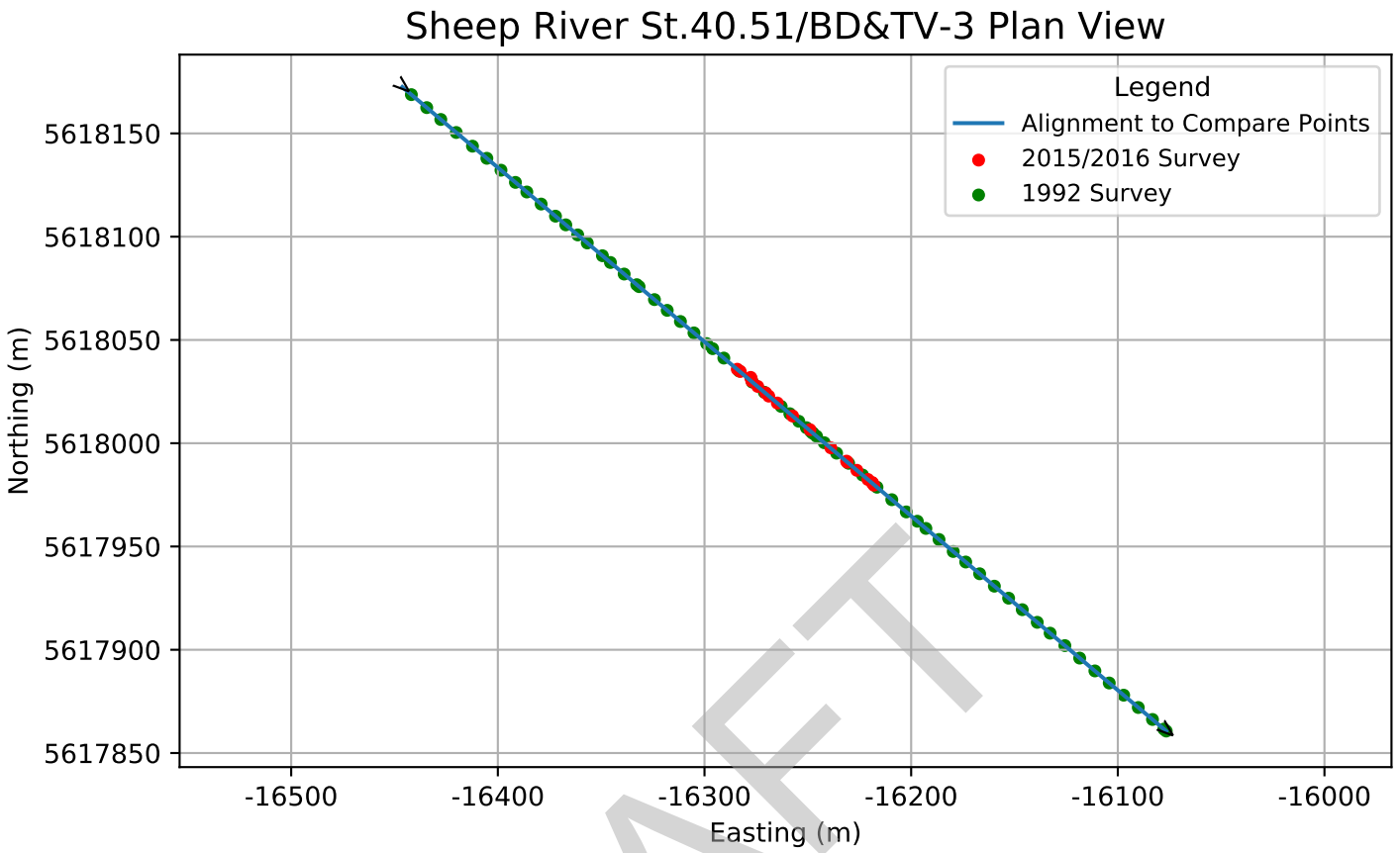

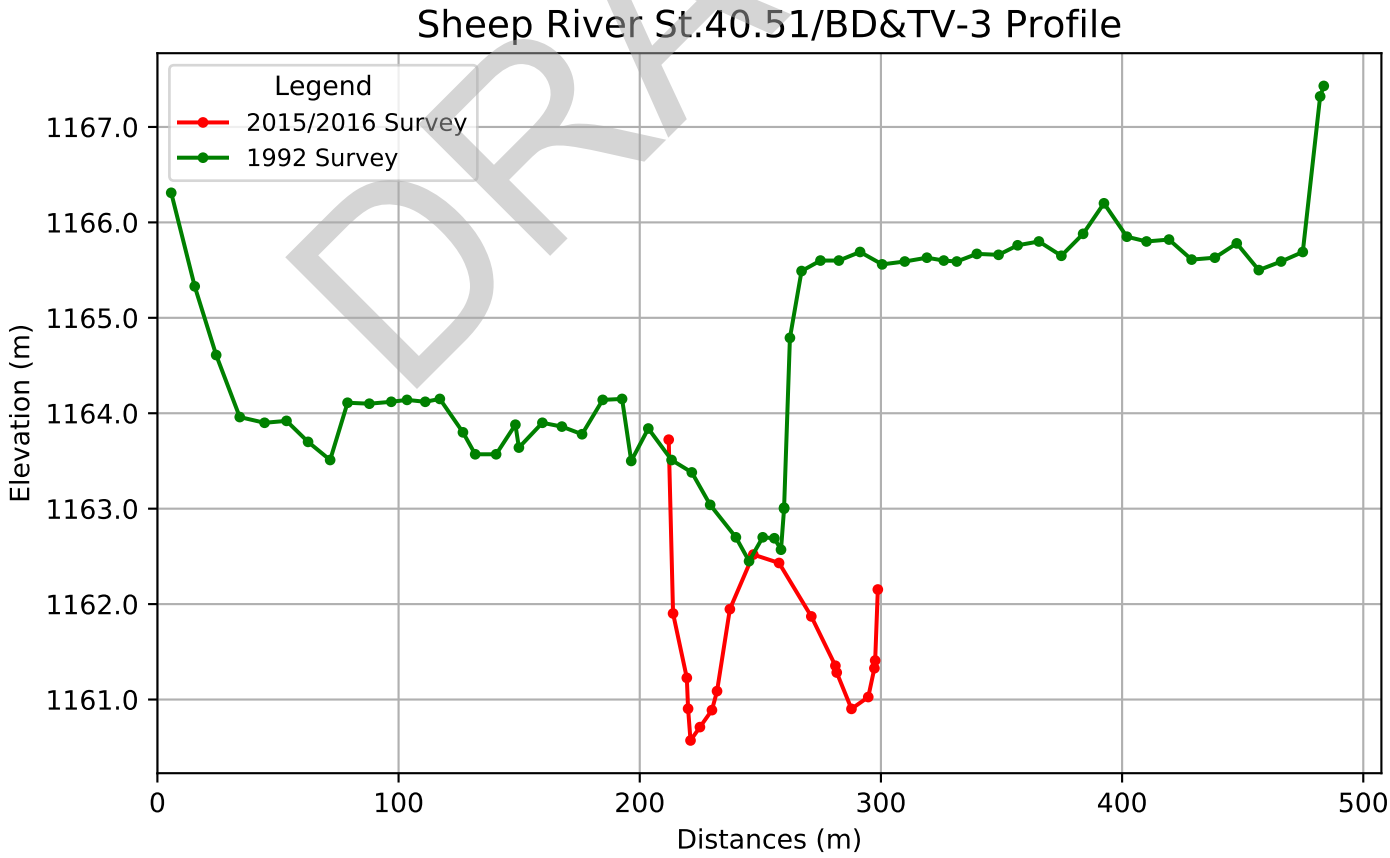

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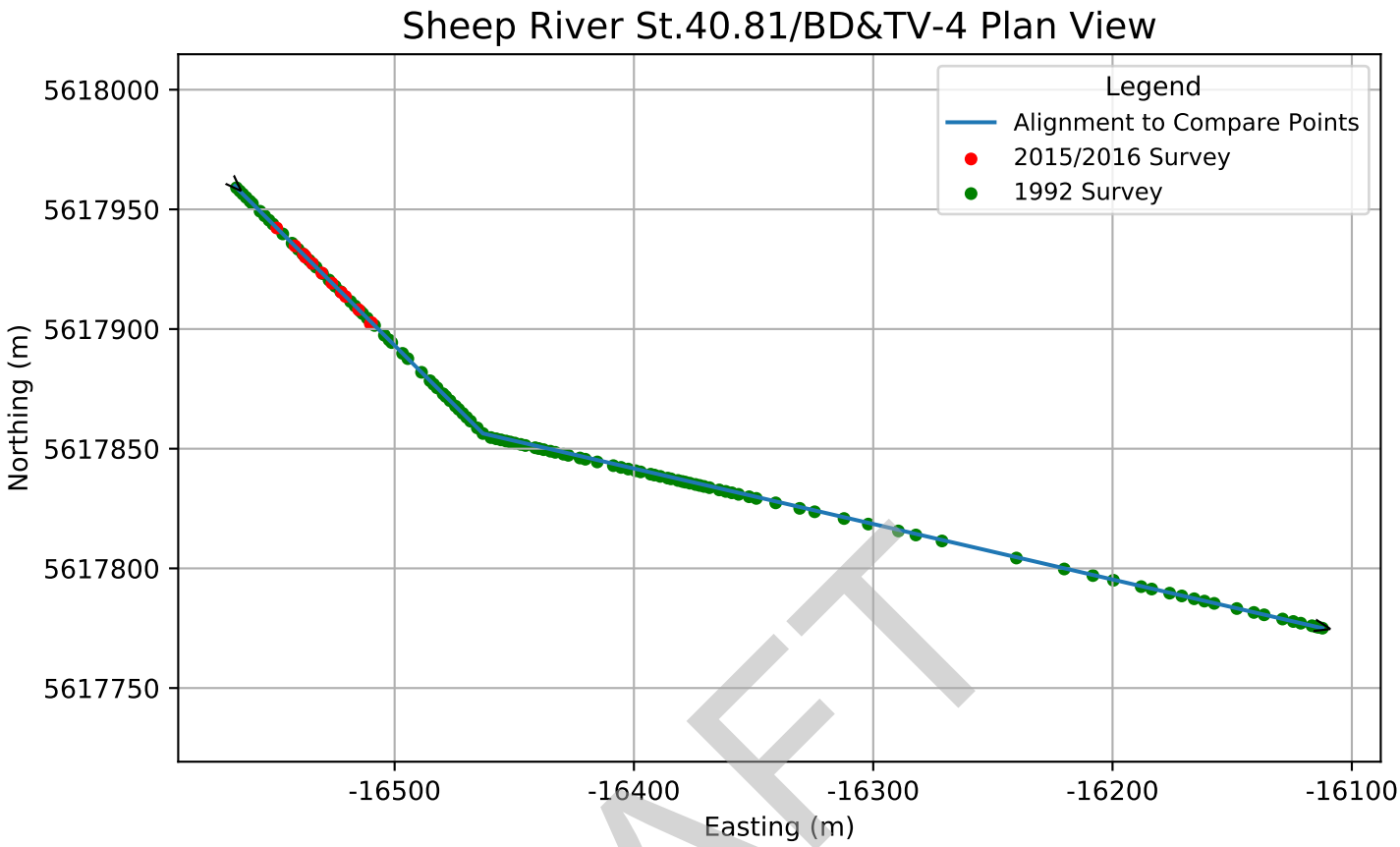

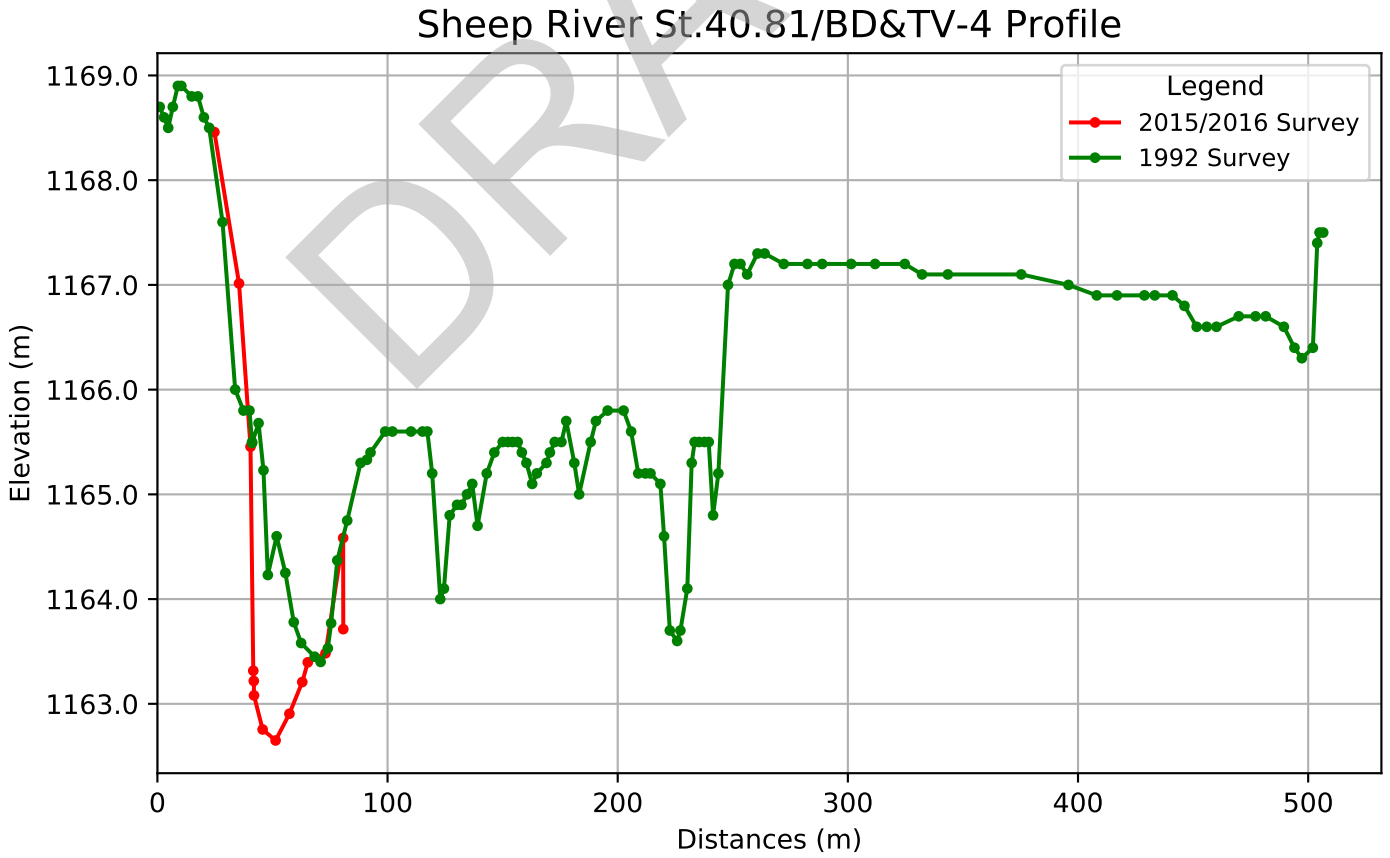

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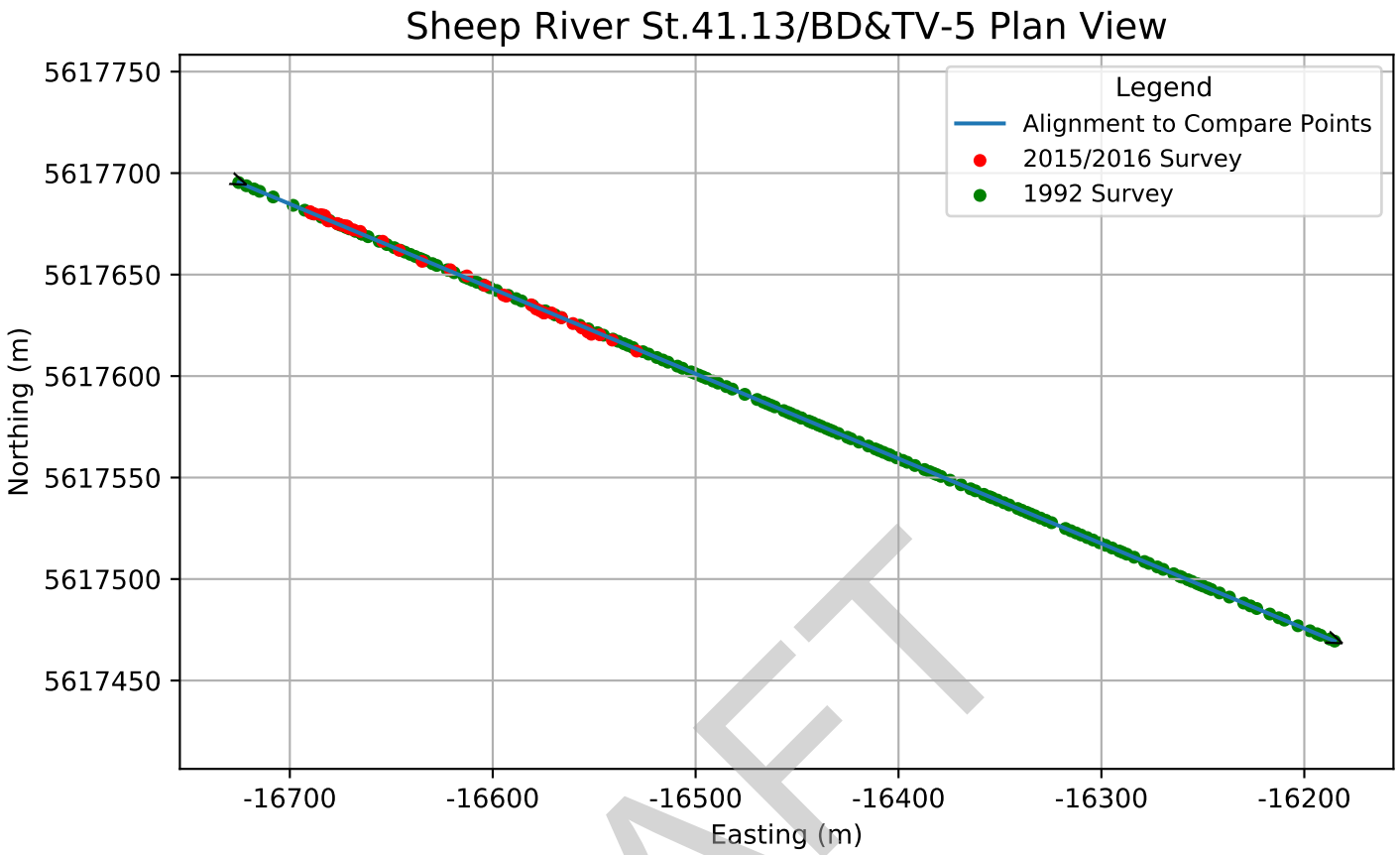

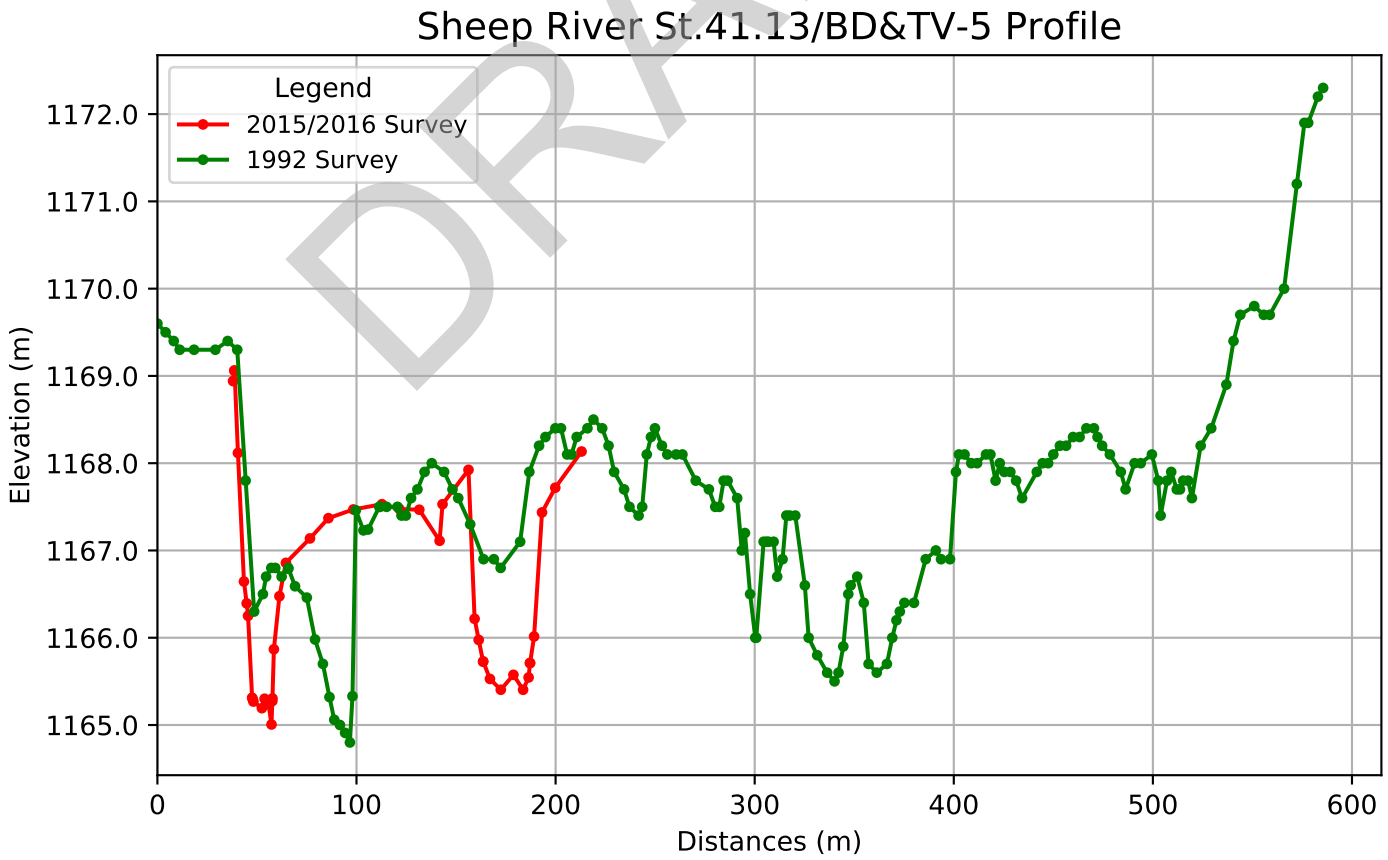

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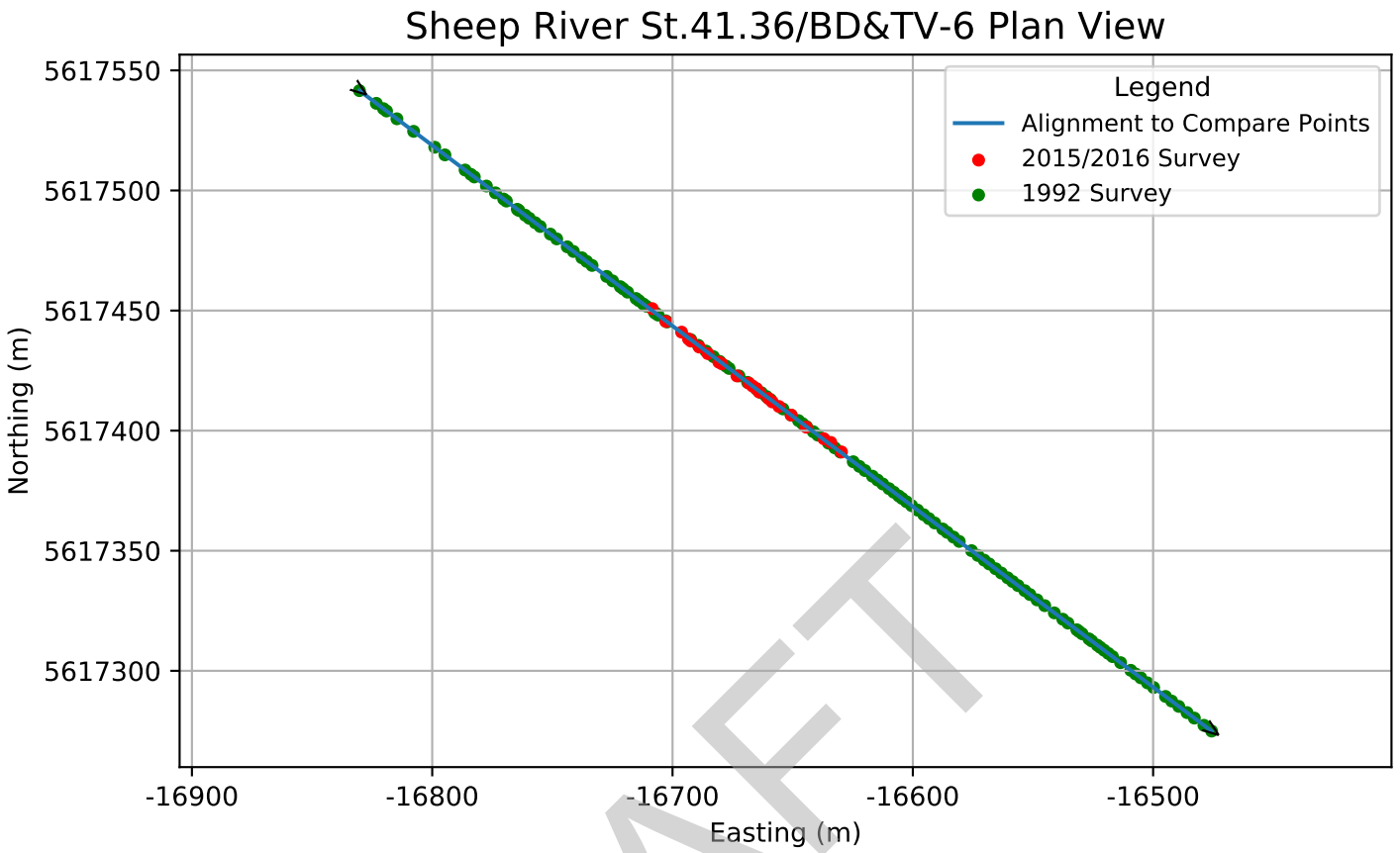

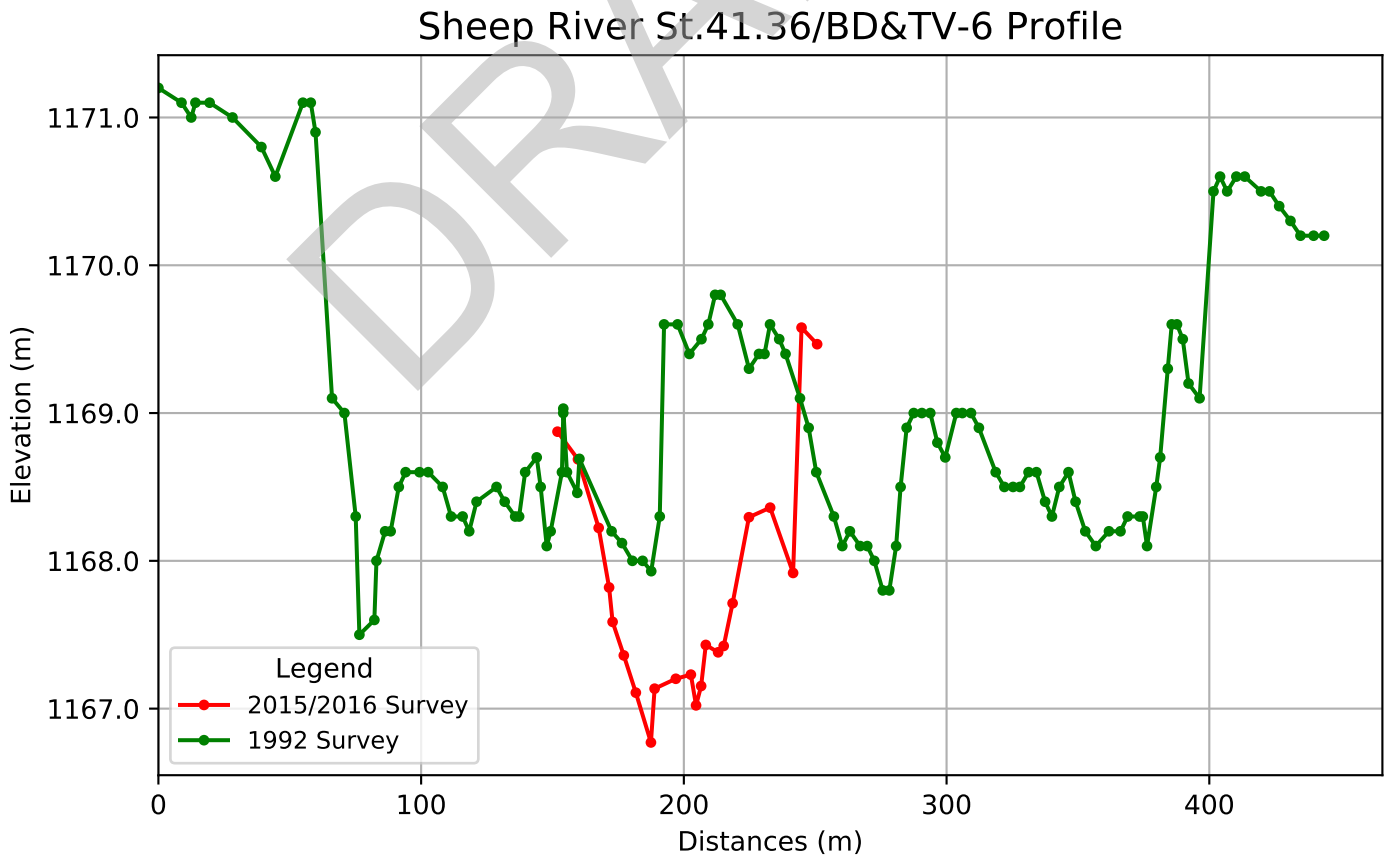

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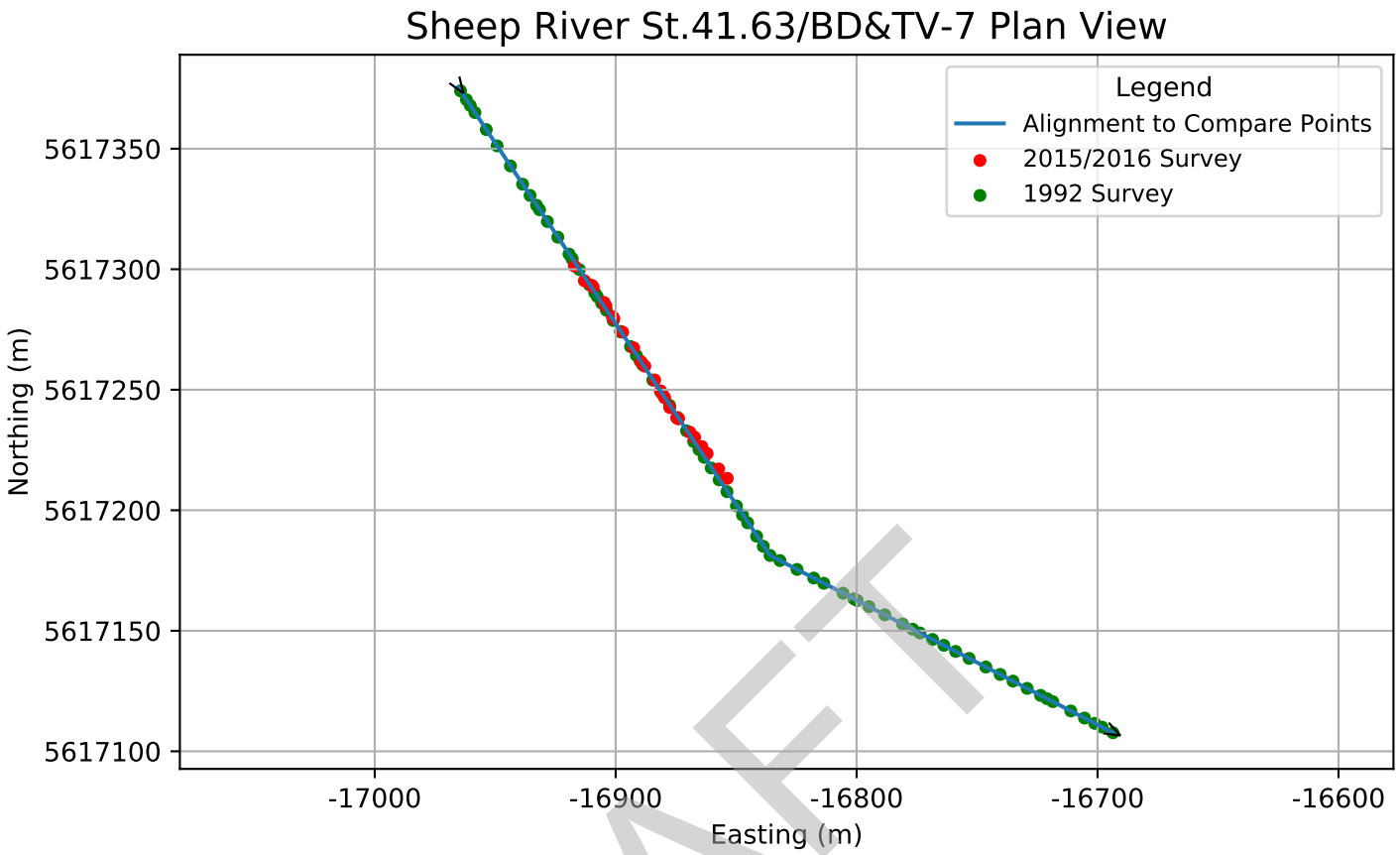

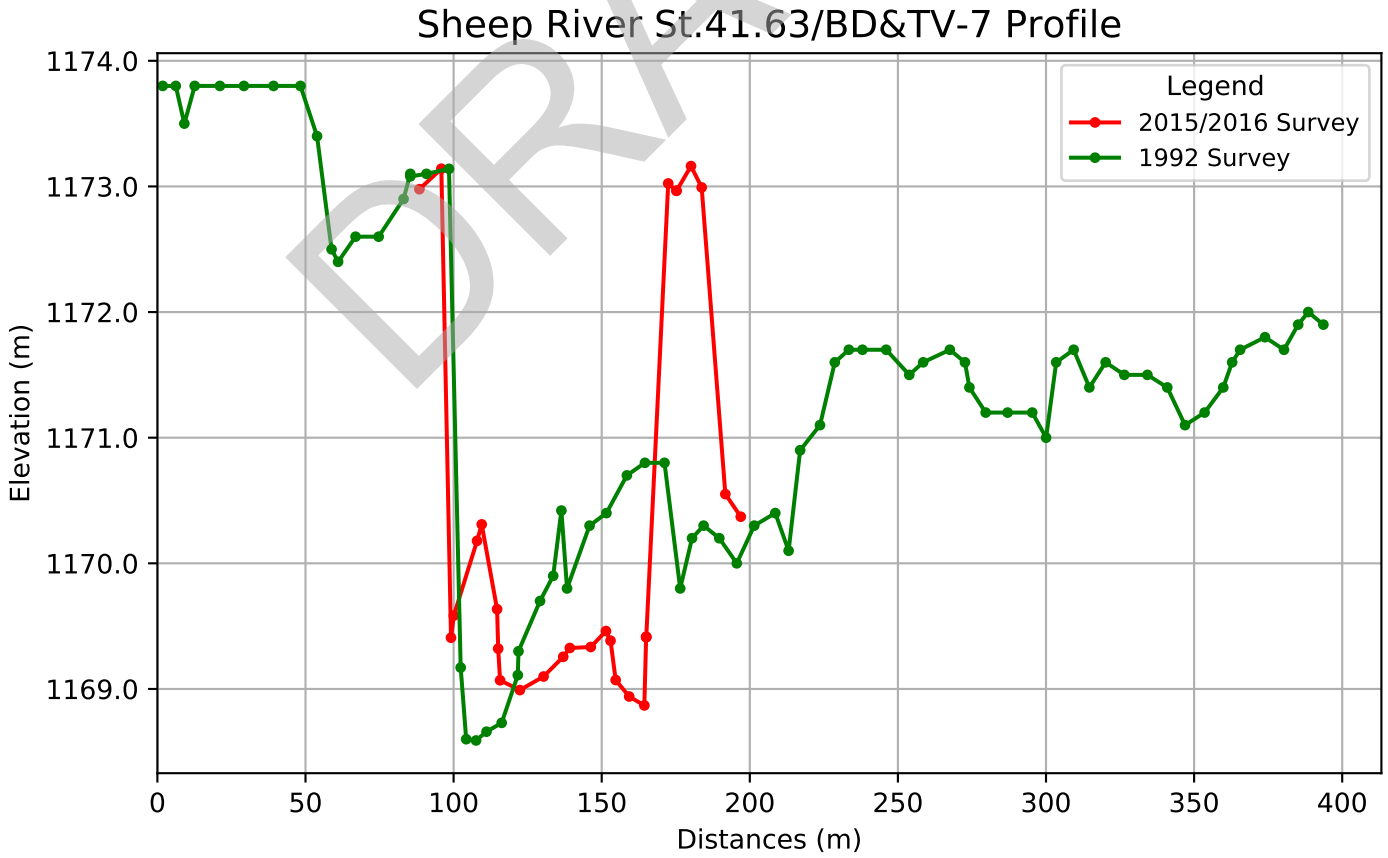

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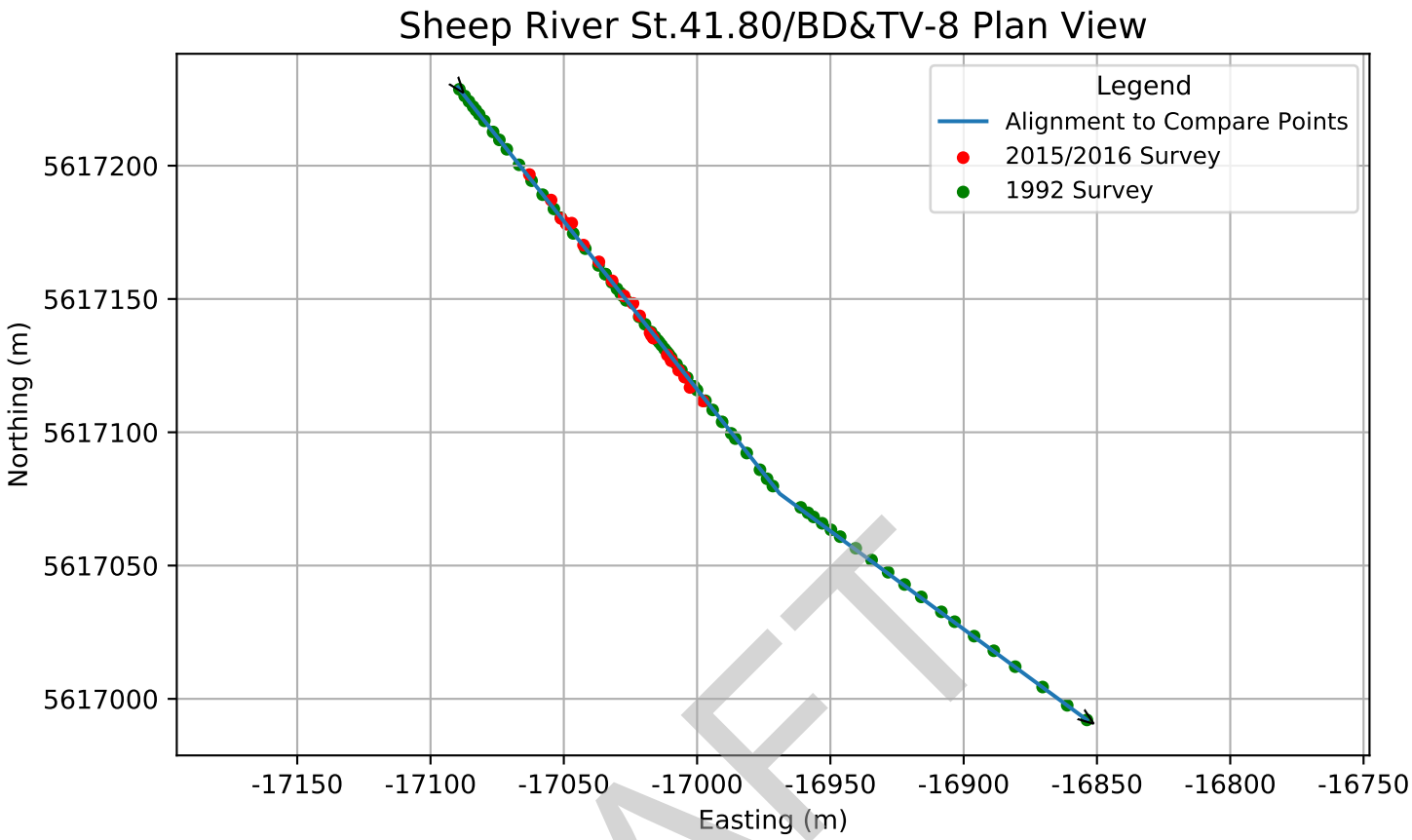

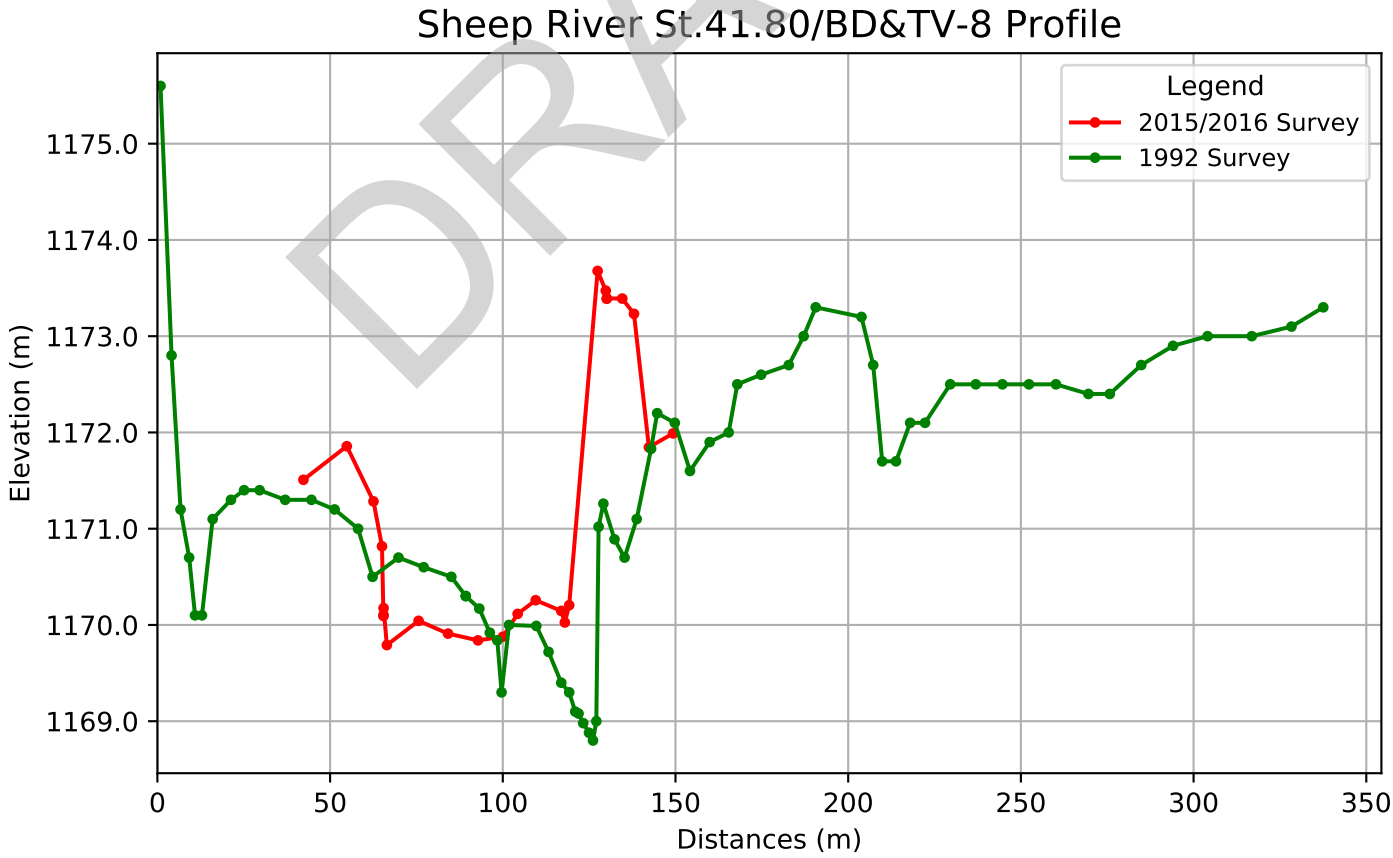

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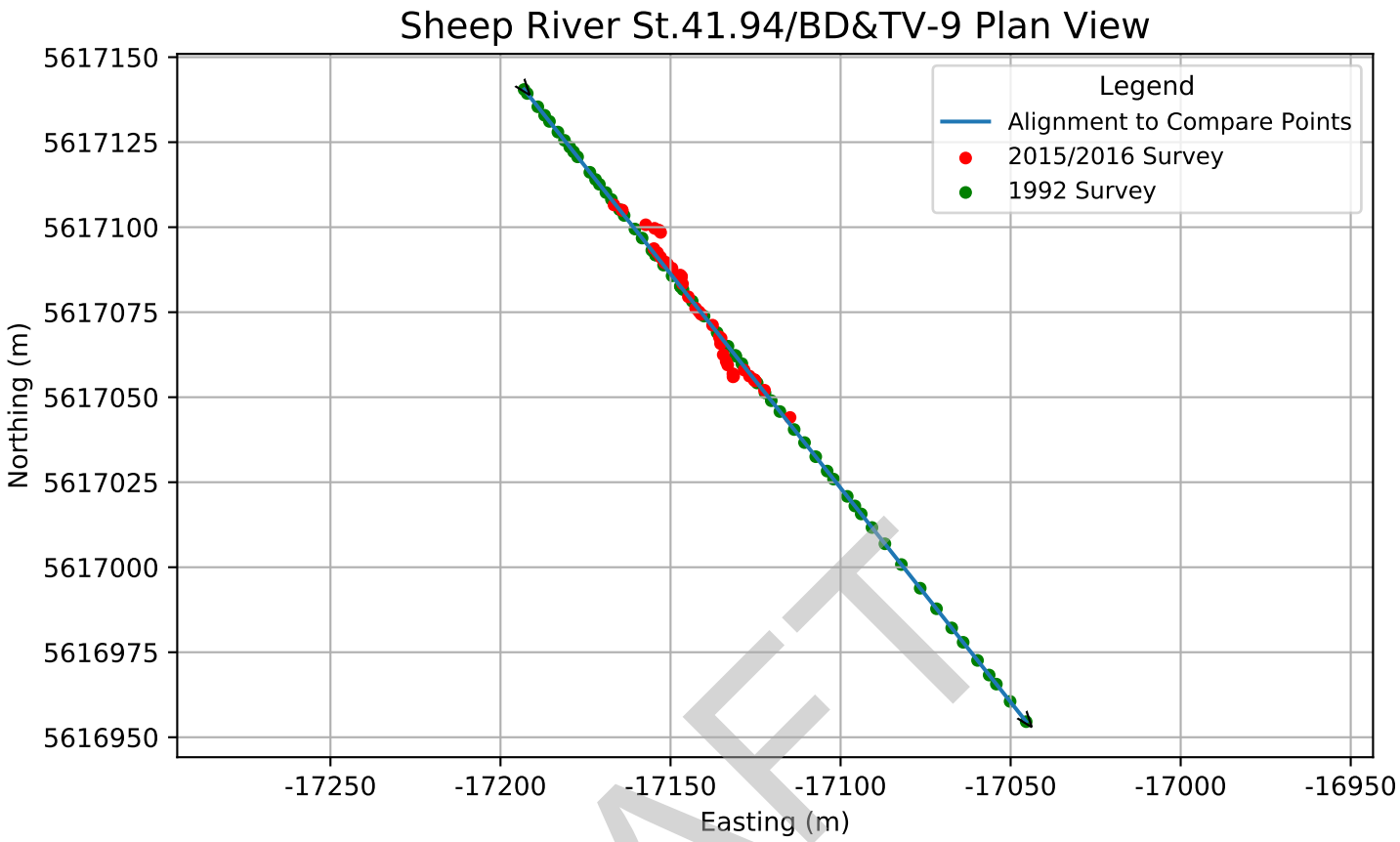

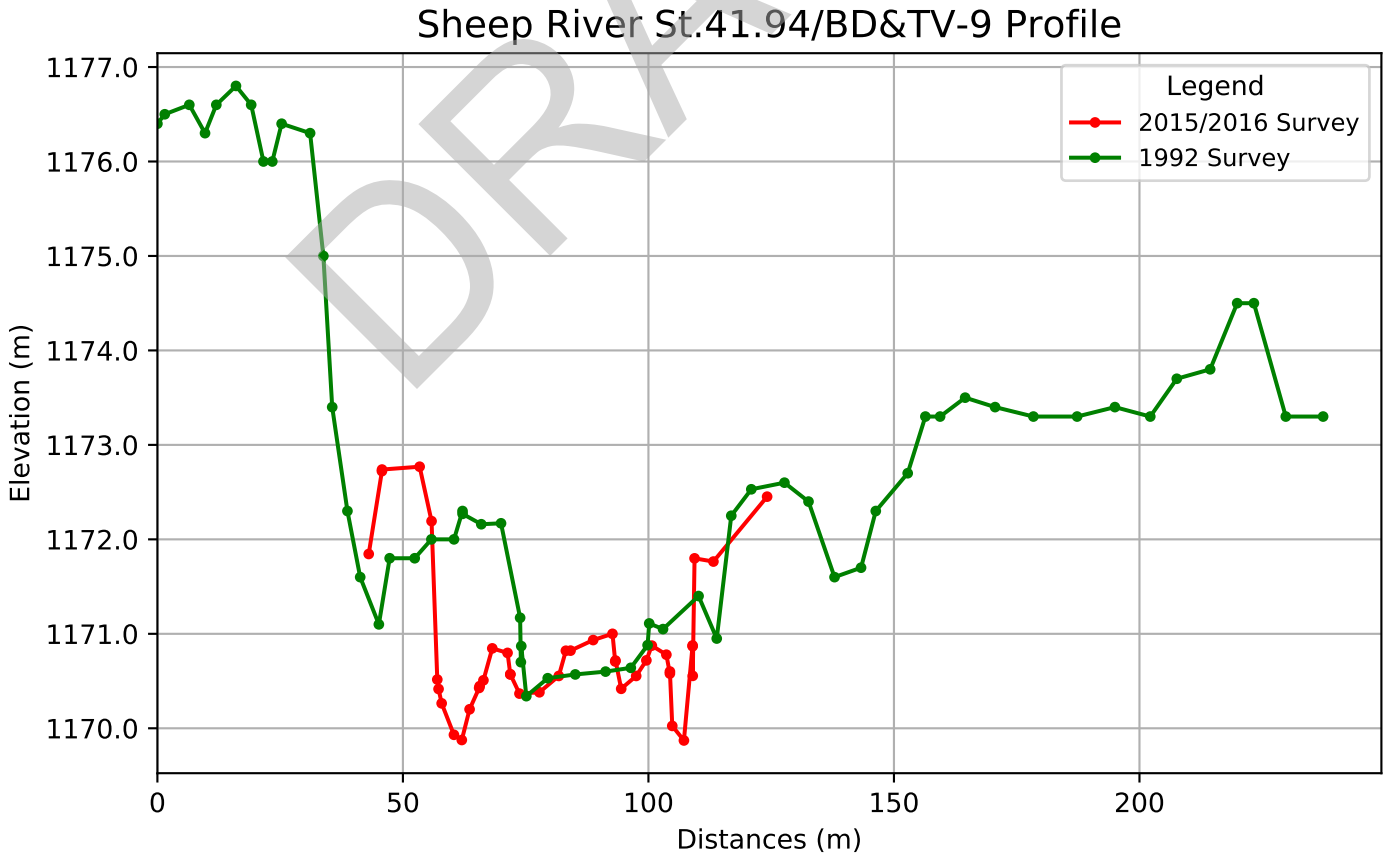

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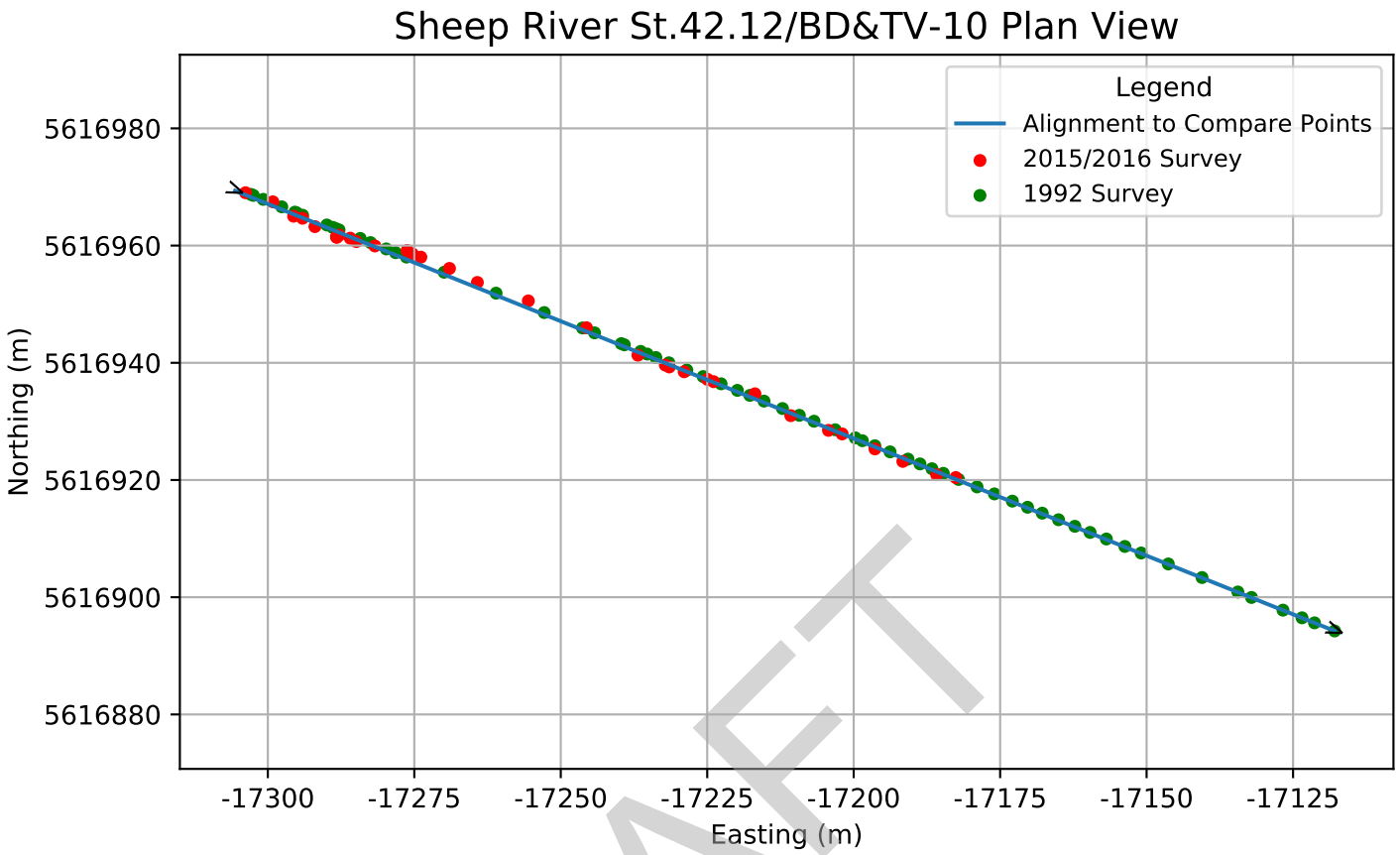

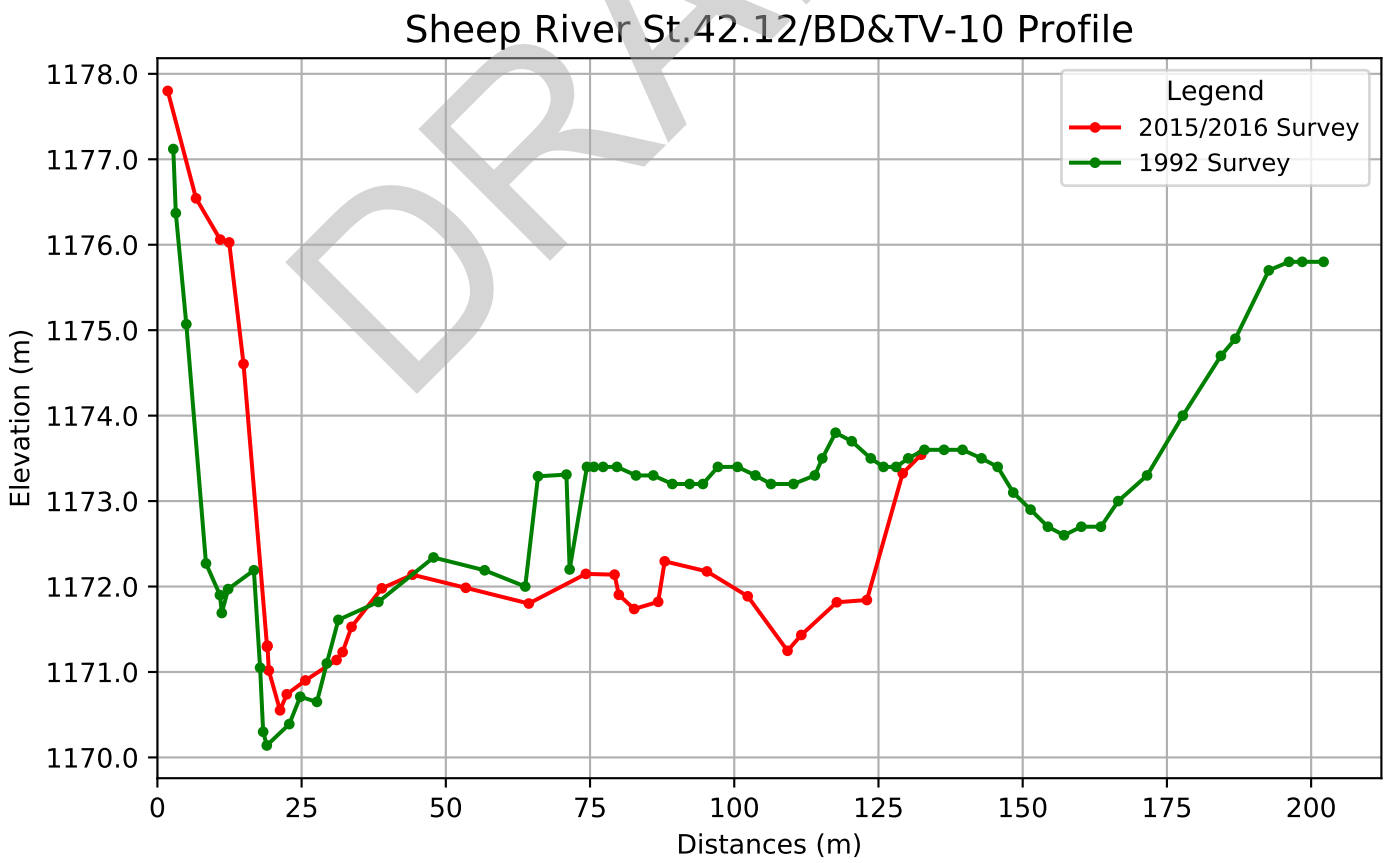

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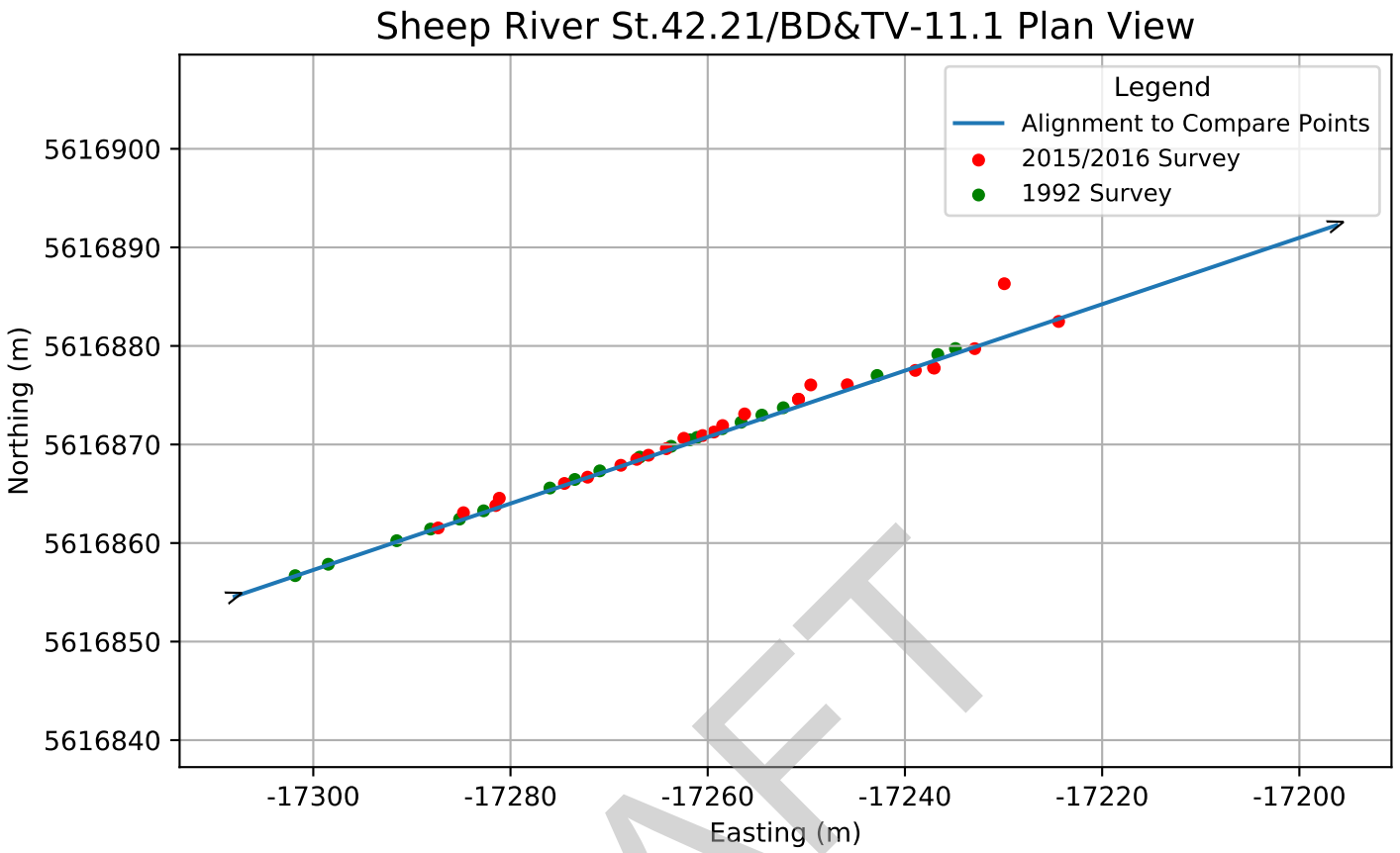

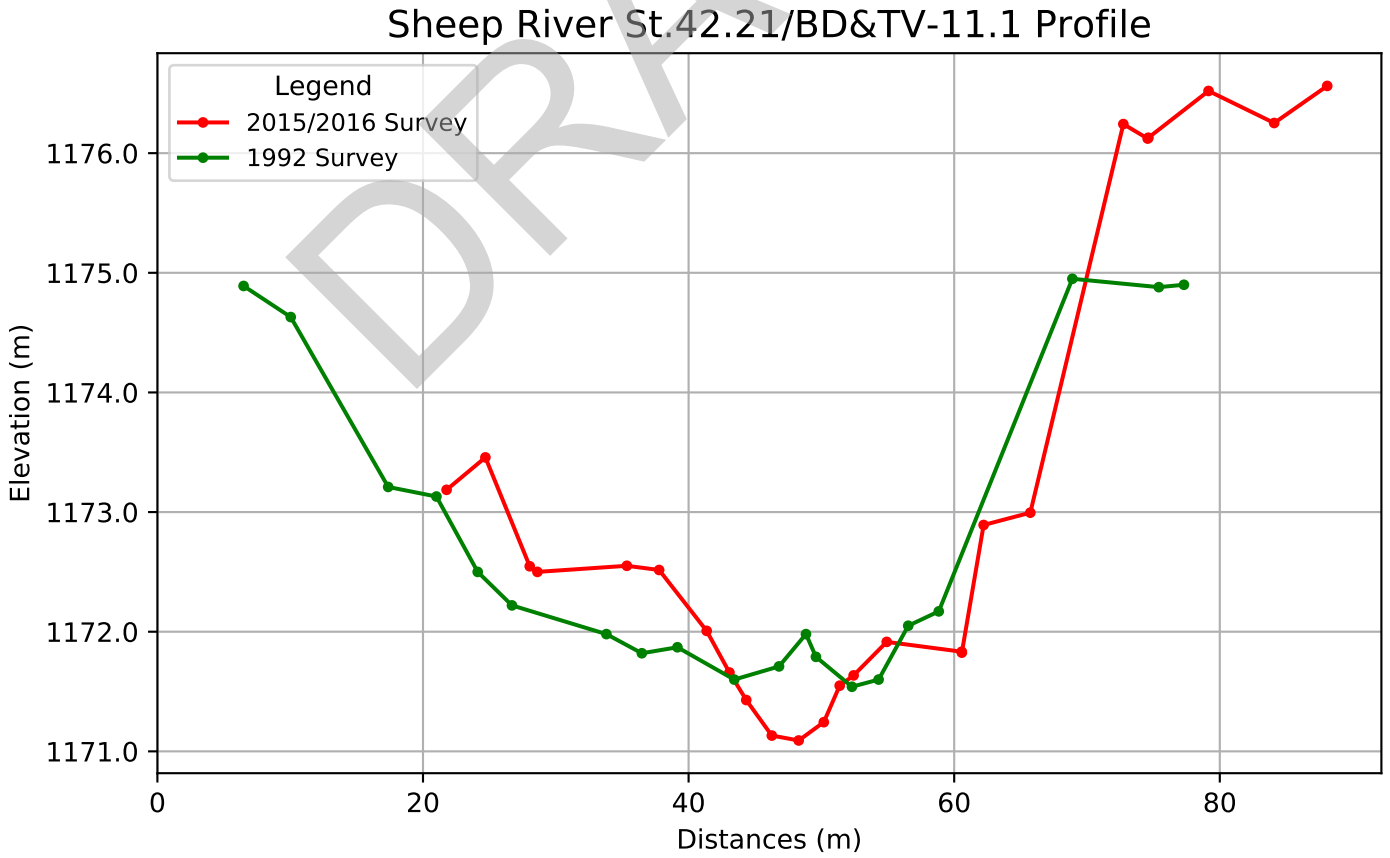

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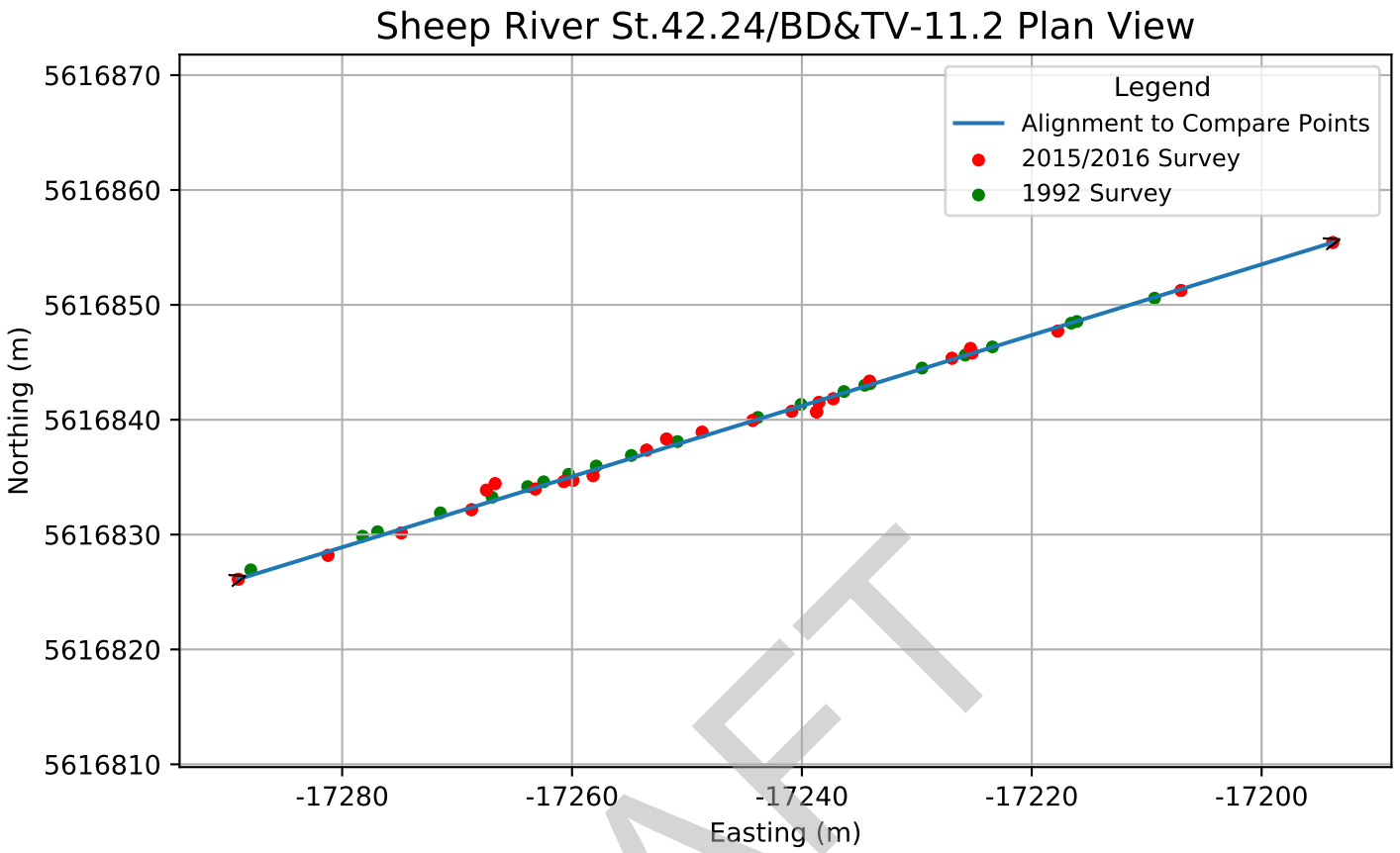

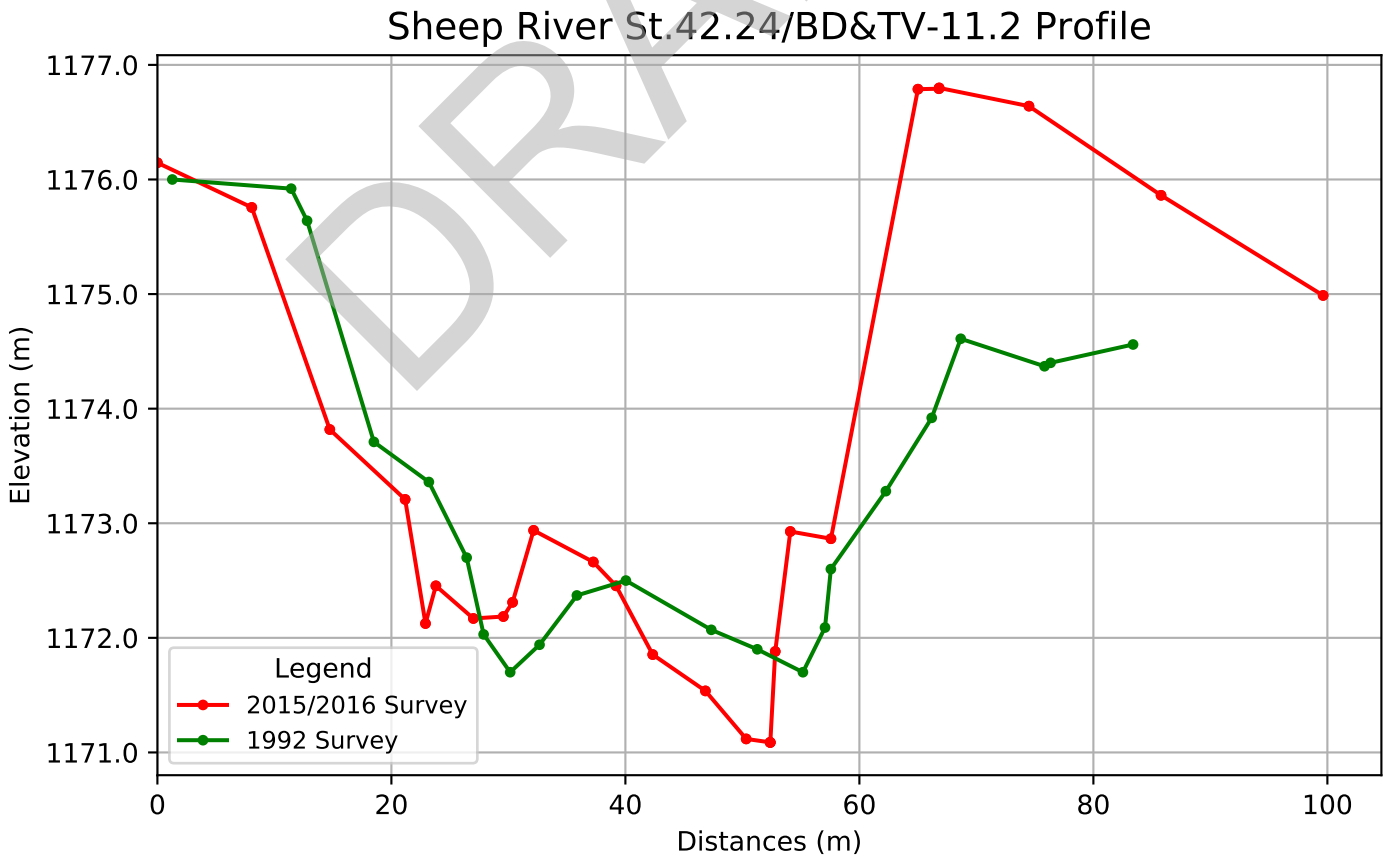

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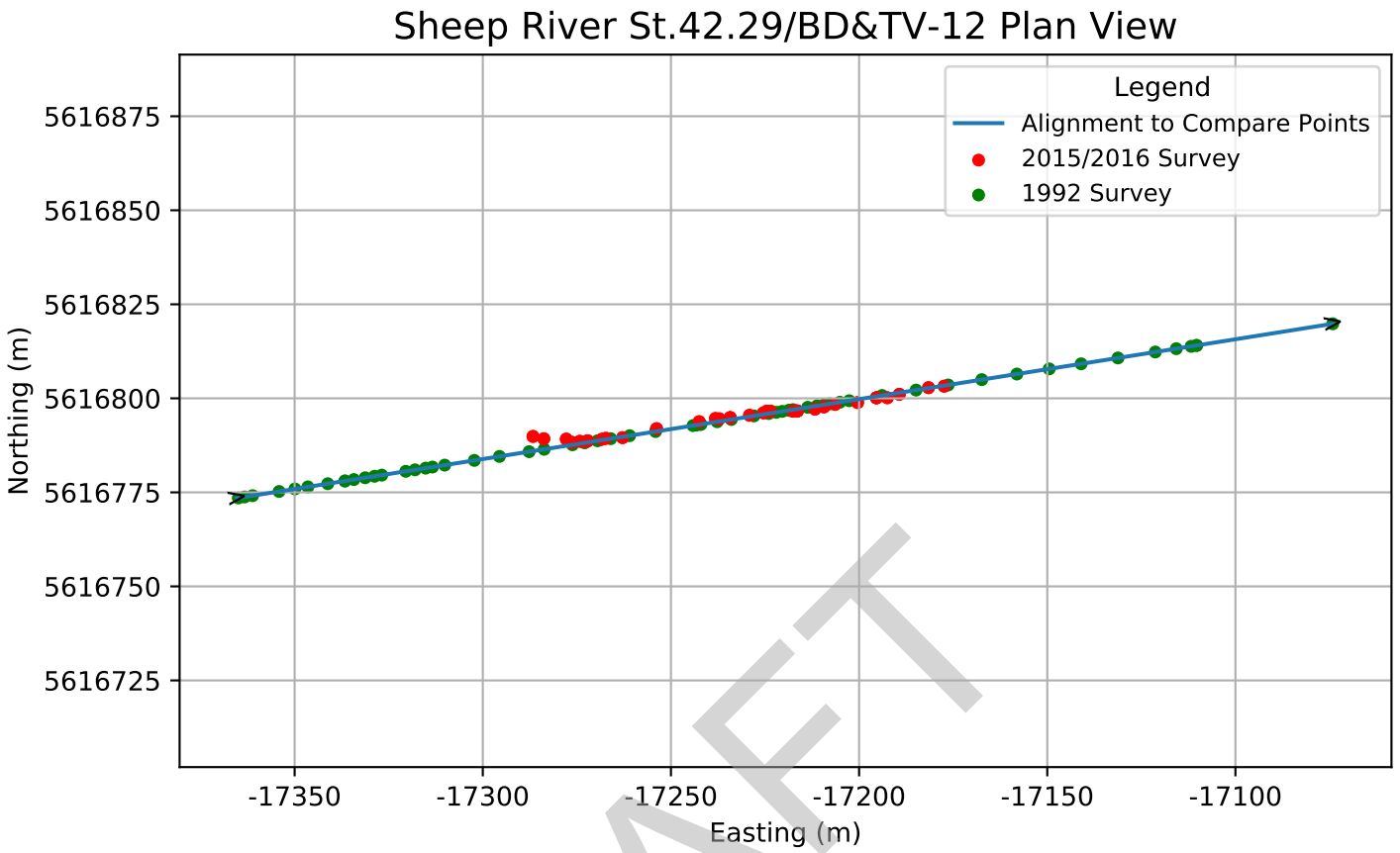

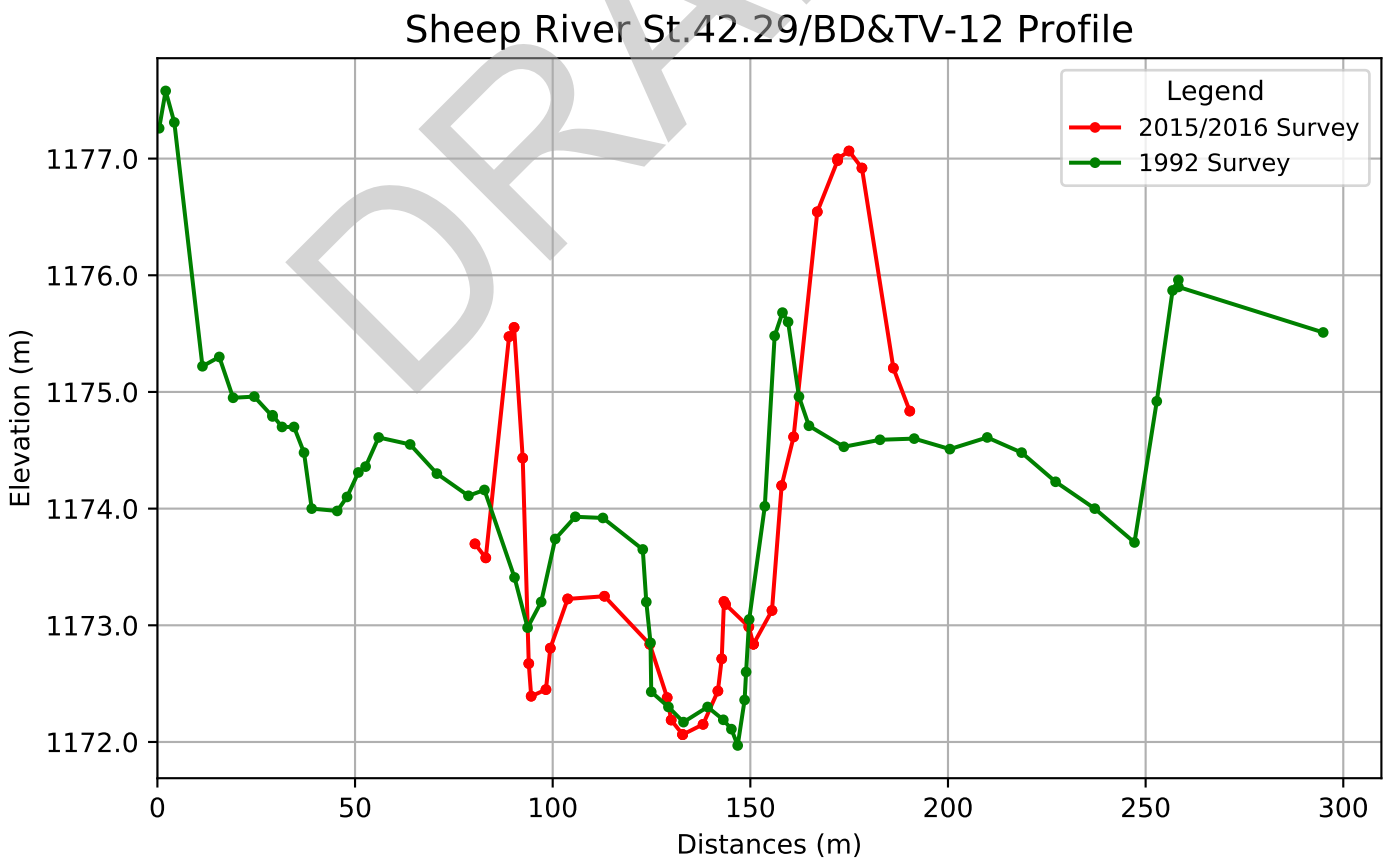

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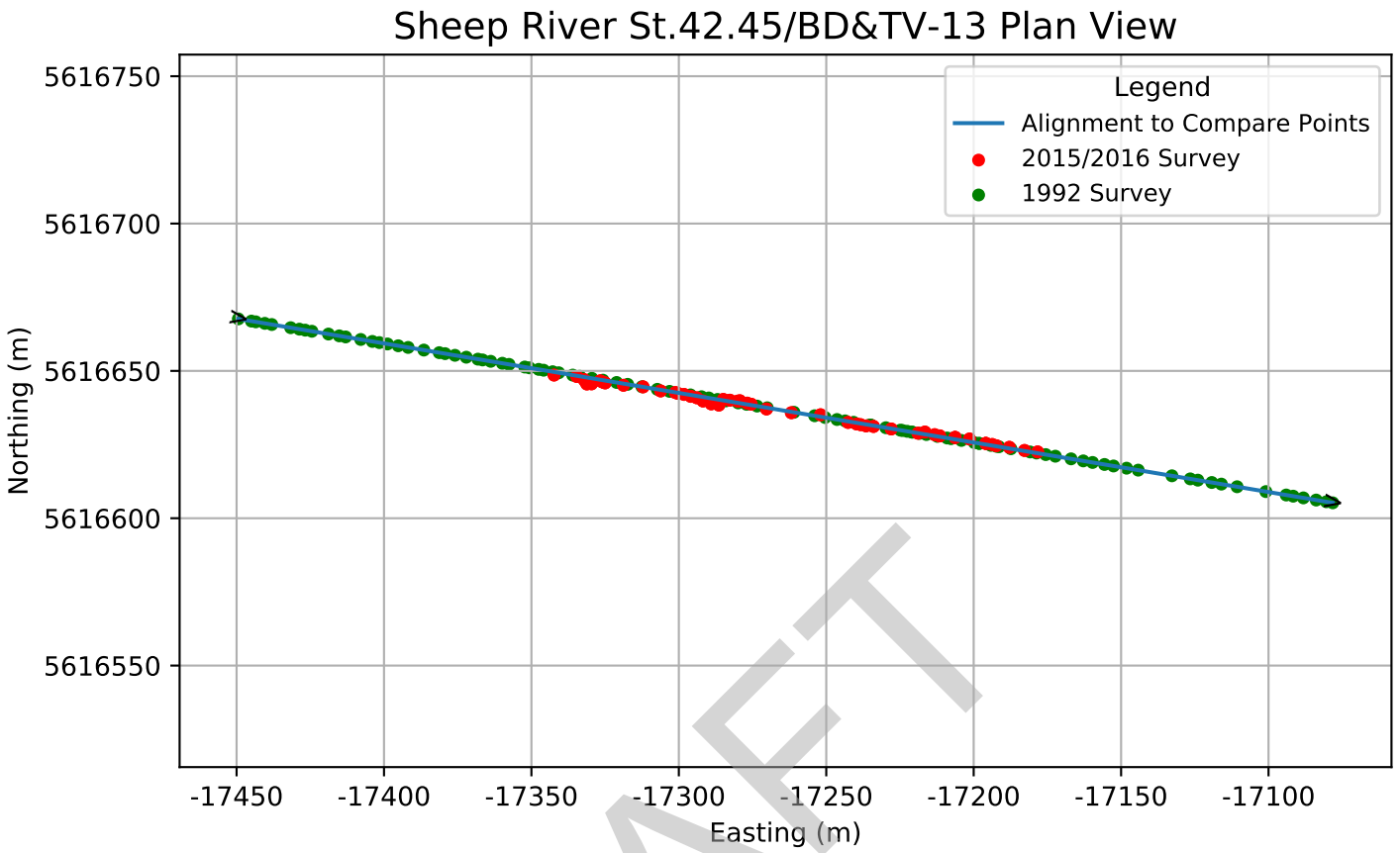

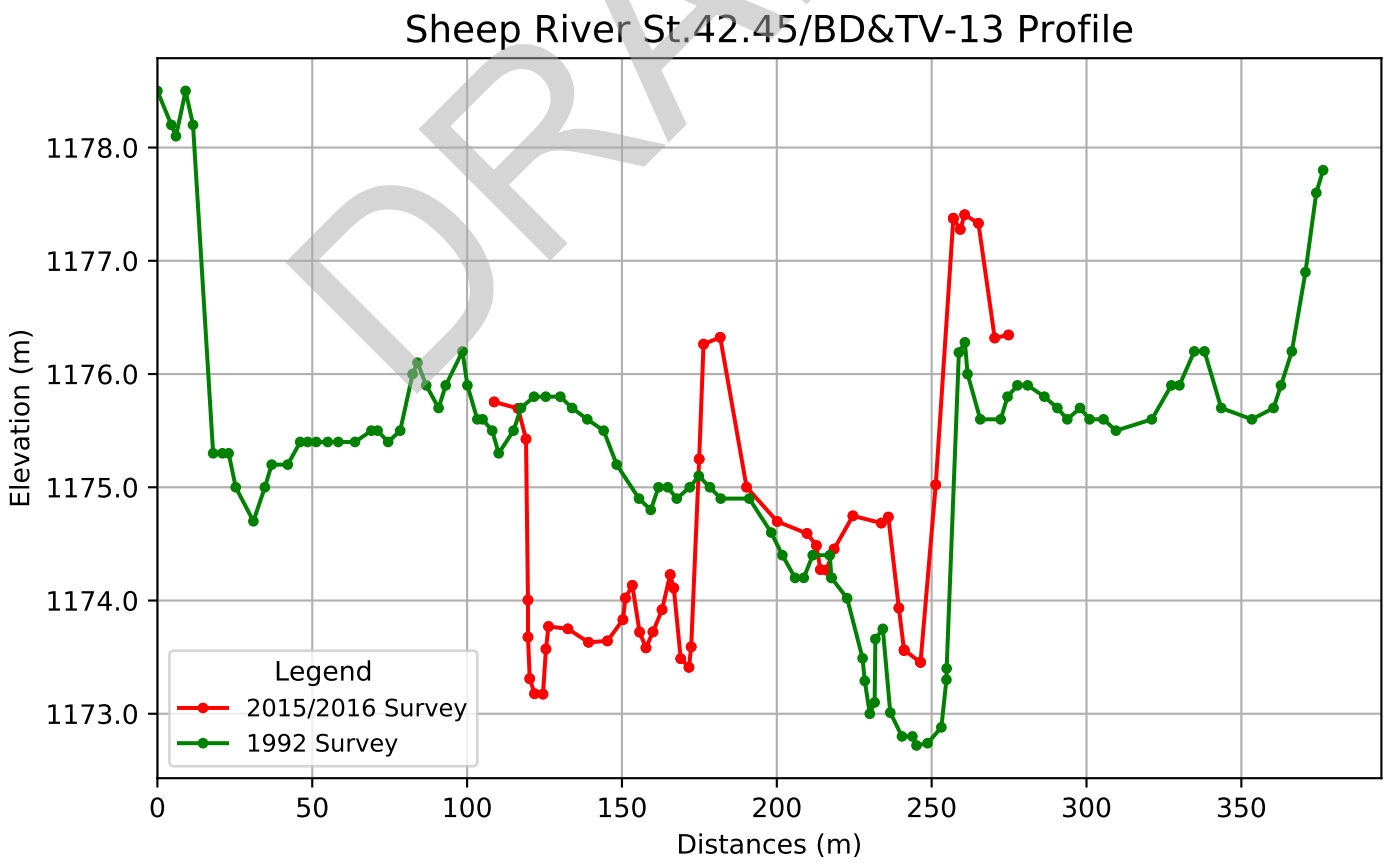

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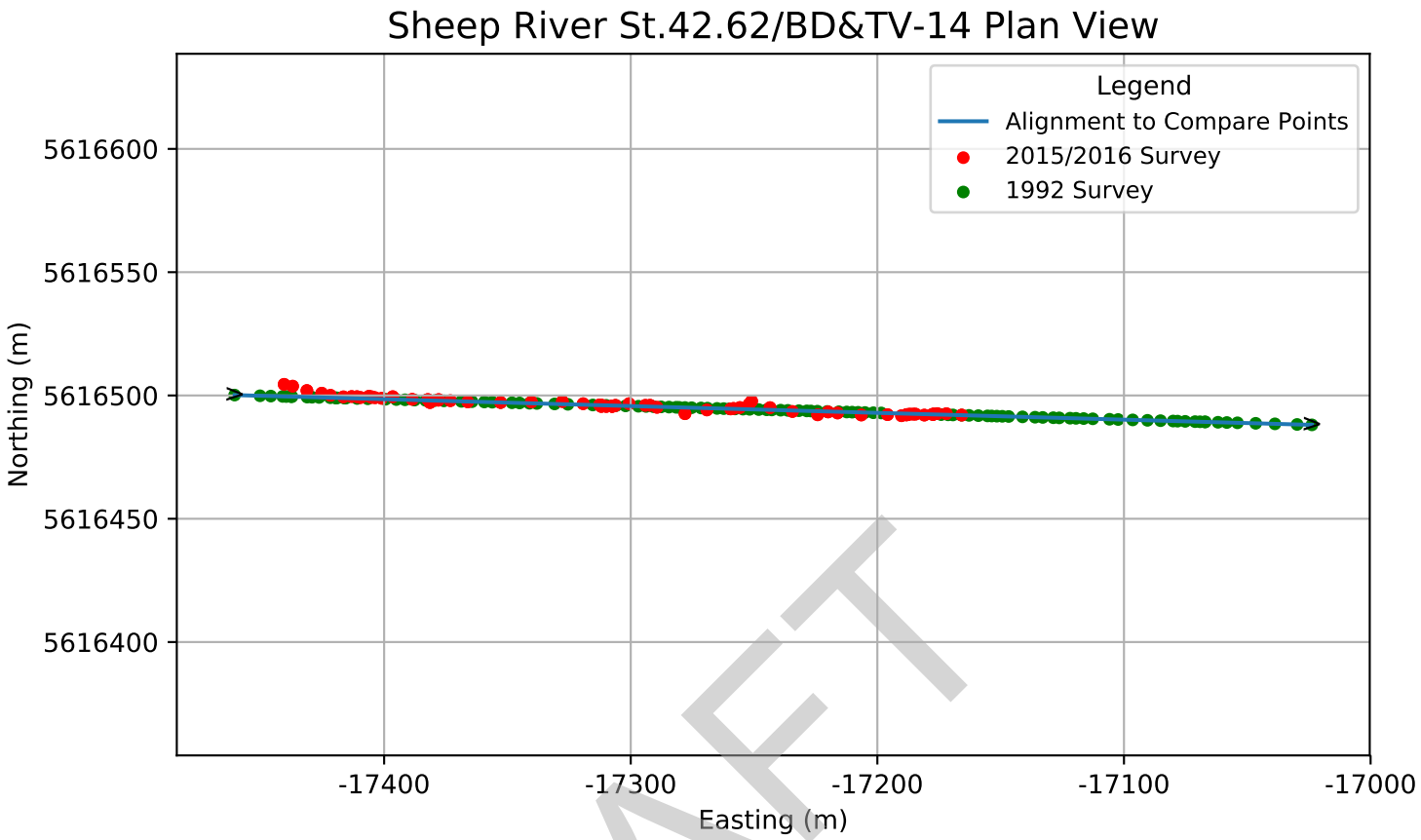

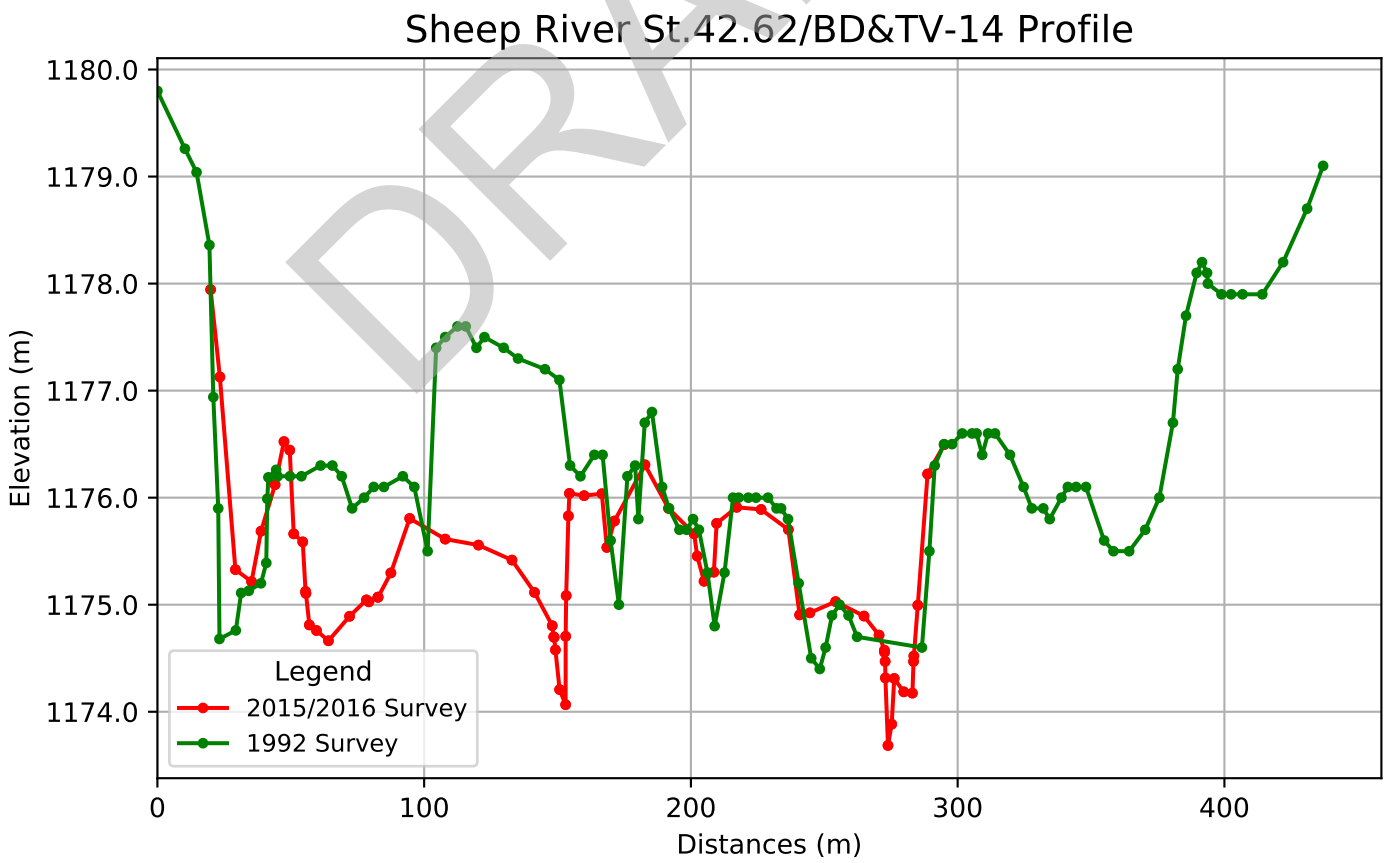

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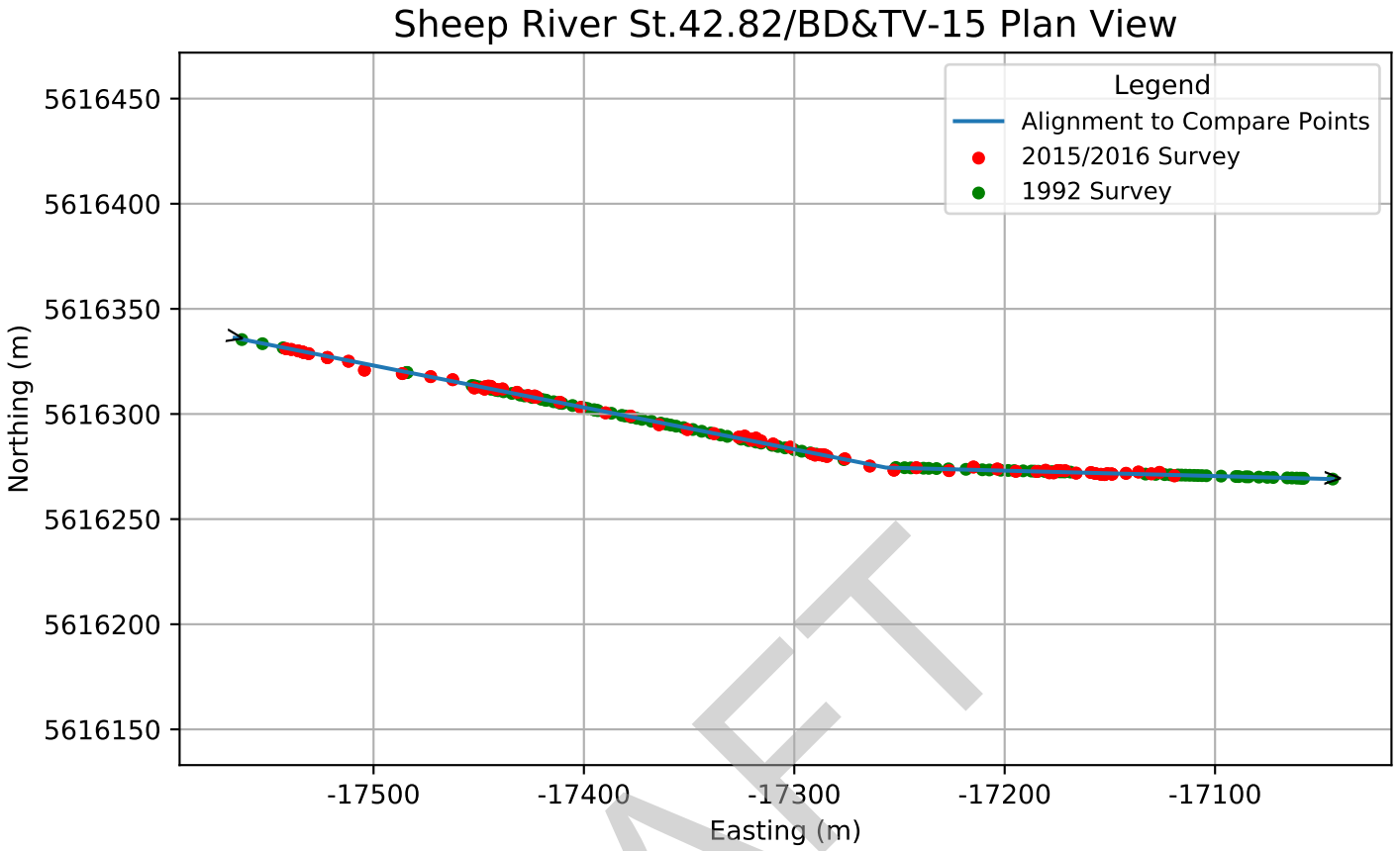

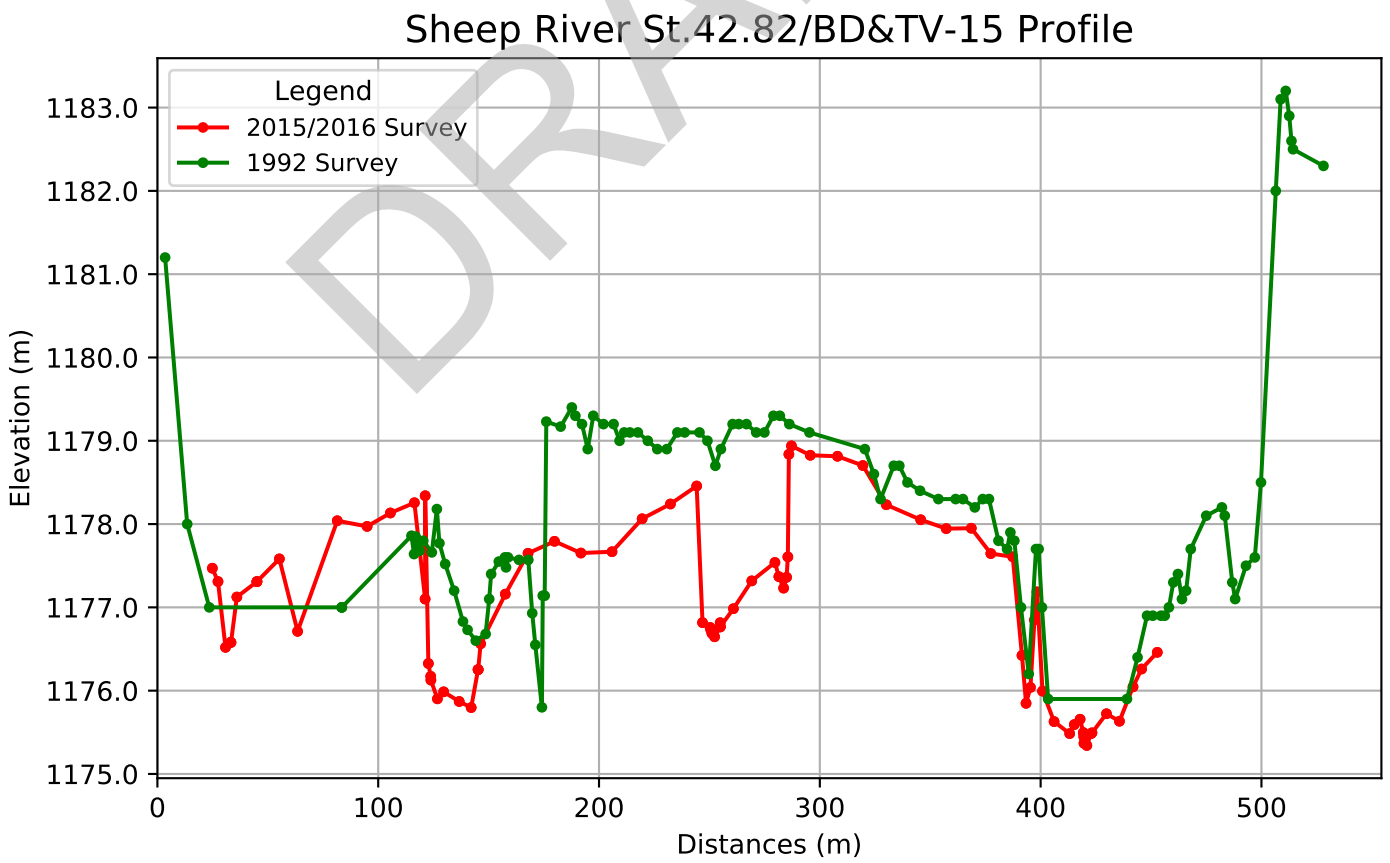

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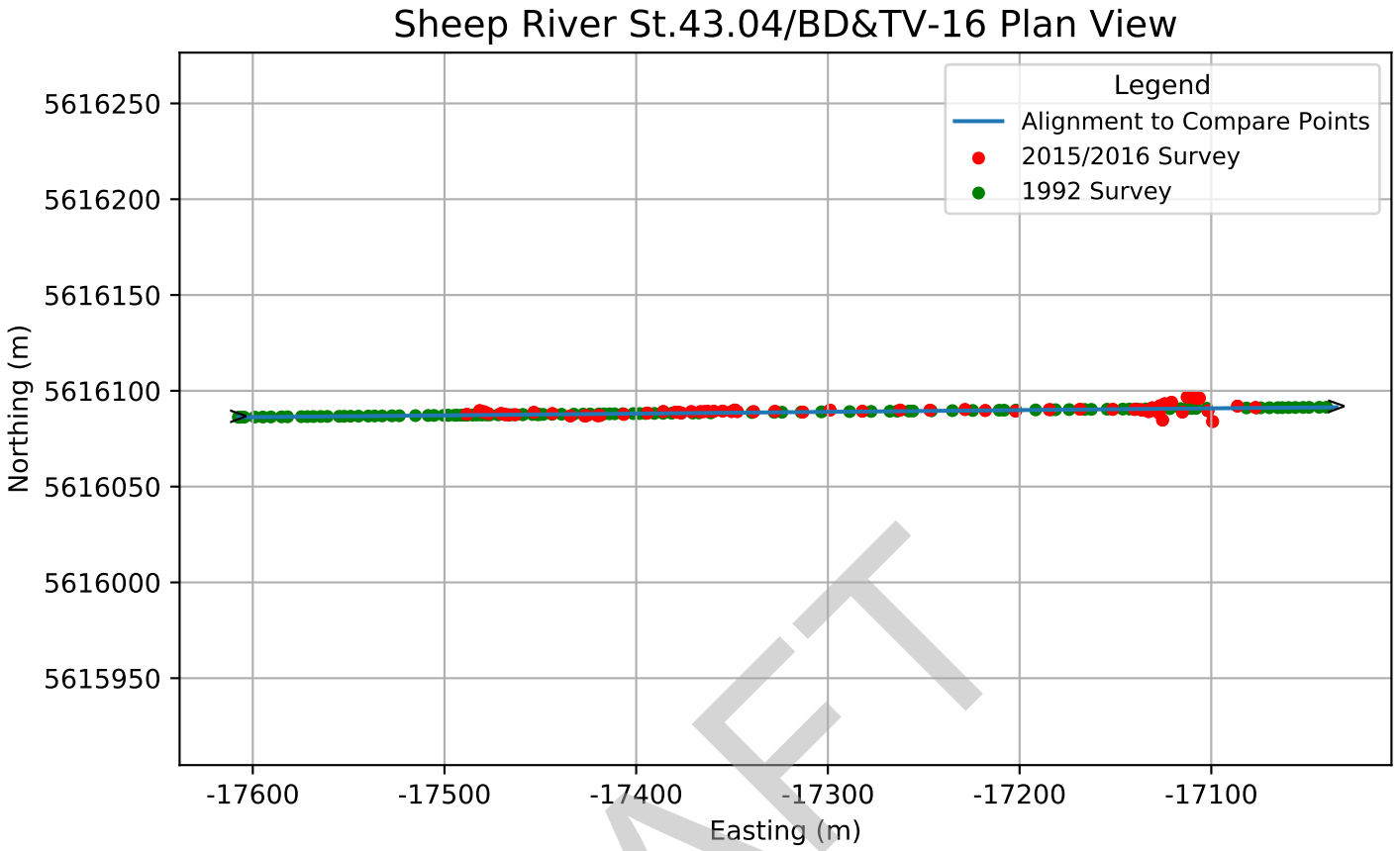

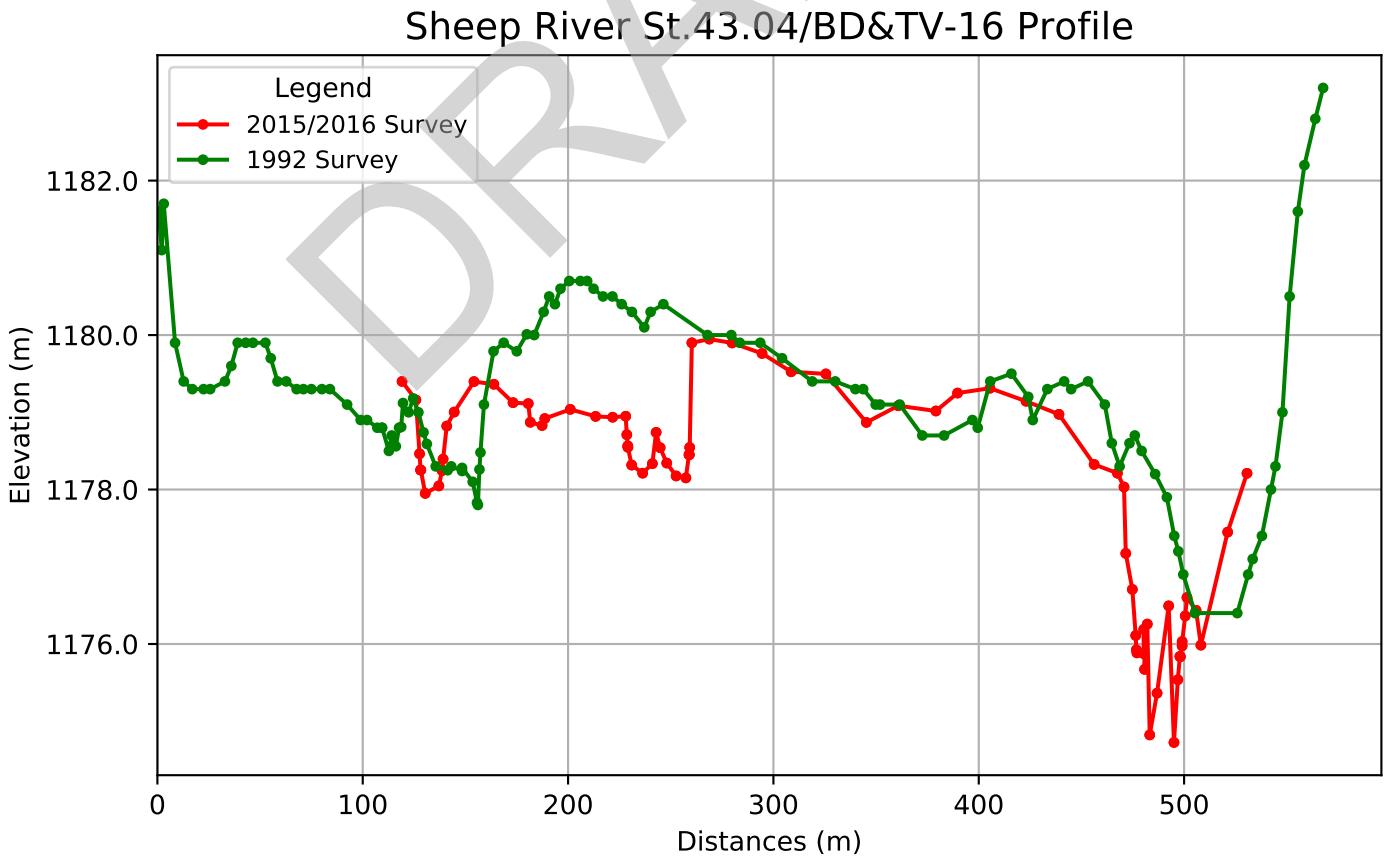

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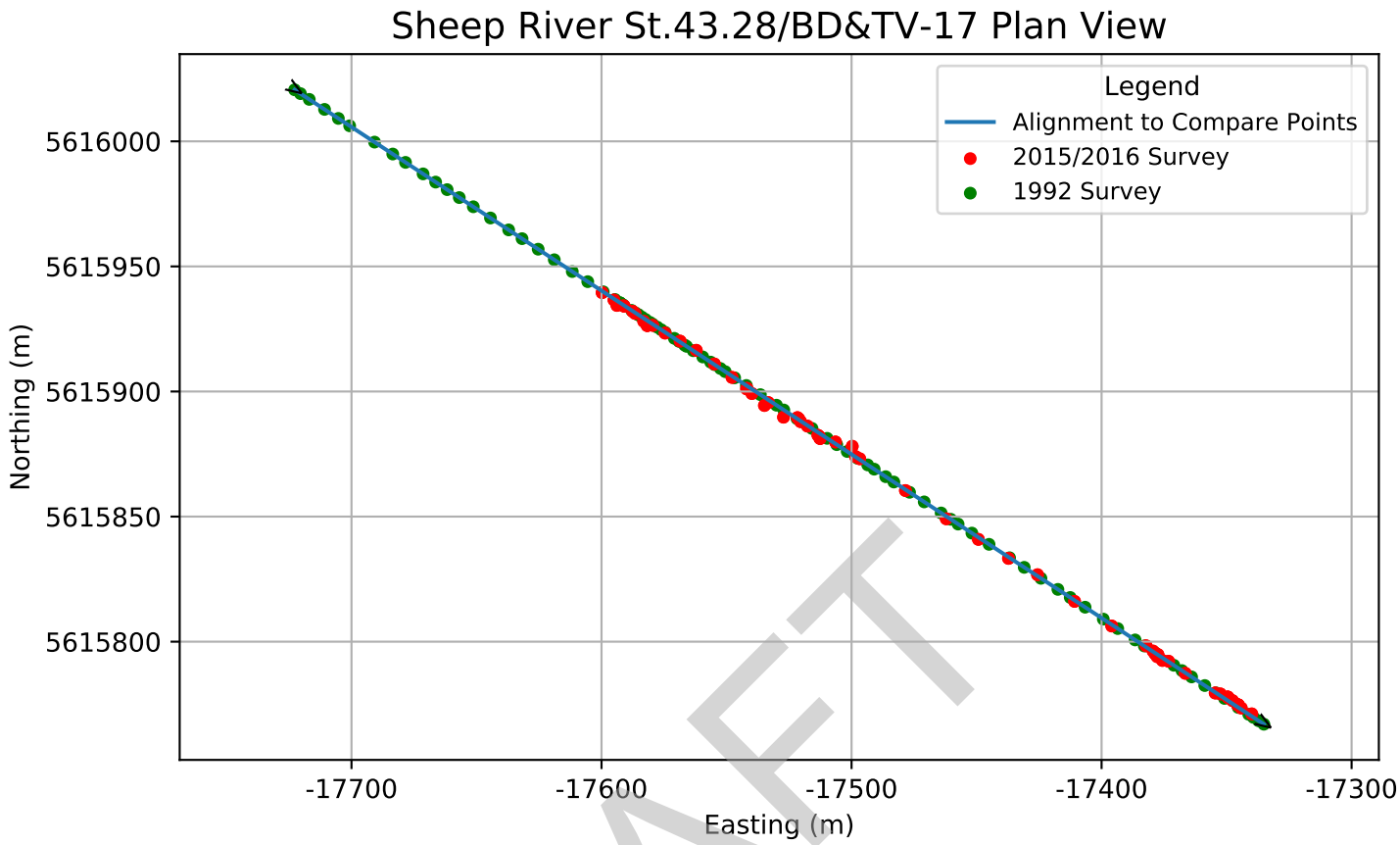

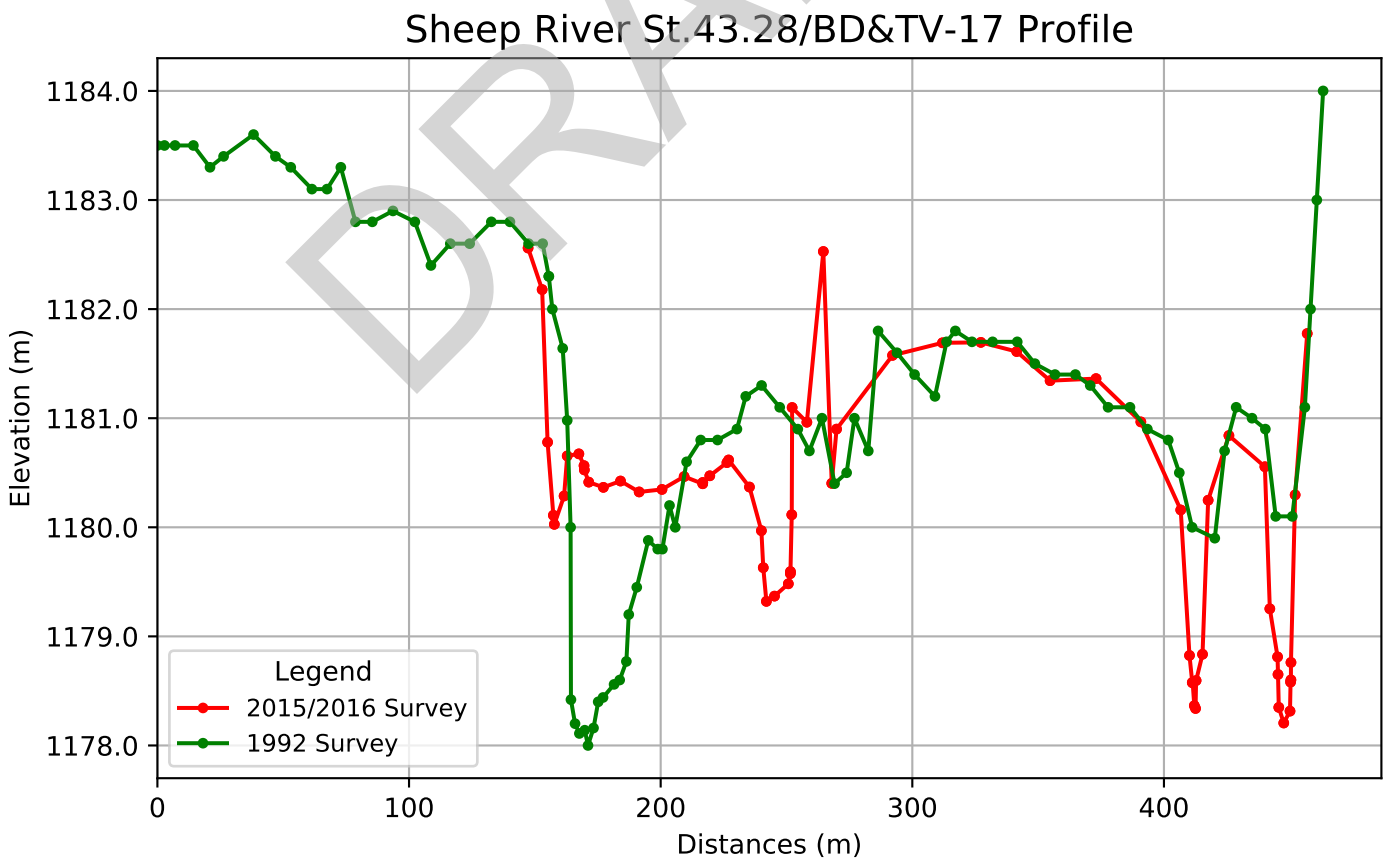

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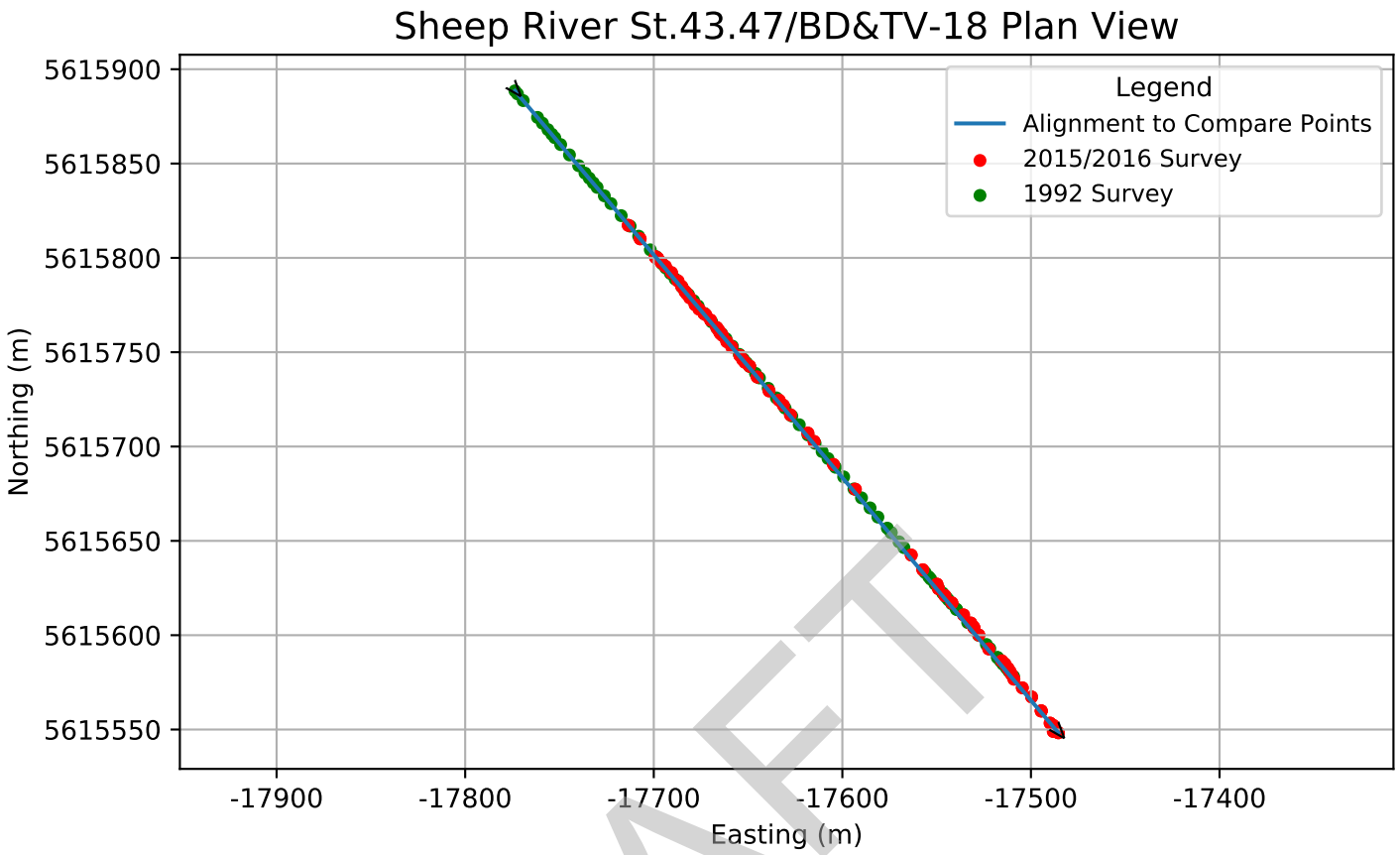

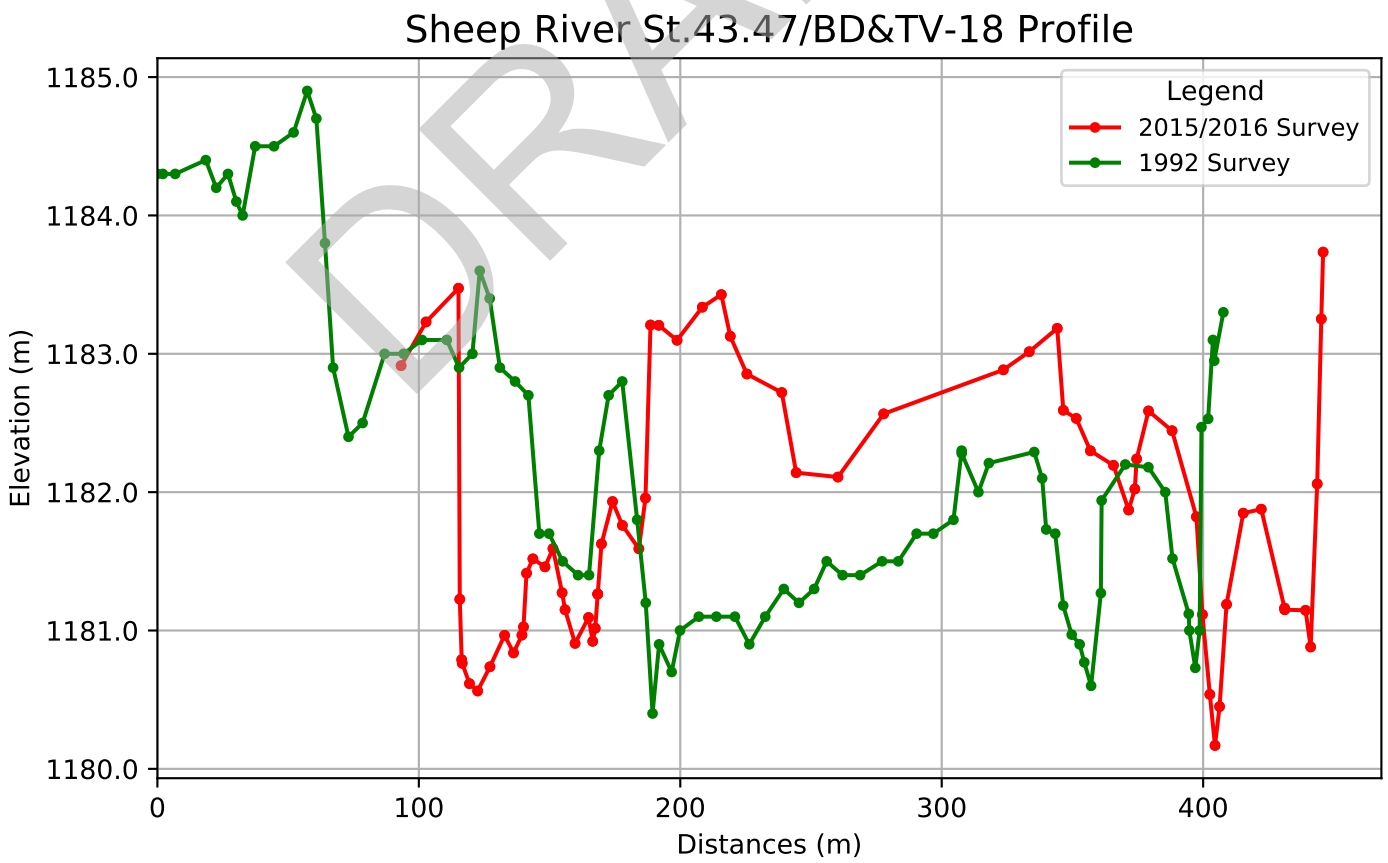

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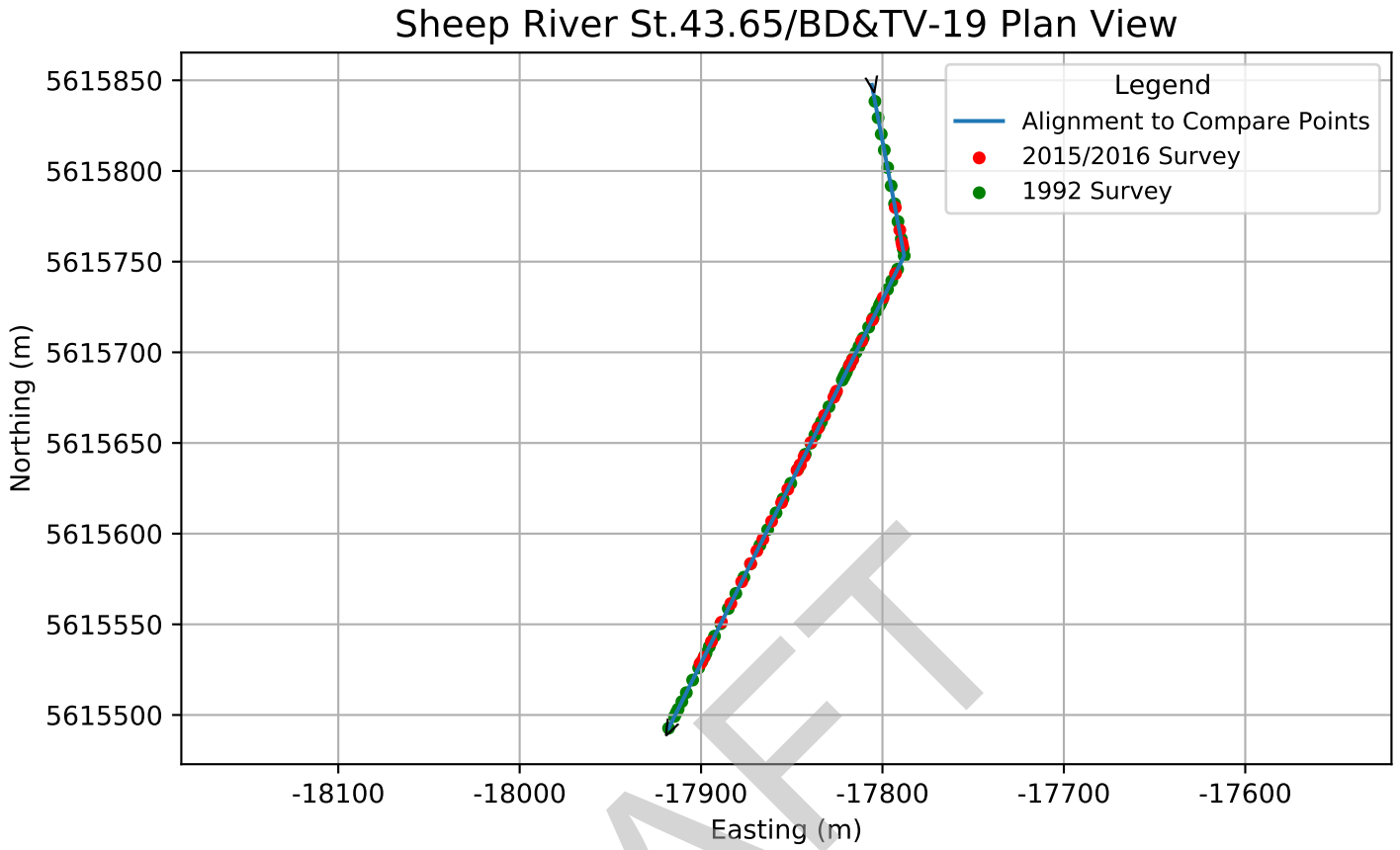

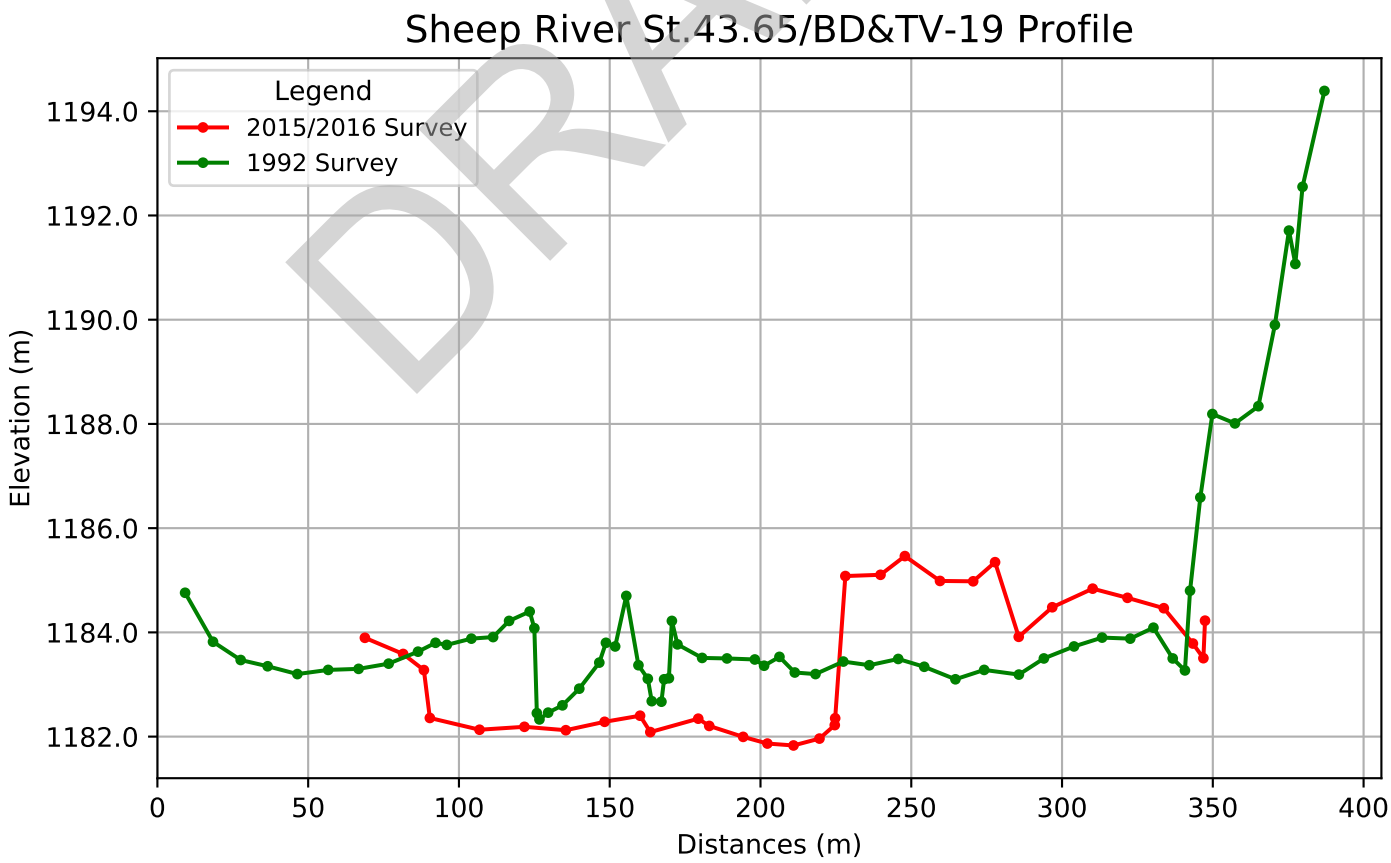

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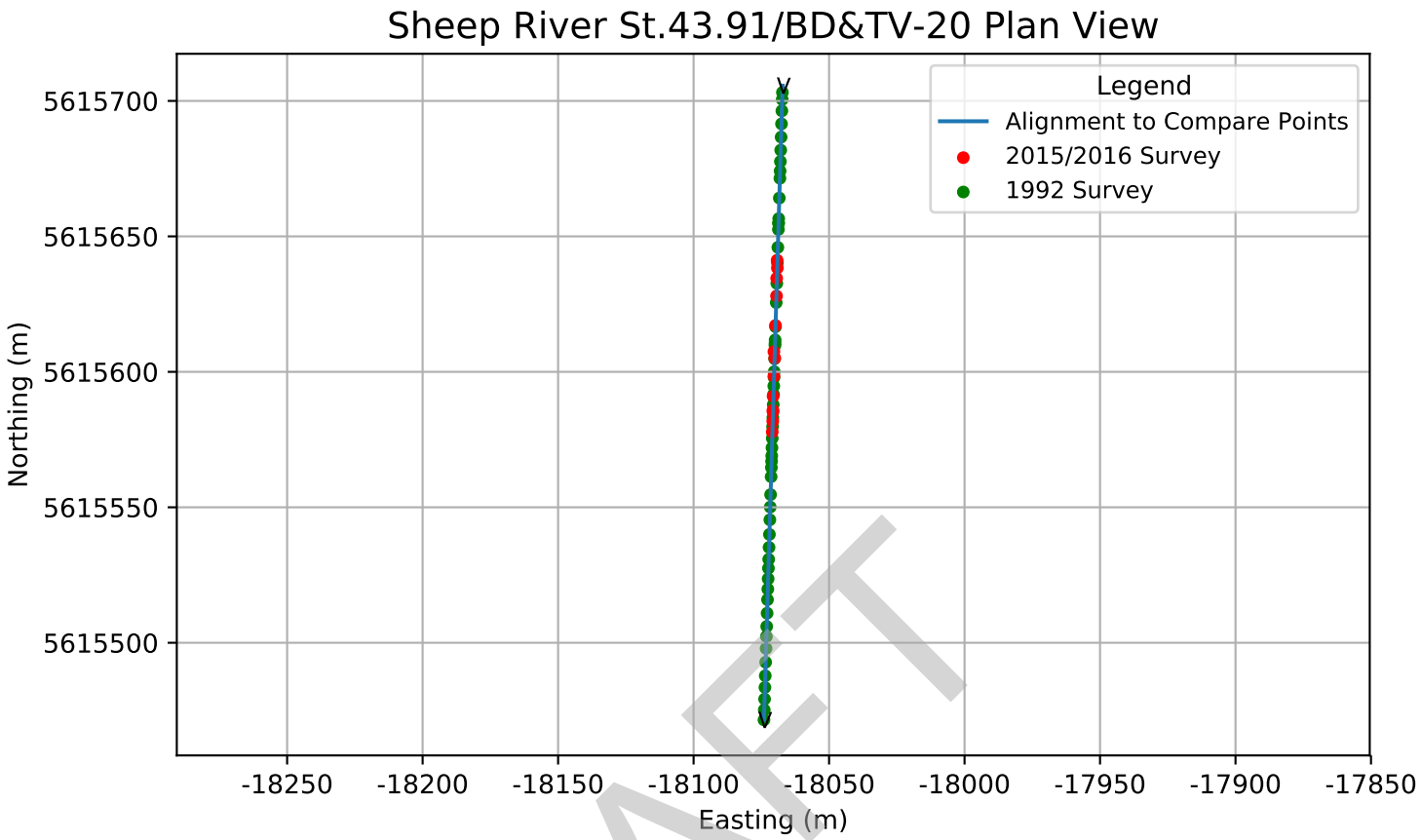

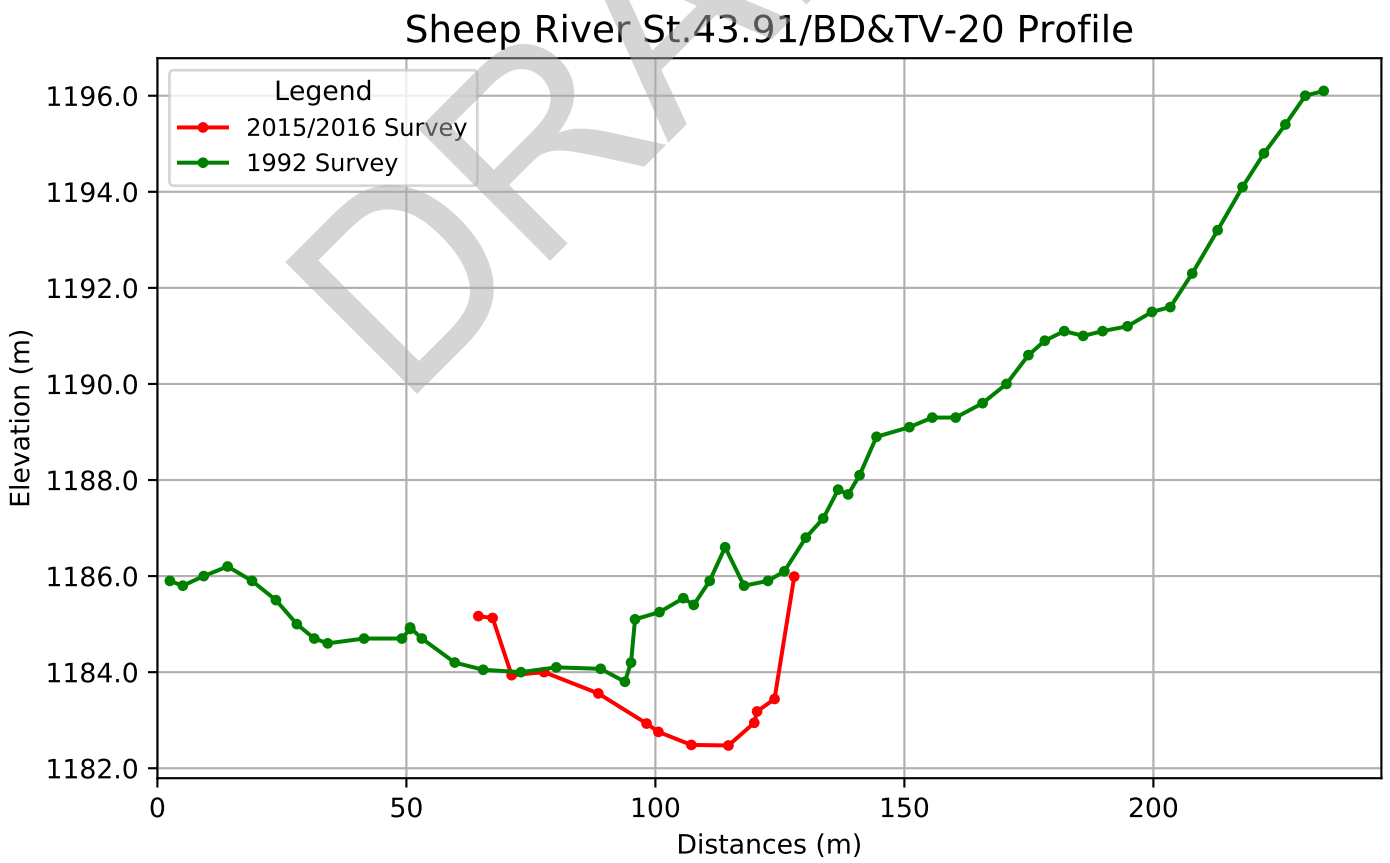

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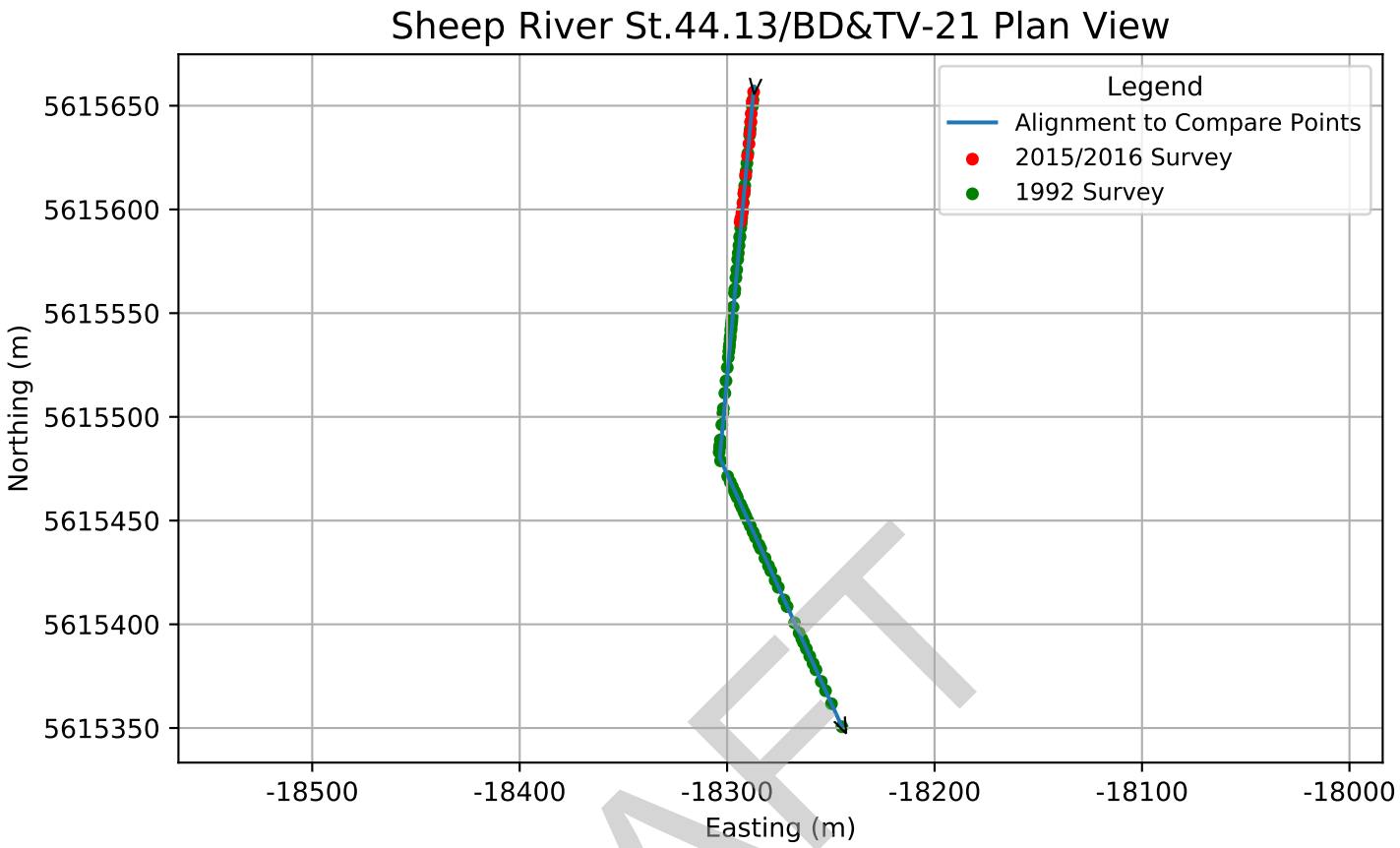

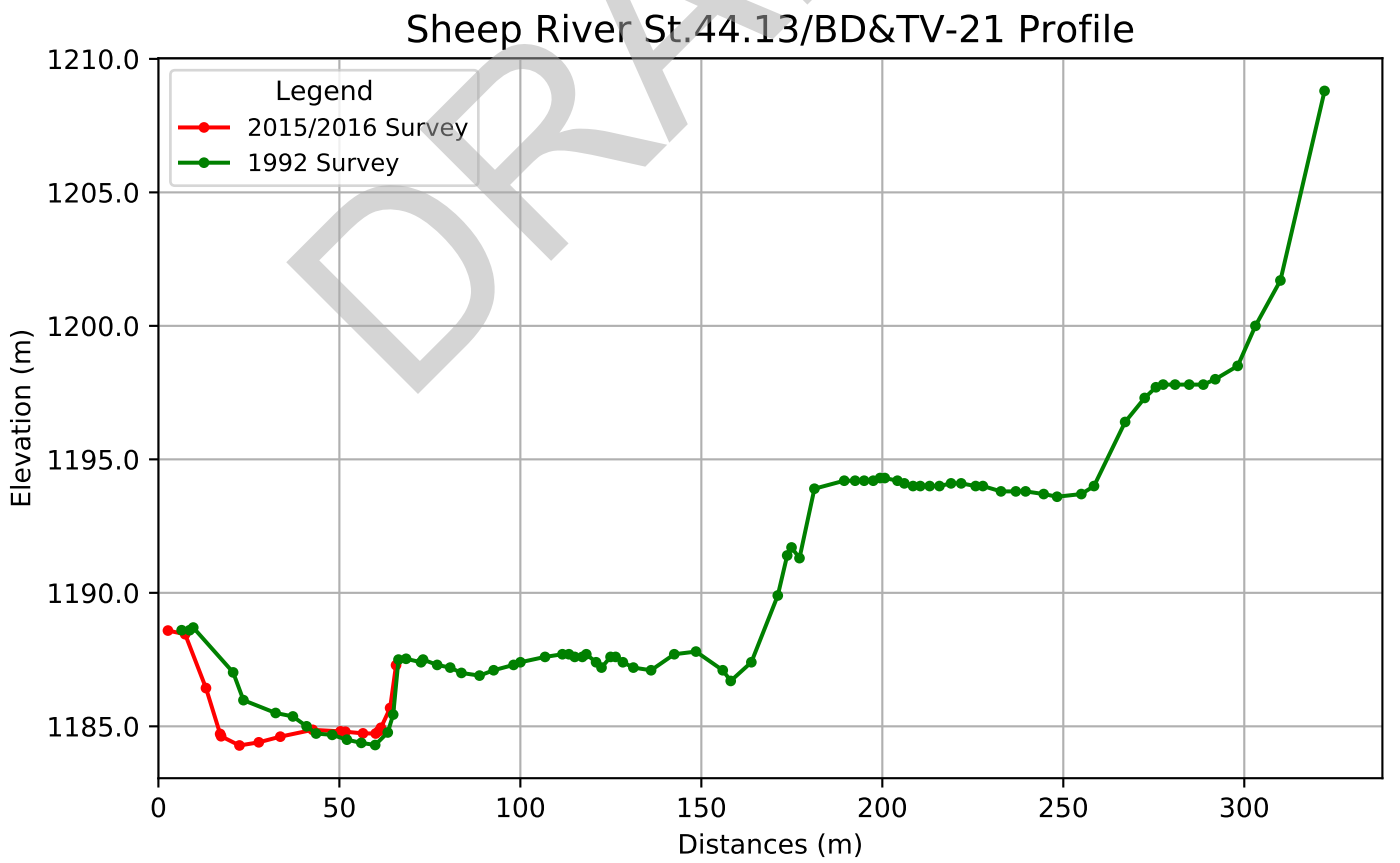

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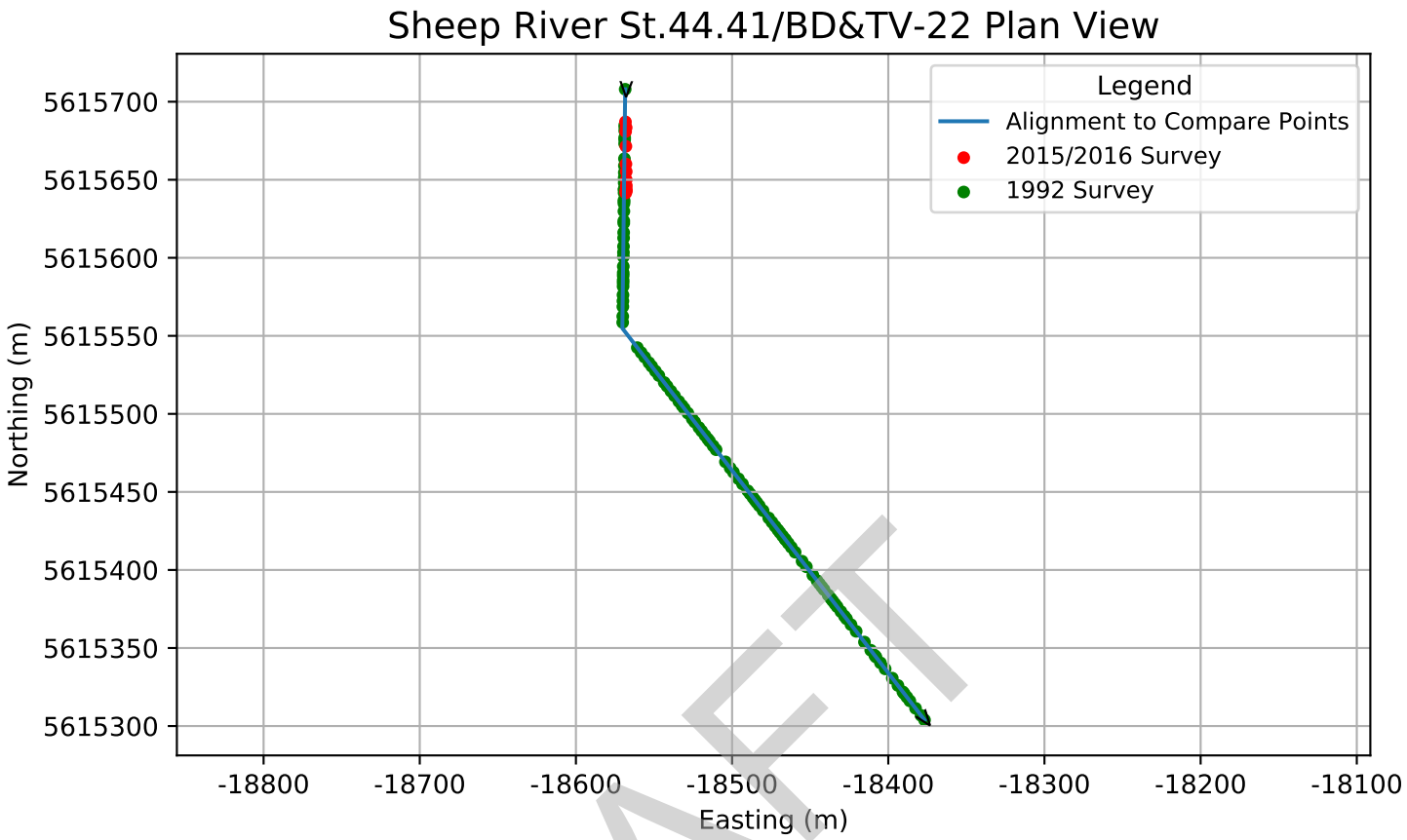

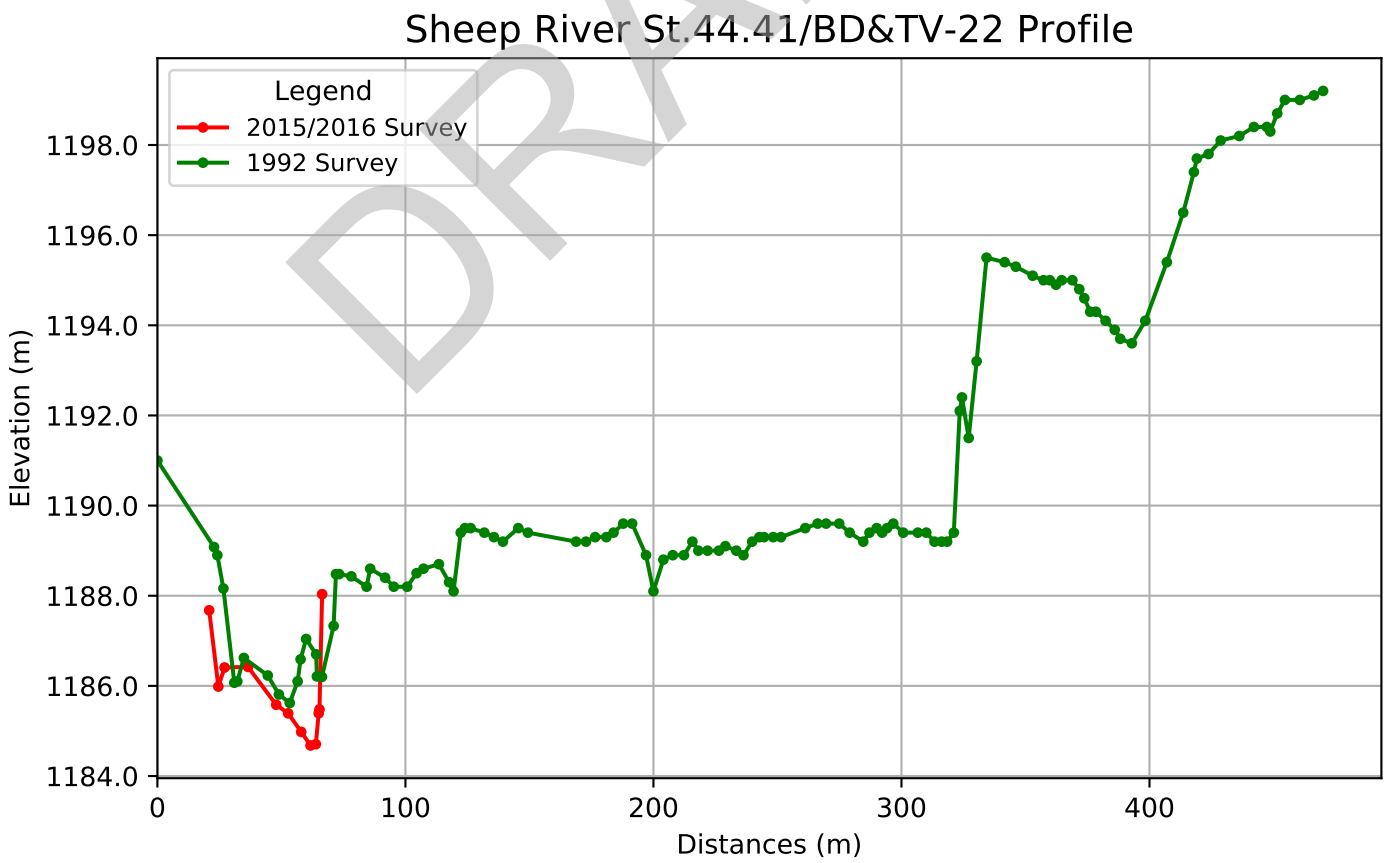

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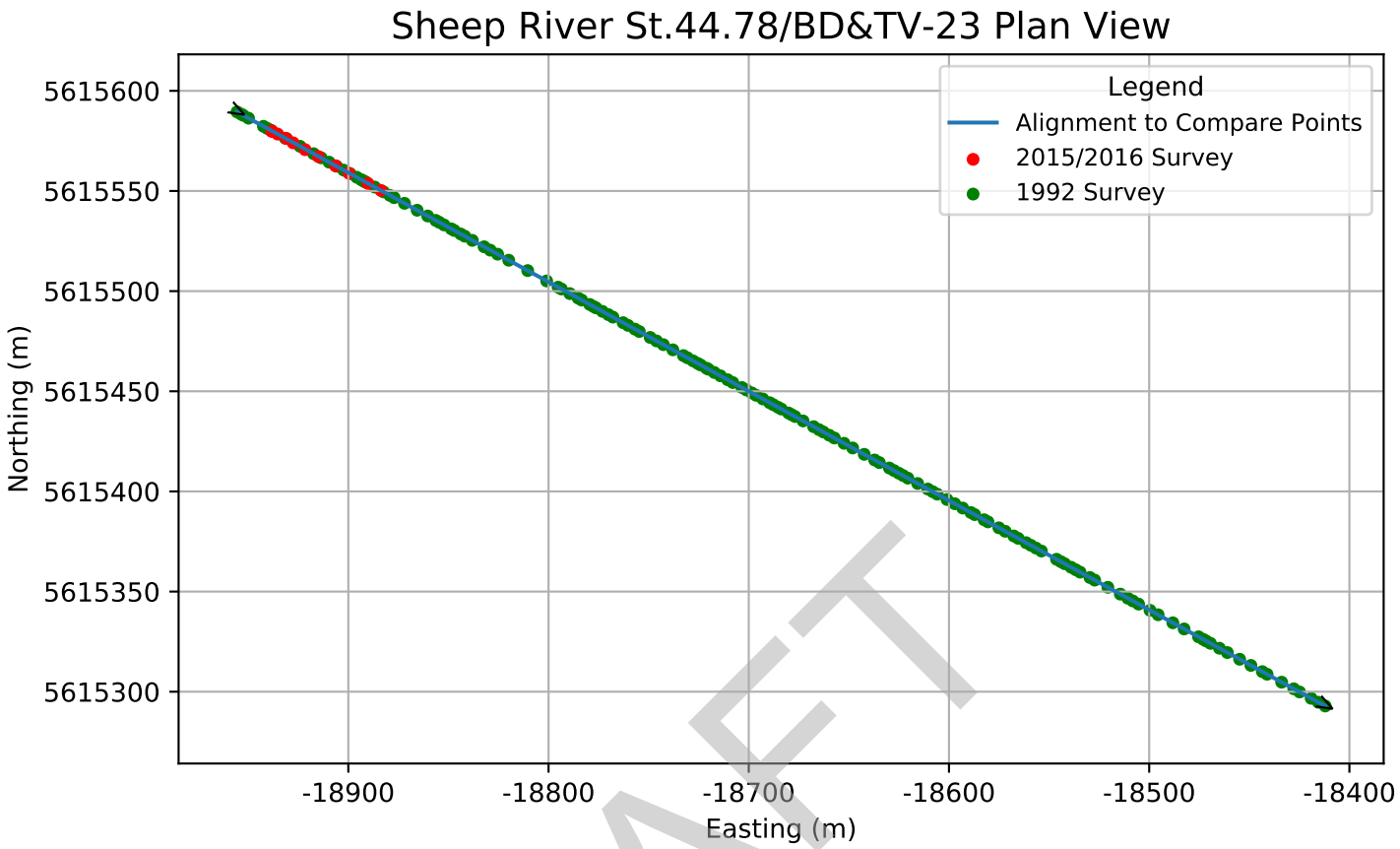

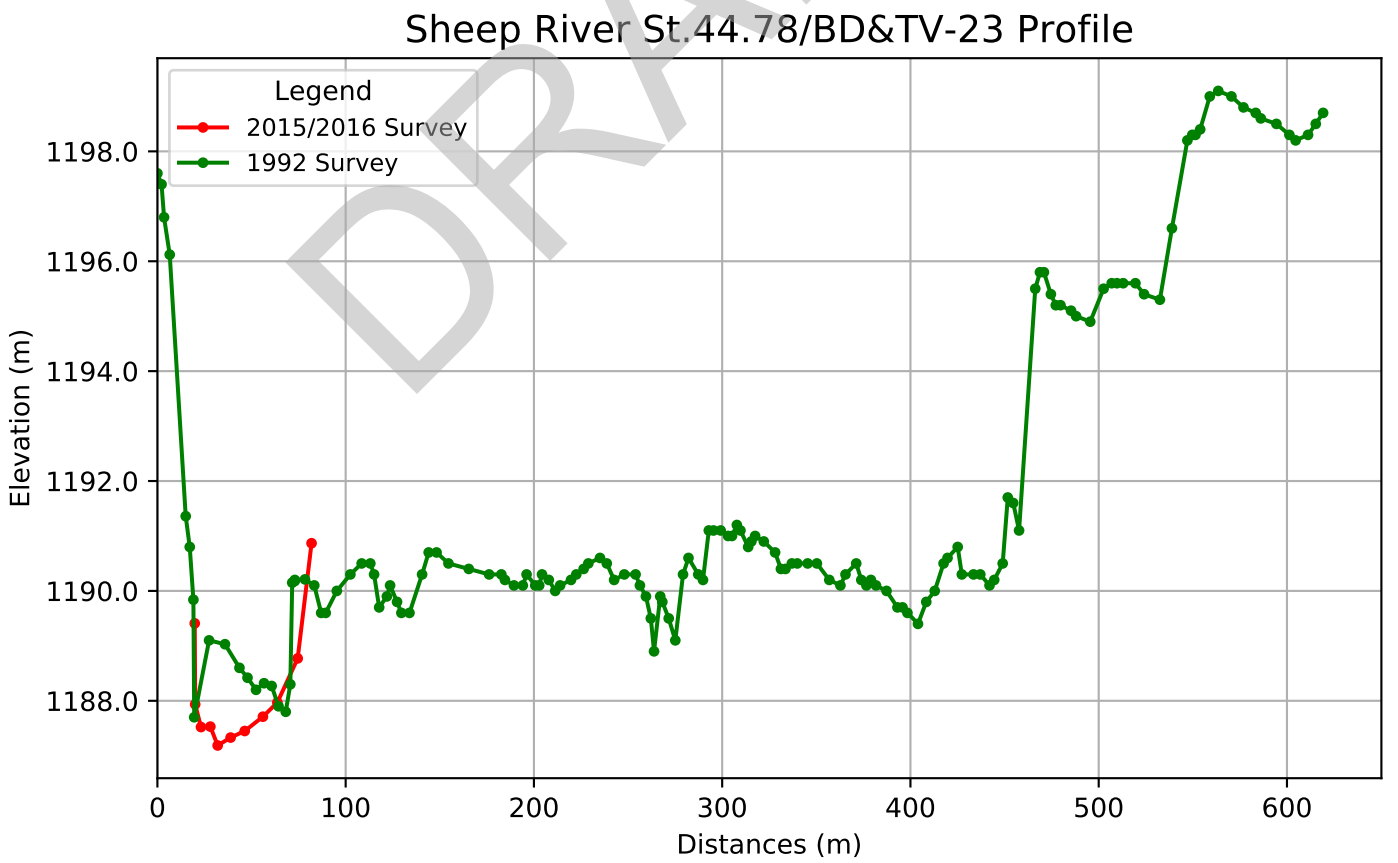

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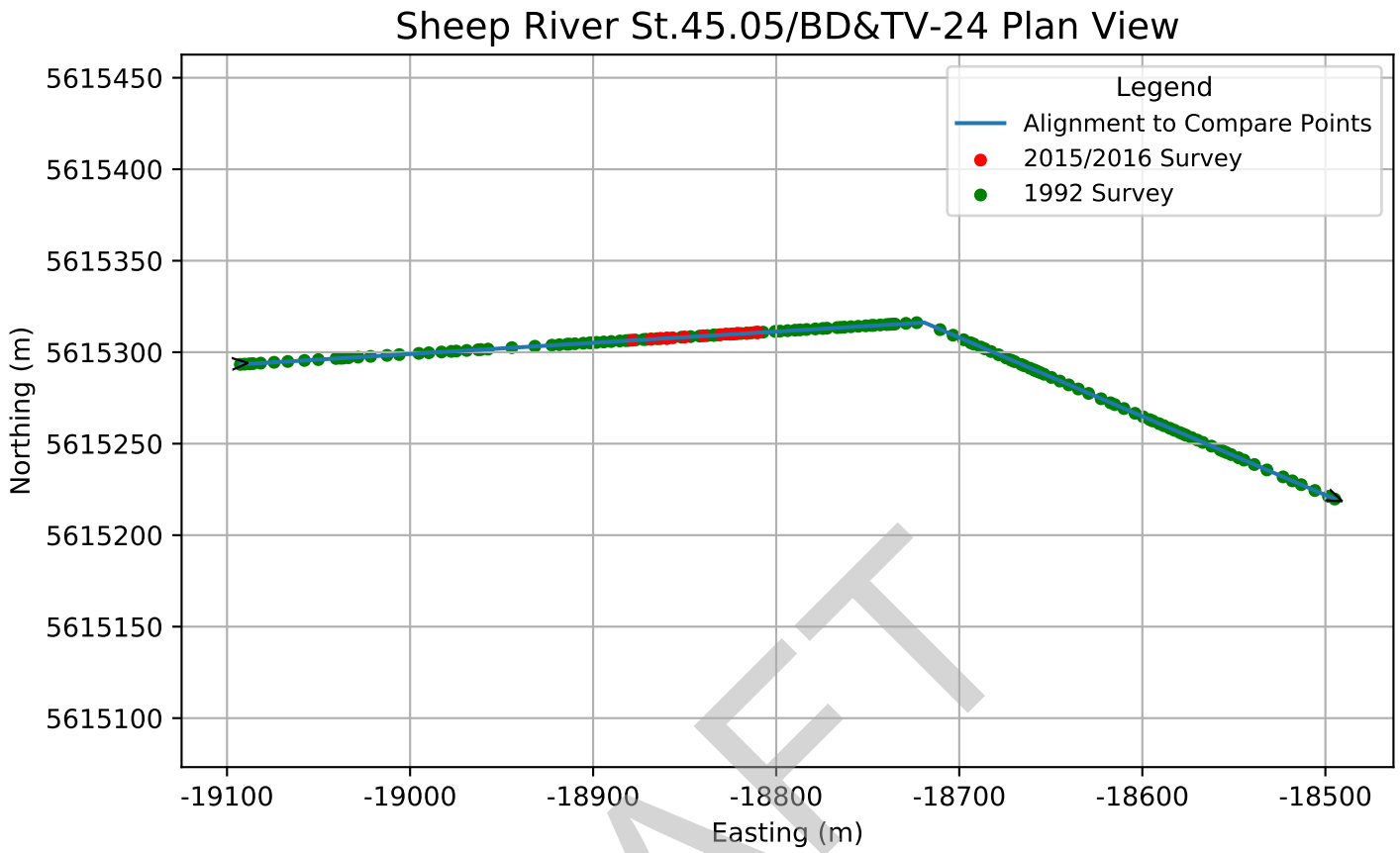

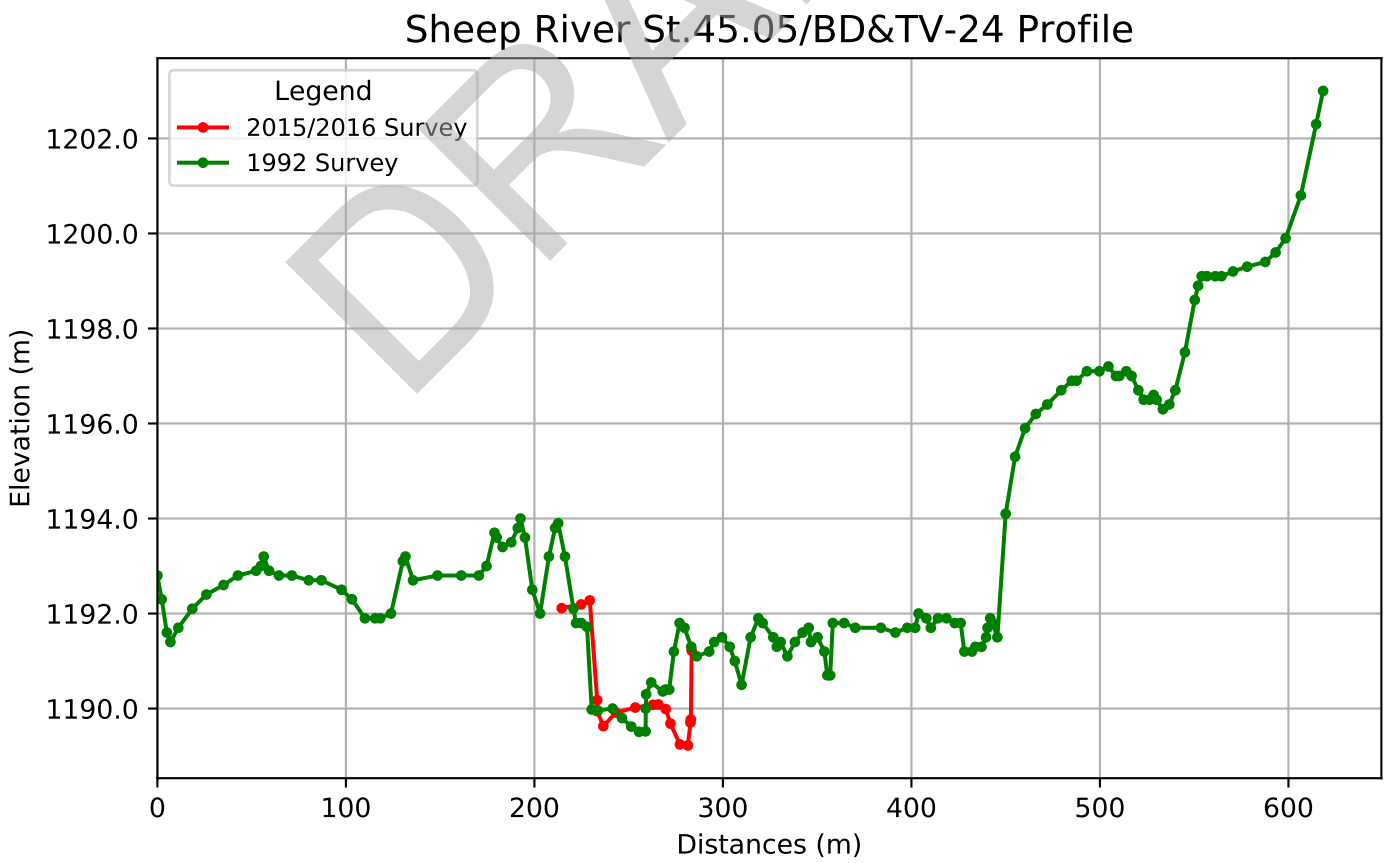

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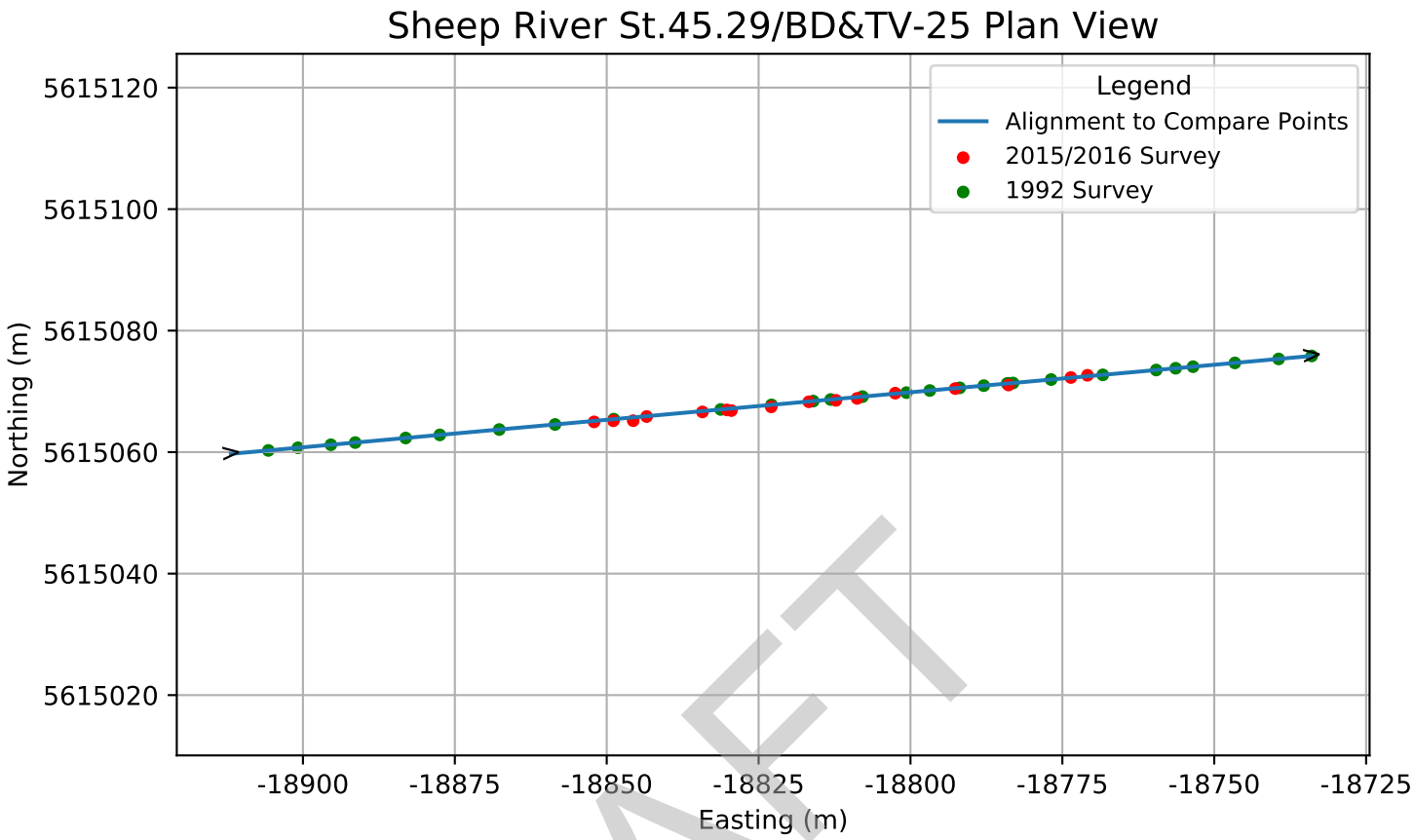

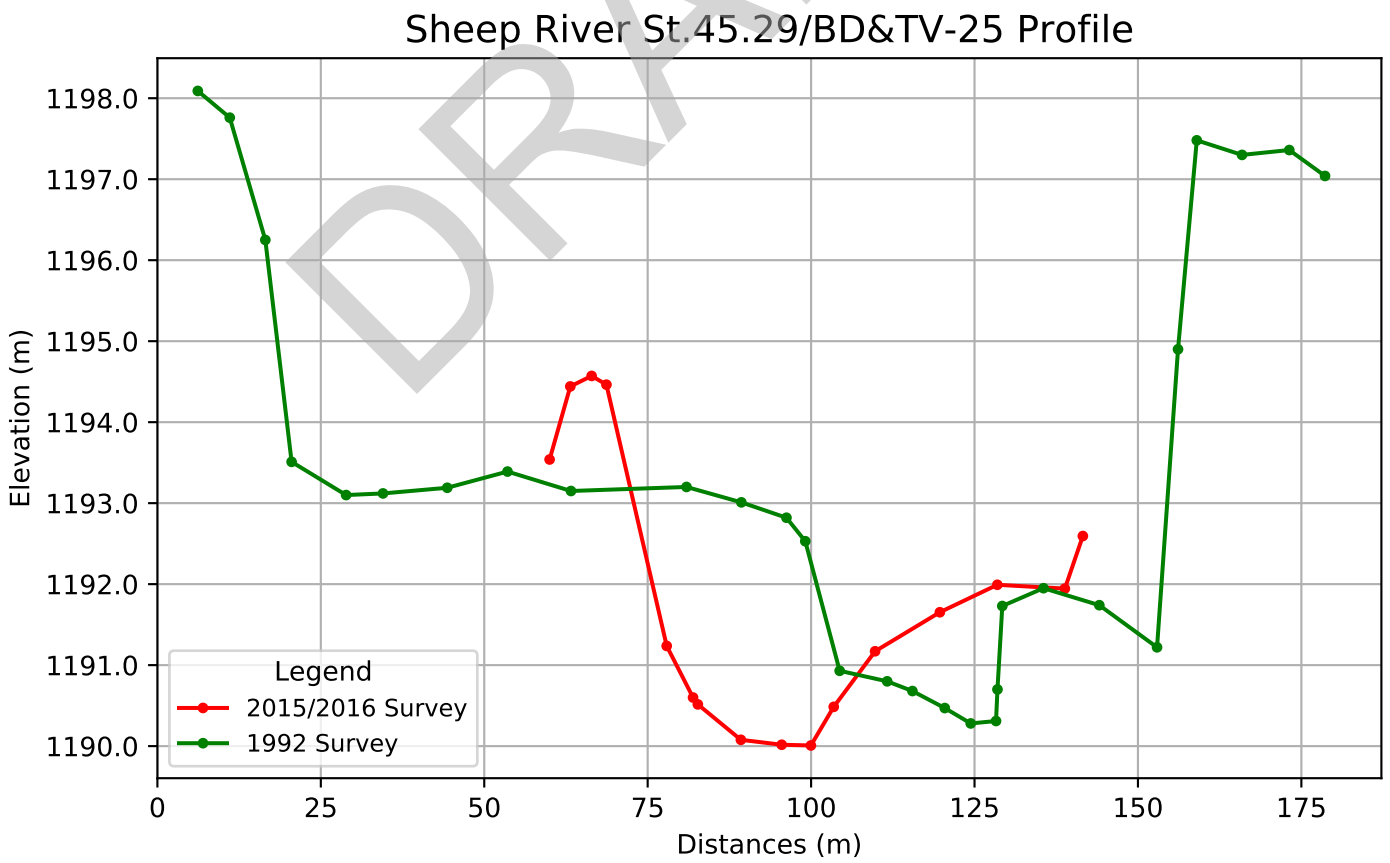

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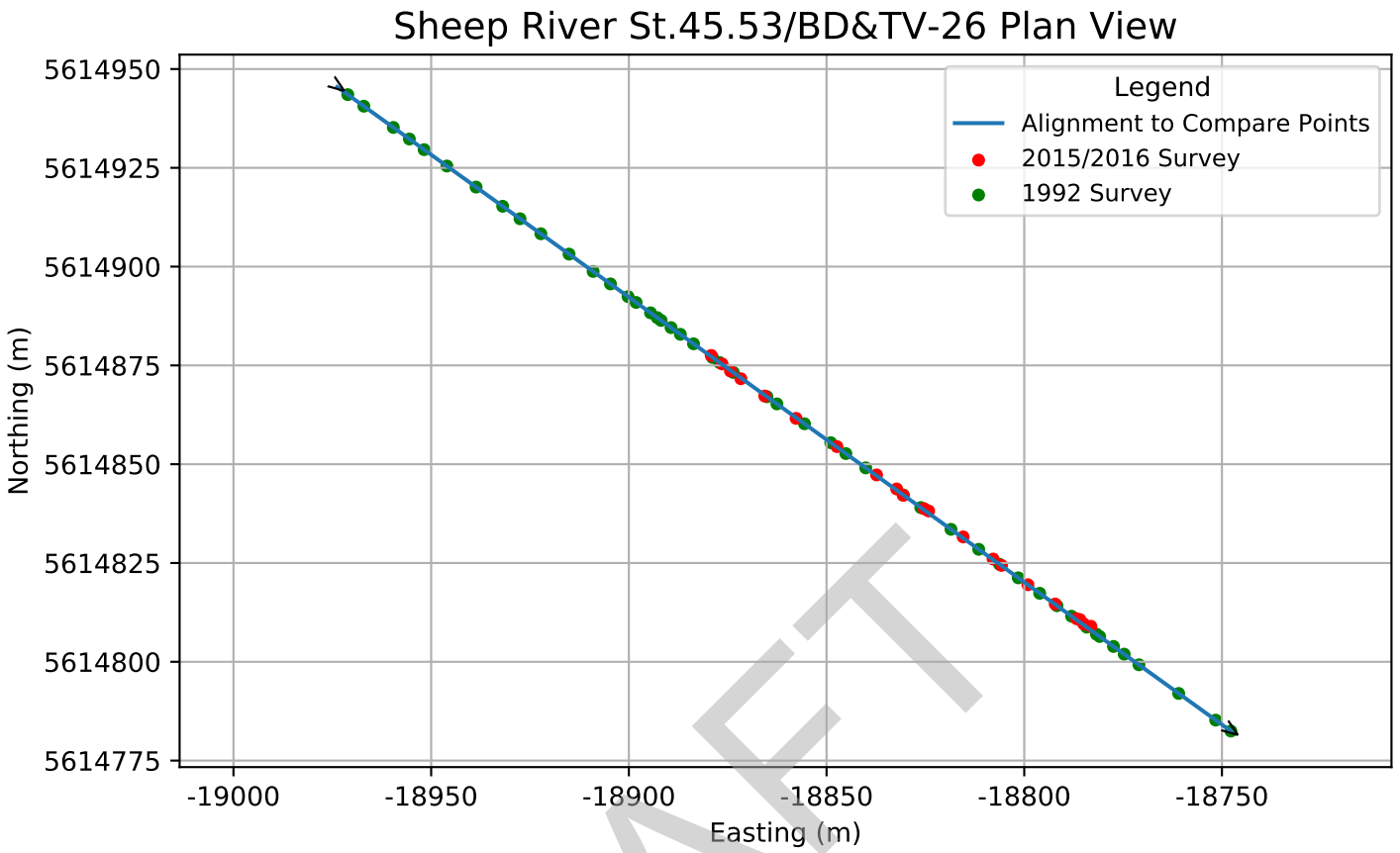

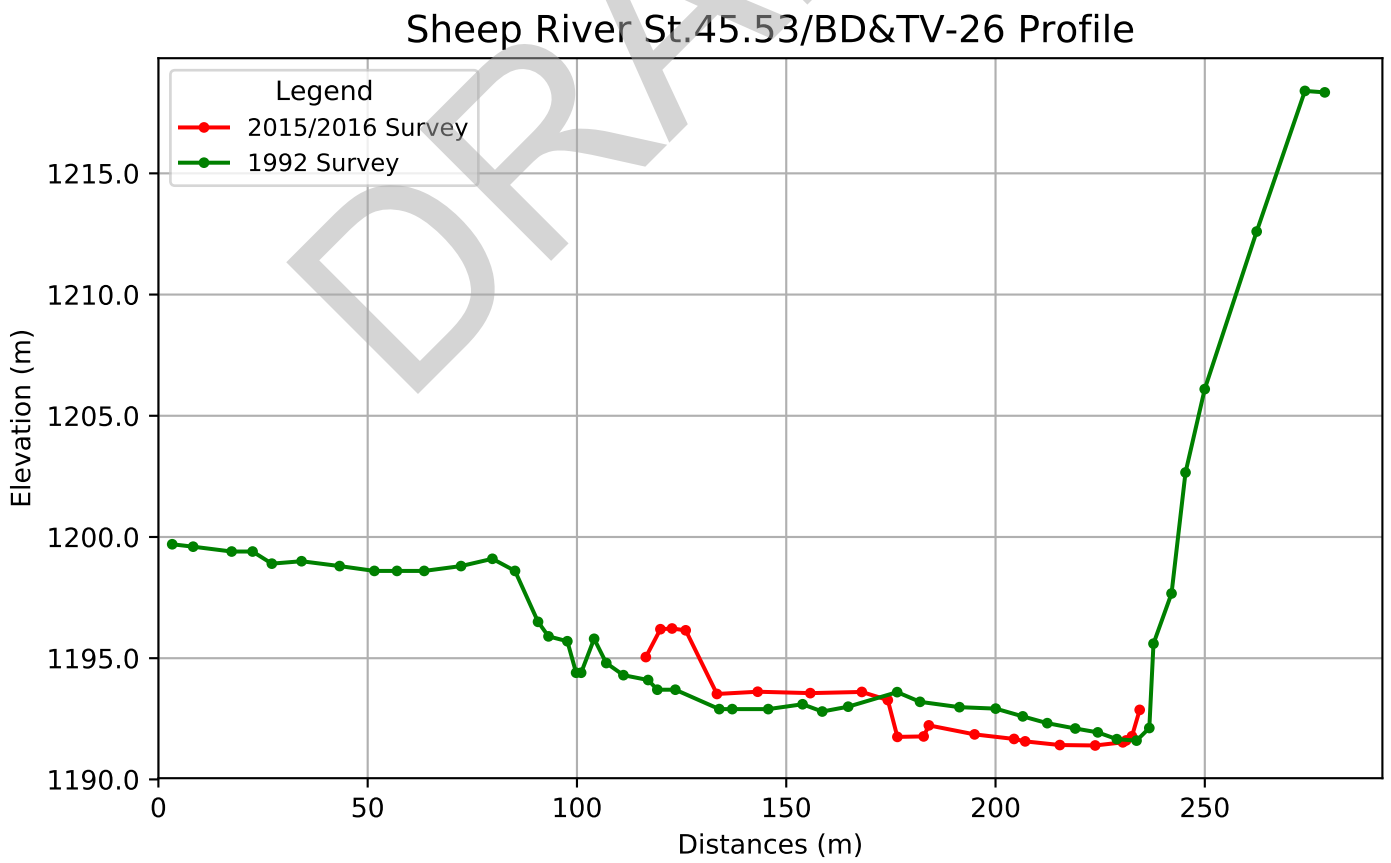

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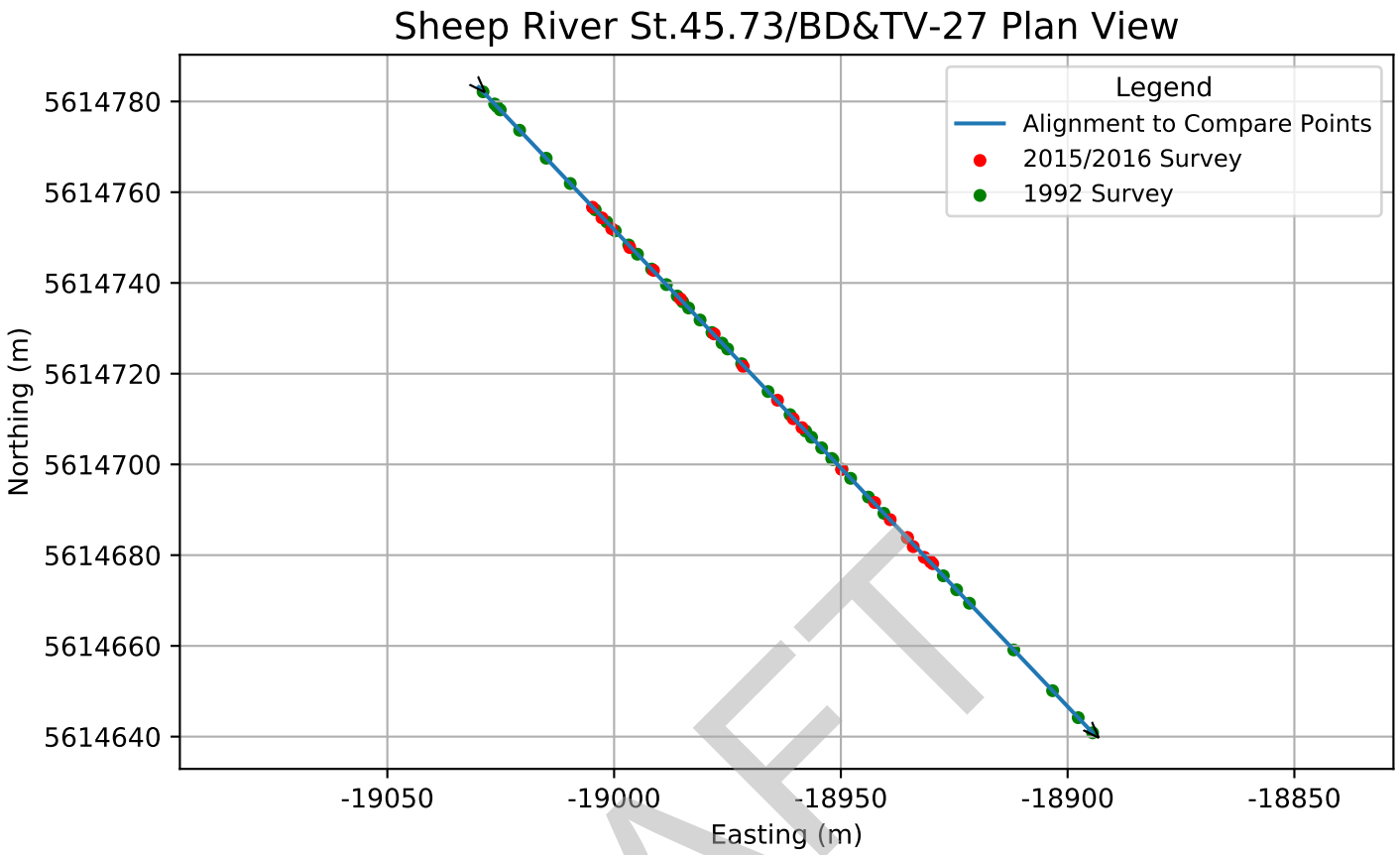

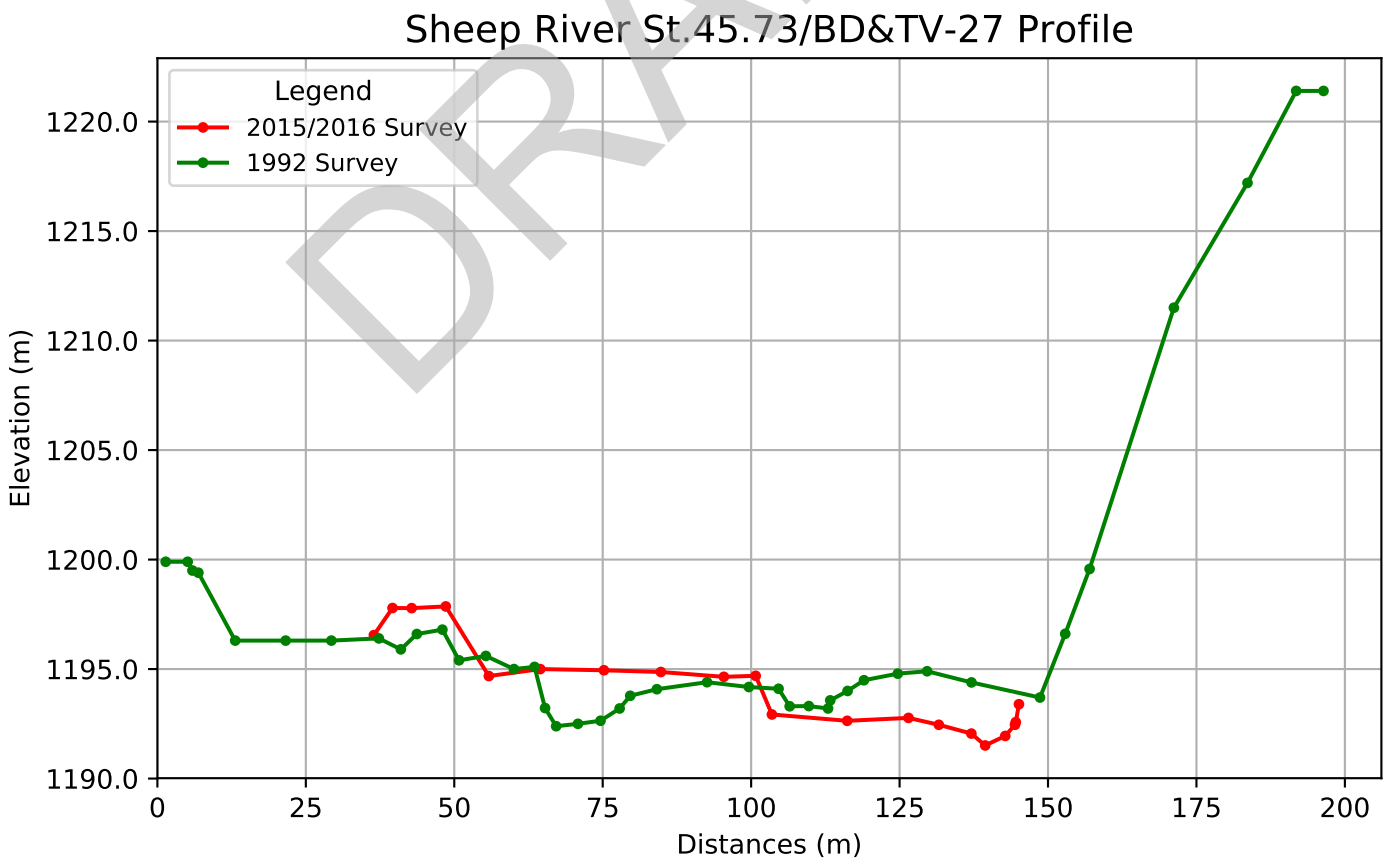

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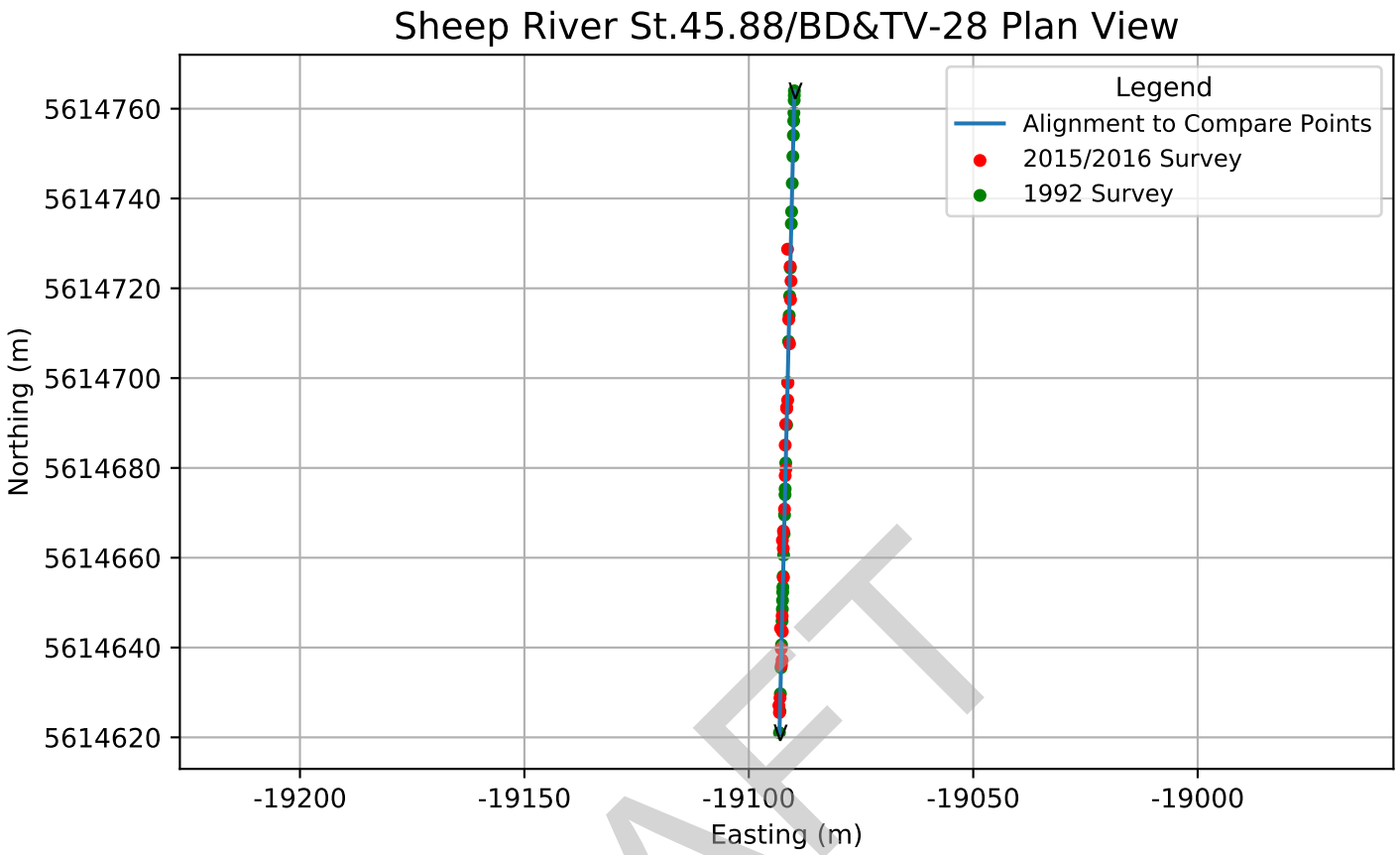

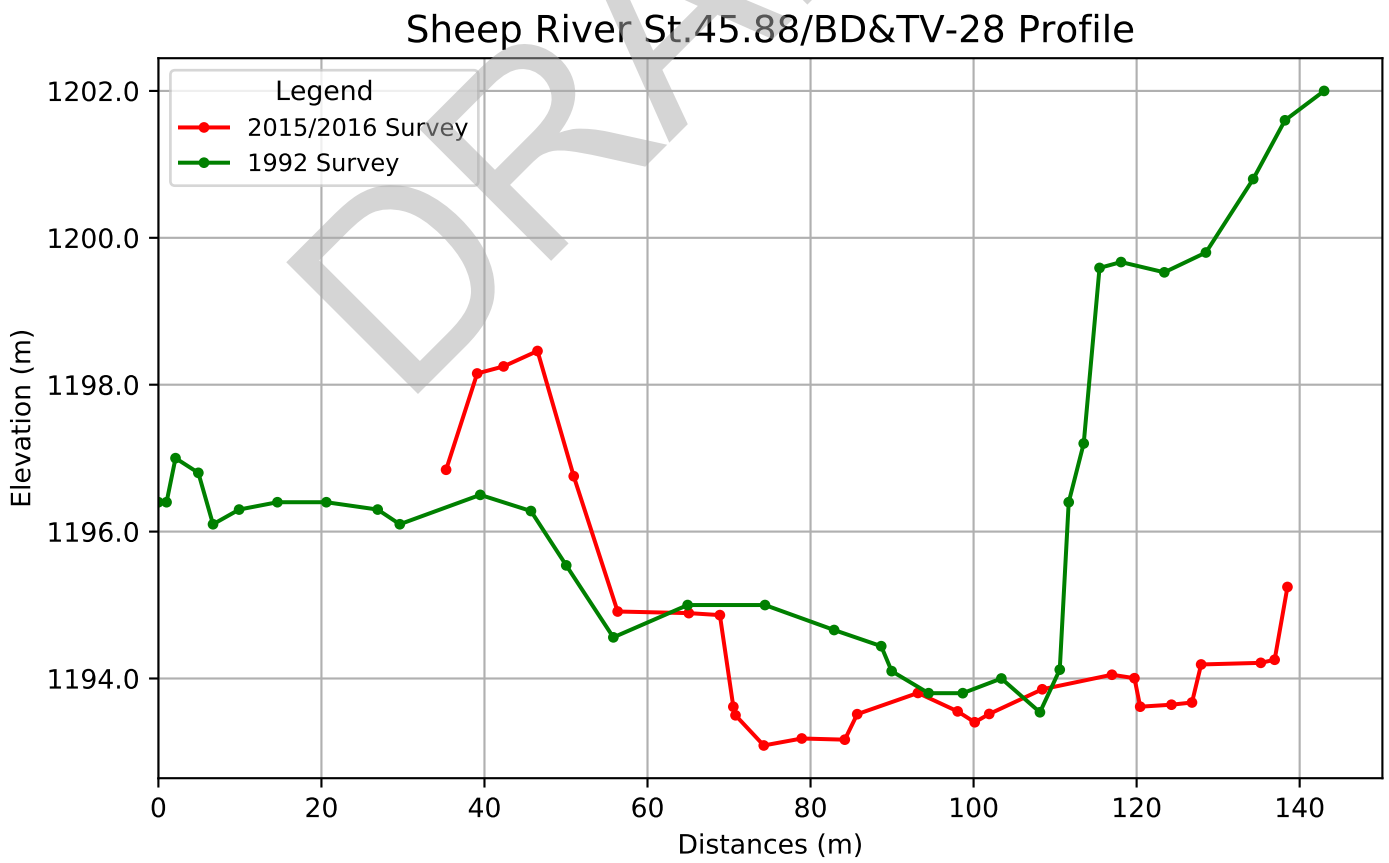

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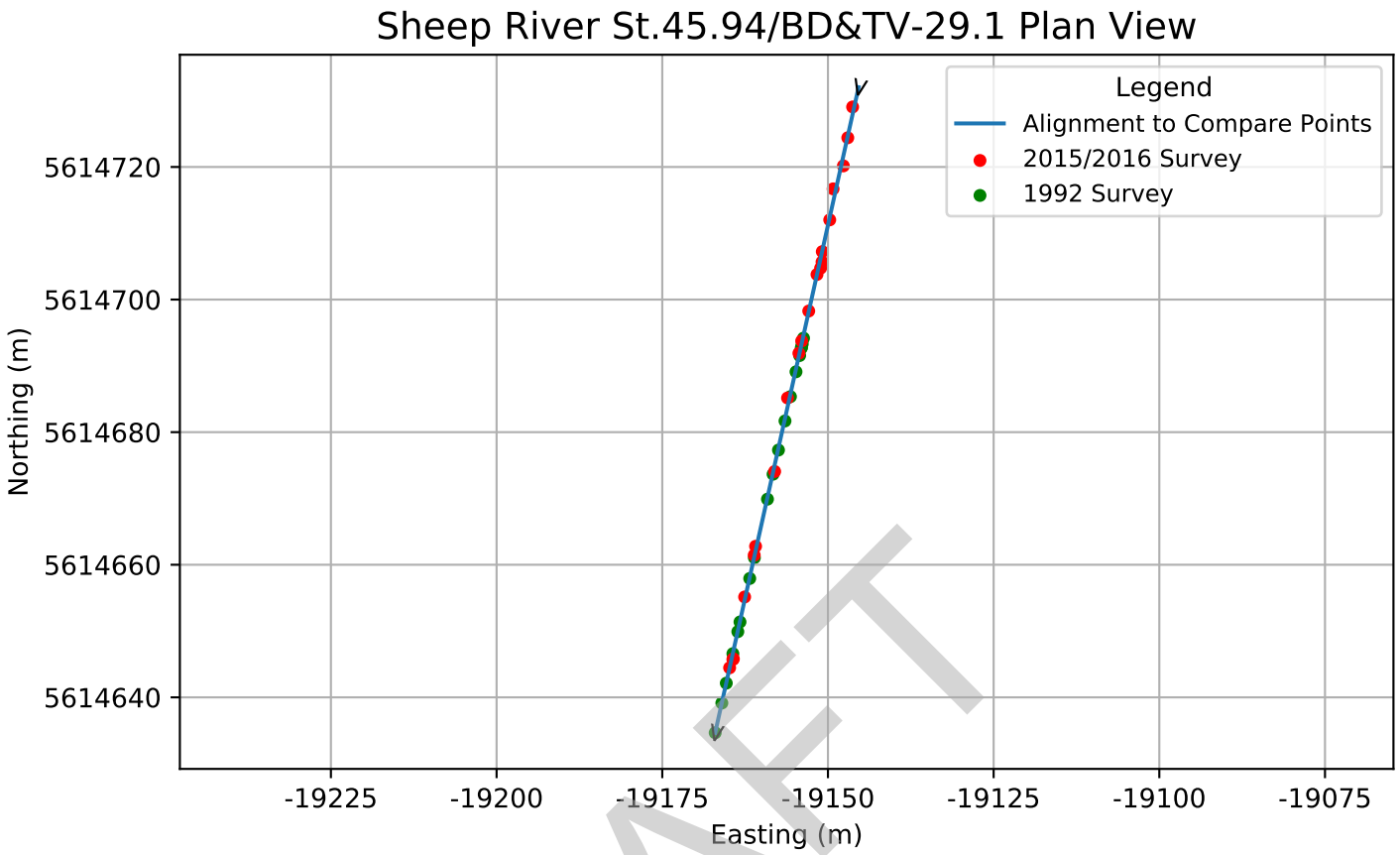

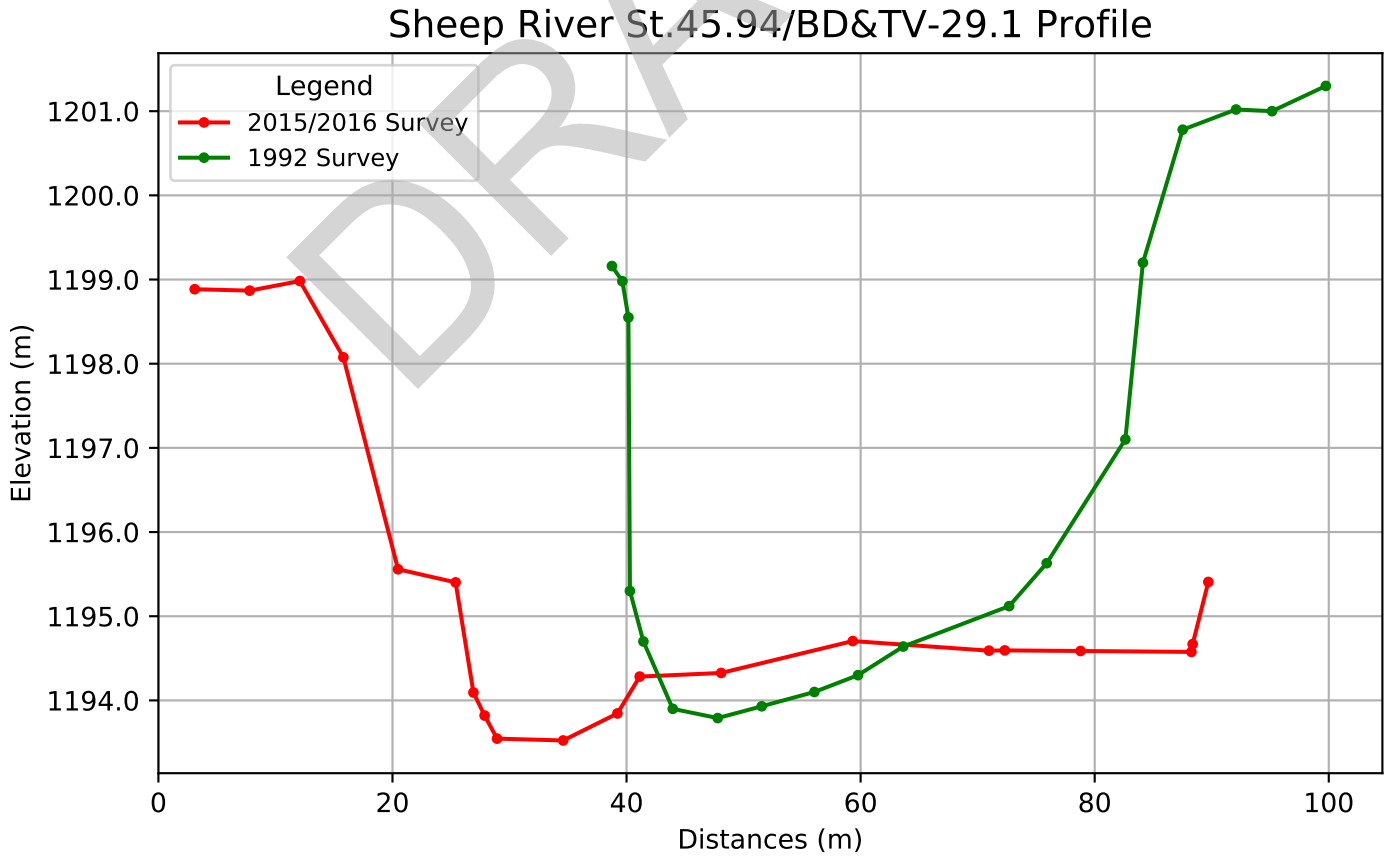

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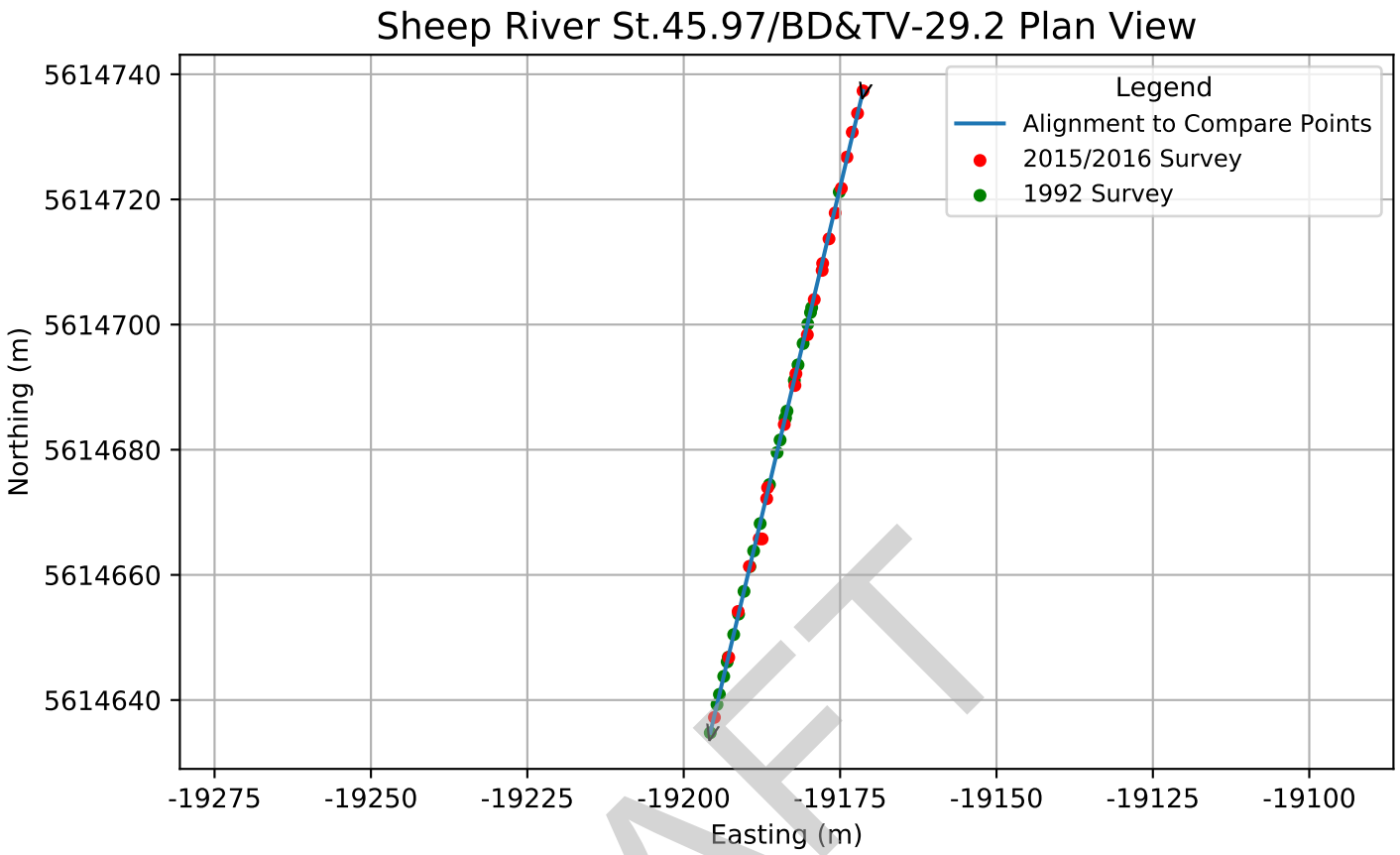

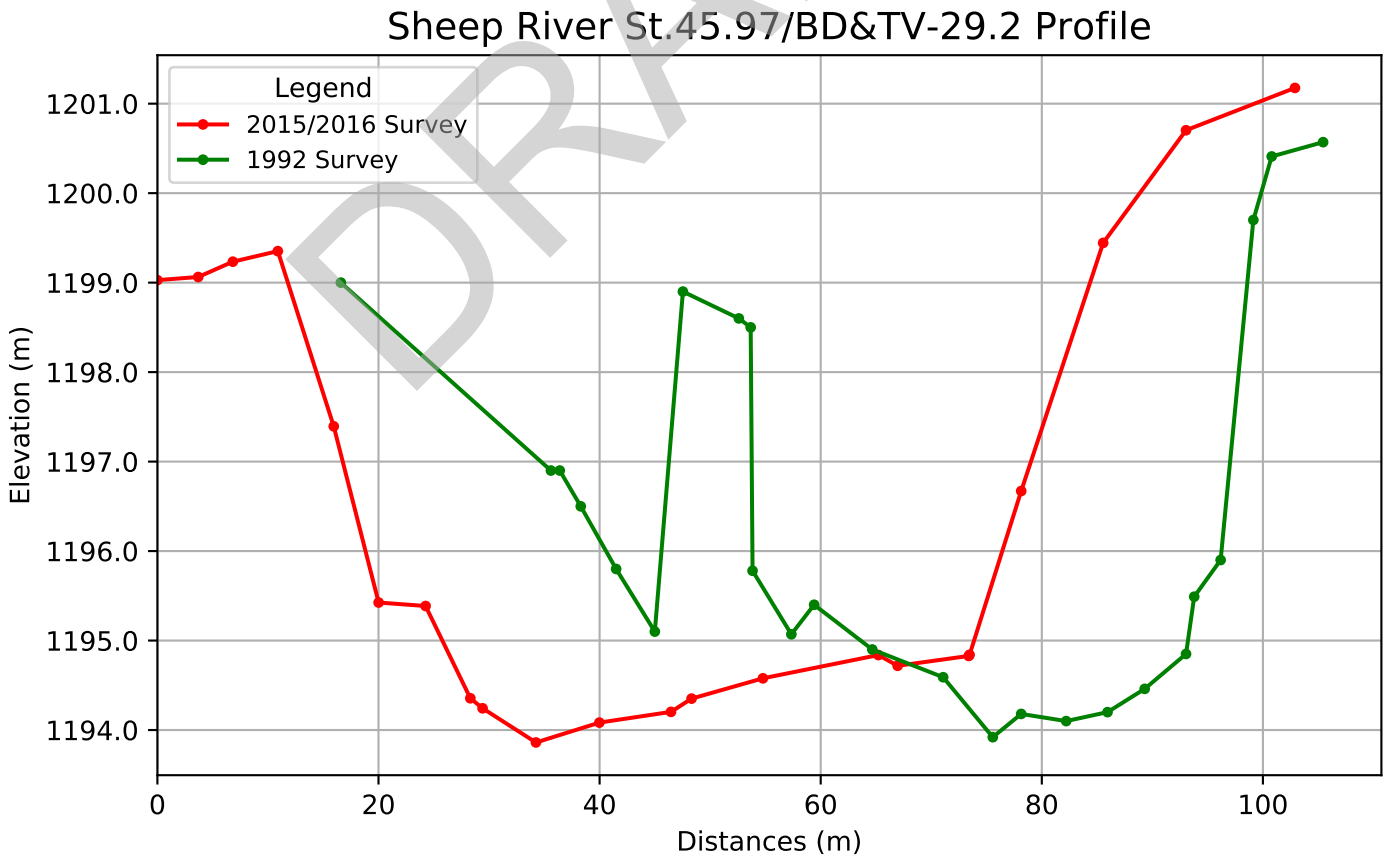

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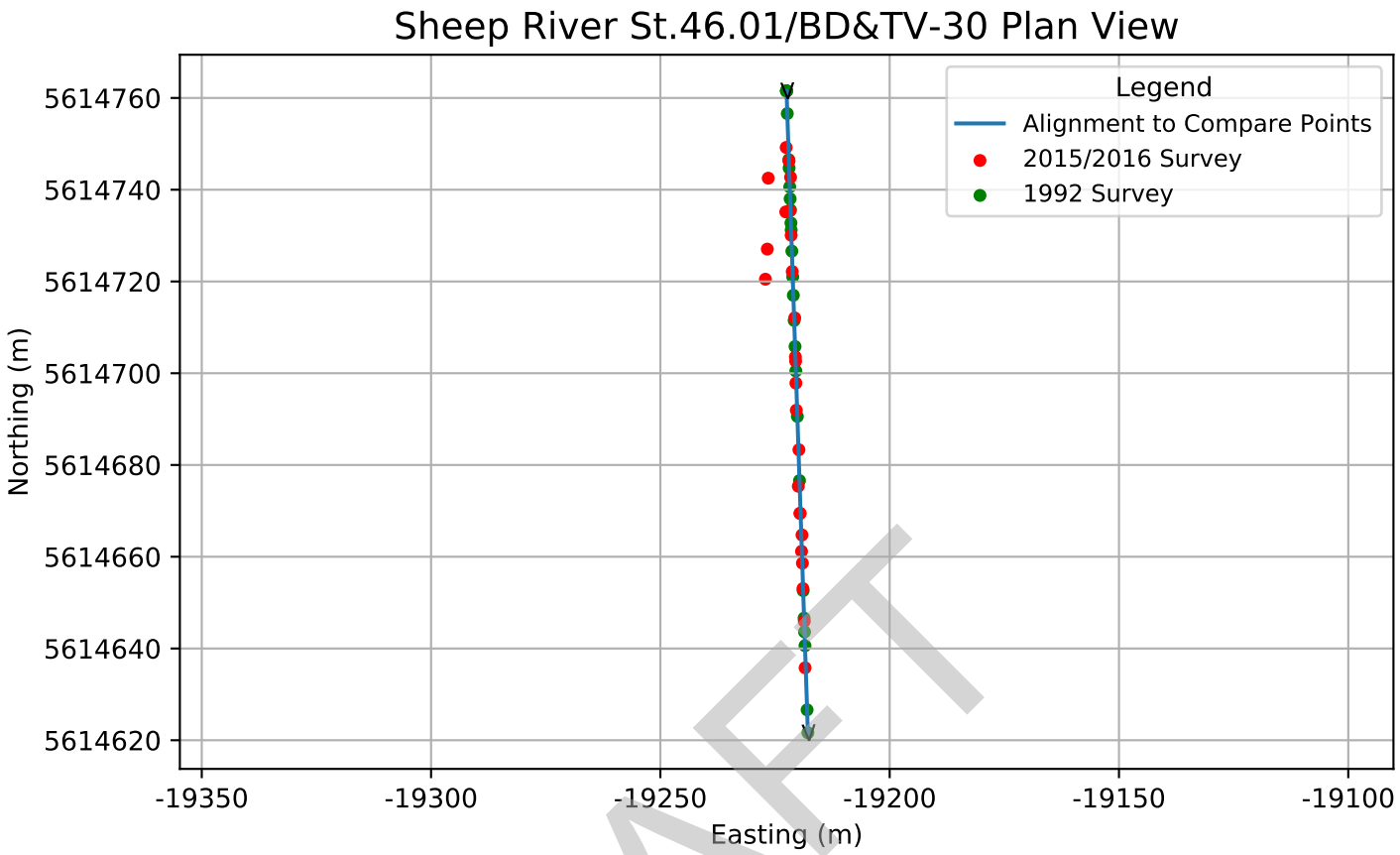

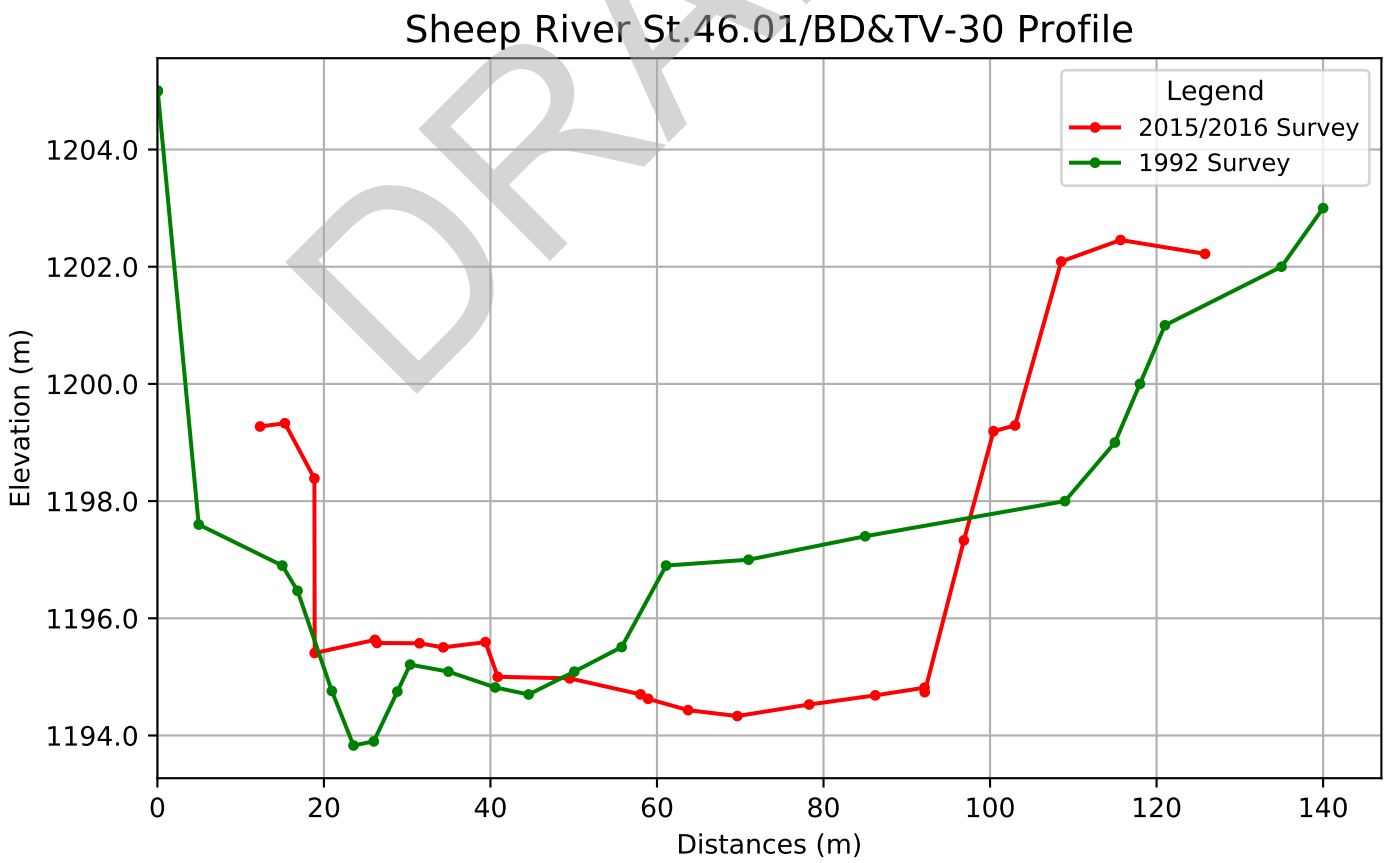

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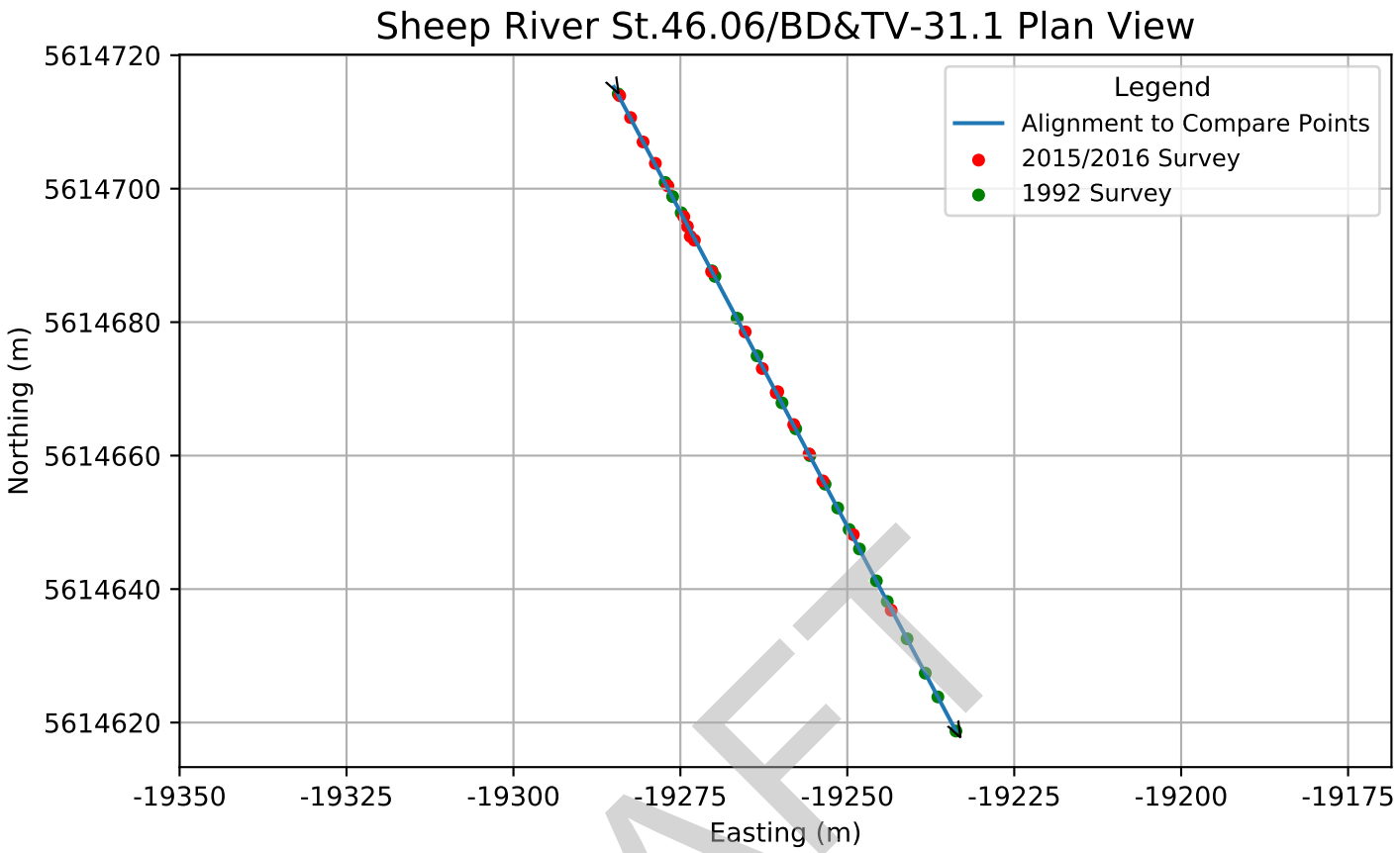

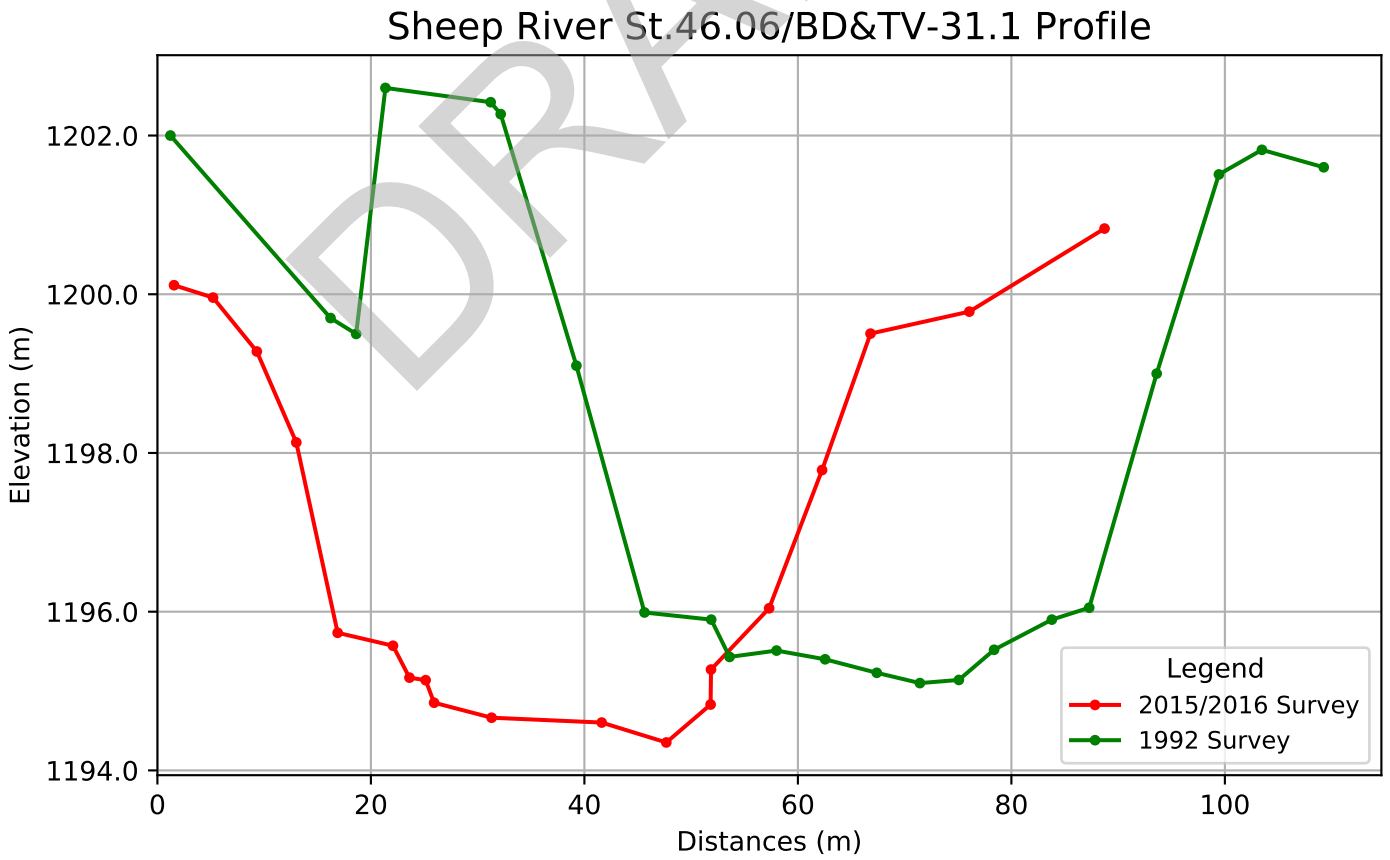

Note:

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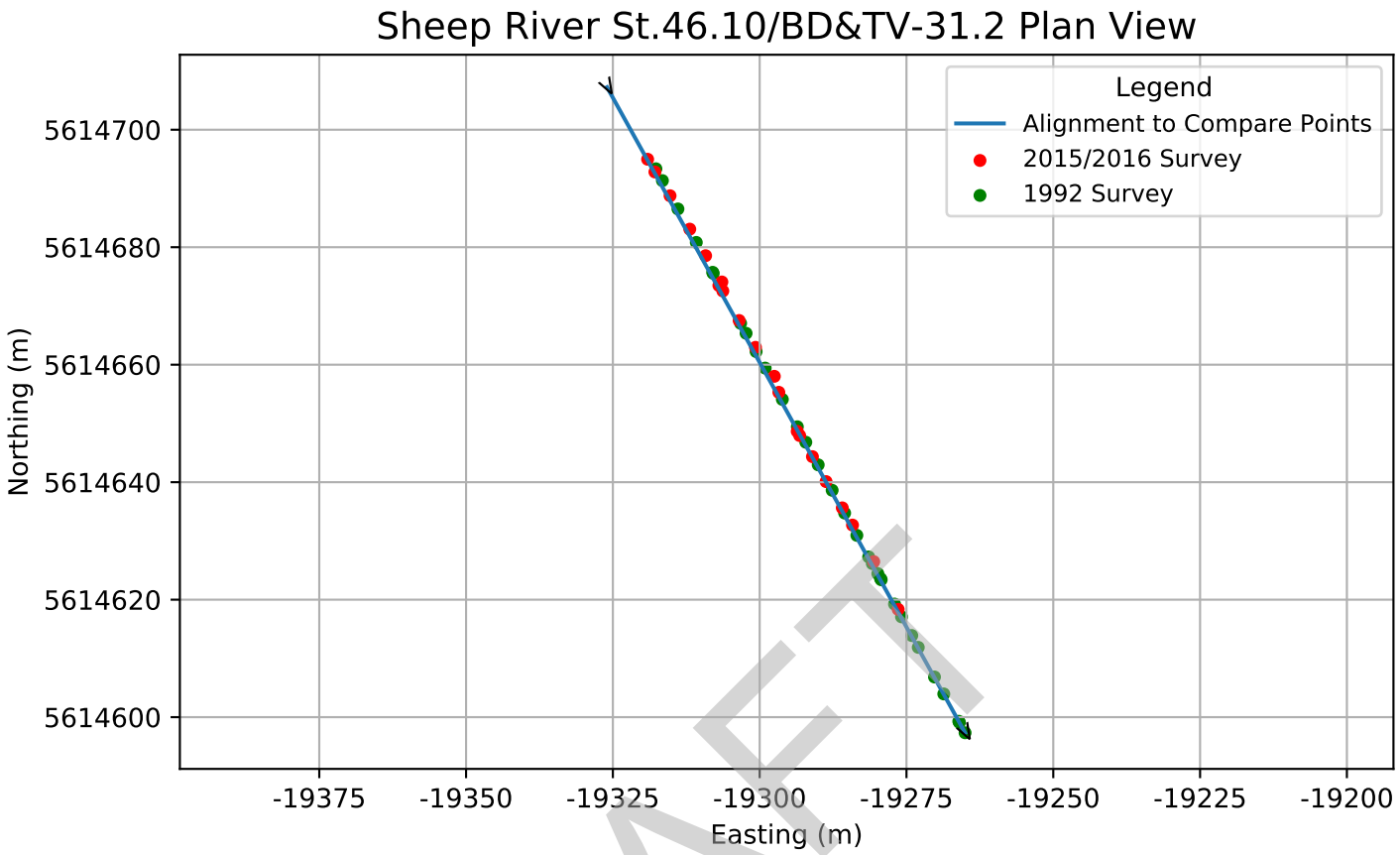

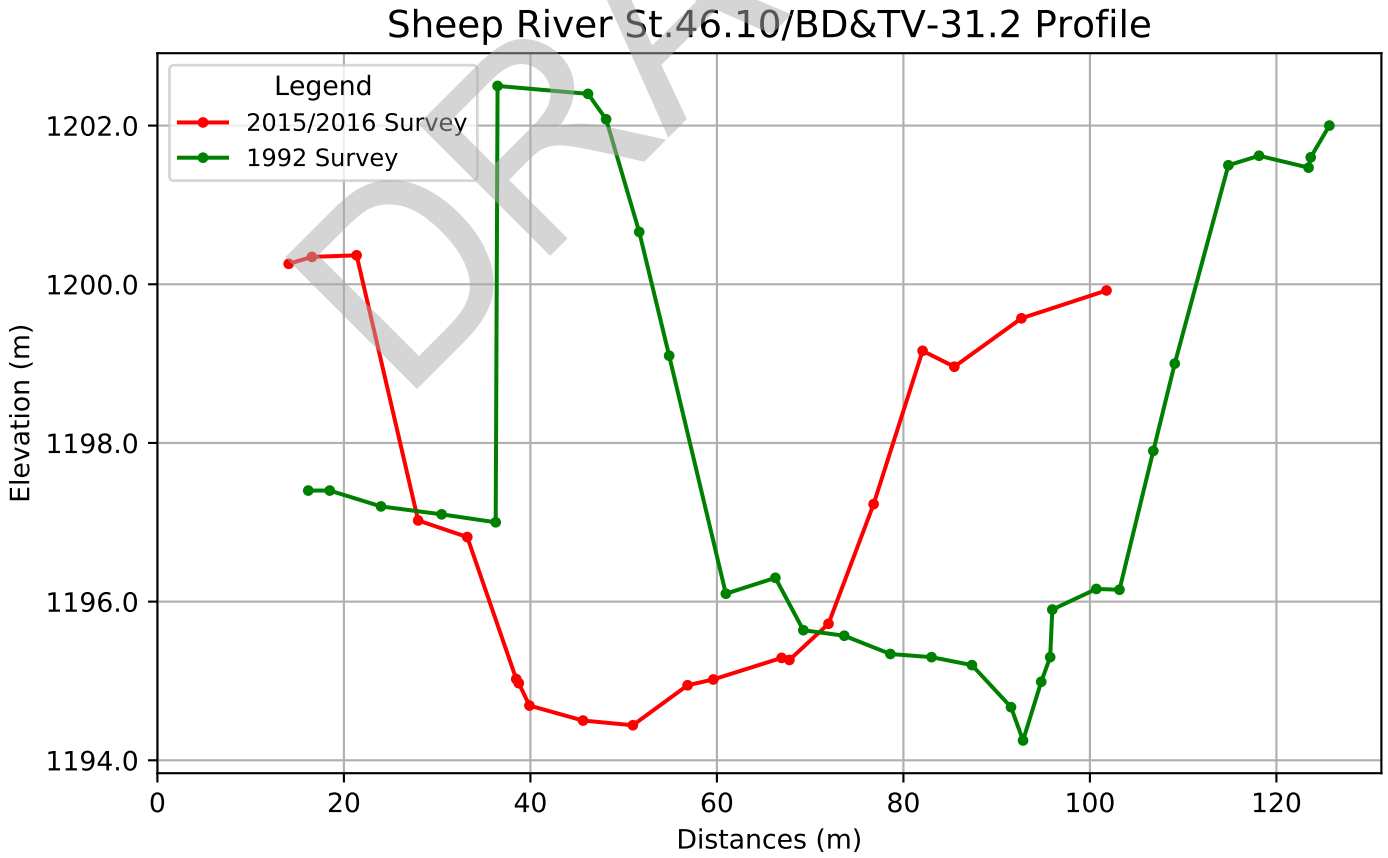

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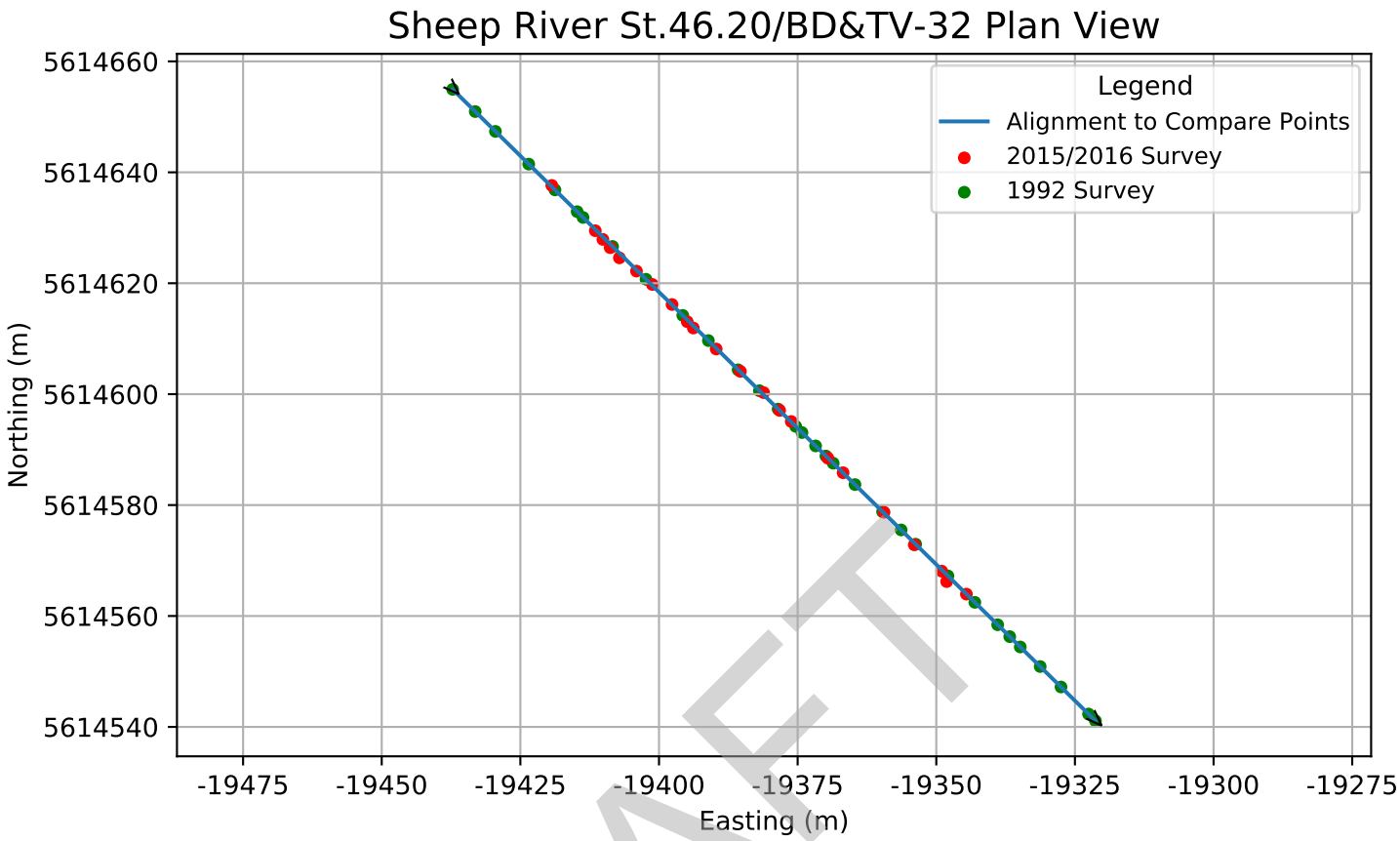

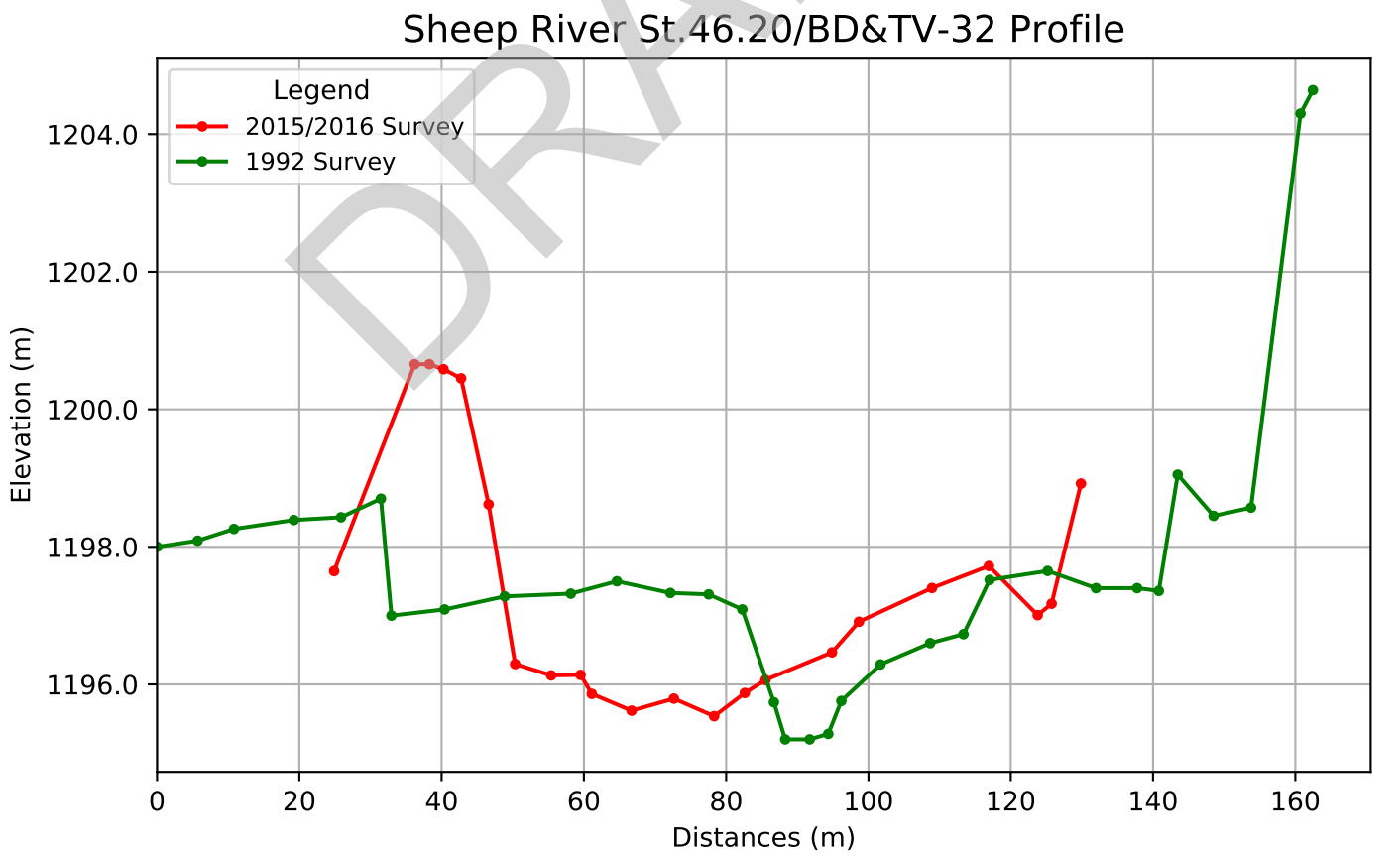

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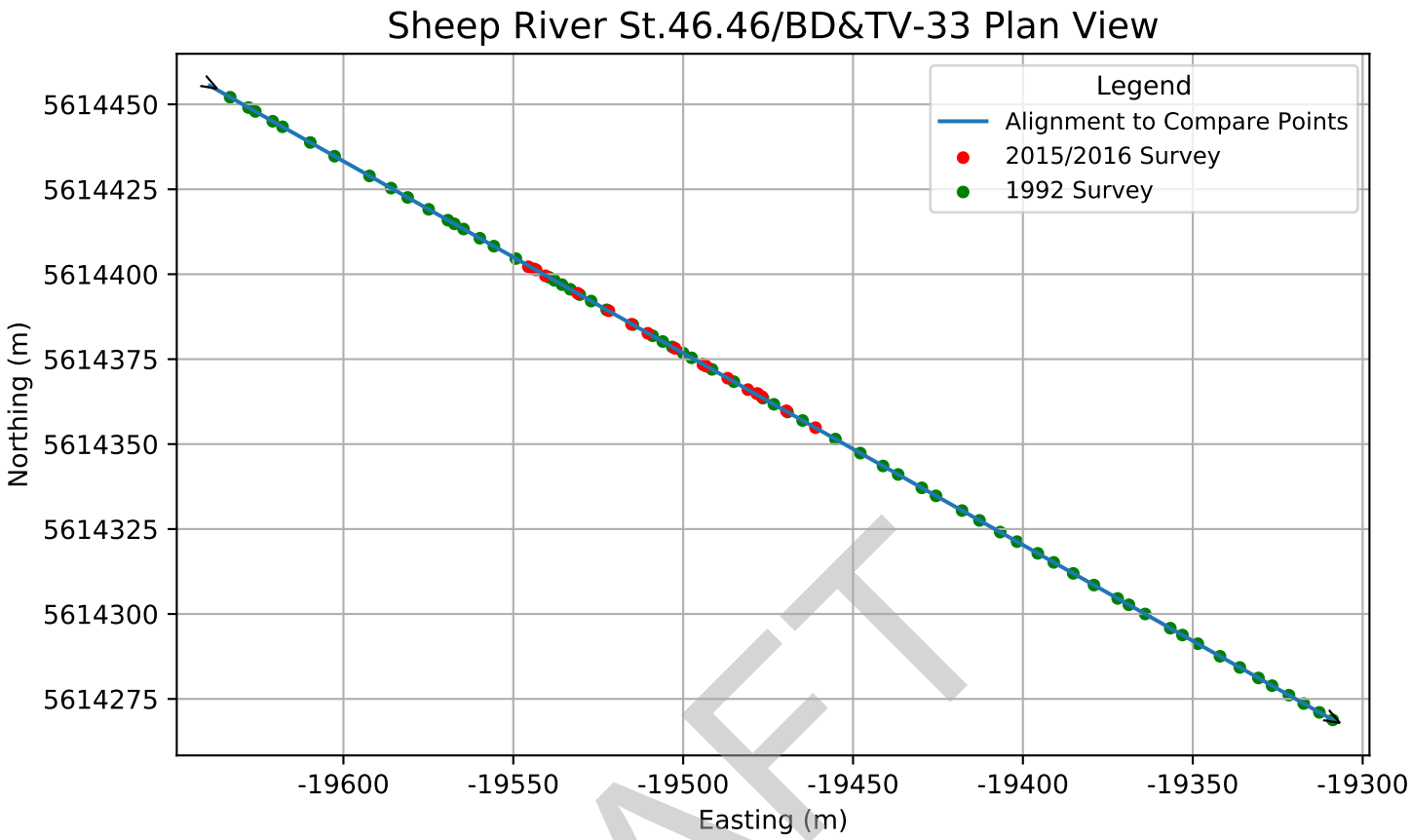

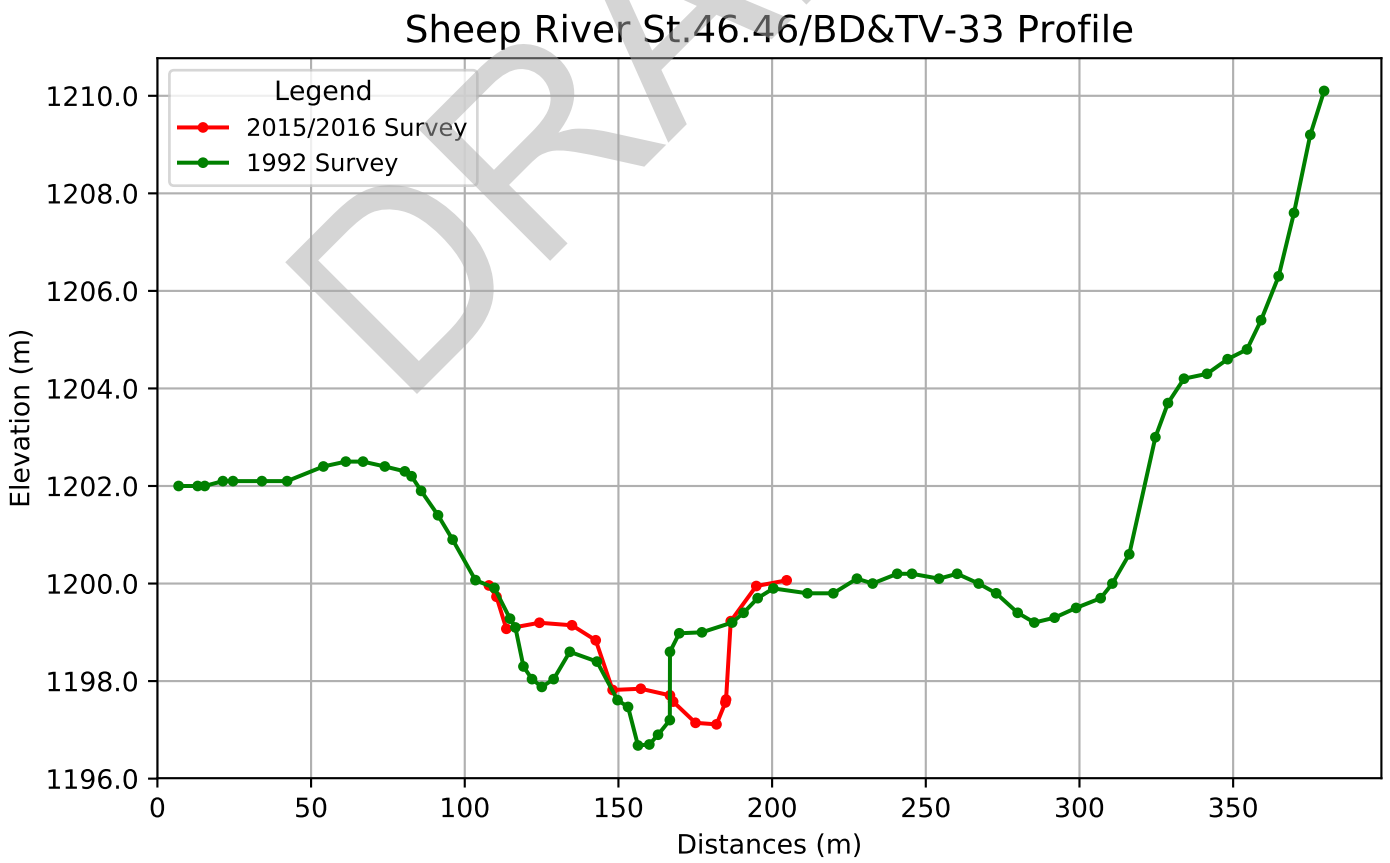

Note:

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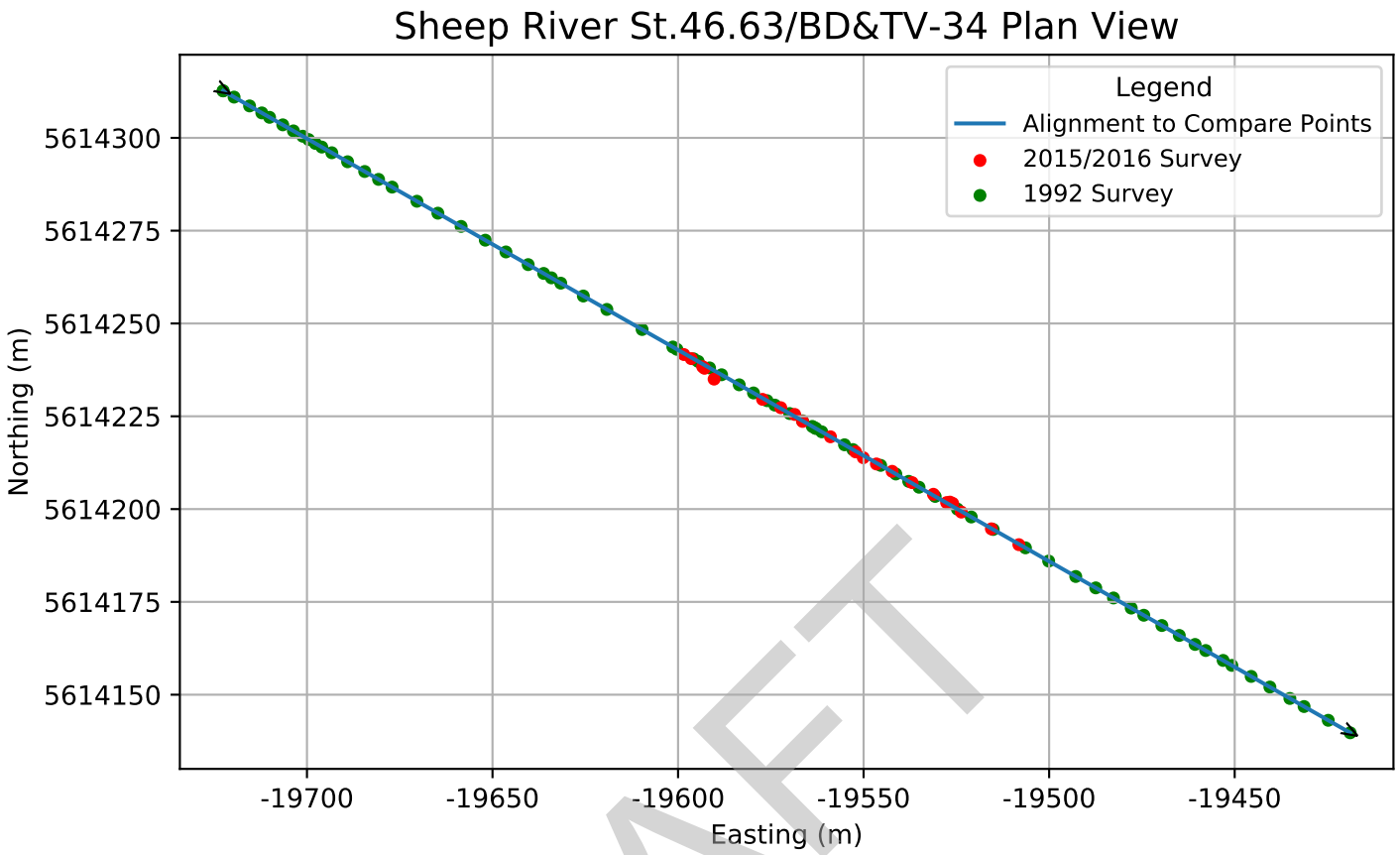

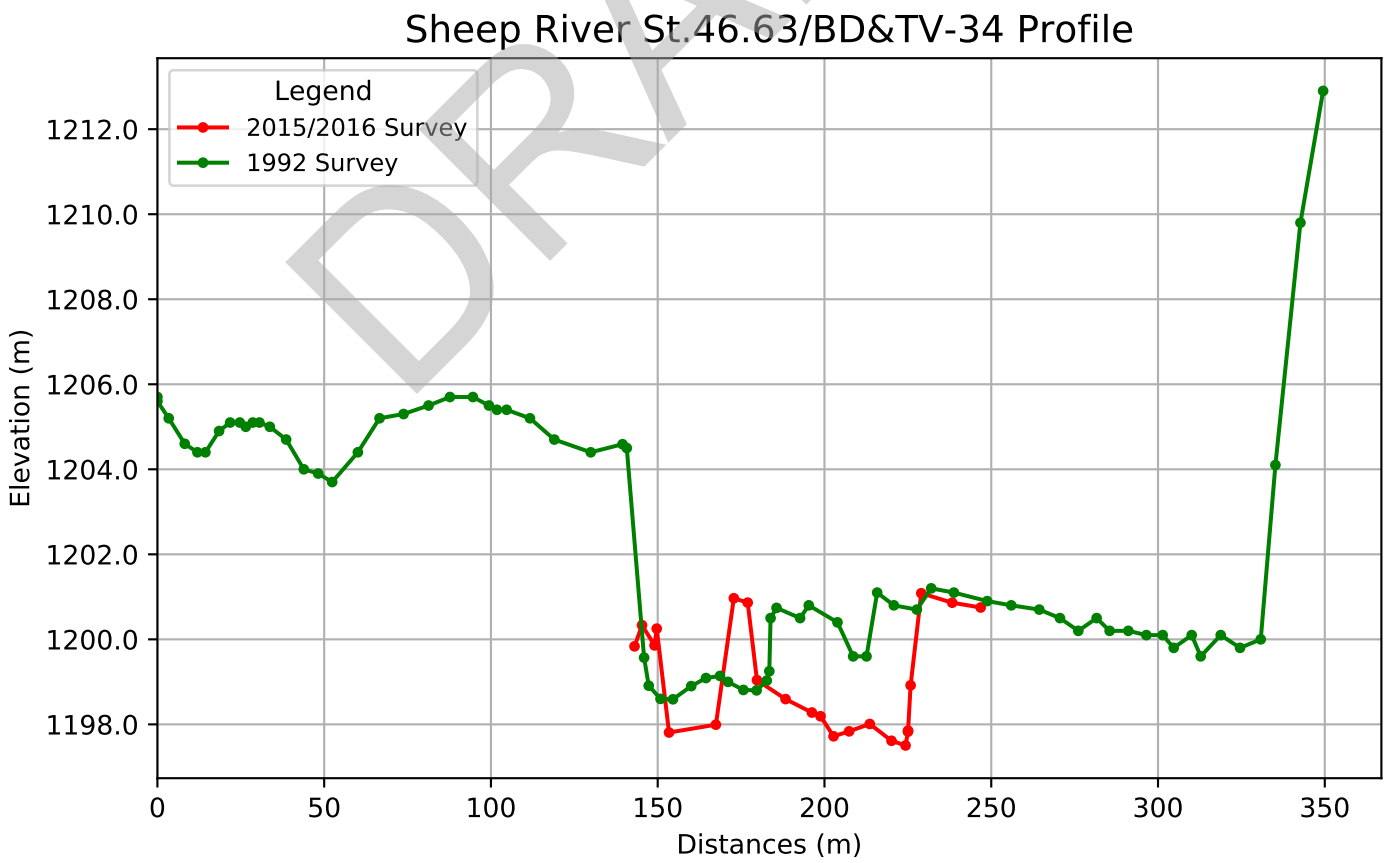

Note:

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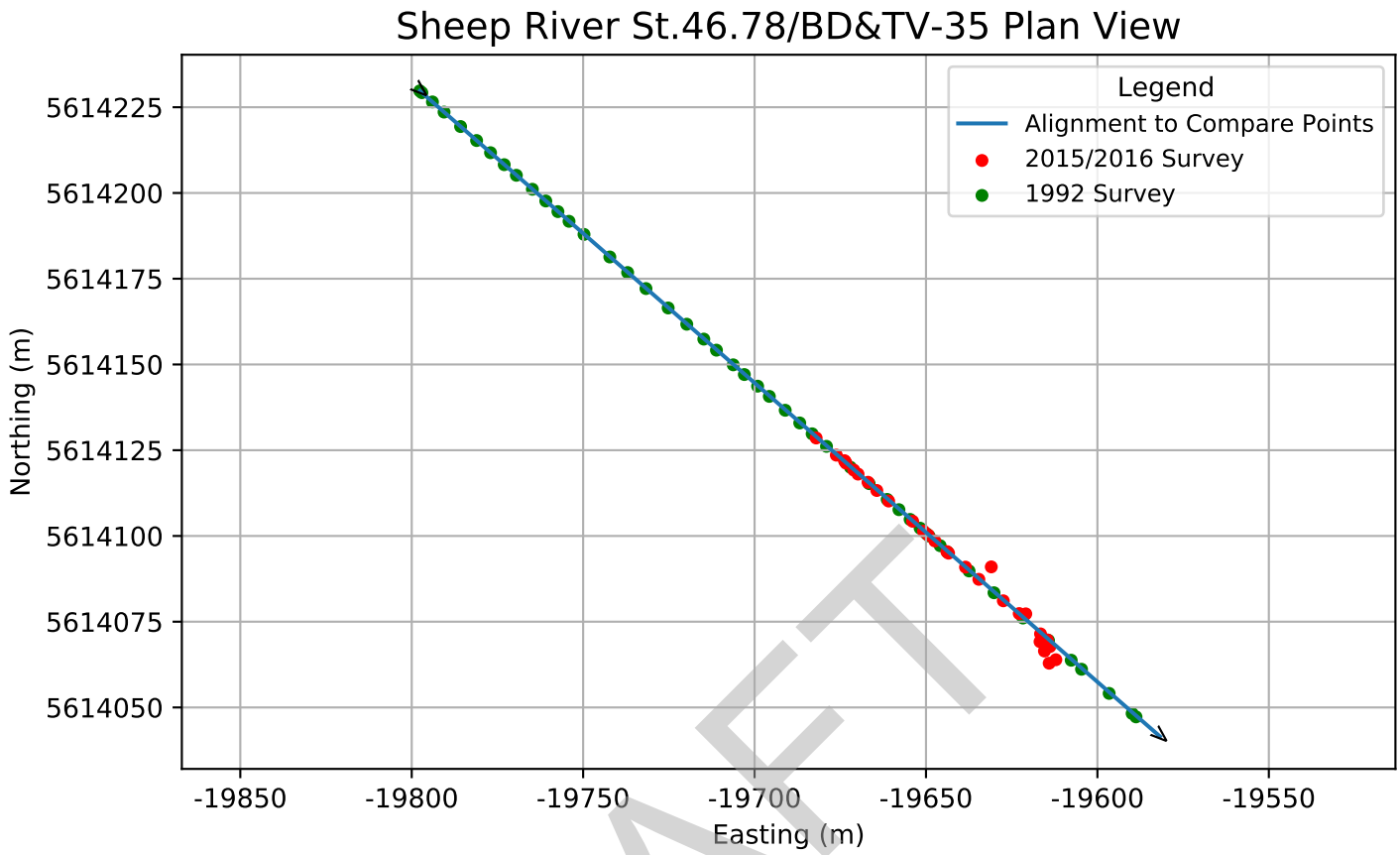

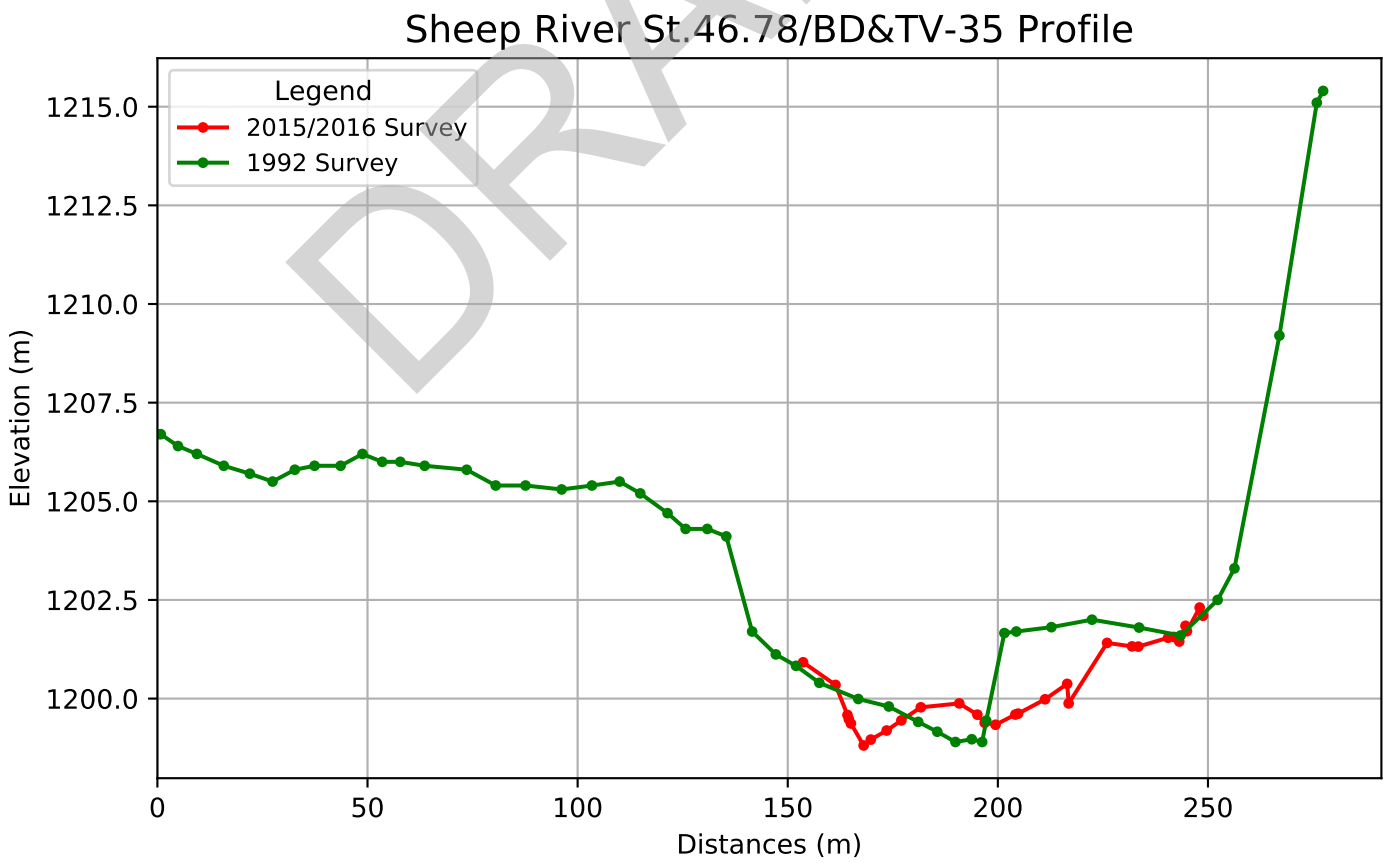

Note:

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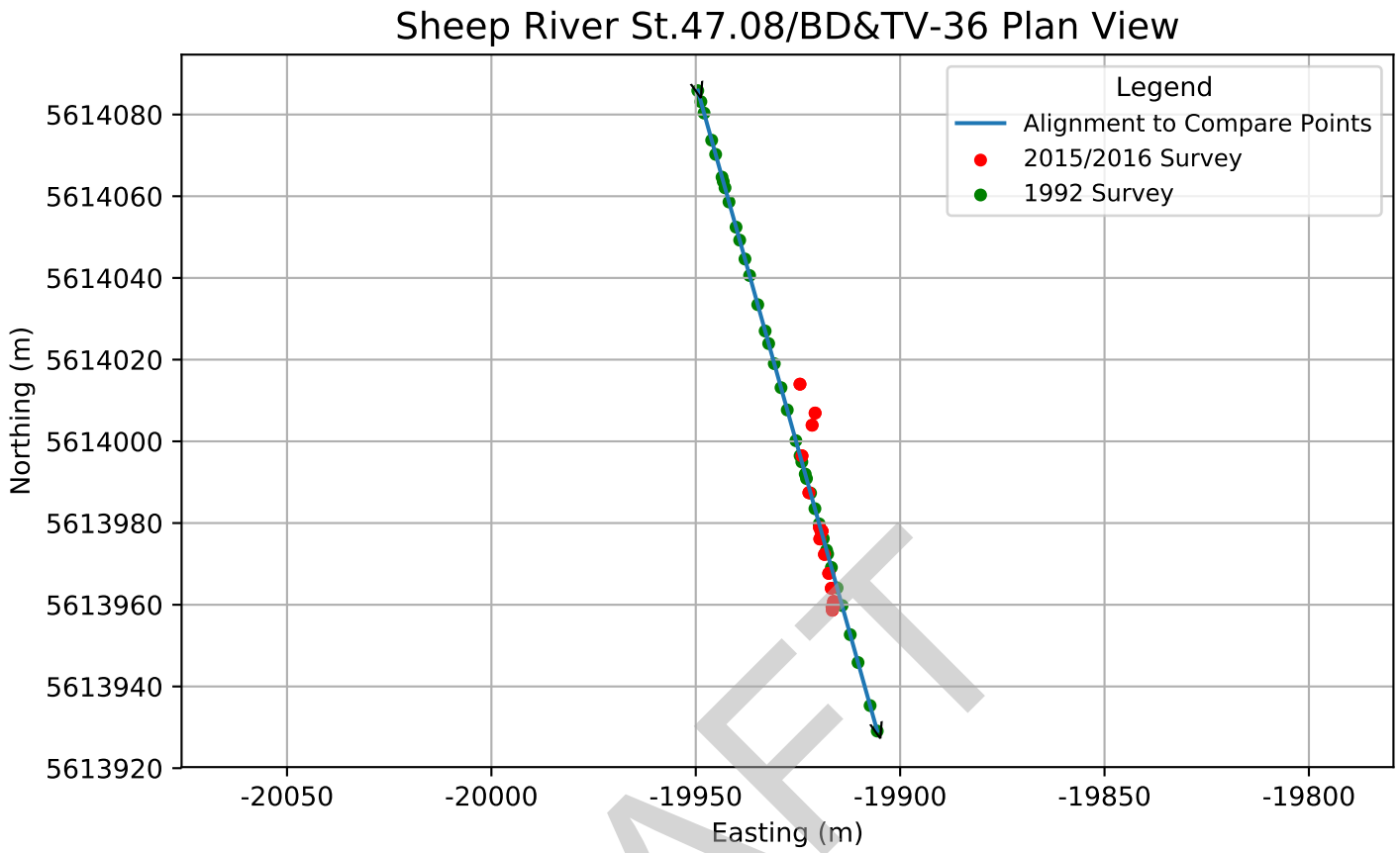

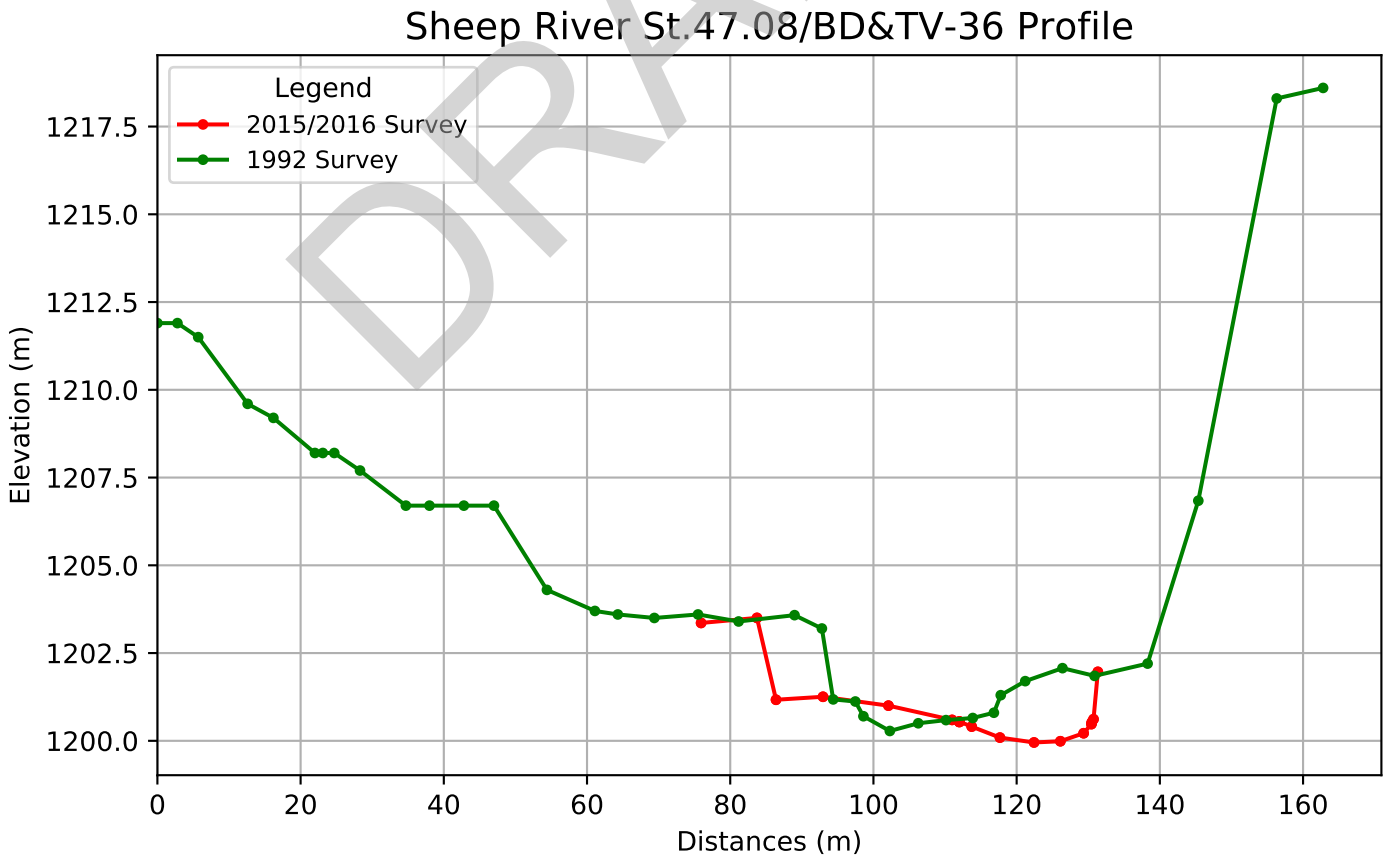

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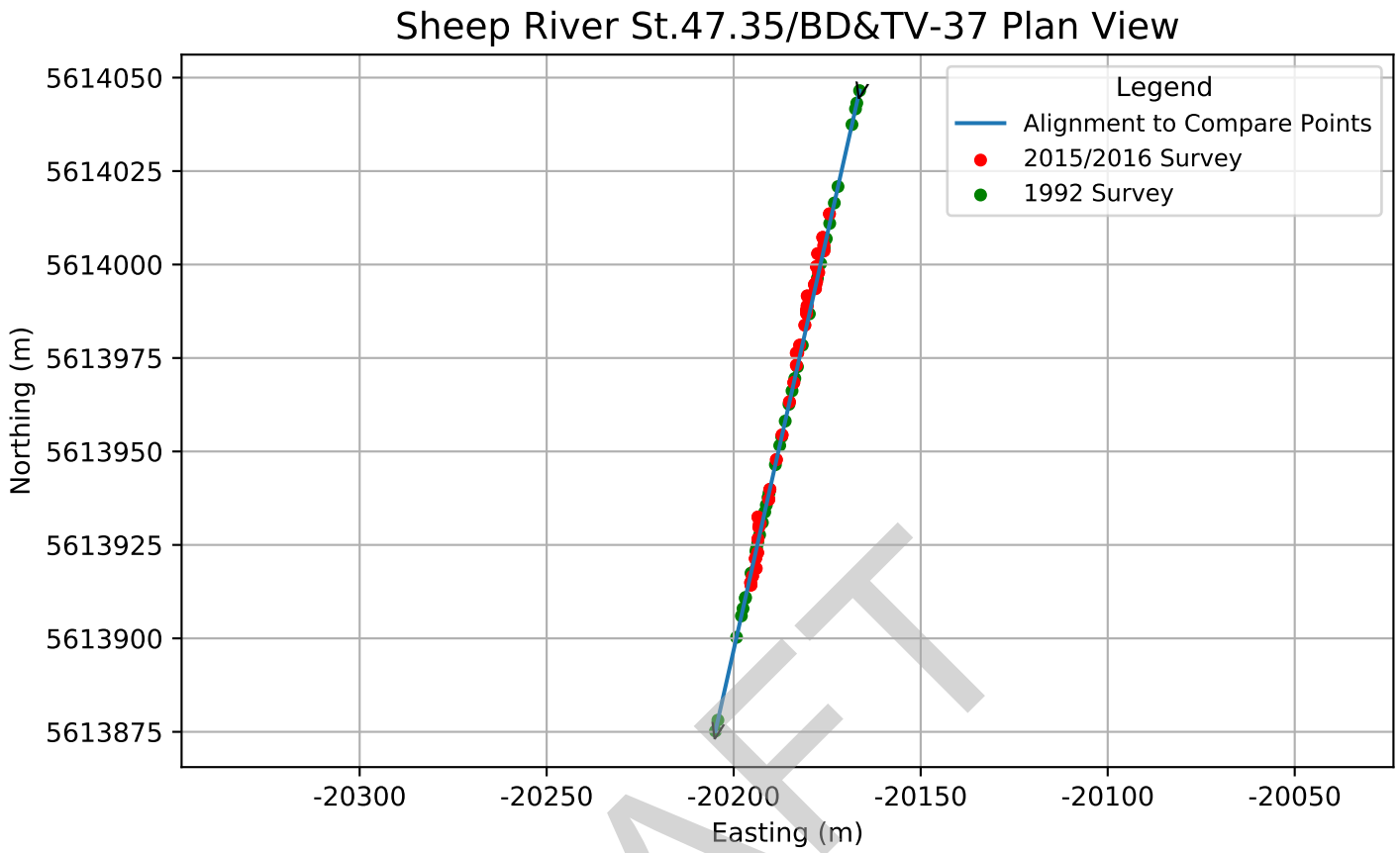

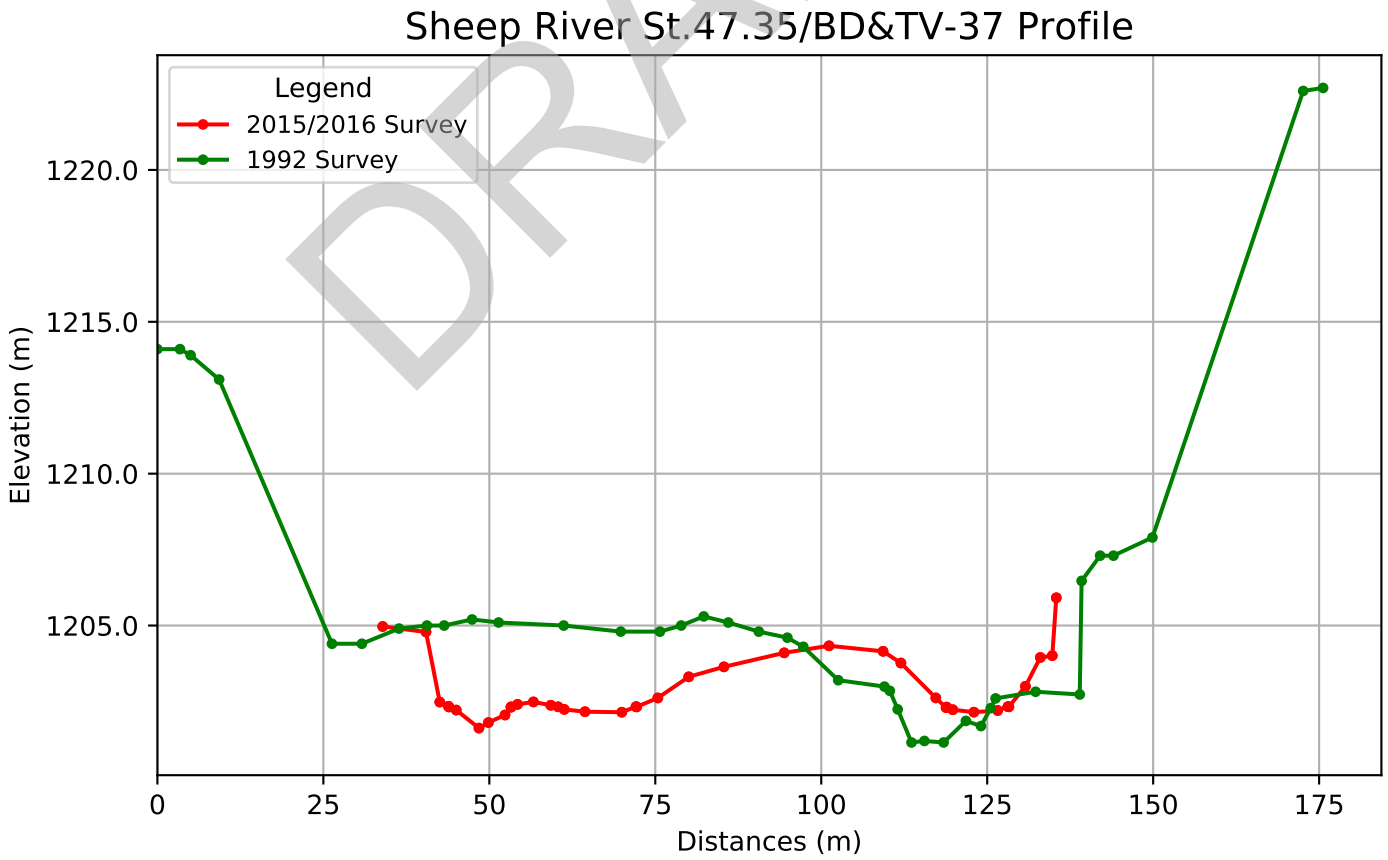

Note:

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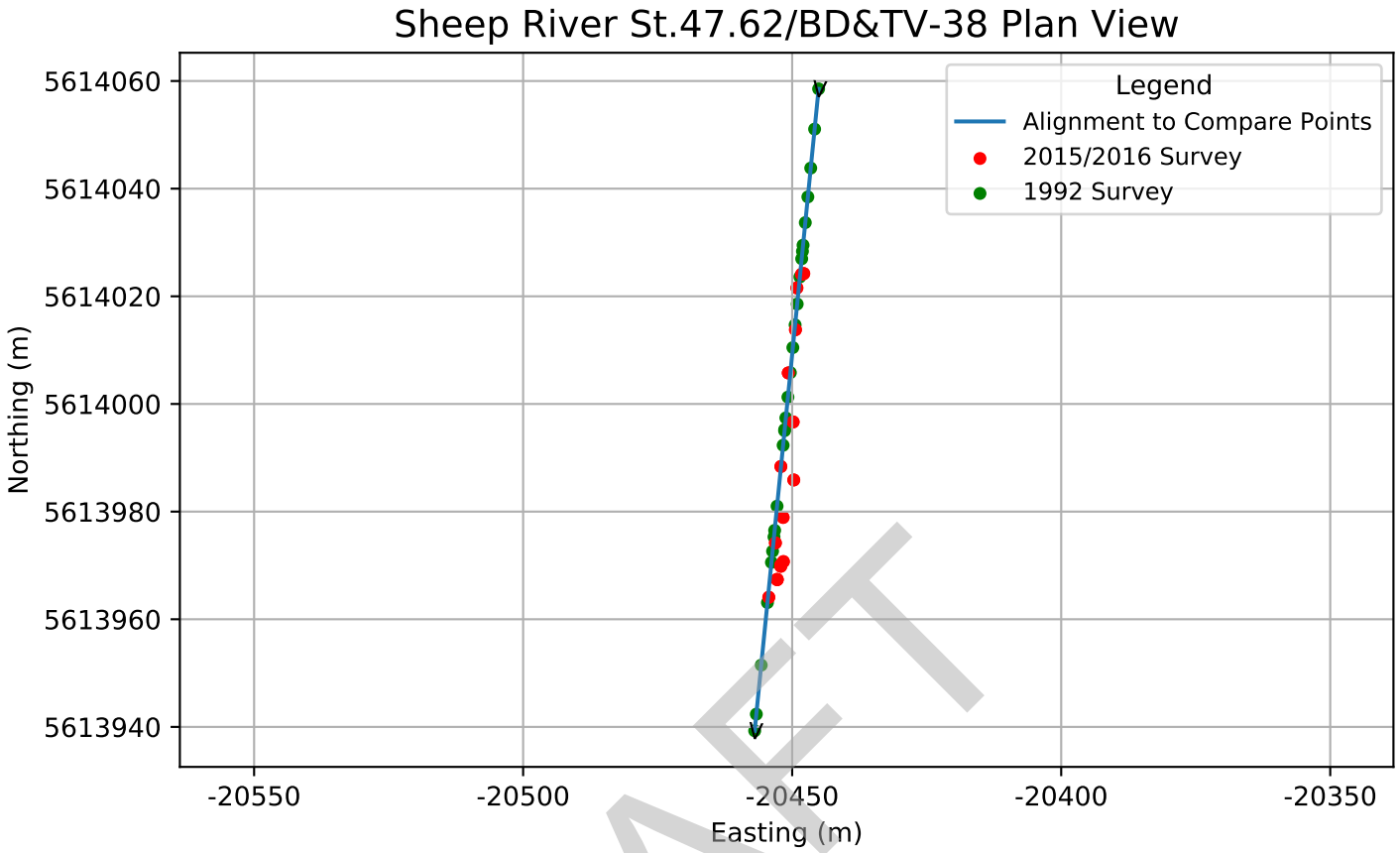

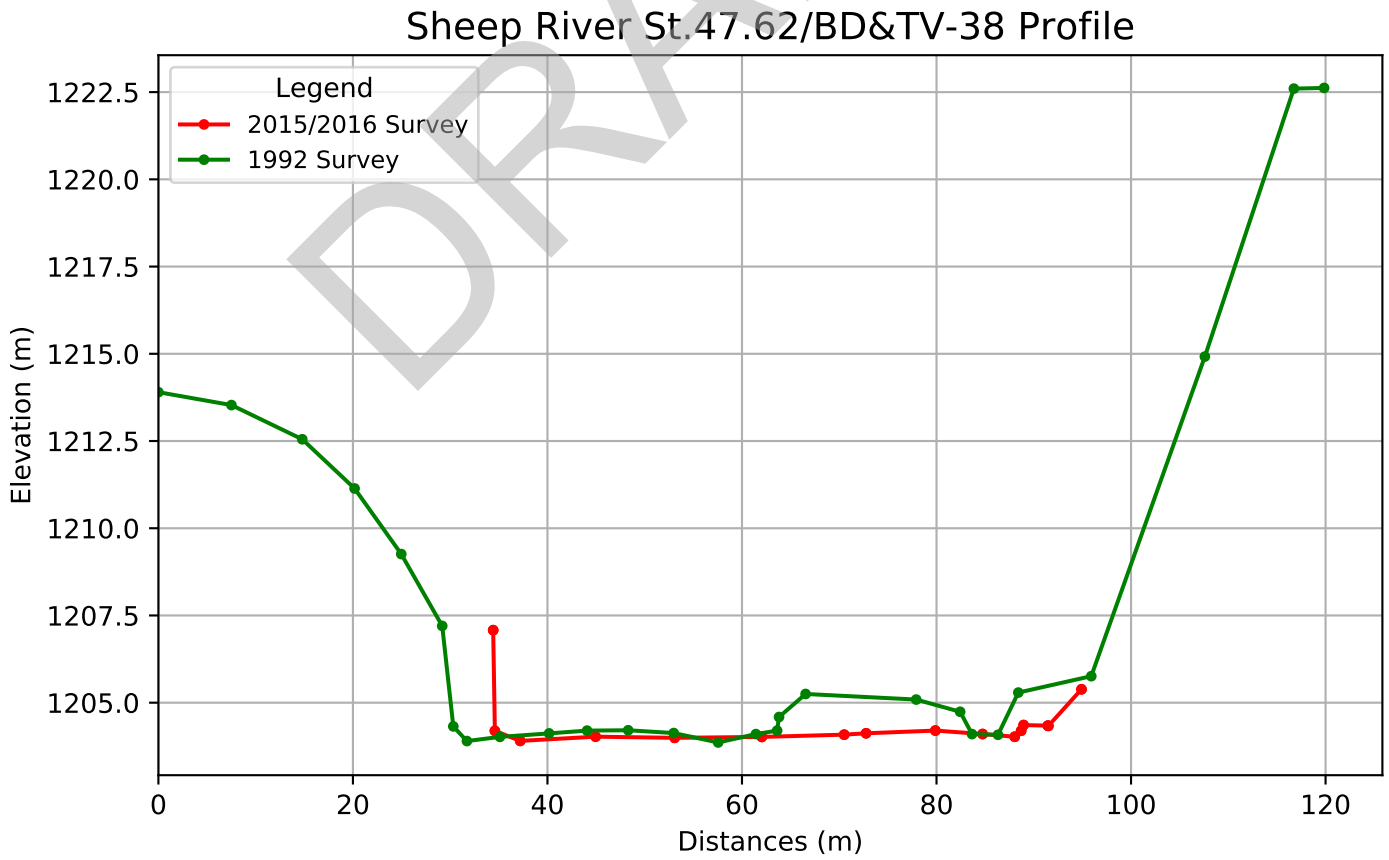

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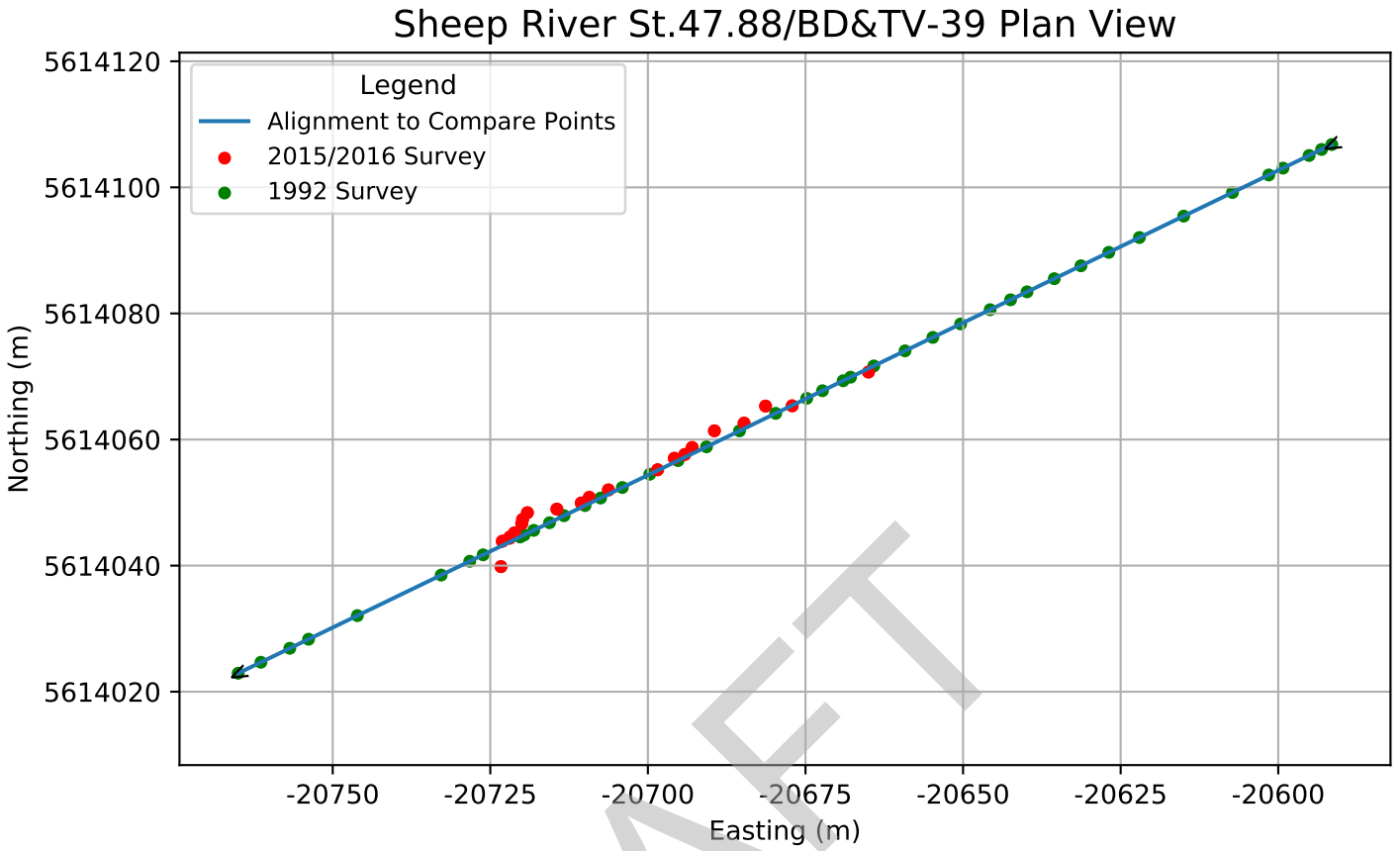
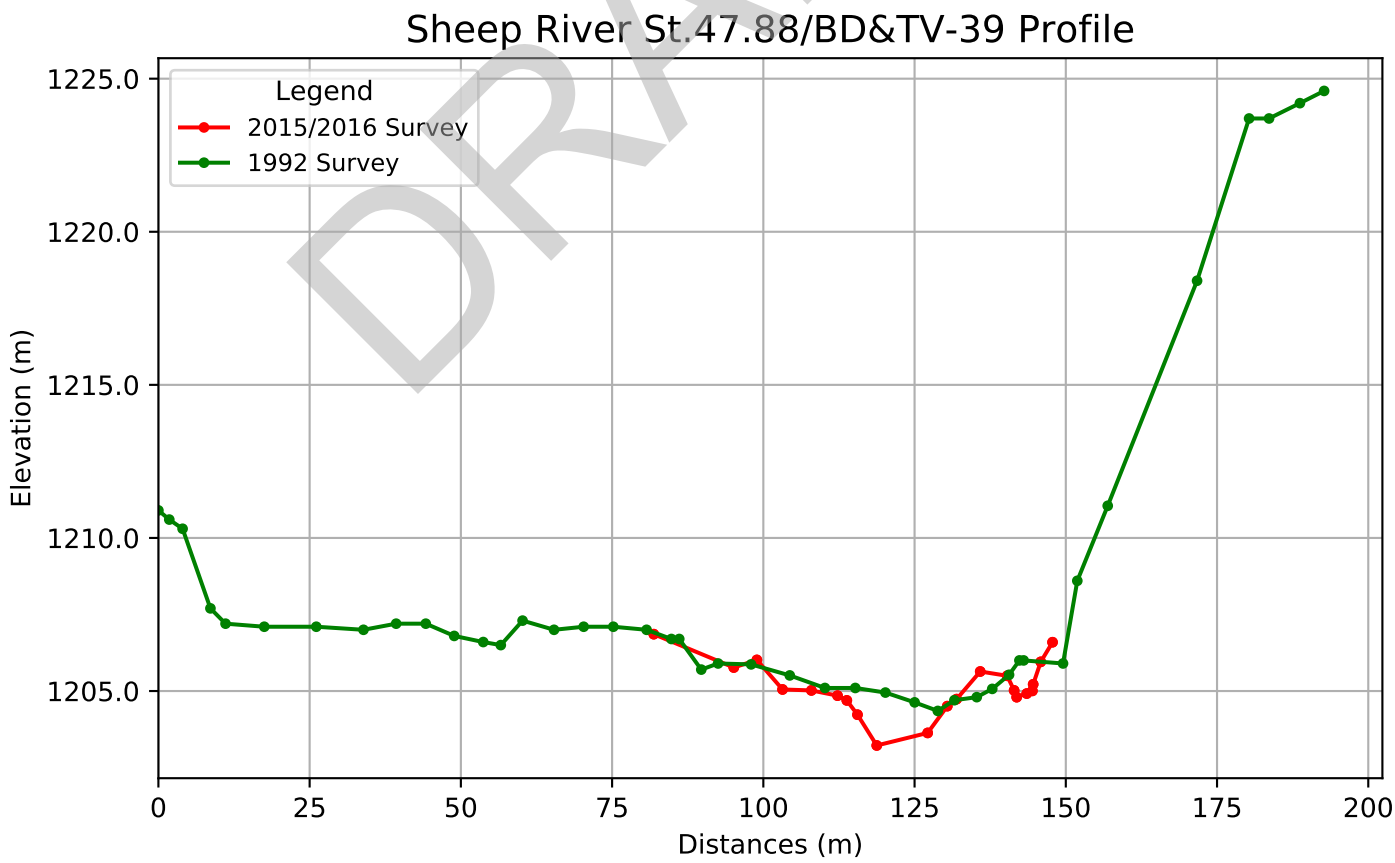


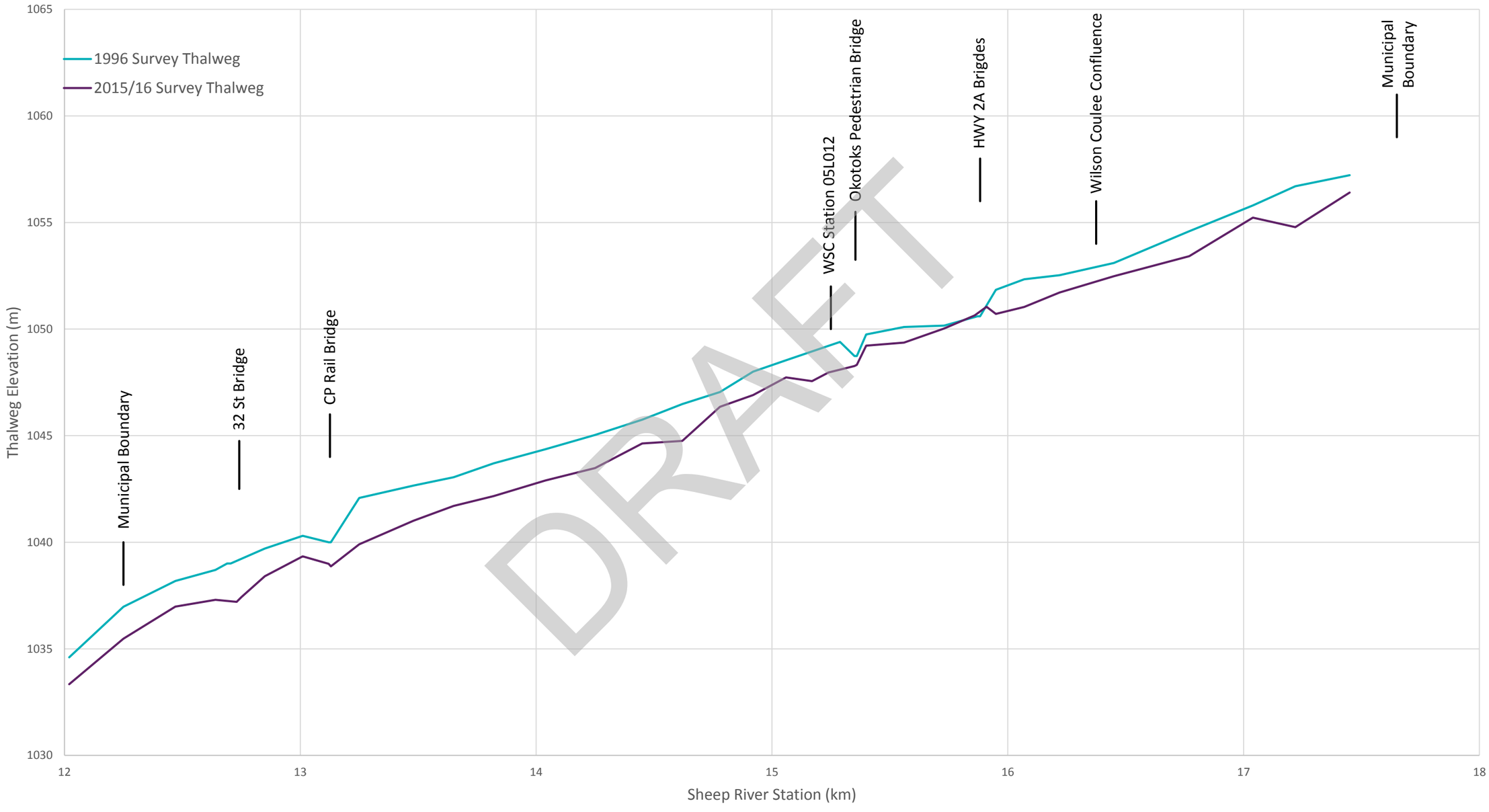


Note:

1.1992 Cross-Section data obtained from file SHEE_ENC_BD_TV.HC2.

Attachment C
Okotoks Thalweg Profile Comparison

Sheep River Stream Profile Comparison - Okotoks



Notes:
1. Stationing corresponds to the distance in kilometres upstream of the confluence with the Highwood River based on 2015/16 survey & aerial imagery.

Sheep River Stream Profile Comparison - Okotoks

1996 Cross Section Number	2015/16 Station & Cross Section Number	1996 Survey Thalweg Elev. (m)	2015/16 Survey Thalweg Elev. (m)
1	12.02	1034.6	1033.338
2	12.25	1036.97	1035.474
3	12.47	1038.18	1036.981
4.1	12.64	1038.7	1037.301
4.2	12.69	1039	Note 1
4.3	12.705	1039	Note 1
	12.73	Note 1	1037.203
	12.75	Note 1	1037.422
5.1	12.85	1039.7	1038.406
5.2	13.01	1040.3	1039.334
6	13.12	1040	1038.99
6.1	13.13	1040	1038.865
6.2	13.25	1042.08	1039.905
7.1	13.48	1042.66	1041.007
7.2	13.65	1043.05	1041.702
8.1	13.82	1043.7	1042.161
8.2	14.04	1044.36	1042.901
9	14.25	1045.03	1043.48
10.1	14.45	1045.75	1044.633
10.2	14.62	1046.48	1044.752
11	14.78	1047.05	1046.355
12.1	14.92	1048	1046.908
12.2	15.06	1048.54	1047.734
12.3	15.17	1048.95	1047.56
	15.24	Note 2	1047.961
13.1	15.289	1049.4	Note 2
13.22	15.35	1048.733	1048.268
13.23	15.36	1048.733	1048.321
13.3	15.4	1049.75	1049.221
14.1	15.56	1050.1	1049.368
14.2	15.73	1050.16	1050.026
	15.86	Note 2	1050.641
15.11	15.872	1050.6	Note 2
15.14	15.883	1050.6	Note 2
	15.91	Note 2	1051.047
15.2	15.95	1051.84	1050.708
16	16.07	1052.34	1051.041
17	16.22	1052.53	1051.715
18	16.45	1053.1	1052.482
19	16.77	1054.59	1053.417
20.1	17.04	1055.8	1055.227
20.2	17.22	1056.7	1054.783
21	17.45	1057.22	1056.406

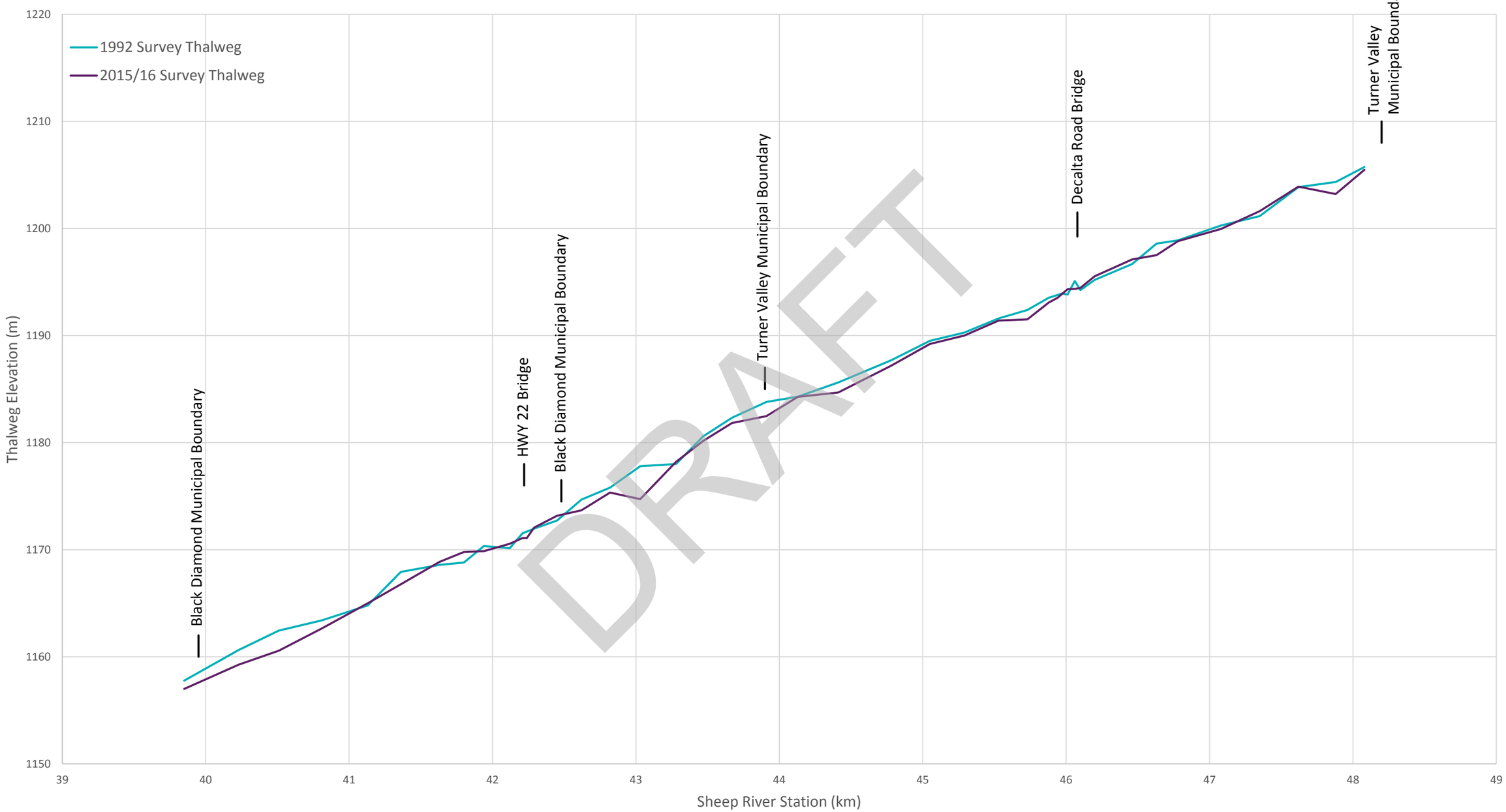
Notes:

1. 32nd Street Bridge alignment surveyed in 2015/16 is slightly different than 1996 surveyed cross sections.
2. 2015/16 cross sections were surveyed at slightly different locations than 1996 survey.

Attachment D

Black Diamond/Turner Valley Thalweg Comparison

Sheep River Stream Profile Comparison - Black Diamond and Turner Valley



Notes:
1. Stationing corresponds to the distance in kilometres upstream of the confluence with the Highwood River based on 2015/16 survey & aerial imagery.

Sheep River Stream Profile Comparison - Black Diamond and Turner Valley

1992 Cross Section Number	2015/16 Station & Cross Section Number	1992 Survey Thalweg Elev (m)	2015/16 Survey Thalweg Elev (m)
1	39.85	1157.77	1156.997
2	40.23	1160.63	1159.266
3	40.51	1162.45	1160.571
4	40.81	1163.4	1162.65
5	41.13	1164.8	1165.006
6	41.36	1167.93	1166.771
7	41.63	1168.59	1168.868
8	41.8	1168.8	1169.791
9	41.94	1170.34	1169.87
10	42.12	1170.14	1170.551
11.1	42.21	1171.54	1171.091
11.2	42.24	1171.7	1171.087
12	42.29	1171.97	1172.063
13	42.45	1172.72	1173.173
14	42.62	1174.68	1173.685
15	42.82	1175.8	1175.342
16	43.03	1177.8	1174.725
17	43.28	1178	1178.206
18	43.47	1180.6	1180.169
19	43.67	1182.33	1181.83
20	43.91	1183.8	1182.474
21	44.13	1184.3	1184.283
22	44.41	1185.62	1184.678
23	44.78	1187.7	1187.187
24	45.05	1189.51	1189.223
25	45.29	1190.28	1190.008
26	45.53	1191.6	1191.4
27	45.73	1192.39	1191.511
28	45.88	1193.54	1193.088
29.1	45.94	1193.79	1193.524
29.2	45.97	1193.92	1193.861
30	46.01	1193.83	1194.332
31.1	46.06	1195.1	1194.352
31.2	46.1	1194.25	1194.442
32	46.2	1195.2	1195.538
33	46.46	1196.68	1197.113
34	46.63	1198.59	1197.504
35	46.78	1198.9	1198.812
36	47.08	1200.28	1199.953
37	47.35	1201.15	1201.623
38	47.62	1203.86	1203.905
39	47.88	1204.35	1203.222
40	48.08	1205.74	1205.479

APPENDIX B – UPDATED CROSS SECTION COMPARISON