ROCKY MOUNTAIN HOUSE FLOOD STUDY

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ALBERTA ENVIRONMENT AND PARKS

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EXECUTIVE SUMMARY

Matrix Solutions Inc. was retained by the Government of Alberta (GoA) to conduct a flood study for the North Saskatchewan River (NSR) and Clearwater River through the Town of Rocky Mountain House and Clearwater County. This flood study is one of several similar studies completed as part of a larger effort by GoA to identify flood hazard areas in communities throughout Alberta to increase public safety and reduce future flood related damages. Information required to complete this study was gathered collectively by Matrix, GeoVerra (surveying subcontractor), key project stakeholders, and GoA (including LiDAR provider Airborne Imaging).

The purpose of the Rocky Mountain House Flood Study was to assess and identify flood hazards along the NSR and the Clearwater River through the Town of Rocky Mountain House and Clearwater County. The key project stakeholders are the Town of Rocky Mountain House and Clearwater County.

The scope of the study includes flood hazard mapping along a 13.4 km reach of the NSR and 4.7 km reach of the Clearwater River. The study reach of the NSR extends from approximately 7 km upstream of the Clearwater River confluence, on the east edge of NE-11-039-08 W5M, through Clearwater County and the Town of Rocky Mountain House, to the south edge of NW-04-040-07 W5M. The Clearwater River study reach extends approximately 4.7 km upstream from the NSR confluence to the north edge of NE-03-039-07 W5M.

The hydrologic analysis of recorded flows and naturalized flows was undertaken to compute 2 to 1,000-year return period flood estimates for the NSR and Clearwater River. These flow estimates were used for hydraulic modelling and flood inundation mapping. The historical recorded streamflow on the Clearwater River near Rocky Mountain (05DB001) from 1914 to 1975 and the amalgamated flows of the Clearwater River near Dovercourt (05DB006) and Prairie Creek near Rocky Mountain House (05DB002) from 1976 to 2020 were used to derive a complete annual maximum instantaneous discharge dataset for the Clearwater River near Rocky Mountain House (05DB001) located within the study area boundary. The recorded/estimated flow data on the Clearwater River were considered as natural flows as no human-made structure that can affect the flows is located on this river.

The recorded/estimated flow data from 1914 to 1972 on the NSR near Rocky Mountain House (05DC001), located within the study area boundary were considered natural. The Bighorn Dam commenced its operation in August 1972; flow data recorded since September 1972 were naturalized by removing the effect of operation of the dam from the recorded flows downstream. A frequency analysis of the recorded/estimated and naturalized annual maximum instantaneous discharges at this location conducted to derive flood frequency estimates.

A frequency analysis of the recorded/estimated annual maximum instantaneous discharges at both locations was conducted. Various 2 parameter and 3 parameter theoretical probability distributions were tested as a part of frequency analysis. These distributions include: Normal, log Normal, 3-parameter log Normal, Pearson Type III, log Pearson Type III, Extreme Value 1 (EV1), Exponential, Weibull, Gamma, and

Gumbel extreme value distributions. Hydrological Frequency Analysis (Hyfran) Plus Version 1.2 software and the Microsoft Excel based tool created for City of Calgary Frequency Analysis (AMEC 2014) were used to compute flood frequency estimates and to perform goodness of fit testing.

Based on a visual inspection of various frequency distributions to the flow data and goodness of fit, the log Pearson Type III distribution has the most representative fit to the recorded data for both the NSR near Rocky Mountain House (05DC001) and the Clearwater River near Rocky Mountain House (05DB001).

The hydraulic model and resulting map products were constructed using LiDAR data provided by GoA and surveyed cross-sections, and hydraulic structure data collected by Altus under Matrix's supervision. All surveyed data was tied together using Alberta Survey Control Network (ASCN) benchmarks that were surveyed independently during the various data collection phases. The hydraulic model was calibrated using surveyed highwater marks collected during the 1972, 1986, and 1998 flood events as well as water levels estimated during the 1915 flood event. Calibration focused on the 1972 highwater marks as this flood was most representative of the design flood adopted for this study

Open water flood frequency maps for the 2-year to 1,000-year flood events are provided in Appendix C. The 1:100-year design flood profile was used in preparing flood hazard maps for the study area. Along the NSR, the floodway generally encompasses the entire inundation area with no viable flood fringe with the exception of a few areas where depth is the governing criteria. The floodway along the NSR is generally situated at or just beyond the main channel with the exception of the confluence area, where the floodway widens into the left and right floodplains. The governing floodway criteria along the Clearwater River alternates between the depth and velocity criteria with select areas where the floodway extends to the inundation extent (no viable flood fringe). Design flood hazard maps are provided in Appendix E.

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1 INTRODUCTION

Matrix Solutions Inc. was retained by the Government of Alberta (GoA) to conduct a flood study for the North Saskatchewan River (NSR) and Clearwater River through the Town of Rocky Mountain House and Clearwater County. Key stakeholders for this project are the Town of Rocky Mountain House and Clearwater County.

This flood study is one of several similar studies completed as part of a larger effort by GoA to identify flood hazard areas in communities throughout Alberta to increase public safety and reduce future flood related damages. Information required to complete this study was gathered collectively by Matrix, GeoVerra (surveying subcontractor), key project stakeholders, and GoA (including its providers of topography and aerial photography information).

1.1 Study Objectives

The key study objectives included the following:

- Survey and base data collection:
  - surveying river cross-sections
  - surveying hydraulic structures
  - integrating survey and digital terrain model (DTM) data

- Open water hydrology assessment:
  - conducting a hydrologic analysis to provide flood frequency estimates for the NSR and Clearwater River

- Open water hydraulic modelling:
  - documenting open water flood history
  - creating, calibrating, and validating a HEC-RAS hydraulic model for the NSR and Clearwater River
  - simulating 13 flood frequency estimates and creating associated water surface profiles

- Open water flood inundation mapping:
  - preparing flood inundation maps for the specified flood frequency events
  - preparing associated electronic GIS data

- Design flood hazard mapping:
  - preparing flood hazard and floodway criteria maps based on various floodway delineation criteria

- Reporting and documentation:
  - preparing a study report and associated electronic GIS study file and digital deliverables database to document methods and results

1.2 Study Area and Reach

The study area includes a 13.4 km reach of the NSR and a 4.7 km reach of the Clearwater River through the Town of Rocky Mountain House and Clearwater County (Figure 1).

The NSR reach extends from approximately 7 km upstream of the Clearwater River confluence, on the east edge of NE-11-039-08 W5M, through Clearwater County and the Town of Rocky Mountain House, to the south edge of NW-04-040-07 W5M. The Clearwater River study reach extends approximately 4.7 km upstream from the NSR confluence to the north edge of NE-03-039-07 W5M. No similar study for this area has been completed in the past.

The NSR begins in the ice fields of Banff and Jasper National Parks and generally flows east toward the Alberta-Saskatchewan boundary. The total area of the NSR Basin from its headwaters on the eastern slopes of the Rocky Mountains to the prairie landscape along the Alberta-Saskatchewan boundary is about 57,000 km^2. Within Alberta, the Brazeau, Nordegg, Ram, Clearwater, Sturgeon, and Vermilion rivers are the major tributaries to the NSR. Flows in the NSR are regulated at two hydroelectric facilities operated by TransAlta: the Brazeau Dam on the Brazeau River since 1961 and the Bighorn Dam on the NSR since 1972. The operations of the dam increase winter flows and reduce maximum discharges during summer months. Flows on the NSR in the Rocky Mountain House area is affected only by the operation of the Bighorn Dam. The drainage area of the NSR near Rocky Mountain House is 11,000 km^2 and located approximately 128 km downstream of the Lake Abraham (reservoir) created by the Bighorn Dam.

The Clearwater River is a tributary of the NSR with its confluence located upstream of the Town of Rocky Mountain House. Most of the Clearwater River watershed is located within Clearwater County, covering a portion of the Rocky Mountains and foothills extending to Banff National Park. The drainage area of the Clearwater River at its confluence with the NSR is approximately 3,220 km^2.

2 SURVEY AND BASE DATA COLLECTION

Matrix conducted a site visit with GoA and the Rocky Mountain House representative on October 1, 2020, to inform the survey work. This included confirming the proposed cross-section locations that were identified during the initial desktop review of the study reach imagery and topography, identifying hydraulic structures to be included in the project, and refining the survey scope. No flood control structures are located within the study reach.

The survey work was completed between October 15 to 19, 2020; GeoVerra led the data collection and quality management process under Matrix's supervision and direction. Data collected along the study reach during the survey included the following:

- river cross-sections
- hydraulic structure (bridges) geometry
- Water Survey of Canada (WSC) hydrometric station benchmarks

- GoA highwater mark benchmarks
- Alberta Survey Control Network (ASCN) benchmarks
- associated georeferenced photographs

Documentation related to survey control, data quality assurance, and survey equipment specifications is included in Appendix A. The scope of work for survey and base data collection did not include the collection of LiDAR topography data. This information was provided to Matrix by the GoA to inform the Rocky Mountain House Flood Study.

2.1 Procedures and Methodology

A brief overview of the procedures and methodology of the various parts of the survey work are summarized below. All survey data collected for the study met the standards and accuracy described in the project Terms of Reference (TOR):

- Ground survey data have an absolute positional accuracy of ±0.05 m, at 95% confidence. Bathymetric survey data have an absolute positional accuracy of ±0.15 m.

- Survey data is reported in 3-Degree Transverse Mercator (3TM) zone 114°, referenced horizontally to the Canadian Spatial Reference System, North American Datum of 1983, Epoch 2002 (NAD83 [CSRS]; Epoch 2002). Vertically, the data is referenced to the Canadian Geodetic Vertical Datum of 1928 (CGVD28). Ellipsoidal heights were transformed to CGVD28 orthometric heights using the HTv2.0 hybrid geoid model.

- The ASCN was used for the survey control for the project. ASCN benchmarks were surveyed using a static Global Navigation Satellite System (GNSS) measurement at a minimum of 4 hours in duration and 2 hours of redundancy.

Summarized quality assurance and accuracy quantification documentation related to the control survey and the daily survey activities is provided in Appendix A1.

2.1.1 Benchmarks

The ASCN benchmarks used for the project's survey control are listed in Table A; each benchmark was ground-surveyed by GeoVerra. A comparison of elevations confirmed consistency between the reported and surveyed values. The GeoVerra benchmark elevations were adopted for this project.

TABLE A Alberta Survey Control Network Benchmarks for Survey Control

ASCN Benchmark ID	3TM Coordinates (m; NAD 83 (CSRS) 3TM 114)		ASCN Ground Elevation (m)	Altus Group 2019 Ground-Surveyed Elevation (m)	Difference (m)
	Easting	Northing			
36509	63,869.561	5,802,379.834	979.161	979.175	-0.014
37754	65,450.069	5,804,452.872	965.992	966.015	-0.023
101980	65,098.374	5,808,756.567	959.061	959.069	-0.008
210732	64,498.356	5,807,768.812	955.054	955.079	-0.025
255232	62,334.051	5,805,750.657	988.524	988.560	-0.036

Benchmarks established by the GoA were also measured by GeoVerra (Table B; reference); several previously established benchmarks were not located and are presumed destroyed. A comparison of elevations confirmed consistence between the reported and surveyed values.

TABLE B Government of Alberta Highwater Mark Benchmarks

GoA Benchmark ID	Approximate 3TM Coordinates (m; NAD 83 (CSRS) 3TM 114)		GoA Surveyed Elevation (m)	GeoVerra 2020 Surveyed Elevation (m)	Difference (m)
	Easting	Northing			
NSASK-116-a	-64998.31	5808785.93	956.660	956.709	-0.049
NSASK-116-b	-64984.26	5808798.35	957.350	957.394	-0.044
NSASK-118-a	-65545.32	5803718.16	965.254	965.274	-0.020
NSASK-120-a	-68749.13	5803459.76	983.426	983.383	0.043
CLR5D-006-b	-63870.52	5801567.70	966.585	966.586	-0.001

2.2 Cross-sections

Channel and overbank cross-sectional geometry, including near overbank topography and channel bathymetry, were surveyed at locations identified in the approved survey plan using a combination of conventional and echo sounding survey methods (Figure 2).

A Trimble® R10 GNSS Real-Time Kinematic (RTK) GPS System (Appendix A2) was used for the collection of most survey data and a Sonarmite MILSpec Single Beam Echosounder (Appendix A3) was used for the portions of the bathymetry where RTK equipment was not practical. The Sonarmite was used in conjunction with a river boat that was navigated along the river for the survey. Data collected by the Sonarmite were validated or corrected using overlapping data collected by the RTK in the portions of the channel nearest the bank. The combined accuracy of points collected through use of RTK GPS with echosounder meet the requirements listed in Section 2.1.

2.3 Hydraulic Structures

Hydraulic structure surveys were completed using standard RTK equipment. An inventory of surveyed hydraulic structures is provided in Table C, listed upstream to downstream, and the structures are shown on Figure 2.

TABLE C Hydraulic Structure Details

Hydraulic Structure Name	River Reach	Approximate River Station (m)	Approximate 3TM Coordinates (m; NAD 83 (CSRS) 3TM 114)	
			Northing	Easting
Highway 752 Bridge	Clearwater River	2,843.25	5,801,599	63,863
Railway bridge	NSR (lower)	5,503.02	5,804,895	64,088
Highway 11A Bridge	NSR (lower)	5,290.36	5,805,073	64,008
Highway 11 Bridge	NSR (lower)	1,032.97	5,808,805	64,952

2.4 Flood Control Structures

No flood control structures are located within the study reach.

3 FLOOD HYDROLOGY

3.1 Flooding History

3.1.1 Historical Floods

Several historical floods along the NSR and the Clearwater River have occurred during the period of record, the six largest of which occurred in 1915, 1952, 1972, 1990, 2005, and 2013. The magnitudes of some of these floods were recorded at the WSC gauging stations and some were estimated following the procedures described in Appendix B.

The largest flood event on the NSR occurred in 1915 with a magnitude of 4,110 m^3/s at the WSC gauging station (05DC001). The largest flood event on the Clearwater River also occurred in 1915 with an estimated magnitude of 1,238 m^3/s at the WSC gauging station (05DB001). The 1915 flood has a return period higher than the 100-year event based on flood frequency estimates completed in this study (Appendix B).

The second highest floods on record on the NSR and the Clearwater River occurred in 2005 with estimated instantaneous peak discharges of 2,558 m^3/s and 1,068 m^3/s, respectively. The 2005 flood on the NSR had a return period in the range of the 60-year whereas the Clearwater River had a return period approximately equivalent to the 100-year flood event.

The Town of Rocky Mountain House and Clearwater County are located within the study reach and have several stormwater outfalls that discharge to the NSR. As a result, summer storm events may result in temporary relatively high contribution to total flow in the NSR; however, since flooding in the NSR and Clearwater River is generally governed by snowmelt runoff events, the likelihood of these events occurring simultaneously is very low and thus the contribution of stormwater outfalls was not investigated for this study.

3.1.2 Recent Floods

No major flood events occurred since 2013. The estimated maximum instantaneous discharge on the NSR in 2013 was 2,406 m^3/s, which represents a return period of about 50-year flood event. The estimated maximum instantaneous discharge on the Clearwater in 2013 was 684 m^3/s, which represents a return period of about a 40-year flood event.

3.1.3 Ice Jam Floods

Based on a review of historical background information, there is no indication of significant ice jam flooding through the study reach on the NSR or Clearwater River. Ice jam flood analysis was not included within the project TOR.

3.2 Flood Frequency Analysis

3.2.1 Overview

The flood frequency estimates for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods with confidence intervals are required at key locations along the NSR and the Clearwater River throughout the study reach. The key locations include:

- at the upstream study area boundary
- at the gauging station located on the NSR near Rocky Mountain House (05DC001)
- at the confluence location of the Clearwater River and the NSR
- at the upstream boundary of the Clearwater River study reach

Hydrologic analysis conducted has been guided by the *Flood Hazard Identification Program Guidelines* (AENV 2011), the *Rocky Mountain House Hazard Study Terms of Reference* (AEP 2020), and the *Guidelines for Determining Flood Flow Frequency, Bulletins 17B and 17C* (USGS 1982, 2018). The estimated flood frequencies were used as model input data for hydraulic modelling and flood inundation mapping.

Recorded historical streamflow data is required to derive flood frequency estimates associated with various return periods. In addition, recorded water levels of a reservoir are required to generate naturalized flows along a river affected by upstream dam operation. A select number of these stations, which have data as early as 1913, are considered key hydrometric stations for the open water hydrology assessment and are provided in Table D and presented on Figure 2.

TABLE D Key Hydrometric Stations

Station Name and ID	Gross Drainage Area (km^2)	Data Period
Lake Abraham near Nordegg (05DC009)	3,890	1972-2012
North Saskatchewan River below Bighorn Plant (05DC010)	3,890	1972-2019
North Saskatchewan River near Saunders (05DC002)	5,160	1915-1923; 1952-1978
North Saskatchewan River near Rocky Mountain House (05DC001)	11,000	1913-1930; 1944- 2020
Ram River near the Mouth (05DC006)	1,860	1967-2019
Clearwater River near Rocky Mountain House (05DB001)	3,220	1914–1931; 1944–1975
Clearwater River near Dovercourt (05DB006)	2,250	1975-2020
Clearwater River above Limestone Creek (05DB003)	1,340	1959-1992
Prairie Creek near Rocky Mountain House (05DB002)	844	1922-1925; 1951-2020

The recorded/estimated flow data from 1914 to 1972 on the NSR near Rocky Mountain House (05DC001), located within the study area boundary were considered natural. The Bighorn Dam commenced its operation in August 1972; flow data recorded since September 1972 are considered regulated. Flows recorded post-1972 were naturalized by removing the effect of dam operations from the recorded downstream flows.

Clearwater River flow data was considered natural as no human-made structure affecting flow is situated on this river. In 1975, the WSC station on the Clearwater River near Rocky Mountain House (05DB001) was moved upstream to a location on the Clearwater River near Dovercourt (05DB006). Prairie Creek enters the Clearwater River between these two WSC stations. The drainage area at Prairie Creek near Rocky Mountain House (05DB002; 844 km^2) plus drainage area of the Clearwater River basin above 05DB006 (2,250 km^2) accounts for 95% of the drainage area of the Clearwater River above 05DB001 (3,220 km^2). As a result, recorded flows covering a period from 1976 to 2019 at both locations were amalgamated at the downstream WSC station (05DB001) to generate a set of streamflow data at this location. The complete streamflow data set (recorded up to 1975 and computed for the period from 1976 to 2019) was used in flood frequency analysis to estimate flood frequencies associated with various return periods at the WSC station on the Clearwater River near Rocky Mountain House (05DB001).

Recorded streamflow data at the WSC stations are available in the WSC database up to 2018. No data is available for the year 2017. Preliminary WSC data (Clearwater River for 2017, 2019 to 2020; NSR for 2017 and 2019) were obtained from AEP for this study and are subject to change.

3.2.2 Flood Frequency Flow Estimates

Hydrologic analysis was undertaken to determine 2-year to 1,000-year return period instantaneous flood estimates for the NSR and the Clearwater River and were used for subsequent hydraulic modelling and flood inundation mapping. Given the availability of flow data records, extending flood frequency estimates beyond approximately the 200-year return period is highly speculative; significant uncertainty exists for estimated flood frequencies with such infrequent return periods. The hydrologic analysis involves evaluation of regional discharge data, extension of the hydrometric record based on a correlation between annual maximum daily discharges and annual maximum instantaneous discharges, naturalization of regulated flows, analysis of the extended data series for statistical outliers, and selection of the most suitable probability distribution. A detailed description of the flood frequency analysis methodology and the flood frequency estimates are provided in Appendix B.

A summary of the flood frequency estimates adopted for this study is provided below in Table E.

TABLE E Flood Frequency Estimates for Hydraulic Modelling

Return Period (years)	Flood Frequency Estimates at the Upstream Boundary on the NSR (m^3/s)	Flood Frequency Estimates at the Upstream Boundary on the Clearwater River (m^3/s)	Flood Frequency Estimates on the NSR Downstream of the Confluence with the Clearwater River (m^3/s)
2	535	139	674
5	769	259	1,028
10	981	374	1,355
20	1,237	517	1,754
35	1,479	658	2,137
50	1,664	761	2,425
75	1,881	895	2,776
100	2,072	1,000	3,072
200	2,576	1,295	3,871
350	3,029	1,584	4,613
500	3,426	1,794	5,220
750	3,825	2,065	5,890
1,000	4,244	2,276	6,520

Note: Naturalized flood frequency estimates in the NSR and natural flood frequency estimates in the Clearwater River.

3.2.3 Comparison to Previous Study

No previous flood risk mapping studies have been completed for this study reach.

4 HYDRAULIC MODELLING

4.1 Available Data

4.1.1 Digital Terrain Model

A 0.5 m grid DTM was procured by AEP and provided to Matrix for use in flood inundation mapping. The horizontal coordinates were provided in Alberta 3TM referenced to NAD83; vertical coordinates are referenced to CGVD28.

Though the DTM has already undergone independent quality control to ensure compliance with the FHIP guidelines accuracy standards, the DTM was compared to surveyed overbank elevations to confirm that the DTM is suitable for use in cross-section extraction and flood mapping. Generally, good agreement was observed between the DTM and overbank surveyed elevations. For the majority of the comparison points (76%), the DTM derived elevations were up to 0.3 m higher than the ground survey, which indicates that the vegetation in these areas was not penetrated by the LiDAR. Larger differences in elevation (ranging from 0.3 m to 1.0 m) were observed in areas of steep surfaces such as along channel banks or roadway embankments. In discussion with AEP, these elevation differences were found to be consistent with those encountered in similar conditions and the DTM was considered acceptable for use in flood mapping.

4.1.2 Existing Models

As mentioned in Section 3.2.3, no previous flood risk mapping studies have been completed for this study reach.

4.1.3 Highwater Marks

4.1.3.1 North Saskatchewan River

The largest recorded flood event on the NSR occurred in June 1915 with a magnitude of 4,110 m^3/s at the Rocky Mountain House gauging station (05DC001). Water levels during this event have been estimated and provided in the Highway 11 bridge as-built drawings (AEP 1971a, 1971b). Two additional significant flood events occurred on June 26, 1972 and July 19, 1986 with peak magnitudes of 1,880 m^3/s and 773 m^3/s, respectively. Highwater mark measurements during these two events were collected by AEP.

4.1.3.2 Clearwater River

The largest recorded flood event on the Clearwater River occurred on June 26, 1972, with a magnitude of 467 m^3/s (GoA 2021) near the Rocky Mountain House gauging station (05DB001). A second significant flood occurred on July 3, 1998, with an estimated peak discharge of 226.7 m^3/s[1]. Highwater mark measurements were collected by AEP during these two events.

The locations of the highwater mark measurements are provided on Figure 2; Table F provides a summary of the highwater mark data and corresponding flows.

[1] Derived from the recorded flows at the Clearwater River near Dovercourt (05DB006) and the Prairie Creek near Rocky Mountain House (05DB002) gauging stations as the WSC gauging station, 05DB001 was discontinued in 1975 (Matrix 2021; Appendix B).

TABLE F Highwater Mark Data and Flows

Alberta Environment and Parks Highwater Mark	River Station (m)	Observed Water Surface Elevation (m)
North Saskatchewan River - June 26, 1972, Event (Q = 1,880 m^3/s)		
1972-NSASK-117-c	5346.492	957.49
1972-NSASK-120-a	12445.2	970.53
North Saskatchewan River - 1915 Flood Event (Q = 4,105 m^3/s)		
Est. 1915 Flood elev.	1003.573	952.20
Est. 1915 Flood elev.	5236.258	959.68
North Saskatchewan River - July 19, 1986, Event (Q = 773 m^3/s)		
1986-NSASK-115-a	2250.499	951.33
1986-NSASK-117-b	5236.258	956.50
1986-NSASK-118-a	8125.992	960.77
1986-NSASK-119-a	12080.08	968.64
Clearwater River – June 26, 1972, Event (Q = 467 m^3/s)		
1972-CLR5D-006-a	2827.816	962.00
Clearwater River – July 3, 1998, Event (Q = 226.7 m^3/s)		
1998-CLR5D-006-b	2827.816	960.30
1998-CLR5D-006-c	2858.693	960.25

4.1.4 Gauge Data and Rating Curves

As discussed in Section 3, WSC gauge 05DC001 (NSR near Rocky Mountain House) is located within the study reach at the Highway 11A bridge. Field recorded stage and discharge data for the gauge was provided by the WSC office for a period spanning July 1986 to June 2021. The maximum recorded discharge at the gauge was 2,165 m^3/s, which represents a return period near the 35-year flood. The stage data was transformed to geodetic elevations based on a gauge datum elevation of 952.607 m. The rating curve based on recorded discharge-elevation data at the 05DC001 gauge is presented on Figure 3, along with the current (2021) and past rating curves (1991, 1994, 1998, and 2018) developed by the WSC.

Rating curve data for the Clearwater River gauging station (05DB001) prior to its relocation in 1975 was obtained from the WSC office; unfortunately, the geodetic datum conversion at this gauge is not available from the WSC nor can it be field verified due to the gauge relocation. Without the datum conversion, comparison of simulated versus past rating curves at the 05DB001 gauge was not possible.

4.2 River and Valley Features

4.2.1 General Description

The modelled reach can be divided into two generalized areas: upstream and downstream of the confluence of the Clearwater River with the NSR. Upstream of the confluence, the upper NSR exhibits a mild winding pattern within a frequently confined streamcut valley; the left[2] overbank is wide and flat

[2] As viewed looking downstream.

floodplain that becomes inundated during higher flood events while the right overbank is a steep and high valley wall that generally confines flow to the main channel. Approaching the confluence, the NSR left and right floodplains become inundated and provide additional conveyance at higher flood events. The upper NSR has a sinuous channel pattern with frequent mid-channel gravel bars (Kellerhals et al. 1972). The bed slope along the upper NSR is approximately 0.0023 m/m. Downstream of the confluence, the lower NSR is relatively straight and occasionally confined as it passes the Rocky Mountain House townsite. Several low-lying gravel bars are situated in the lower NSR and the bed slope is approximately 0.0017 m/m. The Clearwater River exhibits an irregular winding pattern and is confined within a streamcut valley. The Clearwater River is partially incised with occasional islands and mid-channel bars located throughout (Kellerhals et al. 1972). The bed slope along the Clearwater River within the study reach is approximately 0.001 m/m.

4.2.2 Channel Characteristics

The NSR channel cross-section has a bankfull width and depth ranging from about 80 to 245 m and 2.5 to 5.8 m, respectively. The substrate comprises primarily gravel and cobble. The bank material comprises sand/gravel with scattered cobble and erodible rock. The channel banks are slightly unstable with evidence of bank erosion and lateral activity. The Clearwater River cross-section has a bankfull width and depth ranging from about 50 to 80 m and 2.5 to 5.5 m, respectively. The channel substrate comprises primarily gravel; the channel banks are stable and comprises gravel and silt. For most of the study reach, the banks of both the NSR and Clearwater River are vegetated with typical riparian vegetation (i.e., grasses and shrubs) adjacent to interspersed areas of mixed wood trees.

4.2.3 Floodplain Characteristics

In the NSR, the left floodplain is wide and open and comprises partly cultivated and partly forested areas in the upper NSR; several properties and buildings are situated in the lower NSR floodplains. The right floodplain is high and generally confines flow to the main channel. In the lower NSR, the Rocky Mountain House townsite is located on the right floodplain and is elevated approximately 30 m above the NSR. In the Clearwater River, the floodplain is mostly cultivated terrain with some forested areas; several properties are located within the floodplains of the Clearwater River. In the upper NSR, both the left and right floodplains are vegetated with mixed wood trees, shrubs, and grasses.

4.2.4 Anthropogenic Features

A total of four bridges are located within the study reach, including one rail bridge and two vehicle bridges on the NSR and one vehicle bridge on the Clearwater River. Though the embankments are situated sufficiently high so as not to be overtopped during the flood events, flow is constricted through each of the four bridge openings due to the presence of associated embankments. As a result, backwater effects are expected to occur upstream of each crossing, particularly during extreme flood events.

4.3 Model Construction

4.3.1 Methodology

The HEC-RAS hydraulic modelling software (version 5.0.7; USACE 2016a) was used to simulate flood levels through the model reach for flood events associated with various return periods ranging from the 2-year to the 1,000-year flood. HEC-RAS is a hydraulic model that solves 1D or 2D flow equations of conservation of mass and conservation of momentum representing the physical laws governing open channel flows. Specific capabilities include 1) calculation of subcritical, super critical and mixed flow conditions; 2) modelling of effect of obstructions and structures such as bridges, culverts, and flood control structures such as weirs; and 3) modelling of effect of changes in channel geometry due to encroachments, channelization, and flood control dikes or levees. For this project, a 1D HEC-RAS model was developed to simulate flow conditions through the study reach. HEC-GeoRas in ArcGIS Desktop was used to translate merged topographic survey and LiDAR datasets into geometry files to be imported to HEC-RAS.

The study reaches include approximately 13.4 km of the NSR and 4.7 km of the Clearwater River. The downstream model boundary on the NSR has been extended by approximately 600 m such that any uncertainty in boundary conditions does not impact simulated water levels within the study reach.

4.3.2 Geometric Base Data

4.3.2.1 Cross-section Data

A total of 75 channel cross-sections were surveyed, of which 50 are located on the NSR and 25 are located on the Clearwater River. Cross-sections were extended into the floodplain based on the DTM provided to Matrix by AEP. During preliminary model simulations, 10 cross-sections were identified where extension into the overbanks was required to contain the inundation extents at the 10,000-year flood.

The combined channel and floodplain data often amounted to more than 500 points per cross-section. The *minimize area change* point routine in HEC-RAS was used to filter the cross-section data; final sections were examined to ensure that they retained surveyed channel data and appropriately represented the channel geometry.

Ineffective areas were applied at select cross-sections to reflect offline ponding areas that do not actively convey flow and were placed using the approach outlined in the HEC-RAS Hydraulic Reference Manual (USACE 2016b). In addition, levees were also applied to select cross-sections to prevent flooding from extending into overbank locations that cannot be inundated from upstream or downstream modelled cross-sections.

4.3.2.2 Bridge Data

Four bridges throughout the study reaches were included in the hydraulic model, including one rail bridge and two vehicle bridges on the NSR and one vehicle bridge on the Clearwater River (Table 1). Model input data for three bridges was obtained from survey data collected by Geoverra in December 2020 (CN Railroad, Highway 11A, and Highway 752). For the Highway 11 bridge, bridge data was obtained from the as-built drawing (AEP 1971a).

Contraction and expansion coefficients of 0.1 and 0.3, respectively, were adopted for gradual transitions through the study reach. These coefficients were increased to 0.3 and 0.5 around all bridge crossings at which abrupt changes in the effective flow area are encountered. One exception is the Highway 11 bridge where contraction and expansion coefficients of 0.2 and 0.4 were applied at the bridge to provide a reasonable match to observed water levels.

4.3.2.3 Flood Control Structures

No flood control structures are located within the study area.

4.3.3 Calibration

4.3.3.1 Methodology

Model calibration is an iterative process conducted to ensure that the model is providing representative flow behaviour based on comparison of simulated and observed water surface elevations. Though Manning roughness is the primary calibration parameter, adjustments to the ineffective flow area and expansion/contraction coefficients may also be required. Ineffective flow areas were initially defined based on visual inspection of the DTM and were adjusted slightly during the calibration process. Though sufficient adjustment to these parameters may be feasible to match observed water levels very closely, it is important to maintain gradual variations in roughness throughout the study reach and prescribe reasonable values for the given conditions.

The hydraulic model was calibrated and validated against surveyed highwater marks and the corresponding peak discharge for major events that occurred on the NSR and the Clearwater River. The source of data used for the assessment were highwater marks obtained from AEP in addition to observed flow data included with the Highway 11 as-built bridge drawings (AEP 1971b).

For the NSR, the model was calibrated to the 1972 flood event and validated against the 1915 and 1986 flood events, as detailed below:

- 1972 peak flood event
  - Highwater marks measured at the Highway 11A bridge crossing and on Township Road 392 at Range Road 80.
  - Q = 1,880 m^3/s on June 26, 1972, on the NSR at the Rocky Mountain House gauging station (05DC001) and is between the 1:20 and 1:35-year flood[3].

- 1915 peak flood event
  - Estimated water level reported in the Highway 11 bridge as-built drawings.
  - Q = 4,105 m^3/s in June 1915 on the NSR at the Rocky Mountain House gauging station (05DC001) and is between the 1:200 and 1:350-year flood[3].
- 1986 peak flood event
  - Highwater marks measured at the Highway 11A bridge crossing and at various locations along the bank within the study area.
  - Q = 773 m^3/s on July 19, 1986, on the NSR at the Rocky Mountain House gauging station (05DC001) and is between the 1:2 and 1:5-year flood[3].

For this study, the Clearwater River was calibrated to the 1972 flood event and validated against the 1998 flood event, as detailed below:

- 1972 peak flood event
  - Highwater mark measured at the gauging station upstream of the Highway 752 bridge.
  - Q = 467 m^3/s on June 26, 1972, on the Clearwater River near Rocky Mountain House gauging station (05DB001) and is between the 1:10 and 1:20-year flood[3].
- 1998 peak flood event
  - Highwater marks measured at the Highway 752 bridge crossing.
  - Q = 226.7 m^3/s on July 3, 1998 and is between the 1:2 and 1:5-year flood[3]. Note this flow value was derived from the recorded flows at the Clearwater River near Dovercourt (05DB006) and the Prairie Creek near Rocky Mountain House (05DB002) gauging stations as the WSC gauging station, 05DB001 was discontinued in 1975 (Matrix 2021).

In the absence of observed water level data at the downstream boundary, the normal depth boundary condition was adopted based on an assumed energy slope 0.0014 m/m, which is equivalent to the average surveyed lower NSR bed slope. Channel roughness values of 0.032 on the NSR and 0.027 on the Clearwater River provided the best fit to the observed highwater marks for all discharges.

Overbank roughness was selected based on aerial imagery and photographs collected during the survey based on guidance provided in Chow (1959). Though several observed water levels are available for the 1972 event, this discharge is primarily contained within the channel and did not allow for calibration of overbank roughness. However, limited estimated water level data was available for the 1915 event; the selected overbank roughnesses resulted in a reasonable agreement between simulated and estimated water levels at the Highway 11 and 11A bridges.

[3] As compared to return flood estimates reported herein.

4.3.3.2 Calibration Results

Figure 4 (NSR) and Figure 5 (Clearwater River) provide a comparison of the simulated water surface profiles and observed highwater marks for the calibration and validation model runs. Table 2 provides a summary of the simulated and observed water surface elevations.

North Saskatchewan River

For the 1972 event on the NSR, the difference between observed and simulated water level at RS 5346 (between CN Railroad and Hwy 11A bridge) and RS 12445 was 0.08 and 0.39 m, respectively. For the 1986 event, the reach-averaged difference in water level between RS 2250 and RS 12080 was -0.28 m. For the 1915 event, the average difference in water level at RS 1004 and RS 5236 was 0.40 m.

Clearwater River

For the 1972 event on the Clearwater River, the difference in water level at RS 2827 (Highway 752 bridge) was 0.13 m. For the 1998 event, the difference in water level at RS 2827 and RS 2858 was 0.01 and 0.16 m, respectively.

4.3.4 Flood Frequency Profiles

Figures 6 and 7 provide the simulated water surface profiles for the 2-year to 1,000-year flood discharges on the NSR and Clearwater River, respectively. Table 3 provides the water surface elevations at each model cross-section for the range of flood events simulated on the NSR and Clearwater River. The NSR gauging station (05DC001) rating curve, including hydraulic model outputs for the range of modelled discharges, is presented on Figure 3.

4.3.5 Model Sensitivity

Sensitivity analyses were conducted to evaluate the impact of estimated model parameters on simulated water levels for the 100-year design flood and included the following:

- Variation of the downstream water level slope (± 30%)
- Variation of the Manning roughness values (± 20%)

Figures 8 and 9 and Table 4 provide a comparison of the simulated water surface profiles for the variable downstream boundary conditions. The deviation in water surface elevation from the calibrated 100-year flood profile is 0.15 m and -0.06 m for the -30% and +30% downstream slope variation, respectively, as measured at the downstream study boundary (RS 685.044); this difference diminishes to less than 0.05 m by RS 1003.57 on the NSR. The deviation in water surface elevation is nil on the Clearwater River.

The channel roughness adopted for the calibrated profile on the NSR is 0.032; the alternate channel roughness values investigated here are 0.0256 and 0.0384. The channel roughness adopted for the calibrated profile on the Clearwater River is 0.027; the alternate channel roughness values investigated here are 0.0216 and 0.0324. Figures 10 and 11 and Table 5 provide a comparison of the simulated water surface profiles for the variable channel roughness values. For the NSR, the average and maximum difference in water surface elevations as compared to the calibrated profile are 0.35 m and 0.65 m, respectively, for the lower value of n = 0.0256 while these differences are 0.30 m and 0.50 m, respectively, for the higher value of n = 0.0384. At the Clearwater River, the average and maximum difference in water surface elevation is 0.28 and 0.41 m, respectively, for the lower value of n = 0.0216 and 0.24 and 0.33 m, respectively, for the higher value of n = 0.0324.

Figures 12 and 13 and Table 6 provide a comparison of the simulated water surface profiles for the variable overbank roughness conditions (± 20%). For the NSR, the average and maximum difference in water surface elevations as compared to the calibrated profile are 0.07 m and 0.21 m, respectively, for the lowered overbank roughness values while these differences are 0.06 m and 0.20 m, respectively, for the raised overbank roughness values. For the Clearwater River, the average and maximum difference in water surface elevation is 0.07 m and 0.11 m, respectively, for the lowered overbank roughness values while these differences are 0.07 m and 0.09 m, respectively, for the raised overbank roughness values.

These variations are considered to be within the expected modelling accuracy. It is concluded that the hydraulic model based on the assigned overbank and channel roughness values and downstream boundary conditions can be confidently used for developing flood inundation and flood hazard maps for the study reach.

5 FLOOD INUNDATION MAPS

5.1 Methodology

The flood surface profiles for all open water inundation scenarios modelled along the NSR and Clearwater River were interpolated and translated to inundation boundaries through ArcGIS Desktop. For each of the 13 flood inundation scenarios, an initial water surface elevation was generated using the automated triangulated irregular network (TIN) interpolation tools based on results from the hydraulic model using the 3D Analyst extension. The resulting water surface elevation TINs were then translated into a grid format adhering to raster resolution and snapping environments in ArcGIS to ensure all grid outputs are correctly aligned with the input terrain data. The DTM was then subtracted from the interpolated water surface elevation grid to calculate the flood depth grid. The hydroflattened DTM product compared against the interpolated water surface does not have the bathymetry of the channel represented in the topographic surface. When LiDAR is acquired, it can only return the surface of water and not the elevation of the bottom of the channel. As such, the flood depth values calculated in the channel will not be representative of the full flood depth. From the flood depth grid, a first estimate of the inundation extent grid was defined by identifying cells greater than zero. Cells less than zero are indicative of the topography being higher than the modelled water surface elevation. By reclassifying the flood depth surface, the inundation extent grid for a given inundation scenario were delineated with the same resolution as the original DTM. The inundation grid extent was then converted into a polygon, where it was run through a smoothing algorithm (PAEK; 15 m) and a polygon/polygon hole filter (<100 sq. m holes or polygons are removed unless otherwise flagged [see Section 5.3]).

Manual adjustments to the flood profile to accommodate backwater flood and overtopping are described in Section 5.2.

5.2 Water Surface Elevation TIN Modifications

The initial inundation extent was inspected to identify areas of backwater flooding where manual TIN modifications are required to modify water surface elevation where level pooling is expected. To address these areas, the TIN water surface elevation was manipulated through the addition of breaklines and areas of constant water level elevation. In areas where there is a single overtopping point that was otherwise hydraulically confined (e.g., inundation spills over a road at a single location and pools behind it), the TIN surface was adjusted to a level surface in the area behind the road based on the elevation of that overtopping point. Areas where there are multiple overtopping points (e.g., the inundation spills at one point, continues flowing downgrade, and spills again to reconnect with the main channel) were adjusted so that the gradient between the upstream and downstream overtopping points was equal to the gradient in the main channel. The elevation at the overtopping point was based on the interpolated water level surface at upstream and downstream overtopping points. Table G describes where and what type of manual TIN modifications were applied.

TABLE G TIN Profile Modification Summary Table

Location	Description	Side of Channel	Inundation Scenario	Overtopping Point
North Saskatchewan River				
RS 10,790 to RS 10,482	South of Township Road 392	Left	2-Year	Single
RS 10,482 to RS 9,445	North of east end of Township Road 392	Left	100-Year	Single
RS 9,981 to RS 9,445	North of east end of Township Road 392	Left	75-Year	Single
RS 8,866 to RS 7,325	South of NSR and CWR confluence	Left	50-Year	Single
RS 8,126 to RS 7,659	Southeast of Range Road 74	Left	35 to 200-Year	Single
RS 8,126 to RS 5,519	South of CN Rail Bridge	Left	20-Year	Multiple
RS 6,817 to RS 6,227	East of Range Road 74	Left	10-Year	Single
RS 6,817 to RS 6,227	Southeast of Voyageur Drive	Left	35 and 50-Year	Single
RS 6,533 to RS 6,050	East of Voyageur Drive	Left	10-Year	Single
RS 6,533 to RS 6,050	Along west end of Voyageur Road	Left	200-Year	Single
RS 6,050 to RS 5,542	South of CN Rail Bridge	Left	10-Year	Single
RS 6,050 to RS 5,487	Along east end of Voyageur Road	Left	200-Year	Single
RS 5,289 to RS 4,677	West of Range Road 73A	Left	20-Year	Single
RS 5,289 to RS 4,677	Along Range Road 73A	Left	35-Year	Single
RS 2,250 to RS 1,225	East of Range Road 73A	Left	20-Year	Single
RS 2,250 to RS 1,004	South of David Thompson Highway	Left	500-Year	Single
RS 1,925 to RS 1,225	East of Range Road 73A	Left	10-Year	Single
RS 1,925 to RS 1,004	South of David Thompson Highway	Left	350-Year	Single
RS 1,584 to RS 1,225	East of Range Road 73A	Left	5-Year	Single

Location	Description	Side of Channel	Inundation Scenario	Overtopping Point
Confluence				
RS 7,659 (NSR) to RS 498 (CW)	South of NSR and CWR confluence	Left	20-Year	Single
RS 8,866 (NSR) to RS 498 (CW)	South of NSR and CWR confluence	Left and Right	35-Year	Single
Clearwater				
RS 1,099 to RS 683	West of 752 Highway	Right	10-Year	Single

5.3 Flood Inundation Areas

Open water flood inundation maps for the 2-year to 1,000-year flood events are presented in Appendix C.

5.3.1 Key Observations

A summary of key observations from the open water inundation maps is presented below:

- An industrial area located in the left bank of the NSR just upstream of the confluence is impacted by flooding at the 35-year flood and higher (sheet 5 of 15). Residences located along the right bank in this area begin to be impacted by flooding at the 750-year flood and higher.
- The Riverview Campground located on the left bank upstream of Highway 11 is impacted by flooding on the NSR at the 35-year flood and higher (sheet 9 of 15). Several residences adjacent to the campground are impacted by flooding at the 350-year flood and higher.
- An industrial area located along the right bank of the Clearwater River just upstream of the confluence is impacted by flooding at the 35-year flood and higher (sheet 14 of 15).
- A residence and access road located along the right bank of the NSR is impacted by flooding at the 75-year flood and higher (sheet 4 of 15). Several residences located along the left bank in this area begin to be impacted at the 200-year flood and higher (sheets 3 and 4 of 15).
- The Rocky Mountain House Rodeo Grounds located on the left bank of the NSR are impacted by flooding at the 75-year flood and higher (sheet 7 of 15).
- Several residences located on the NSR left bank near Voyageur Drive begin to be impacted by flooding at the 200-year flood and higher (sheet 6 of 15). The water treatment plant located on the right bank immediately upstream of Highway 11A bridge is impacted at the 350-year flood and higher.
- A residence with several outbuildings located on the left bank of the NSR just downstream of the CN Rail bridge is impacted by flooding at the 350-year flood and higher (sheet 1 of 15).

- Range Road 73A and several adjacent residences located on the left bank of the NSR are impacted by flooding at the 350-year flood and higher (sheet 8 of 15).

- Several residences located along the left and right banks of the Clearwater River near the Highway 752 bridge are impacted by flooding at the 350-year flood and higher (sheets 12 and 13).

- Flood impacts to the vehicle/rail bridges is summarized below:

  - CN Rail Bridge – bridge/embankment not overtopped
  - Highway 11A Bridge – road segment to the east overtopped at the 500-year flood and above
  - Highway 11 Bridge – road segment to the south overtopped at the 750-year flood and above
  - Highway 752 bridge – bridge/road not overtopped

5.3.2 Flood Polygon Discontinuities

Flood polygon discontinuities refer to those areas that are topographically isolated from the directly inundated areas but hydraulically connected via a hydraulic structure such as a culvert.

Several culverts affecting otherwise isolated areas were identified throughout the study area based on a review of aerial imagery; note that these culverts were not surveyed or field verified. All of these identified culverts are shown on the open water flood inundation maps and their associated isolated areas were included in the inundation mapping. There are potentially other culverts that were not identified during aerial imagery review that may result in inundation of isolated areas that are not shown on the maps. However, these areas were reviewed by Matrix and GoA and were removed from the maps because hydraulic connection could not be confirmed, or because inundation within these areas would not meaningfully affect nearby landowners or stakeholders.

6 FLOODWAY DETERMINATION

6.1 Design Flood Selection

Flood hazard identification involves delineation of floodway and flood fringe zones for a specified design flood. As per the FHIP guidelines (AENV 2011), the 100-year flood was adopted as the open water design flood and is defined based on flood statistics available at the time of the study. A description of key terms from the FHIP guidelines (AENV 2011), incorporating technical changes as indicated in the TOR (AEP 2020) regarding how floodways are mapped in Alberta is provided in sections below.

6.2 Floodway and Flood Fringe Terminology

Flood hazard mapping identifies the area flooded during the design flood event and is typically divided into floodway and fringe zones. Flood hazard maps can also show additional flood hazard information including areas of relatively high hazard within the flood fringe and incremental areas at risk for more severe floods, like the 200-year and 500-year floods. Flood hazard mapping is typically used for long-term flood hazard area management and land use planning.

- Floodway: when a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazards where flows are deepest, fastest, and most destructive during the 100-year design flood. The floodway generally includes the main channel of a stream and a portion of the adjacent overbank area. Previously mapped floodways do not typically become larger when a flood hazard map is updated, even if the flood hazard area gets larger or design flood levels get higher.

- Flood fringe: the flood fringe is the portion of the flood hazard area outside of the floodway. The flood fringe typically represents areas with shallower, slower, and less destructive flooding during the 100-year design flood. However, areas with deep or fast-moving water may also be identified as high hazard flood fringe within the flood fringe. Areas at risk behind flood berms may also be mapped as protected flood fringe areas.

- Design flood levels: design flood levels are the computed water levels associated with the design flood.

6.3 Flood Hazard Identification

6.3.1 Floodway Determination Criteria

The computed water levels associated with the design flood are used as the design flood levels in flood hazard identification and mapping process. Some important factors considered in floodway determination criteria include the following:

- In areas being mapped for the first time, the floodway typically represents the area of highest hazard where flows are deepest, fastest, and most destructive during the design flood. The following criteria, based on those described in current FHIP guidelines, are used to delineate the floodway in such cases:

  - Areas in which the depth of water exceeds 1 m, or the flow velocities are greater than 1 m/s, shall be part of the floodway. Exceptions may be made for small backwater areas, ineffective flow areas, and to support creation of a hydraulically smooth floodway.

  - In no case should the floodway extend into the main channel area.

  - For reaches of supercritical flow, the floodway boundary should correspond to the edge of inundation or the main channel, whichever is larger.

- When a flood hazard map is updated, an existing floodway will not change in most circumstances. Exceptions to this would be:

  - A floodway could get larger if main channel shifts outside of a previously defined floodway.

    - A floodway could get smaller if an area of previously defined floodway is no longer flooded by the design flood.

- Areas of deeper or faster moving water outside of the floodway are identified as high hazard flood fringe. These high hazard flood fringe zones are identified in all areas, whether they are newly mapped or have an existing floodway. The depth and velocity criteria used to define high hazard flood fringe zones are aligned with the 1 m depth and 1 m/s velocity floodway determination criteria for newly-mapped areas.

- All areas protected by dedicated flood berms that are not overtopped during the design flood are excluded from the floodway. Areas behind flood berms will still be mapped as flooded if they are overtopped, but areas at risk of flooding behind dedicated flood berms that are not overtopped will be mapped as a protected flood fringe zone.

There were no previously developed flood hazard maps for the study area and no flood control structures are located within the study reach. Floodway stations were selected using the above-mentioned factors and considering geomorphic and landscape features under the design flood levels along the NSR and Clearwater River (Table 7).

6.3.2 Design Flood Profile

Table 8 lists the water surface elevations computed for the 100-year design flood on the NSR and Clearwater River. The water surface profiles for the NSR and Clearwater River are plotted on Figures 14 and 15, respectively.

6.3.3 Floodway Criteria Maps

Floodway criteria maps are a tool for determining floodway and flood fringe extents for the design flood including boundaries of high hazard flood fringe and protected flood fringe areas. The Open Water Floodway Criteria Maps (sheet 1 to 16, Appendix D) provided in the Maps and Drawings section of this report show:

- inundation extents of the 100-year open water design flood
- areas where the depth of water is 1 m or greater and the corresponding 1 m depth contour
- the portions of each cross-section where the computed velocity is 1 m/s or greater
- the proposed floodway boundary, as well as the floodway stations corresponding to the floodway determination criteria
- isolated areas of non-flooded, high ground (i.e., “dry” areas) within the design flood extent
- the location and extent of all cross-sections used in the HEC-RAS model
- additional information concerning flood criteria maps are provided in the section below

6.3.4 Flood Hazard Maps

Flood hazard maps for the 100-year design flood are provided in Appendix E. The floodway is primarily governed by the 1 m depth contour for the Sturgeon River. Manual adjustments to the floodway boundary were made in some locations in consultation with AEP to maintain a hydraulically smooth floodway between cross-sections; this resulted in some areas with flow depths greater than 1 m being classified as flood fringe. These areas are categorized as high hazard flood fringe zone.

6.3.4.1 Areas within the Floodway

Along the NSR, the floodway generally encompasses the entire inundation area with no viable flood fringe. The floodway in this area is generally situated at or just beyond the main channel with a width ranging from about 115 to 425 m. The floodway occasionally extends beyond the main channel and into the floodplain in low-lying areas or through inside channel bends. Nearing the confluence, the floodway widens into the left and right floodplains with a total width ranging from 600 to 1,000 m. Downstream of the confluence, the right floodway station generally extends to the inundation limit (no viable flood fringe) and is situated just beyond the main channel. Through the Rocky Mountain House townsite, neither the floodway nor flood fringe impact infrastructure existing at the time of this study. Floodplain impacted by the floodway generally consists of cultivated or forested land, though several outbuildings, an industrial area, and private/tertiary roads (including Range Road 73A) are situated within the floodway. Further, there appear to be two residences situated within the floodway on the left bank of the NSR:

- on sheet 3, approximately 50 m downstream of RS 9981
- on sheets 5/6, immediately downstream of RS 6533

Along the Clearwater River, the floodway is more prone to inundating the floodplains and varies in width from about 90 to 450 m. The governing floodway criteria typically alternates between the depth and velocity criteria with select areas where the floodway extends to the inundation extent. Floodplain impacted by the floodway generally consists of cultivated or forested land. One industrial area and what appear to be two residences are also situated within the floodway (residences located on sheet 11, immediately downstream of RS 4926 on the right bank and at RS 4245 on the left bank).

6.3.4.2 Areas within the Flood Fringe

As noted above, there is minimal flood fringe located along the NSR, with the exception of some low-lying areas or through inside channel bends. The flood fringe generally consists of cultivated or forested land, with several outbuildings, an industrial area, one residence (left bank, sheet 3 of 15), and a tertiary road (Range Road 73A). On the Clearwater River, there are more areas with designated flood fringe, primarily located through inside channel bends and consisting of cultivated land with a few outbuildings.

Areas of high hazard flood fringe (>1 m depth) are present at along the NSR at the following locations:

- On the NSR right bank immediately upstream of the confluence (sheet 5 of 15)

- On the NSR left bank just downstream of the Rocky Mountain House rodeo grounds (sheet 7/8 of 15)
- On the NSR right bank just downstream of the Highway 11 bridge (sheet 10 of 15)
- On the Clearwater River left bank just downstream of the upstream model limit (sheet 11 of 15)
- On the Clearwater River right bank jus downstream of the Highway 752 bridge (sheet 13 of 15)

7 POTENTIAL CLIMATE CHANGE IMPACTS

Climate change projections for Alberta generally predict an increase in annual temperatures and precipitation as well as increased intensity and frequency of extreme events (Alberta WaterPortal 2018). In an effort to quantify these impacts, the 100-year flood magnitude was increased by 10% and 20% with resulting water levels compared to the baseline elevations. Table H provides a summary of the average increase in water level (as compared to baseline water levels) in the NSR and Clearwater River for an increase of 10% and 20% to the 100-year flood discharge. Based on these results, and the similar impacts in water surface rise in the upper and lower river reaches, it would be reasonable to apply a freeboard 0.5 m to simulated design water levels when attempting to account for climate change concerns. This freeboard has not been incorporated in the flood mapping presented herein.

TABLE H Computed Water Levels for Potential Climate Change Impacts

Location	Water Level Difference (m)[1]	
	10% Increase	20% Increase
Upper North Saskatchewan River (RS 14181 to 7325)	**Q = 2,279 m^3/s**	**Q = 2,486 m^3/s**
Average	0.21	0.41
Lower North Saskatchewan River (RS 6817 to 0)	**Q = 3,379 m^3/s**	**Q = 3,686 m^3/s**
Average	0.26	0.51
Clearwater River (RS 4926 to 253)	**Q = 1,100 m^3/s**	**Q = 1,200 m^3/s**
Average	0.23	0.44

1. As compared to baseline water levels.

8 CONCLUSIONS

Flow estimates for the 2-year to 1,000-year flood events on the NSR and Clearwater River near Rocky Mountain House were estimated using flood frequency analysis based on a review of annual peak discharges recorded at two hydrometric stations, the Clearwater River near Rocky Mountain House (05DC001) and the NSR near Rocky Mountain House (05DC001).

The hydraulic model and resulting map products were constructed using LiDAR data provided by GoA and surveyed cross-sections, and hydraulic structure data collected by GeoVerra under Matrix's supervision. All surveyed data was tied together using ASCN benchmarks that were surveyed independently during the various data collection phases. The hydraulic model was calibrated using surveyed highwater marks collected during the 1972, 1986, and 1998 flood events as well as water levels estimated during the 1915 flood event. Calibration focused on the 1972 highwater marks as this flood was most representative of the design flood adopted for this study. To best fit the 1972 calibration data, channel roughness ranged from 0.032 (NSR) to 0.037 (Clearwater River), and overbank roughness ranged from 0.02 (cultivated areas) to 0.1 (tree/brush).

A summary of major conclusions from the open water inundation maps (Appendix C) for the 2-year to 1,000-year flood events is presented below:

- An industrial area located in the left bank of the NSR just upstream of the confluence is impacted by flooding at the 35-year flood and higher (sheet 5 of 15). Residences located along the right bank in this area begin to be impacted by flooding at the 750-year flood and higher.
- The Riverview Campground located on the left bank of the NSR upstream of Highway 11 is impacted by flooding at the 35-year flood and higher (sheet 9 of 15). Several residences adjacent to the campground are impacted by flooding at the 350-year flood and higher.
- An industrial area located along the right bank of the Clearwater River just upstream of the confluence is impacted by flooding at the 35-year flood and higher (sheet 14 of 15).
- A residence and access road located along the right bank of the NSR is impacted by flooding at the 75-year flood and higher (sheet 4 of 15). Several residences located along the left bank in this area begin to be impacted at the 200-year flood and higher (sheets 3 and 4 of 15).
- The Rocky Mountain House Rodeo Grounds located on the left bank of the NSR are impacted by flooding at the 75-year flood and higher (sheet 7 of 15).
- Several residences located on the NSR left bank near Voyageur Drive begin to be impacted by flooding at the 200-year flood and higher (sheet 6 of 15). The water treatment plant located on the right bank immediately upstream of Highway 11A bridge is impacted at the 350-year flood and higher.
- A residence with several outbuildings located on the left bank of the NSR just downstream of the CN Rail bridge is impacted by flooding at the 350-year flood and higher (sheet 1 of 15).
- Range Road 73A and several adjacent residences located on the left bank of the NSR are impacted by flooding at the 350-year flood and higher (sheet 8 of 15).
- Several residences located along the left and right banks of the Clearwater River near the Highway 752 bridge are impacted by flooding at the 350-year flood and higher (sheets 12 and 13).
- Overtopping of the vehicle bridges occurs at the following flood events and higher:
    - CN Rail Bridge – bridge/embankment not overtopped
    - Highway 11A Bridge – road segment to the east overtopped at the 500-year flood and above
    - Highway 11 Bridge – road segment to the south overtopped at the 750-year flood and above
    - Highway 752 bridge – bridge/road not overtopped

The 100-year design flood profile was used to develop the flood hazard maps for the study reach. Along the NSR, the floodway generally encompasses the entire inundation area with no viable flood fringe with the exception of a few areas where depth is the governing criteria. The floodway along the NSR is generally situated at or just beyond the main channel with the exception of the confluence area, where the floodway widens into the left and right floodplains. Through the Rocky Mountain House townsite, neither the floodway nor flood fringe impact infrastructure existing at the time of this study. Along the NSR, the floodway generally consists of cultivated of forested land, though several outbuildings, an industrial area, private/tertiary roads, and what appear to be two residences are situated within the floodway.

The governing floodway criteria along the Clearwater River alternates between the depth and velocity criteria with select areas where the floodway extends to the inundation extent (no viable flood fringe). Along the Clearwater River, the floodway also consists of cultivated or forested land with one industrial area and what appear to be two residences situated within its extents. Design flood hazard maps are provided in Appendix E.

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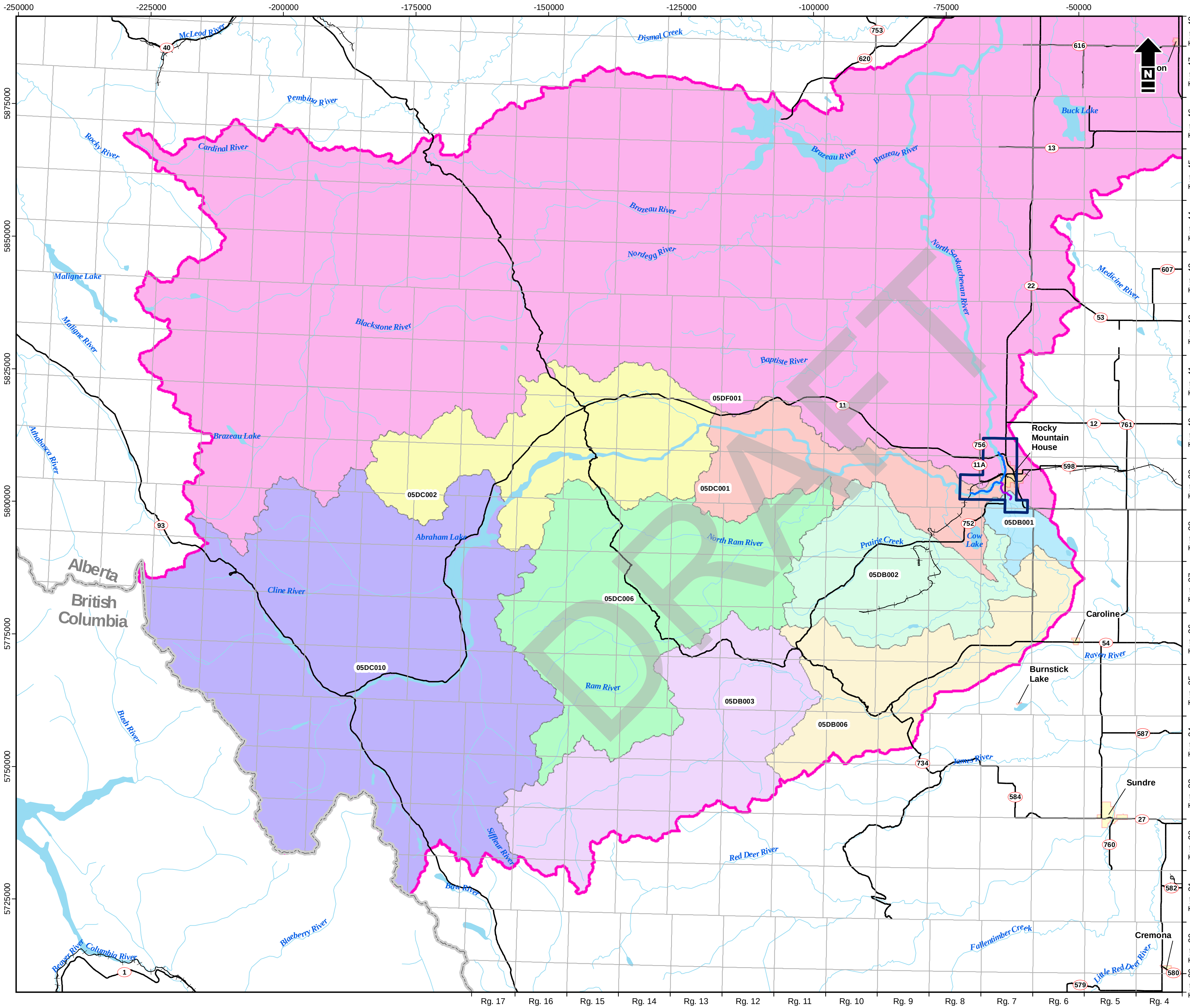

North Saskatchewan River Basin
LiDAR and Aerial Image Acquisition Extent
Community
Water Body
Watercourse
Clearwater River Study Reach
North Saskatchewan River Study Reach
Highway
Railway

WSC Subwatershed ID, WSC Subwatershed Name

05DB006, CLEARWATER RIVER NEAR DOVERCOURT
05DB003, CLEARWATER RIVER ABOVE LIMESTONE CREEK
05DB001, CLEARWATER RIVER NEAR ROCKY MOUNTAIN HOUSE
05DB002, PRAIRIE CREEK NEAR ROCKY MOUNTAIN HOUSE
05DC001, NORTH SASKATCHEWAN RIVER NEAR ROCKY MOUNTAIN HOUSE
05DC002, NORTH SASKATCHEWAN RIVER AT SAUNDERS
05DC006, RAM RIVER NEAR THE MOUTH
05DC010, NORTH SASKATCHEWAN RIVER BELOW BIGHORN PLANT
05DF001, NORTH SASKATCHEWAN RIVER AT EDMONTON

1:750,000 kilometres
7.5 0 7.5 15
NAD 1983 CSRS 3TM 114

Reference: Data obtained from AltaLIS © Government of Alberta and GeoBase® used under license. Water Survey of Canada watershed boundaries obtained from Agriculture and Agri-foods Canada (2013) used under license.

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Alberta

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Rocky Mountain House Flood Hazard Study

Location Plan

Date:	Project:	Submitter:	Reviewer:
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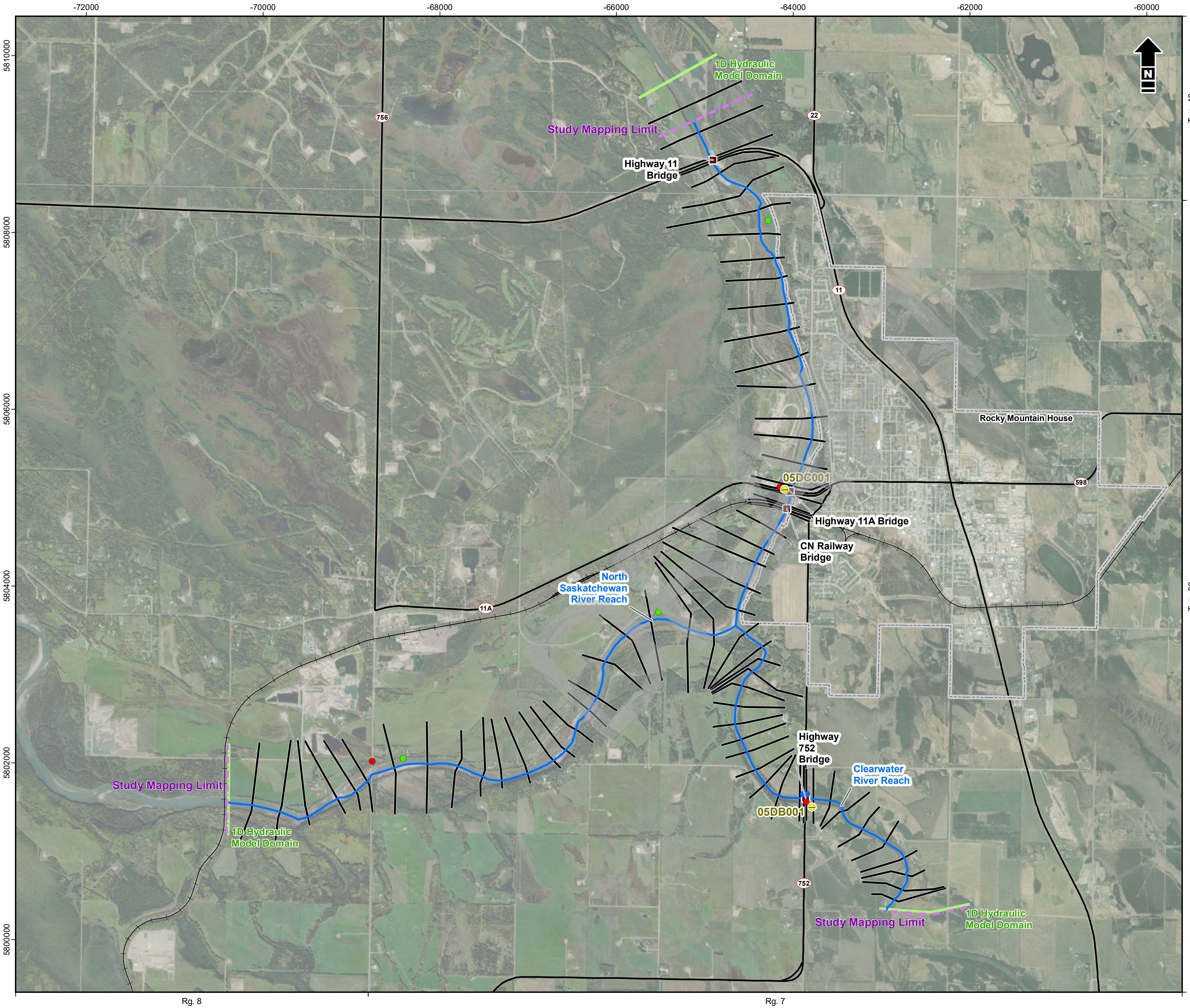
Figure 1

Classification: Public



- Study Reach
- Cross Section
- Study Mapping Limit
- 1D Hydraulic Model Domain
- Municipal Boundary (Urban)
- Highway
- Railway
- Road/Railroad Bridge
- Hydrometric Station
- High Water Mark Location | 1972 Survey
- High Water Mark Location | 1986 Survey
- High Water Mark Location | 1998 Survey

1:45,000 metres
500 0 500 1,000
NAD 1983 CSRS 3TM 114

Reference: Data obtained from GeoBase® used under license. Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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Rocky Mountain House Flood Hazard Study

Study Area, Cross Sections, Hydraulic Structures, and Highwater Mark Locations

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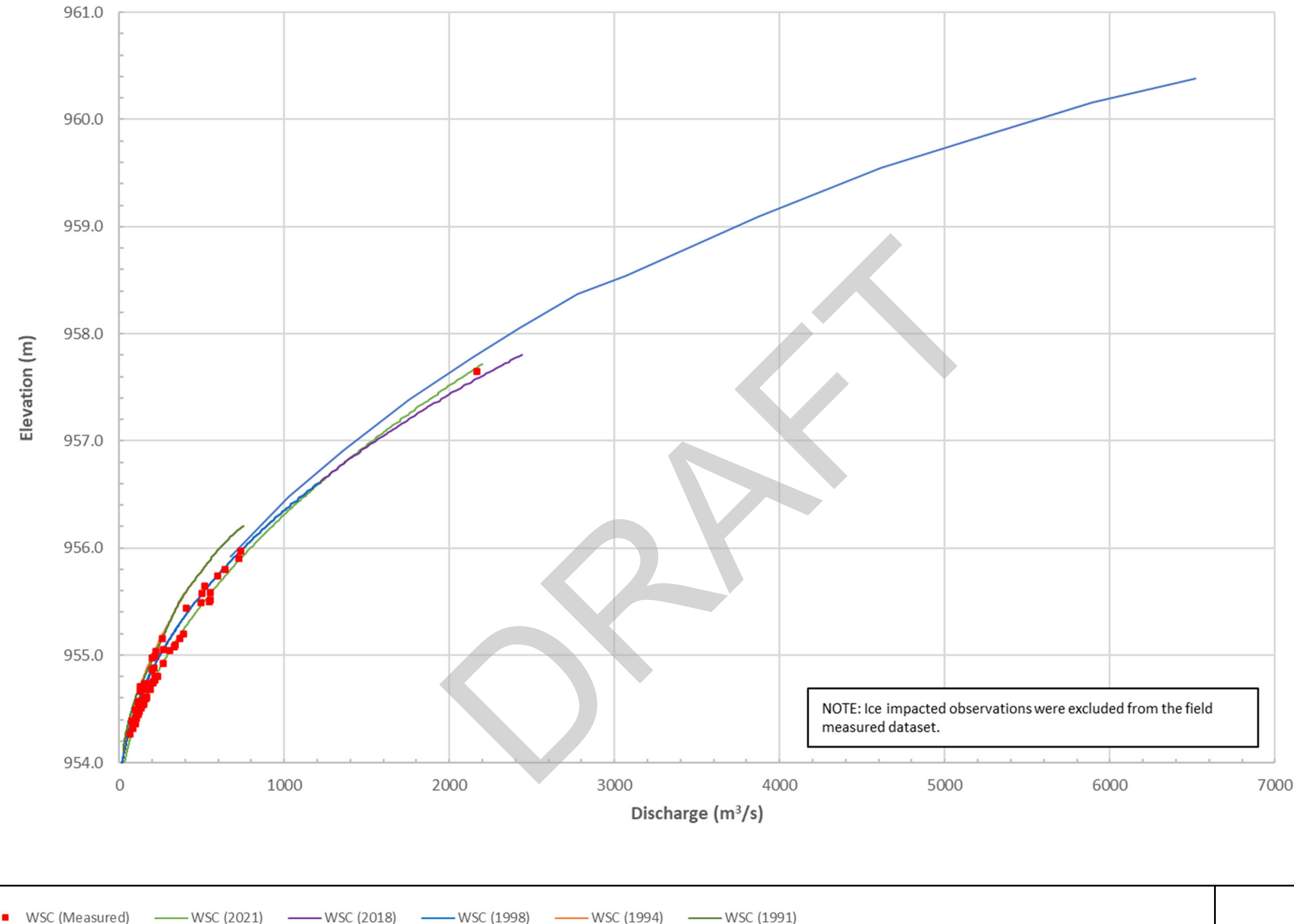
Figure 2



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North Saskatchewan River near Rocky Mountain House (05DC001), Rating Curve

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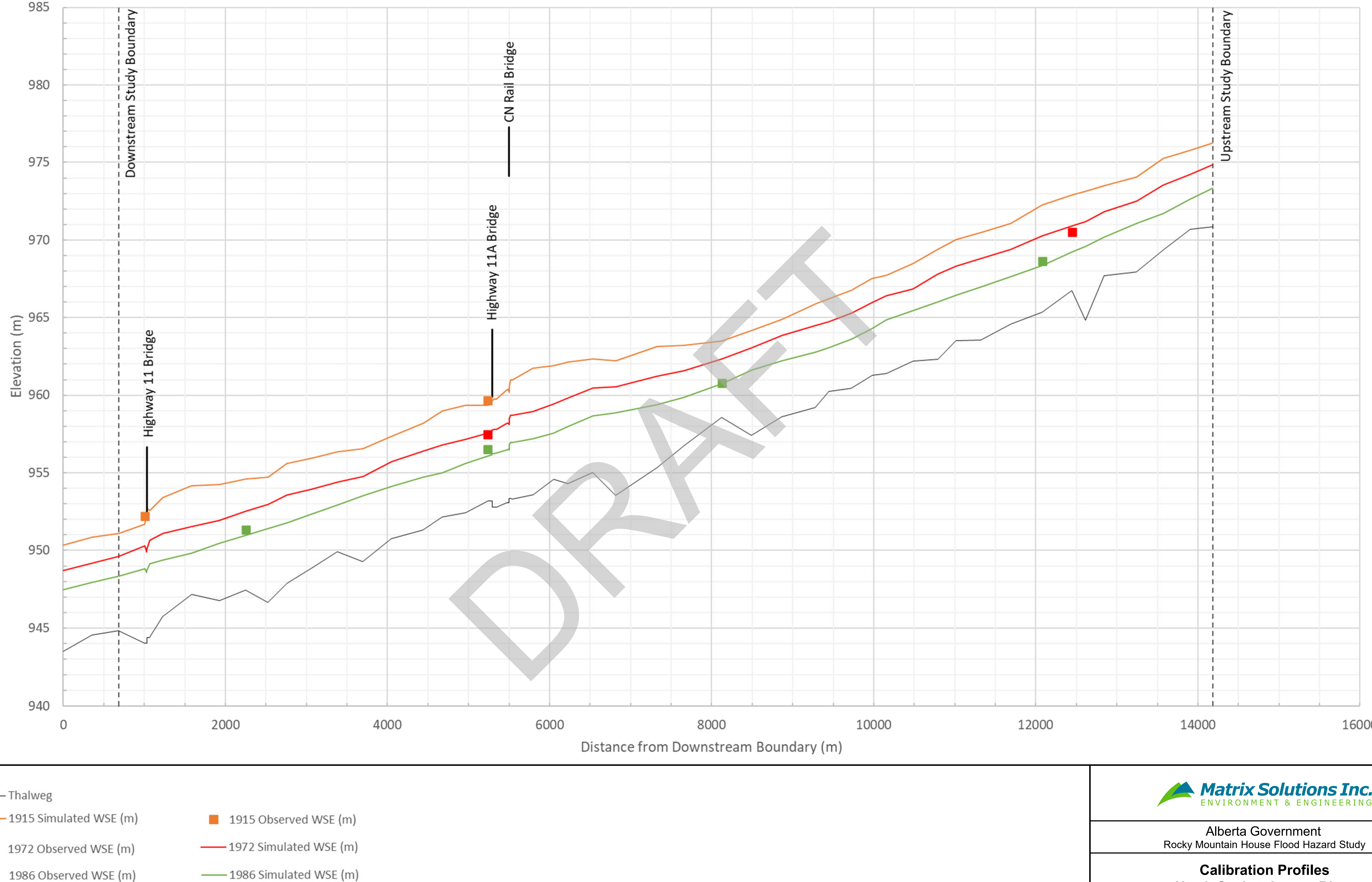
Figure 3



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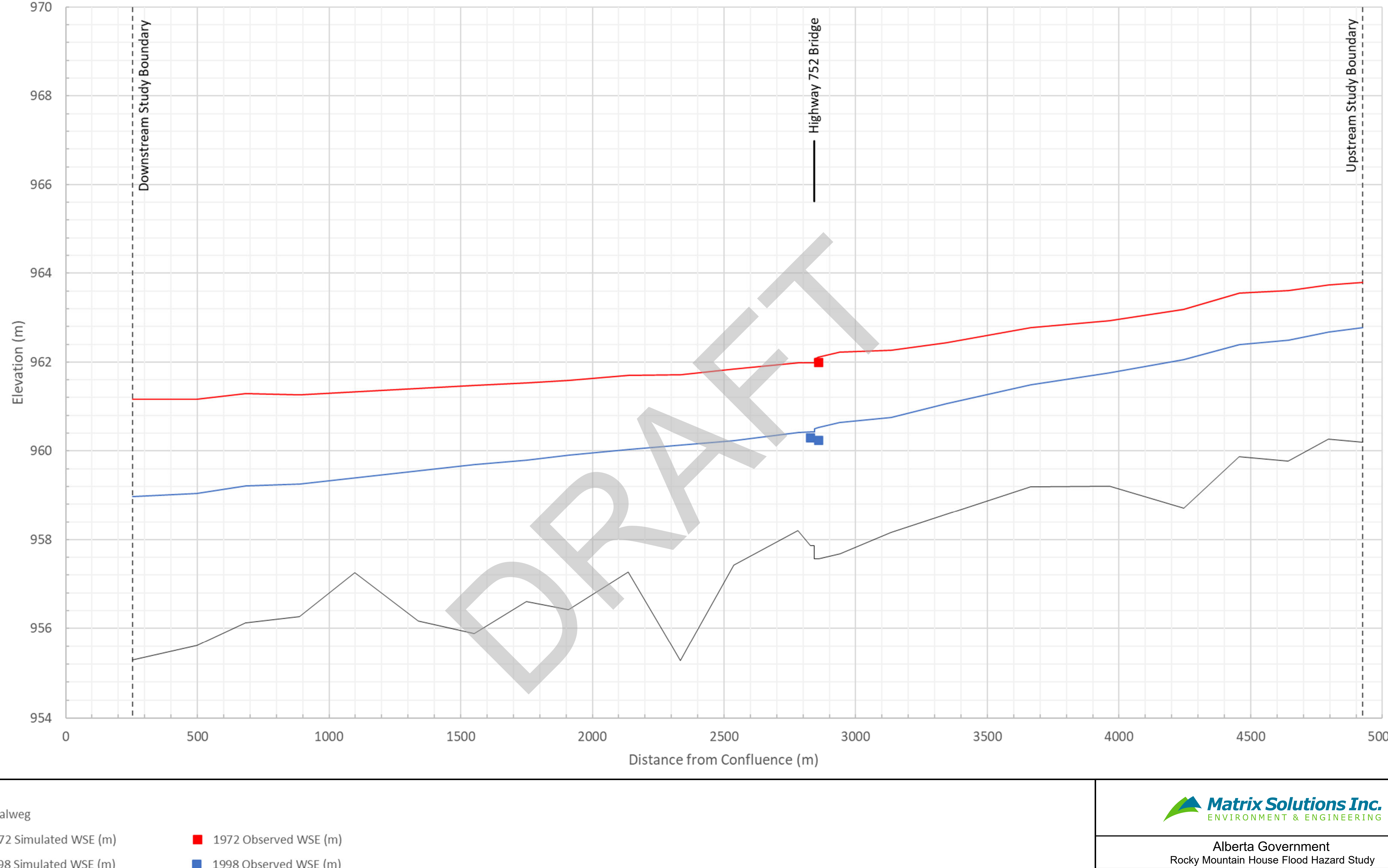
Rocky Mountain House Flood Hazard Study

Calibration Profiles
North Saskatchewan River

Date: March 2022	Project: 31781	Submitter: P.Rogers	Reviewer: M.Shome

Figure 4



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Calibration Profiles
Clearwater River

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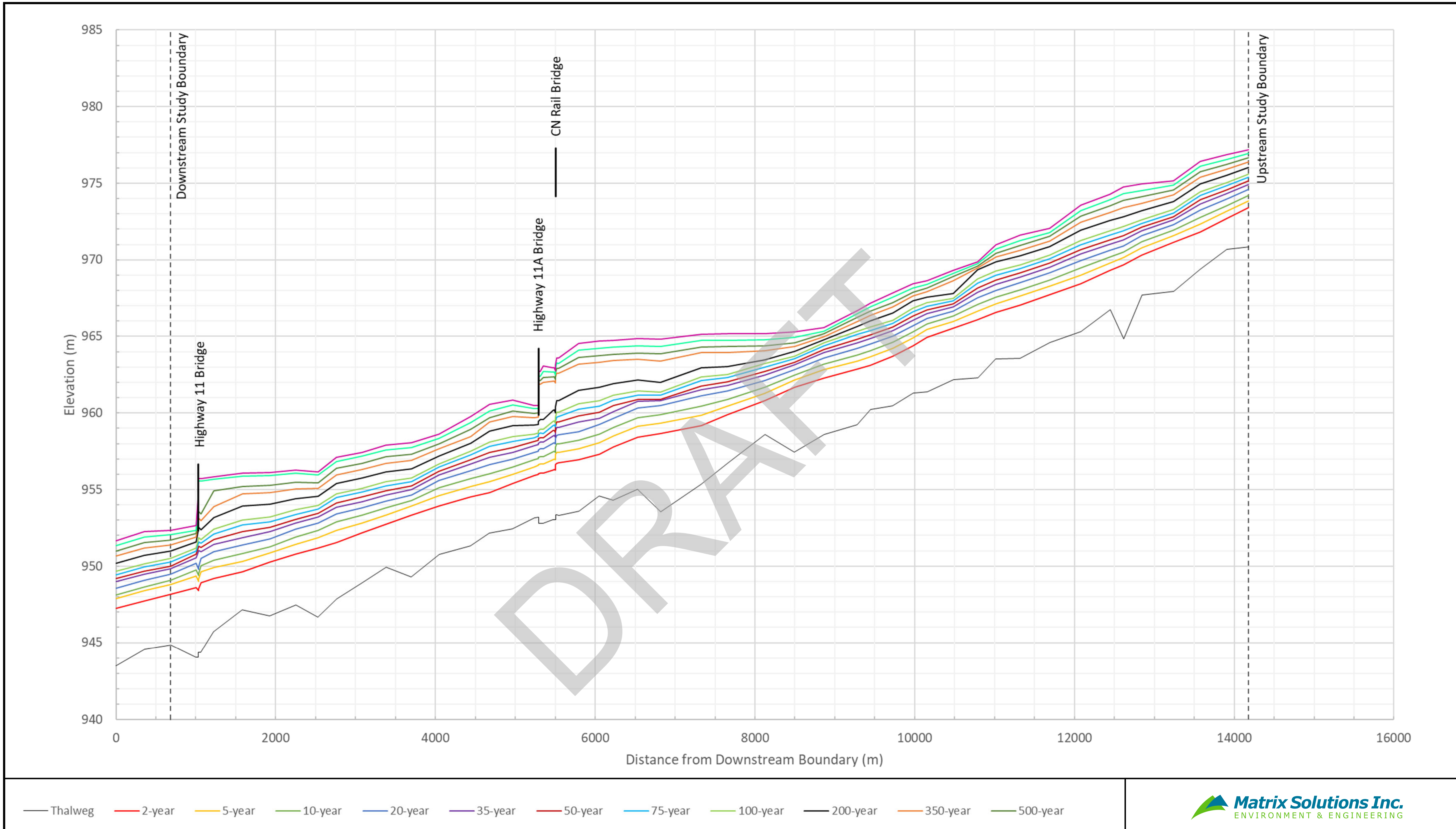
Figure 5



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Flood Frequency Profiles
North Saskatchewan River

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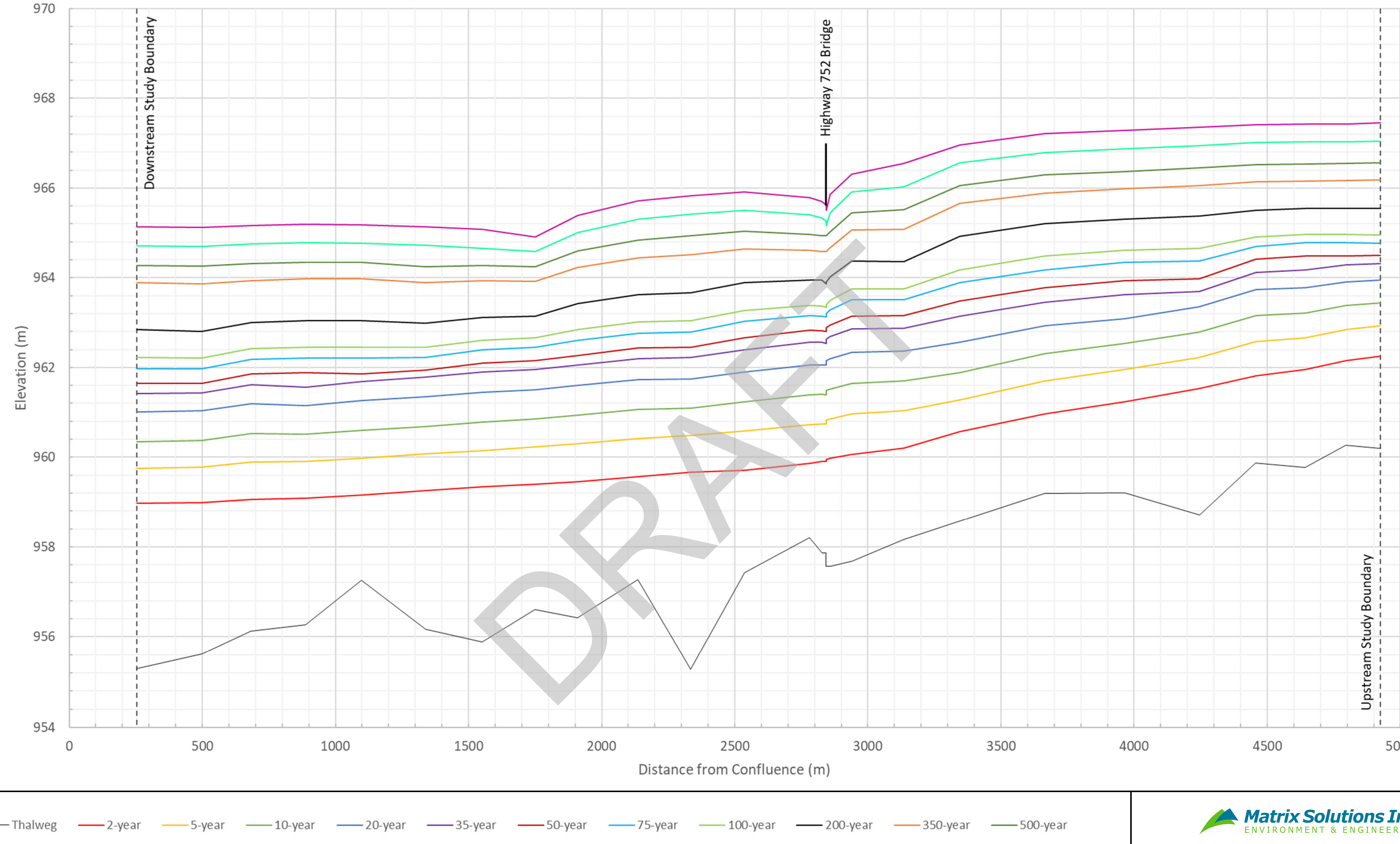
Figure 6



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Flood Frequency Profiles
Clearwater River

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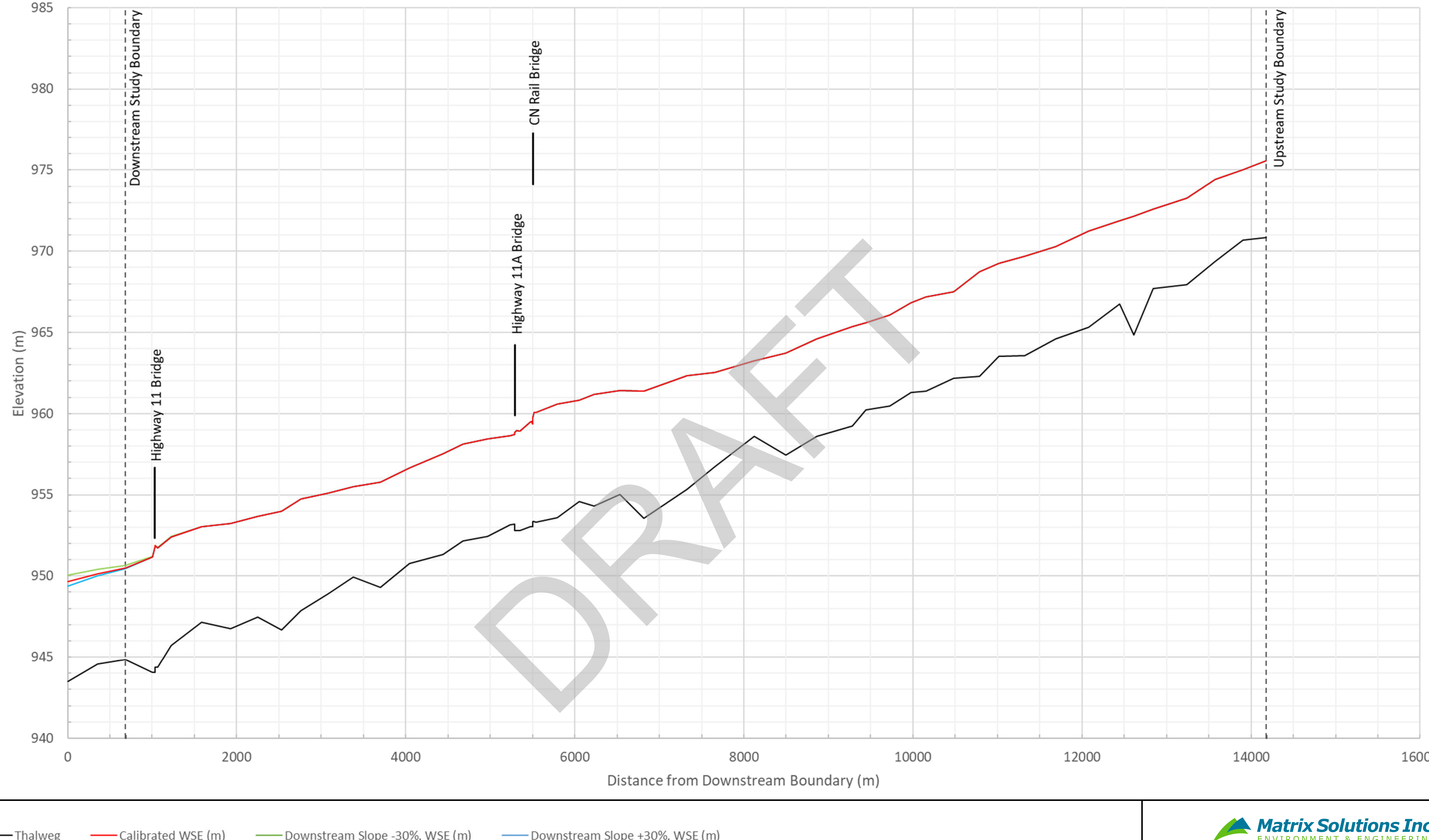
Figure 7

Classification: Public



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Sensitivity Analysis Profiles
Variable Downstream Boundary Conditions
North Saskatchewan River

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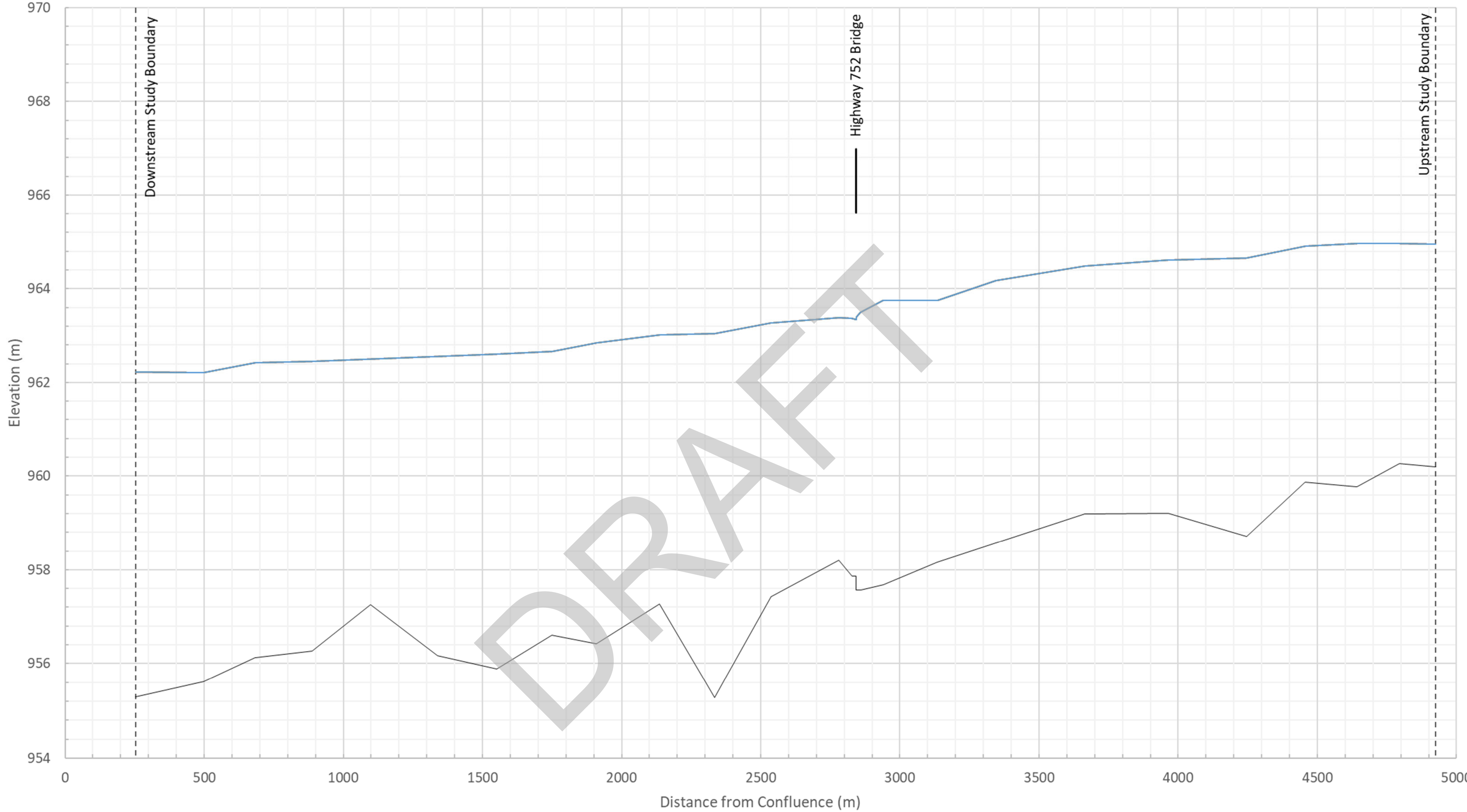
Figure 8



Thalweg — Calibrated WSE (m) — Downstream Slope -30%, WSE (m) — Downstream Slope +30%, WSE (m)

Note: All three profiles are coincident and indiscernible in this view.

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Sensitivity Analysis Profiles
Variable Downstream Boundary Conditions
Clearwater River

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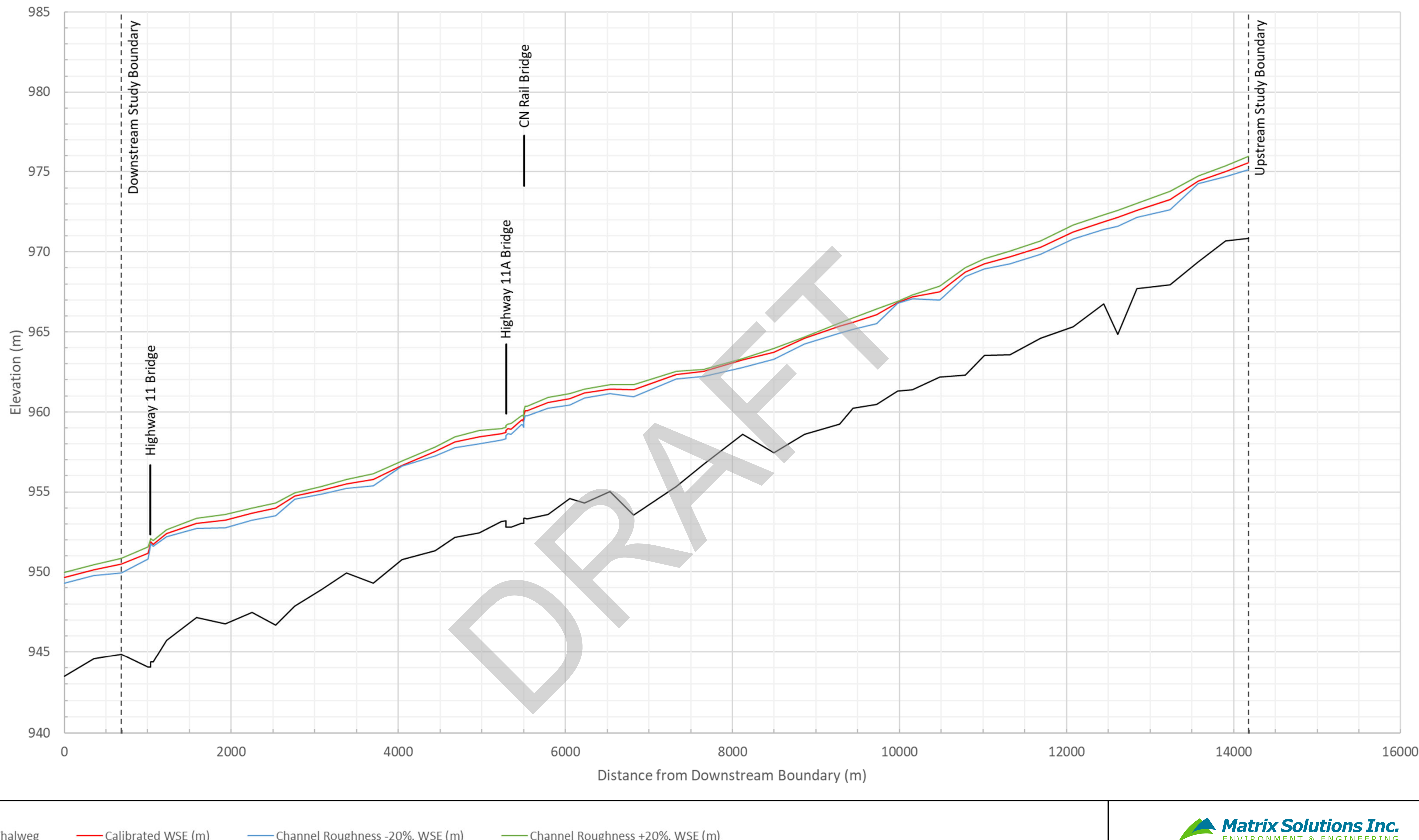
Figure 9



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Sensitivity Analysis Profiles
Variable Channel Manning Roughness
North Saskatchewan River

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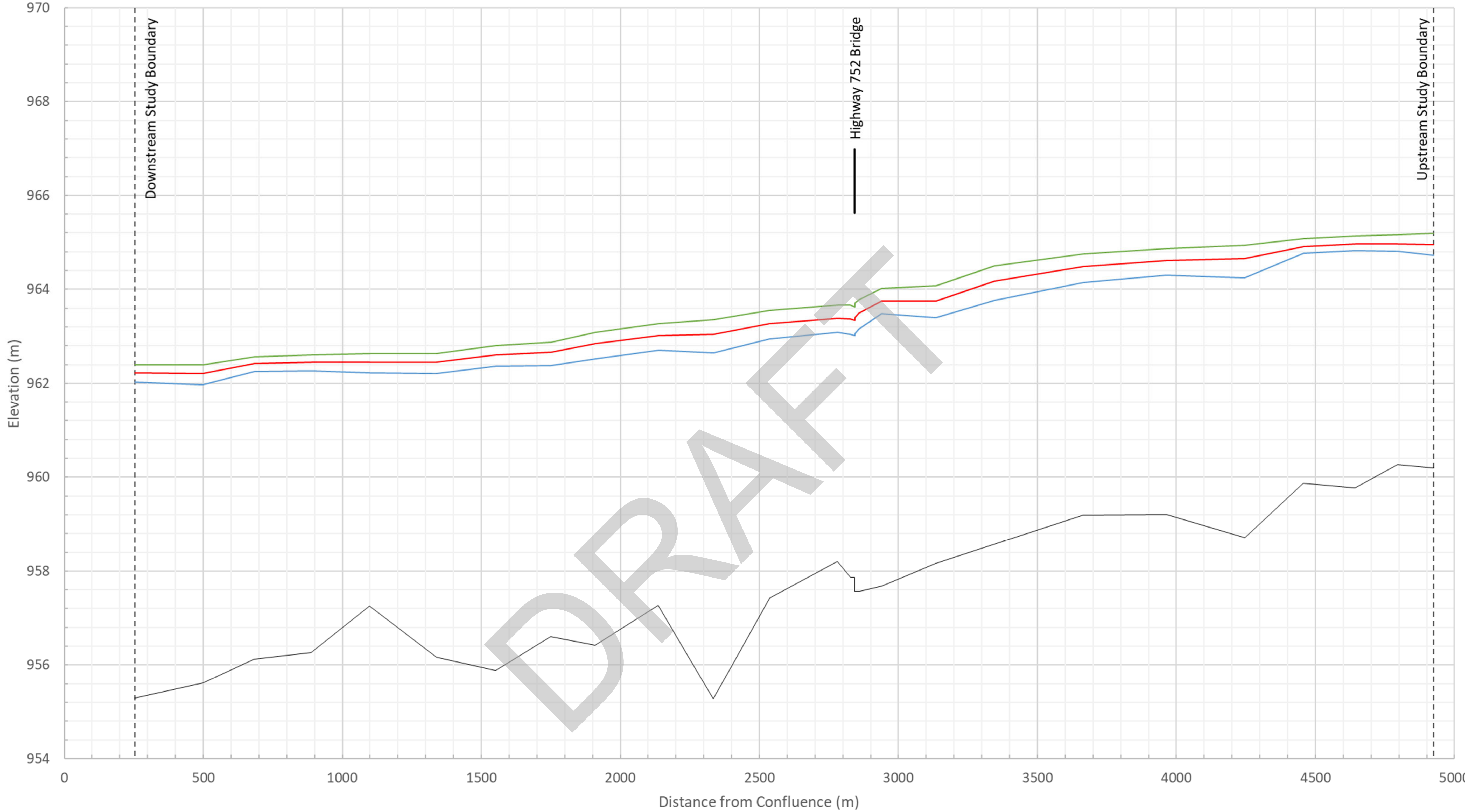
Figure 10



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Sensitivity Analysis Profiles
Variable Channel Manning Roughness
Clearwater River

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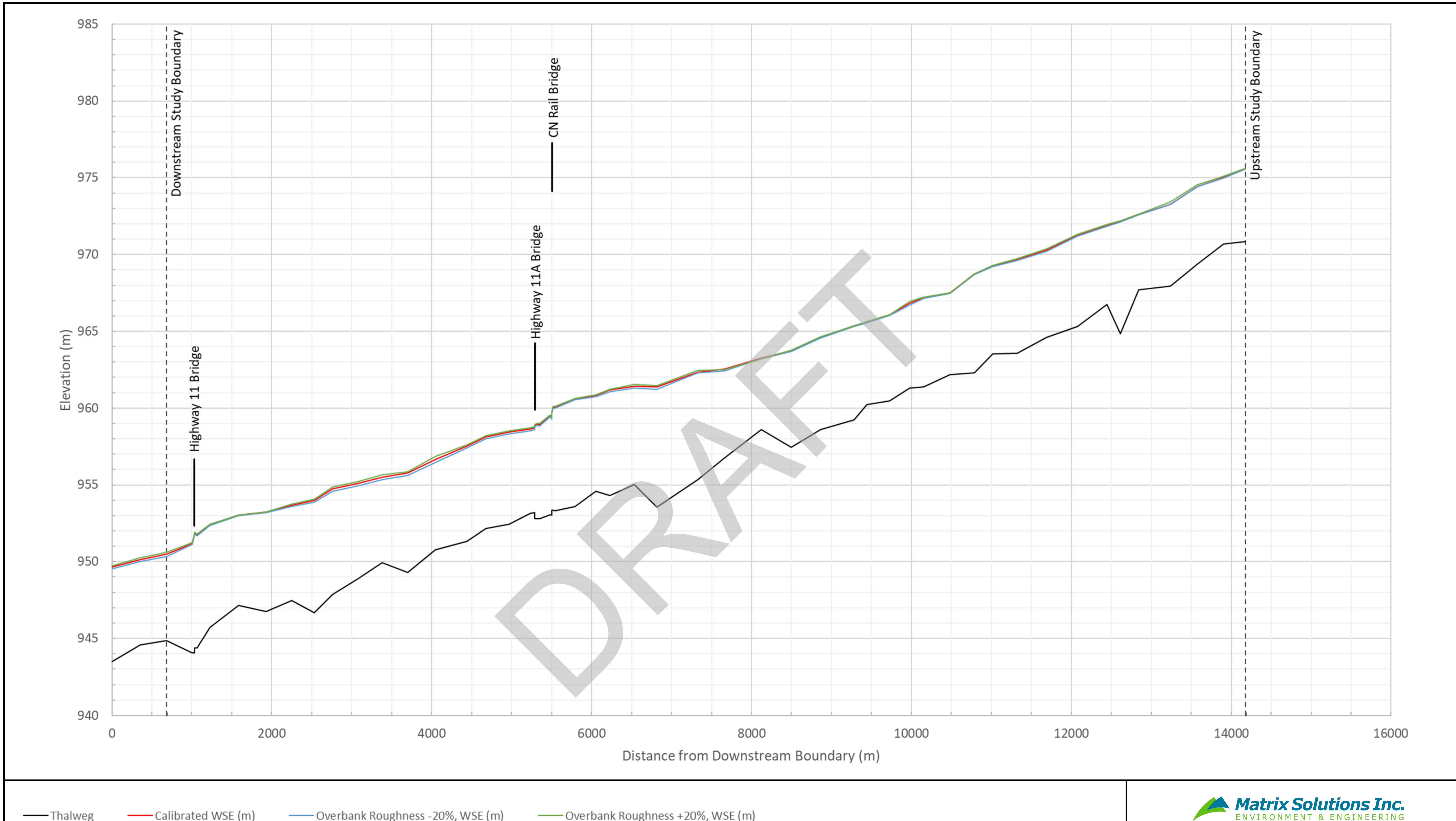
Figure 11



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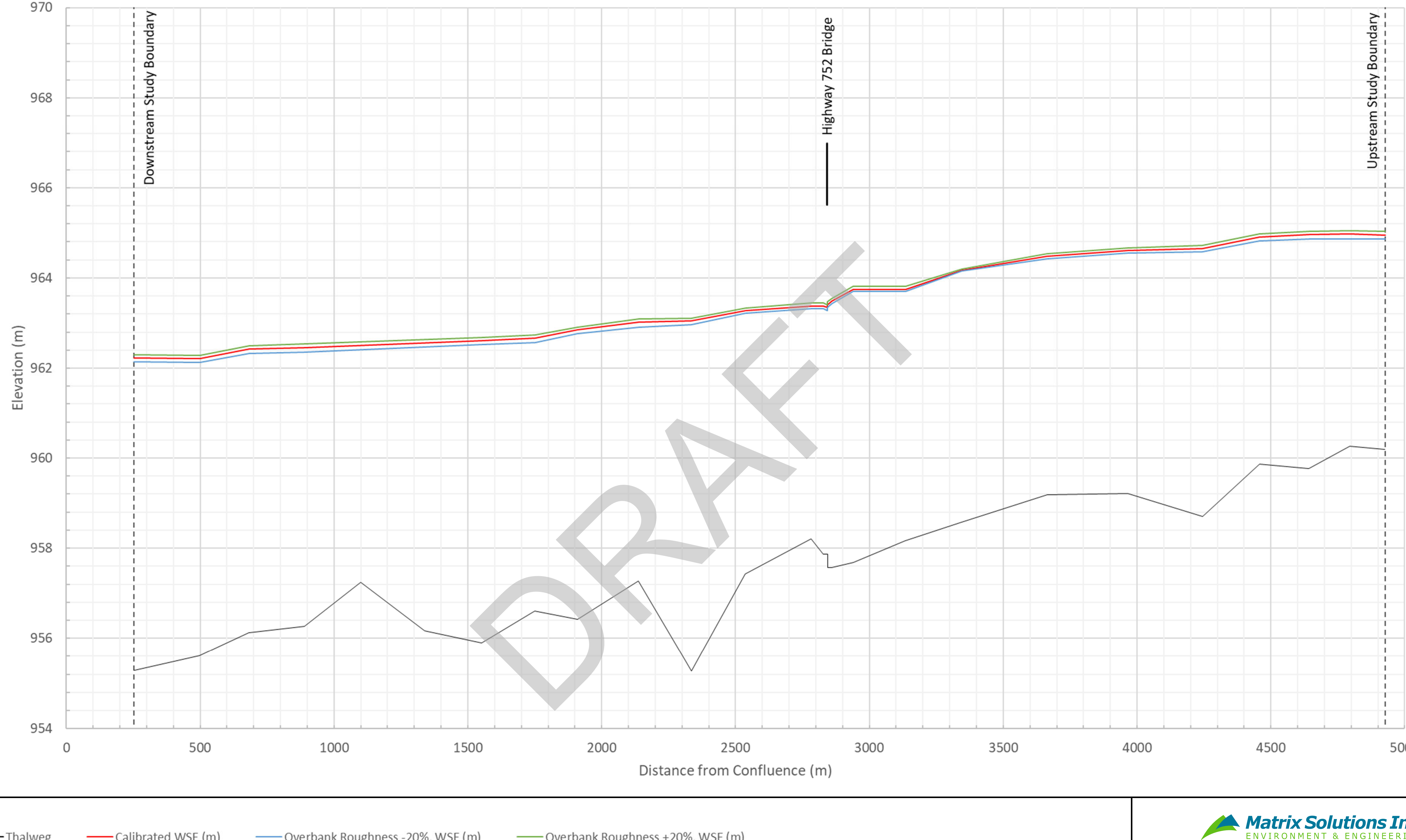
Sensitivity Analysis Profiles
Variable Overbank Manning Roughness
North Saskatchewan River

Date: March 2022	Project: 31781	Submitter: P.Rogers	Reviewer: M.Shome

Figure 12



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Sensitivity Analysis Profiles
Variable Overbank Manning Roughness
Clearwater River

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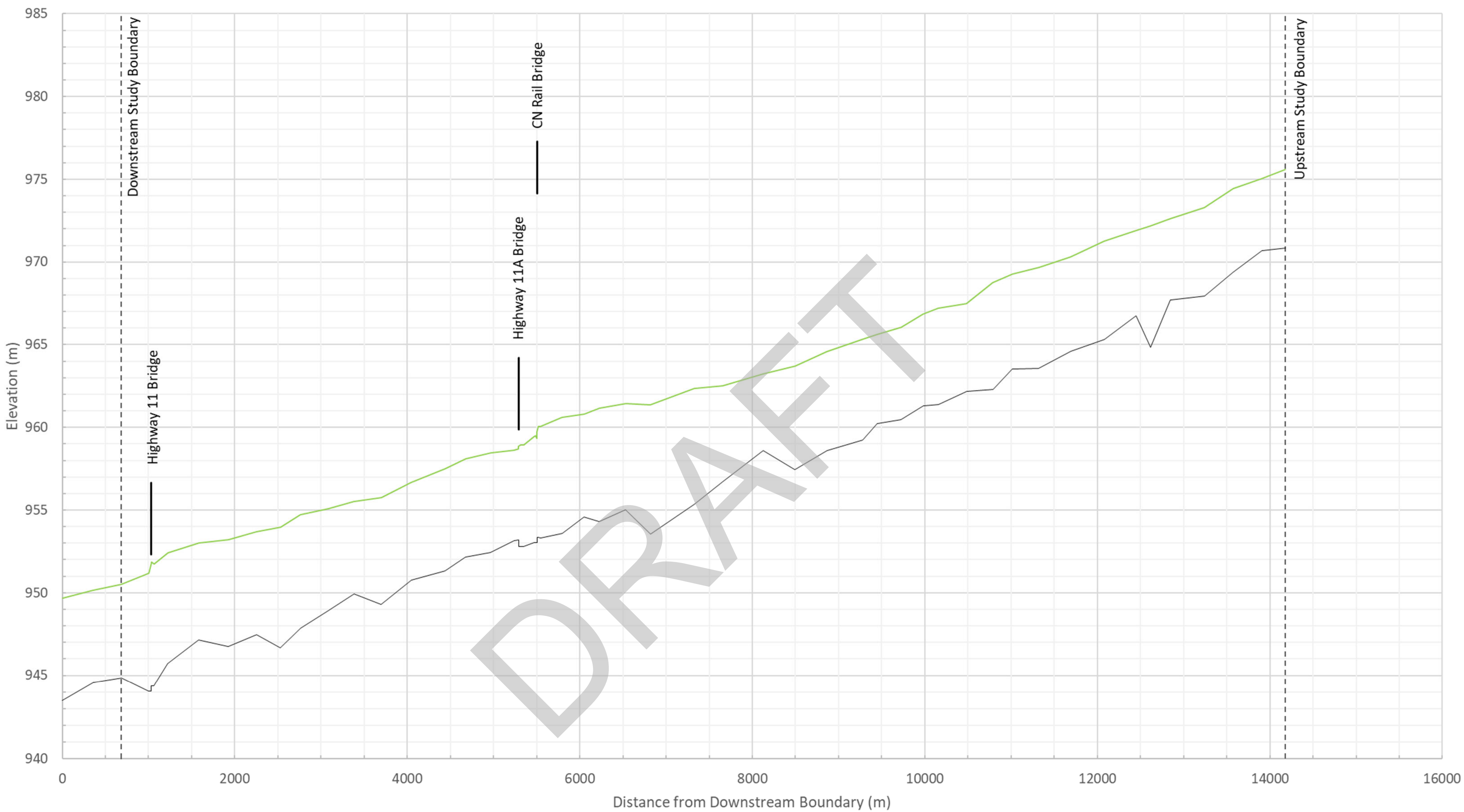
Figure 13



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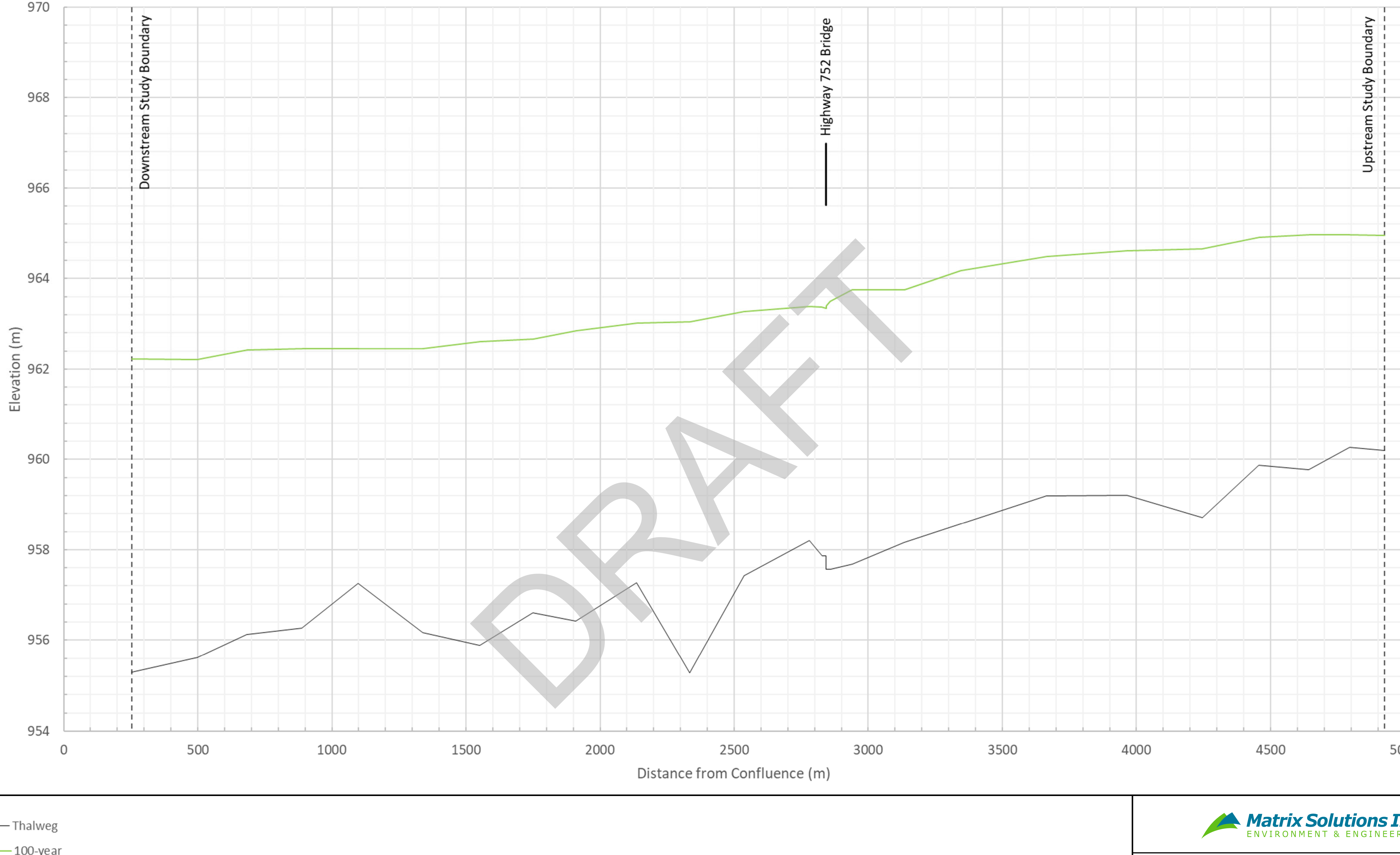
Rocky Mountain House Flood Hazard Study

Design Flood Profile
North Saskatchewan River

Date: March 2022	Project: 31781	Submitter: P.Rogers	Reviewer: M.Shome

Figure 14



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Rocky Mountain House Flood Hazard Study

Design Flood Profile
Clearwater River

Date:	Project:	Submitter:	Reviewer:
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Figure 15

TABLE 1 Bridge Details

Bridge Name	Bounding Cross-section	Details
CN Railroad Bridge (NSR)	5519 and 5487	• 258.6 m long timber trestle bridge with hexagonal concrete piers • Deck width of 3.91 m • Average low chord elevation, El. 974.12 m • Average high chord elevation, El. 976.5 m
Highway 11A Bridge (NSR)	5315 and 5289	• 170.9 m long concrete bridge with two 1.5 m wide rounded nose piers • Deck width of 13.28 m • Average low chord elevation, El. 960.44 m • Average high chord elevation, El. 963.63 m
Highway 11 Bridge (NSR)	1065 and 1004	• 167.6 m long concrete bridge with four rounded nose concrete piers • Deck width of 13.72 m • Average low chord elevation, El. 952.46 m • Average high chord elevation, El. 955.24 m
Highway 752 Bridge (CWR)	2859 and 2828	• 89.2 m long concrete bridge with three 1.33 m wide triangular nose concrete piers • Deck width of 10.52 m • Average low chord elevation, El. 966.75 m • Average guard rail elevation, El. 965.76 m

TABLE 2 Calibration Results

AEP High Water Mark	River Station (m)	Simulated Water Surface Elevation (m)	Observed Water Surface Elevation (m)	Difference (m)
North Saskatchewan River - June 26, 1972 Event (Q = 1,880 m^3/s)				
1972-NSASK-117-c	5346	957.57	957.49	0.08
1972-NSASK-120-a	12445	970.92	970.53	0.39
North Saskatchewan River - 1915 Flood Event (Q = 4,105 m^3/s)				
Est. 1915 Flood elev.	1004	951.71	952.20	-0.49
Est. 1915 Flood elev.	5236	959.36	959.68	-0.32
North Saskatchewan River - July 19, 1986 Event (Q = 773 m^3/s)				
1986-NSASK-115-a	2250	950.97	951.33	-0.36
1986-NSASK-117-b	5236	956.08	956.50	-0.42
1986-NSASK-118-a	8126	960.73	960.77	-0.04
1986-NSASK-119-a	12080	968.35	968.64	-0.29
Clearwater River – June 26, 1972 Event (Q = 467 m^3/s)				
1972-CLR5D-006-a	2828	961.87	962.00	-0.13
Clearwater River – July 3, 1998 Event (Q = 226.7 m3/s)				
1998-CLR5D-006-b	2828	960.31	960.30	0.01
1998-CLR5D-006-c	2859	960.41	960.25	0.16

TABLE 3 Computed Flood Frequency Water Levels

Cross-section	River Station (m)[1]	Water Surface Elevation (m)												
		2-year flood	5-year flood	10-year flood	20-year flood	35-year flood	50-year flood	75-year flood	100-year flood	200-year flood	350-year flood	500-year flood	750-year flood	1,000-year flood
North Saskatchewan River														
NS047	14181	973.41	973.86	974.21	974.59	974.93	975.15	975.39	975.58	976.04	976.39	976.67	976.93	977.18
NS046	13904	972.71	973.16	973.53	973.96	974.34	974.57	974.83	975.03	975.51	975.91	976.24	976.55	976.85
NS045	13575	971.80	972.34	972.78	973.26	973.66	973.94	974.22	974.44	974.97	975.41	975.77	976.10	976.43
NS044	13241	971.15	971.59	971.93	972.29	972.60	972.81	973.05	973.27	973.82	974.25	974.56	974.86	975.15
NS043	12843	970.30	970.80	971.18	971.58	971.89	972.12	972.38	972.61	973.20	973.68	974.12	974.54	974.96
NS042	12615	969.67	970.13	970.50	970.92	971.30	971.58	971.89	972.16	972.82	973.39	973.87	974.31	974.75
NS041	12445	969.31	969.79	970.19	970.64	971.02	971.30	971.62	971.89	972.57	973.10	973.52	973.92	974.30
NS040	12080	968.45	969.01	969.47	969.96	970.37	970.66	970.99	971.26	971.93	972.44	972.84	973.21	973.56
NS039	11692	967.73	968.27	968.69	969.14	969.51	969.77	970.05	970.29	970.86	971.22	971.52	971.79	972.07
NS038	11319	967.05	967.63	968.05	968.50	968.87	969.14	969.43	969.68	970.28	970.63	970.95	971.27	971.62
NS037	11014	966.56	967.13	967.57	968.02	968.41	968.68	968.99	969.26	969.88	970.17	970.44	970.72	971.00
NS036	10790	966.09	966.65	967.07	967.52	967.90	968.17	968.48	968.74	969.37	969.46	969.60	969.74	969.86
NS035	10482	965.52	965.99	966.33	966.66	966.93	967.12	967.33	967.49	967.82	968.62	968.92	969.11	969.30
NS034	10156	964.94	965.45	965.82	966.18	966.50	966.73	966.98	967.20	967.56	967.91	968.16	968.40	968.65
NS033	9981	964.38	964.89	965.28	965.70	966.07	966.33	966.61	966.84	967.34	967.65	967.90	968.15	968.42
NS032	9724	963.72	964.23	964.61	965.03	965.39	965.62	965.87	966.06	966.52	966.91	967.22	967.55	967.85
NS031	9445	963.13	963.66	964.06	964.49	964.86	965.10	965.39	965.61	966.01	966.36	966.65	966.91	967.15
NS030	9280	962.87	963.40	963.79	964.22	964.57	964.84	965.13	965.35	965.67	965.99	966.25	966.48	966.69
NS029	8866	962.29	962.82	963.21	963.60	963.93	964.15	964.38	964.60	964.77	964.99	965.17	965.35	965.57
NS028	8493	961.69	962.14	962.48	962.83	963.14	963.32	963.54	963.72	964.02	964.34	964.60	964.93	965.28
NS027	8126	960.81	961.30	961.67	962.10	962.47	962.71	963.00	963.24	963.47	964.05	964.39	964.78	965.17
NS026	7659	959.90	960.45	960.89	961.43	961.81	962.03	962.31	962.52	963.02	963.96	964.33	964.76	965.17
NS025	7325	959.17	959.87	960.45	961.11	961.52	961.77	962.10	962.34	962.96	963.94	964.31	964.74	965.15
NS024	6817	958.64	959.35	959.89	960.47	960.80	960.90	961.15	961.38	962.01	963.40	963.86	964.36	964.82
NS023	6533	958.43	959.15	959.71	960.31	960.76	960.87	961.18	961.43	962.14	963.49	963.92	964.40	964.85
NS022	6227	957.77	958.49	959.04	959.65	960.08	960.50	960.86	961.17	961.93	963.41	963.83	964.31	964.76
NS021	6050	957.31	958.05	958.63	959.25	959.65	960.06	960.46	960.82	961.68	963.31	963.74	964.23	964.69
NS020	5795	956.96	957.67	958.21	958.79	959.40	959.81	960.24	960.60	961.47	963.21	963.63	964.11	964.56
NS019B	5542	956.74	957.44	957.98	958.56	959.06	959.41	959.76	960.06	960.79	962.60	962.90	963.24	963.57
NS019BB	5519	956.73	957.42	957.97	958.55	959.05	959.40	959.75	960.05	960.79	962.61	962.91	963.26	963.60
NS019AA	5487	956.30	956.97	957.49	958.05	958.53	958.87	959.21	959.50	960.20	962.07	962.34	962.67	962.97
NS019A	5470	956.28	956.95	957.47	958.02	958.50	958.84	959.18	959.47	960.17	962.07	962.34	962.66	962.97
NS018B	5346	956.08	956.68	957.15	957.65	958.09	958.39	958.67	958.92	959.56	962.01	962.33	962.71	963.08
NS018BB	5315	956.06	956.67	957.15	957.65	958.09	958.40	958.69	958.94	959.57	961.89	962.12	962.41	962.70
NS018AA	5289	956.00	956.58	957.03	957.52	957.93	958.23	958.48	958.71	959.26	959.74	960.00	960.30	960.49
NS018A	5236	955.91	956.49	956.95	957.43	957.85	958.14	958.39	958.63	959.20	959.70	959.98	960.30	960.50
NS017	4964	955.41	956.00	956.48	956.99	957.44	957.75	958.15	958.45	959.16	959.78	960.14	960.54	960.84
NS016	4677	954.82	955.50	956.04	956.62	957.11	957.44	957.82	958.12	958.80	959.40	959.71	960.14	960.56
NS015	4438	954.52	955.21	955.72	956.24	956.66	956.95	957.27	957.51	958.03	958.47	958.94	959.36	959.78
NS014	4047	953.92	954.61	955.11	955.59	955.96	956.20	956.46	956.66	957.19	957.67	958.00	958.34	958.62
NS013	3698	953.32	953.93	954.27	954.65	954.99	955.24	955.52	955.76	956.37	956.90	957.31	957.74	958.06
NS012	3383	952.73	953.33	953.79	954.25	954.65	954.93	955.25	955.51	956.17	956.73	957.14	957.58	957.89
NS011	3081	952.16	952.83	953.32	953.81	954.22	954.51	954.84	955.10	955.76	956.33	956.73	957.17	957.44
NS010	2761	951.56	952.33	952.89	953.42	953.85	954.13	954.47	954.73	955.40	955.97	956.40	956.84	957.10
NS009	2528	951.19	951.85	952.33	952.83	953.21	953.46	953.74	953.97	954.57	955.08	955.44	955.97	956.17

Cross-section	River Station (m)[1]	Water Surface Elevation (m)												
		2-year flood	5-year flood	10-year flood	20-year flood	35-year flood	50-year flood	75-year flood	100-year flood	200-year flood	350-year flood	500-year flood	750-year flood	1,000-year flood
NS008	2250	950.79	951.41	951.90	952.40	952.81	953.07	953.39	953.67	954.41	955.06	955.49	956.07	956.29
NS007	1925	950.27	950.85	951.28	951.77	952.24	952.54	952.90	953.22	954.03	954.80	955.26	955.92	956.13
NS006	1584	949.63	950.32	950.82	951.38	951.88	952.27	952.68	953.03	953.93	954.72	955.19	955.86	956.07
NS005	1225	949.18	949.91	950.40	950.94	951.42	951.74	952.10	952.40	953.18	953.87	954.93	955.66	955.85
NS004B	1065	948.93	949.62	950.05	950.52	950.93	951.21	951.49	951.74	952.38	952.97	953.43	955.56	955.73
NS004A	1004	948.60	949.35	949.75	950.19	950.56	950.79	950.99	951.18	951.60	951.92	952.14	952.34	952.67
NS003	685	948.16	948.80	949.06	949.48	949.85	950.01	950.29	950.49	950.97	951.38	951.70	952.04	952.34
NS002[2]	356	947.74	948.39	948.63	949.06	949.46	949.67	949.94	950.15	950.70	951.17	951.54	951.92	952.26
NS001[2]	0	947.24	947.89	948.14	948.57	948.98	949.18	949.45	949.66	950.20	950.65	951.00	951.36	951.68
Clearwater River														
CW024	4926	962.25	962.93	963.44	963.95	964.32	964.50	964.77	964.95	965.55	966.18	966.56	967.05	967.45
CW023	4796	962.16	962.85	963.38	963.90	964.29	964.49	964.78	964.97	965.54	966.17	966.55	967.03	967.43
CW022	4642	961.96	962.66	963.21	963.78	964.18	964.48	964.78	964.96	965.54	966.16	966.54	967.03	967.42
CW021	4457	961.82	962.58	963.16	963.73	964.12	964.41	964.70	964.91	965.50	966.14	966.52	967.01	967.41
CW020	4245	961.53	962.23	962.79	963.35	963.69	963.97	964.37	964.65	965.37	966.05	966.45	966.95	967.36
CW019	3964	961.24	961.95	962.53	963.08	963.62	963.94	964.34	964.61	965.30	965.98	966.37	966.87	967.28
CW018	3664	960.96	961.70	962.31	962.93	963.45	963.78	964.18	964.48	965.20	965.89	966.29	966.79	967.21
CW017	3344	960.57	961.28	961.89	962.57	963.14	963.48	963.89	964.17	964.93	965.66	966.05	966.56	966.96
CW016	3134	960.21	961.03	961.70	962.37	962.88	963.16	963.51	963.75	964.36	965.08	965.52	966.03	966.55
CW015	2940	960.06	960.96	961.64	962.34	962.86	963.15	963.51	963.75	964.37	965.06	965.44	965.91	966.31
CW014B	2859	959.97	960.85	961.52	962.20	962.69	962.95	963.28	963.49	964.02	964.67	965.03	965.45	965.85
CW014A	2828	959.90	960.74	961.40	962.06	962.56	962.82	963.15	963.37	963.95	964.59	964.94	965.34	965.70
CW013	2781	959.86	960.73	961.39	962.06	962.56	962.83	963.16	963.38	963.95	964.61	964.97	965.41	965.79
CW012	2536	959.71	960.58	961.23	961.90	962.40	962.66	963.03	963.27	963.89	964.64	965.04	965.51	965.91
CW011	2335	959.66	960.48	961.10	961.75	962.22	962.45	962.79	963.05	963.67	964.52	964.94	965.42	965.83
CW010	2137	959.57	960.42	961.06	961.73	962.20	962.44	962.76	963.02	963.62	964.44	964.84	965.31	965.72
CW009	1909	959.46	960.30	960.94	961.60	962.06	962.27	962.61	962.85	963.42	964.23	964.60	965.01	965.39
CW008	1751	959.40	960.23	960.86	961.51	961.96	962.15	962.45	962.66	963.14	963.92	964.24	964.59	964.91
CW007	1552	959.34	960.15	960.78	961.44	961.90	962.09	962.40	962.61	963.12	963.94	964.28	964.65	965.08
CW006	1338	959.26	960.07	960.69	961.35	961.78	961.94	962.23	962.45	962.99	963.89	964.25	964.72	965.14
CW005	1099	959.15	959.98	960.60	961.26	961.69	961.86	962.21	962.45	963.05	963.97	964.34	964.77	965.18
CW004	888	959.09	959.90	960.51	961.15	961.56	961.88	962.21	962.45	963.04	963.97	964.34	964.78	965.19
CW003	683	959.06	959.89	960.53	961.19	961.62	961.86	962.18	962.42	963.00	963.94	964.32	964.75	965.16
CW002	498	958.99	959.78	960.37	961.03	961.43	961.65	961.97	962.21	962.81	963.87	964.26	964.70	965.12
CW001	253	958.97	959.75	960.35	961.01	961.42	961.64	961.97	962.23	962.85	963.89	964.27	964.71	965.13

1 River station 0 is located at the downstream end of the model and increases moving upstream.

2 Indicates cross-sections located outside of the study reach.

TABLE 4 Sensitivity Analysis, Variable Downstream Boundary Conditions at 100-year Flood

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Downstream Slope -30%	Calibrated Profile	Downstream Slope +30%
	S = 0.00098	S = 0.0014	S = 0.00182
North Saskatchewan			
14181	975.58	975.58	975.58
13904	975.03	975.03	975.03
13575	974.44	974.44	974.44
13241	973.27	973.27	973.27
12843	972.61	972.61	972.61
12615	972.16	972.16	972.16
12445	971.89	971.89	971.89
12080	971.26	971.26	971.26
11692	970.29	970.29	970.29
11319	969.68	969.68	969.68
11014	969.26	969.26	969.26
10790	968.74	968.74	968.74
10482	967.49	967.49	967.49
10156	967.20	967.20	967.20
9981	966.84	966.84	966.84
9724	966.06	966.06	966.06
9445	965.61	965.61	965.61
9280	965.35	965.35	965.35
8866	964.60	964.60	964.60
8493	963.72	963.72	963.72
8126	963.24	963.24	963.24
7659	962.52	962.52	962.52
7325	962.34	962.34	962.34
6817	961.38	961.38	961.38
6533	961.43	961.43	961.43
6227	961.17	961.17	961.17
6050	960.82	960.82	960.82
5795	960.60	960.60	960.60
5542	960.06	960.06	960.06
5519	960.05	960.05	960.05
5503	959.74	959.74	959.74
5503	959.35	959.35	959.35
5487	959.50	959.50	959.50
5470	959.47	959.47	959.47
5346	958.92	958.92	958.92
5315	958.94	958.94	958.94
5290	958.84	958.84	958.84
5290	958.70	958.70	958.70
5289	958.71	958.71	958.71
5236	958.63	958.63	958.63
4964	958.45	958.45	958.45
4677	958.12	958.12	958.12

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Downstream Slope -30%	Calibrated Profile	Downstream Slope +30%
	S = 0.00098	S = 0.0014	S = 0.00182
4438	957.51	957.51	957.51
4047	956.66	956.66	956.66
3698	955.76	955.76	955.76
3383	955.51	955.51	955.51
3081	955.10	955.10	955.10
2761	954.73	954.73	954.73
2528	953.97	953.97	953.97
2250	953.67	953.67	953.67
1925	953.23	953.22	953.22
1584	953.03	953.03	953.02
1225	952.42	952.40	952.40
1065	951.76	951.74	951.73
1033	951.88	951.87	951.86
1033	951.83	951.81	951.81
1004	951.22	951.18	951.17
685	950.64	950.49	950.43
356[2]	950.41	950.15	950.03
0[2]	950.07	949.66	949.39
average difference	0.00		0.00
maximum difference	0.15		-0.06
Clearwater River			
4926	964.95	964.95	964.95
4796	964.97	964.97	964.97
4642	964.96	964.96	964.96
4457	964.91	964.91	964.91
4245	964.65	964.65	964.65
3964	964.61	964.61	964.61
3664	964.48	964.48	964.48
3344	964.17	964.17	964.17
3134	963.75	963.75	963.75
2940	963.75	963.75	963.75
2859	963.49	963.49	963.49
2843	963.40	963.40	963.40
2843	963.34	963.34	963.34
2828	963.37	963.37	963.37
2781	963.38	963.38	963.38
2536	963.27	963.27	963.27
2335	963.05	963.05	963.05
2137	963.02	963.02	963.02
1909	962.85	962.85	962.85
1751	962.66	962.66	962.66
1552	962.61	962.61	962.61
1338	962.45	962.45	962.45
1099	962.45	962.45	962.45
888	962.45	962.45	962.45

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Downstream Slope -30%	Calibrated Profile	Downstream Slope +30%
	S = 0.00098	S = 0.0014	S = 0.00182
683	962.42	962.42	962.42
498	962.21	962.21	962.21
253	962.23	962.23	962.23
average difference	0.00		0.00
maximum difference	0.00		0.00

1 River station 0 is located at the downstream end of the model and increases moving upstream.
2 Indicates cross-sections located outside of the study reach.

TABLE 5 Sensitivity Analysis, Variable Channel Manning Roughness at 100-year Flood

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Channel Roughness -20%	Calibrated Profile	Channel Roughness +20%
	$n_{channel}$ = 0.0256	$n_{channel}$ = 0.032	$n_{channel}$ = 0.0384
North Saskatchewan			
14181	975.12	975.58	975.98
13904	974.70	975.03	975.36
13575	974.27	974.44	974.73
13241	972.62	973.27	973.77
12843	972.16	972.61	973.04
12615	971.60	972.16	972.61
12445	971.40	971.89	972.32
12080	970.81	971.26	971.66
11692	969.83	970.29	970.70
11319	969.27	969.68	970.03
11014	968.93	969.26	969.56
10790	968.46	968.74	969.02
10482	966.98	967.49	967.87
10156	967.05	967.20	967.32
9981	966.78	966.84	966.92
9724	965.52	966.06	966.42
9445	965.14	965.61	965.86
9280	964.91	965.35	965.54
8866	964.25	964.60	964.68
8493	963.27	963.72	963.96
8126	962.78	963.24	963.33
7659	962.21	962.52	962.67
7325	962.04	962.34	962.55
6817	960.96	961.38	961.70
6533	961.13	961.43	961.69
6227	960.88	961.17	961.42
6050	960.44	960.82	961.14
5795	960.23	960.60	960.91
5542	959.76	960.06	960.36
5519	959.77	960.05	960.34
5503	959.39	959.74	960.06
5503	959.02	959.35	959.67
5487	959.20	959.50	959.79
5470	959.18	959.47	959.75
5346	958.58	958.92	959.26
5315	958.64	958.94	959.24
5290	958.51	958.84	959.16
5290	958.33	958.70	959.04
5289	958.34	958.71	959.04
5236	958.26	958.63	958.96
4964	958.00	958.45	958.84
4677	957.78	958.12	958.44

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Channel Roughness -20%	Calibrated Profile	Channel Roughness +20%
	$n_{channel}$ = 0.0256	$n_{channel}$ = 0.032	$n_{channel}$ = 0.0384
4438	957.23	957.51	957.80
4047	956.60	956.66	956.92
3698	955.36	955.76	956.15
3383	955.21	955.51	955.77
3081	954.85	955.10	955.34
2761	954.53	954.73	954.95
2528	953.51	953.97	954.32
2250	953.25	953.67	953.99
1925	952.74	953.22	953.58
1584	952.71	953.03	953.34
1225	952.21	952.40	952.65
1065	951.60	951.74	951.96
1033	951.75	951.87	952.07
1033	951.69	951.81	952.02
1004	950.82	951.18	951.55
685	949.94	950.49	950.83
356[2]	949.77	950.15	950.45
0[2]	949.29	949.66	949.96
average difference	-0.35		0.30
maximum difference	-0.65		0.50
Clearwater River			
4926	964.73	964.95	965.19
4796	964.81	964.97	965.16
4642	964.83	964.96	965.14
4457	964.77	964.91	965.08
4245	964.24	964.65	964.94
3964	964.30	964.61	964.87
3664	964.14	964.48	964.76
3344	963.77	964.17	964.50
3134	963.40	963.75	964.07
2940	963.48	963.75	964.02
2859	963.16	963.49	963.78
2843	963.06	963.40	963.71
2843	963.01	963.34	963.63
2828	963.05	963.37	963.67
2781	963.08	963.38	963.66
2536	962.95	963.27	963.55
2335	962.65	963.05	963.35
2137	962.71	963.02	963.27
1909	962.52	962.85	963.09
1751	962.38	962.66	962.88
1552	962.36	962.61	962.81
1338	962.21	962.45	962.64
1099	962.23	962.45	962.63
888	962.26	962.45	962.61

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Channel Roughness -20%	Calibrated Profile	Channel Roughness +20%
	$n_{channel}$ = 0.0256	$n_{channel}$ = 0.032	$n_{channel}$ = 0.0384
683	962.25	962.42	962.56
498	961.97	962.21	962.39
253	962.02	962.23	962.40
average difference	-0.28		0.24
maximum difference	-0.41		0.33

1 River station 0 is located at the downstream end of the model and increases moving upstream.
2 Indicates cross-sections located outside of the study reach.

TABLE 6 Sensitivity Analysis, Variable Overbank Manning Roughness at 100-year Flood

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Overbank Roughness -20%	Calibrated Profile	Overbank Roughness +20%
North Saskatchewan			
14181	975.56	975.58	975.61
13904	974.99	975.03	975.10
13575	974.42	974.44	974.54
13241	973.26	973.27	973.44
12843	972.58	972.61	972.63
12615	972.11	972.16	972.20
12445	971.83	971.89	971.94
12080	971.20	971.26	971.31
11692	970.22	970.29	970.35
11319	969.63	969.68	969.72
11014	969.21	969.26	969.30
10790	968.71	968.74	968.75
10482	967.45	967.49	967.52
10156	967.15	967.20	967.24
9981	966.71	966.84	966.94
9724	966.04	966.06	966.07
9445	965.57	965.61	965.64
9280	965.31	965.35	965.37
8866	964.55	964.60	964.63
8493	963.68	963.72	963.75
8126	963.20	963.24	963.23
7659	962.41	962.52	962.50
7325	962.28	962.34	962.44
6817	961.24	961.38	961.48
6533	961.32	961.43	961.53
6227	961.06	961.17	961.24
6050	960.76	960.82	960.86
5795	960.56	960.60	960.62
5542	960.01	960.06	960.10
5519	960.01	960.05	960.09
5503	959.68	959.74	959.78
5503	959.29	959.35	959.40
5487	959.45	959.50	959.55
5470	959.41	959.47	959.52
5346	958.85	958.92	958.98
5315	958.87	958.94	959.00
5290	958.76	958.84	958.91
5290	958.61	958.70	958.78
5289	958.61	958.71	958.78
5236	958.52	958.63	958.71
4964	958.34	958.45	958.53
4677	958.01	958.12	958.20
4438	957.41	957.51	957.59

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Overbank Roughness -20%	Calibrated Profile	Overbank Roughness +20%
4047	956.45	956.66	956.86
3698	955.61	955.76	955.87
3383	955.34	955.51	955.64
3081	954.93	955.10	955.23
2761	954.58	954.73	954.85
2528	953.88	953.97	954.05
2250	953.58	953.67	953.75
1925	953.20	953.22	953.22
1584	953.01	953.03	953.04
1225	952.36	952.40	952.44
1065	951.68	951.74	951.79
1033	951.81	951.87	951.91
1033	951.76	951.81	951.86
1004	951.11	951.18	951.24
685	950.33	950.49	950.60
356[2]	950.02	950.15	950.25
0[2]	949.54	949.66	949.75
average difference	-0.07		0.06
maximum difference	-0.21		0.20
Clearwater River			
4926	964.86	964.95	965.03
4796	964.87	964.97	965.05
4642	964.87	964.96	965.04
4457	964.82	964.91	964.98
4245	964.58	964.65	964.72
3964	964.55	964.61	964.66
3664	964.42	964.48	964.54
3344	964.16	964.17	964.19
3134	963.70	963.75	963.81
2940	963.70	963.75	963.82
2859	963.43	963.49	963.55
2843	963.34	963.40	963.47
2843	963.28	963.34	963.40
2828	963.32	963.37	963.44
2781	963.32	963.38	963.45
2536	963.22	963.27	963.33
2335	962.96	963.05	963.11
2137	962.91	963.02	963.09
1909	962.77	962.85	962.91
1751	962.57	962.66	962.73
1552	962.53	962.61	962.68
1338	962.35	962.45	962.54
1099	962.35	962.45	962.54
888	962.36	962.45	962.53
683	962.32	962.42	962.50
498	962.13	962.21	962.28

River Station (m)[1]	Simulated Water Surface Elevation at 100-year Flood (m)		
	Overbank Roughness -20%	Calibrated Profile	Overbank Roughness +20%
253	962.14	962.23	962.30
average difference	-0.07		0.07
maximum difference	-0.11		0.09

1 River station 0 is located at the downstream end of the model and increases moving upstream.
2 Indicates cross-sections located outside of the study reach.

TABLE 7 Floodway Stations and Limiting Floodway Determination Criteria

River Station (m)[2]	Floodway Stations (m)		Governing Floodway Criterion	
	Left Station	Right Station	Left Station	Right Station
North Saskatchewan River				
14181	591.823	734.166	no viable flood fringe	no viable flood fringe
13904	628.048	894.102	no viable flood fringe	hydraulically smoothed
13575	730.880	1084.986	no viable flood fringe	depth criteria
13241	740.613	913.253	no viable flood fringe	no viable flood fringe
12843	654.566	824.970	no viable flood fringe	no viable flood fringe
12615	509.690	709.103	no viable flood fringe	no viable flood fringe
12445	411.053	599.060	velocity criteria	no viable flood fringe
12080	424.352	574.770	no viable flood fringe	no viable flood fringe
11692	413.050	529.439	no viable flood fringe	no viable flood fringe
11319	333.075	492.148	no viable flood fringe	no viable flood fringe
11014	594.514	781.749	no viable flood fringe	depth criteria
10790	573.986	744.914	no viable flood fringe	no viable flood fringe
10482	594.636	725.686	no viable flood fringe	no viable flood fringe
10156	505.882	749.395	no viable flood fringe	no viable flood fringe
9981	427.925	695.379	no viable flood fringe	velocity criteria
9724	365.569	536.823	no viable flood fringe	velocity criteria
9445	37.133	378.700	no viable flood fringe	no viable flood fringe
9280	116.178	438.498	no viable flood fringe	no viable flood fringe
8866	188.840	441.969	no viable flood fringe	hydraulically smoothed
8493	307.657	731.907	no viable flood fringe	depth criteria
8126	256.462	670.741	no viable flood fringe	depth criteria
7659	797.260	1184.355	no viable flood fringe	hydraulically smoothed
7325	505.586	1521.476	no viable flood fringe	depth criteria
6817	473.293	1166.198	hydraulically smoothed	no viable flood fringe
6533	409.842	1161.272	depth criteria	no viable flood fringe
6227	418.515	1102.978	no viable flood fringe	no viable flood fringe
6050	314.293	871.671	depth criteria	no viable flood fringe
5795	171.001	579.520	no viable flood fringe	no viable flood fringe
5542	150.541	539.062	no viable flood fringe	no viable flood fringe
5519	335.843	537.253	no viable flood fringe	no viable flood fringe
5487	347.004	548.420	no viable flood fringe	depth criteria
5470	156.744	500.988	depth criteria	depth criteria
5346	308.939	480.167	hydraulically smoothed	depth criteria
5315	339.636	511.006	no viable flood fringe	no viable flood fringe
5289	342.151	510.686	no viable flood fringe	no viable flood fringe
5236	305.291	682.737	hydraulically smoothed	depth criteria
4964	273.210	707.303	no viable flood fringe	no viable flood fringe
4677	508.531	771.106	hydraulically smoothed	no viable flood fringe
4438	623.965	787.898	velocity criteria	no viable flood fringe
4047	643.828	849.963	velocity criteria	no viable flood fringe
3698	391.304	776.657	no viable flood fringe	no viable flood fringe
3383	316.593	809.271	no viable flood fringe	no viable flood fringe
3081	246.164	713.201	no viable flood fringe	no viable flood fringe

River Station (m)[2]	Floodway Stations (m)		Governing Floodway Criterion	
	Left Station	Right Station	Left Station	Right Station
2761	259.946	674.379	no viable flood fringe	no viable flood fringe
2528	366.053	652.643	no viable flood fringe	no viable flood fringe
2250	415.010	811.422	no viable flood fringe	no viable flood fringe
1925	712.644	1215.539	no viable flood fringe	no viable flood fringe
1584	449.005	1061.703	no viable flood fringe	depth criteria
1225	262.612	850.802	no viable flood fringe	depth criteria
1065	311.968	463.486	no viable flood fringe	no viable flood fringe
1004	300.771	457.387	no viable flood fringe	no viable flood fringe
685	411.516	748.473	no viable flood fringe	velocity criteria
Clearwater River				
4926	30.713	139.515	no viable flood fringe	depth criteria
4796	132.330	296.909	no viable flood fringe	hydraulically smoothed
4642	276.934	486.555	no viable flood fringe	no viable flood fringe
4457	356.899	661.647	hydraulically smoothed	depth criteria
4245	258.713	559.603	depth criteria	no viable flood fringe
3964	176.227	483.710	depth criteria	no viable flood fringe
3664	222.861	408.450	no viable flood fringe	depth criteria
3344	278.196	442.312	no viable flood fringe	depth criteria
3134	254.304	346.493	depth criteria	no viable flood fringe
2940	222.921	317.896	depth criteria	no viable flood fringe
2859	206.829	291.640	depth criteria	hydraulically smoothed
2828	205.019	320.731	no viable flood fringe	velocity criteria
2781	202.665	305.464	depth criteria	velocity criteria
2536	238.872	354.610	no viable flood fringe	velocity criteria
2335	204.271	316.603	depth criteria	velocity criteria
2137	181.205	277.152	depth criteria	depth criteria
1909	180.389	303.798	depth criteria	depth criteria
1751	167.868	274.700	depth criteria	depth criteria
1552	167.459	317.997	no viable flood fringe	depth criteria
1338	195.020	321.748	hydraulically smoothed	no viable flood fringe
1099	257.212	665.037	depth criteria	depth criteria
888	466.262	870.768	depth criteria	no viable flood fringe
683	429.300	865.294	depth criteria	no viable flood fringe
498	393.521	783.122	depth criteria	no viable flood fringe
253	189.486	802.676	depth criteria	no viable flood fringe

1 River station 0 is located at the downstream end of the model and increases moving upstream.

TABLE 8 Design Flood Water Surface Elevations

Cross-Section	River Station (m)[1]	100-year Water Surface Elevation (m)
North Saskatchewan River		
NS047	14181	975.58
NS046	13904	975.03
NS045	13575	974.44
NS044	13241	973.27
NS043	12843	972.61
NS042	12615	972.16
NS041	12445	971.89
NS040	12080	971.26
NS039	11692	970.29
NS038	11319	969.68
NS037	11014	969.26
NS036	10790	968.74
NS035	10482	967.49
NS034	10156	967.20
NS033	9981	966.84
NS032	9724	966.06
NS031	9445	965.61
NS030	9280	965.35
NS029	8866	964.60
NS028	8493	963.72
NS027	8126	963.24
NS026	7659	962.52
NS025	7325	962.34
NS024	6817	961.38
NS023	6533	961.43
NS022	6227	961.17
NS021	6050	960.82
NS020	5795	960.60
NS019B	5542	960.06
NS019BB	5519	960.05
NS019AA	5487	959.50
NS019A	5470	959.47
NS018B	5346	958.92
NS018BB	5315	958.94
NS018AA	5289	958.71
NS018A	5236	958.63
NS017	4964	958.45
NS016	4677	958.12
NS015	4438	957.51
NS014	4047	956.66
NS013	3698	955.76
NS012	3383	955.51
NS011	3081	955.10
NS010	2761	954.73
NS009	2528	953.97
NS008	2250	953.67

Cross-Section	River Station (m)[1]	100-year Water Surface Elevation (m)
NS007	1925	953.22
NS006	1584	953.03
NS005	1225	952.40
NS004B	1065	951.74
NS004A	1004	951.18
NS003	685	950.49
NS002[2]	356	950.15
NS001[2]	0	949.66
Clearwater River		
CW024	4926	964.95
CW023	4796	964.97
CW022	4642	964.96
CW021	4457	964.91
CW020	4245	964.65
CW019	3964	964.61
CW018	3664	964.48
CW017	3344	964.17
CW016	3134	963.75
CW015	2940	963.75
CW014B	2859	963.49
CW014A	2828	963.37
CW013	2781	963.38
CW012	2536	963.27
CW011	2335	963.05
CW010	2137	963.02
CW009	1909	962.85
CW008	1751	962.66
CW007	1552	962.61
CW006	1338	962.45
CW005	1099	962.45
CW004	888	962.45
CW003	683	962.42
CW002	498	962.21
CW001	253	962.23

1 River station 0 is located at the downstream end of the model and increases moving upstream.
2 Indicates cross-sections located outside of the study reach.

APPENDIX A
Survey and Base Data Collection Documentation

APPENDIX A1
Survey Control and RTK Survey Quality Assurance Documentation

GeoVerra

Field Notes Title Page

Job No. 20-A0404-002 **Page 1 of** 5

Client: MATRIX

Client Representative:

Date Started: MAY 13 21 **Date Finished:**

Location: NORTH SASK RVR. TOPO
ROCKY MTN HOUSE

PURPOSE OF SURVEY

FLOOD STUDY

DRAFT

Field Representative: KEN DOWELL

Survey Assistant: EVELYN DOWELL

Equipment Used:	**Type**	**Serial #**
Rover:	R10-2	
Base Station:	R10	
Total Station:		

Comments:

☐ **Check List Complete**

If found please contact: 1-800-465-6233

GeoVerra

RTK OBSERVATION DATA SHEET

Job No. 20-A0404 Page 2 of 5

Client: MATRIX Date: MAY 15, 21

Base:

Antenna Type: R10 Serial Number: 0562

Height: 1.335 m. ____ ft ☑ Lvr of Ext. ☐ Cen of Bmpr ☐ Bot of Mnt ☐ ____

Base set at Point # 101 ☑ Known ☐ Autonomous (60 sec.)

Description: ASCM

Base Lat: N. ____ Ground N. ____

Base Long: W. ____ Ground E. ____

☐ Height above Ellipse ____ m. ☐ Ground Elevation ____ m.

Rover: Antenna Type R10-2

Height: 1.80 m. ____ ft ☐ Cen of Bmpr ☐ Bot of Mnt

☑ Bot of Quick Release ☐ ____

Vertical Projection: Set and confirmed ☐ GSD95 ☑ HT 2.0

Remote Elevation to: ____ at: ____ m.

Horizontal Projection:

☐ Mapping Plane Zone: 3TM 114°

☐ Single Point (Base) Ground Origin Pt. # ____

☐ Control Points Control File: ____

Points Used: ____

Adjustment Residuals: N. ____ m. E. ____ m.

Scale: ____ Rotation: ____

Check Point Number(s): 200 & 102

Check Point Residuals: N. ____ m. E. ____ m. Elev ____

Point Numbers observed from this base set up:

STATIC FILE: 05621350.T02

Field Representative: KEN DOWELL

Weather CLEAR 13 °C ____ kPa

DRAFT

GeoVerra

ROD 1.8

1000 TEST (SONARMITE)

200 FD-NL

111 S-NL

ROD 2.2

111 ✓

ROD 1.8

1001-1015 G

1001, 1002, 1010 H2O LEVEL

200 FD-NL ✓

↓ MAY 16 21 ↓

ROD 1.8

200 FD-NL ✓

102 ASCM ✓

~~F~~ 1016-1431 SONAR

ROD 2.4

1432-1451 G

1433, 1438, 1442, 1447 H2O LVL

ROD 1.8

1452 BOAT (MEANINGLESS) PARKED AT

1453-1461 G

1455

1462-1944 SONAR

1945-1979 G

ROD 2,2

~~159~~ 1980-1981 G

GeoVerra

RTK OBSERVATION DATA SHEET

Job No. 20-A0404 Page 4 of 5

Client: MATRIX Date: MAY 16 21

Base:

Antenna Type: R10 Serial Number: 0562

Height: 1.423 m. ____ ft ☑ Lvr of Ext. ☐ Cen of Bmpr ☐ Bot of Mnt ☐ _____

Base set at Point # 101 ☑ Known ☐ Autonomous (60 sec.)

Description: ASCM

Base Lat: N. ________________ Ground N. ___________

Base Long: W. ________________ Ground E. ___________

☐ Height above Ellipse ______m. ☐ Ground Elevation ______m.

Rover: Antenna Type R10-2

Height: 1.8 m. _____ft ☐ Cen of Bmpr ☐ Bot of Mnt

☑ Bot of Quick Release ☐ ________

Vertical Projection: Set and confirmed ☐ GSD95 ☑ HT 2.0

Remote Elevation to: ______________ at: ______________m.

Horizontal Projection:

☐ Mapping Plane Zone: 3TM 114°

☐ Single Point (Base) Ground Origin Pt. # ________________

☐ Control Points Control File: ________________

Points Used: ________________

Adjustment Residuals: N. ___________m. E. ___________m.

Scale: ________________ Rotation: ________________

Check Point Number(s): 200 + 102

Check Point Residuals: N. ✓ m. E. ✓ m. Elev ✓

Point Numbers observed from this base set up:

STATIC FILE 05621360.T02

Field Representative: KEN DOWELL

Weather CLEAR 15 °C _______ kPa

DRAFT

GeoVerra

ROD 2.4

1982 - 1998 G

ROD 1.8

1999 - 2003 G

ROD 2.4

2004 - 2020

2011 - 2013 CREEK

~~2035 - 2036~~ "

ROD 1.8

2021 - 2081 G

2035 - 2036 CREEK

ROD 2.4

2082 - 2086 G

ROD 1.8

2087 - 2107

ROD 2.4

2108

ROD 2.45

2109 - 2112 G

200 FD-NL ✓

GeoVerra

Field Notes Title Page

Job No. 222062 **Page 1 of** 9

Client: AEP

Client Representative: N/A

Date Started: Oct 14, 2020 **Date Finished:** TBD, 2020

Location: Rocky Mountain House

PURPOSE OF SURVEY

Cross section surveys

Field Representative: Ryder Kiehl

Survey Assistant: Ken Emaas

Equipment Used:	**Type**	**Serial #**
Rover:	R10	5748470246
Base Station:	R10	5747470184
Total Station:		

Comments:

☐ **Check List Complete**

If found please contact: 1-800-465-6233

GeoVerra

RTK OBSERVATION DATA SHEET

Job No. 222062 **Page** 2 **of** 9

Client: AEP **Date:** Oct 16, 2020

Base:

Antenna Type: R10 Serial Number: 574740184

Height: 1.472m. ____ ft ☒ Lvr of Ext. ☐ Cen of Bmpr ☐ Bot of Mnt ☐ ____

Base set at Point # 101 ☒ Known ☐ Autonomous (60 sec.)

Description: ASCM 37754

Base Lat: N. ____ Ground N. ____

Base Long: W. ____ Ground E. ____

☐ Height above Ellipse ____ m. ☐ Ground Elevation ____ m.

Rover: Antenna Type R10

Height: 2 m. ____ ft ☐ Cen of Bmpr ☐ Bot of Mnt

☐ Bot of Quick Release ☐ ____

Vertical Projection: Set and confirmed ☐ GSD95 ☐ HT 2.0

Remote Elevation to: ____ at: ____ m.

Horizontal Projection:

☒ Mapping Plane Zone: 3TM

☐ Single Point (Base) Ground Origin Pt. # ____

☐ Control Points Control File: ____

Points Used: ____

Adjustment Residuals: N. ____ m. E. ____ m.

Scale: ____ Rotation: ____

Check Point Number(s): 2284 to 2018

Check Point Residuals: N. 0.004 m. E. 0.018 m. Elev 0.009

Point Numbers observed from this base set up:

2215-2284

Field Representative: Ryder Kiehl

Weather ____ °C ____ kPa

GeoVerra

RTK OBSERVATION DATA SHEET

Job No. 222062 **Page** 3 **of** 9

Client: AEP **Date:** Oct 17, 2020

Base:

Antenna Type: R10 Serial Number: 574740184

Height: 1.361 m. ____ ft ☒ Lvr of Ext. ☐ Cen of Bmpr ☐ Bot of Mnt ☐ ____

Base set at Point # 101 ☒ Known ☐ Autonomous (60 sec.)

Description: ASCM 37754

Base Lat: N. ____ Ground N. ____

Base Long: W. ____ Ground E. ____

☐ Height above Ellipse ____ m. ☐ Ground Elevation ____ m.

Rover: Antenna Type R10

Height: 2 m. ____ ft ☐ Cen of Bmpr ☐ Bot of Mnt

☐ Bot of Quick Release ☐ ____

Vertical Projection: Set and confirmed ☐ GSD95 ☐ HT 2.0

Remote Elevation to: ____ at: ____ m.

Horizontal Projection:

☒ Mapping Plane Zone: 3TM

☐ Single Point (Base) Ground Origin Pt. # ____

☐ Control Points Control File: ____

Points Used: ____

Adjustment Residuals: N. ____ m. E. ____ m.

Scale: ____ Rotation: ____

Check Point Number(s): 2416 to 2018

Check Point Residuals: N. 0.002 m. E. 0.003 m. Elev 0.002

Point Numbers observed from this base set up:

2285-2416

Field Representative: Ryder Kiehl

Weather ____ °C ____ kPa

GeoVerra

RTK OBSERVATION DATA SHEET

Job No. 222062 **Page** 4 **of** 9

Client: AEP **Date:** Oct 18, 2020

Base:

Antenna Type: R10 Serial Number: 574740184

Height: 1.434 m. ____ ft ☒ Lvr of Ext. ☐ Cen of Bmpr ☐ Bot of Mnt ☐ ____

Base set at Point # 101 ☒ Known ☐ Autonomous (60 sec.)

Description: ASCM 37754

Base Lat: N. ____ Ground N. ____

Base Long: W. ____ Ground E. ____

☐ Height above Ellipse ____ m. ☐ Ground Elevation ____ m.

Rover: Antenna Type R10

Height: 2 m. ____ ft ☐ Cen of Bmpr ☐ Bot of Mnt

☐ Bot of Quick Release ☐ ____

Vertical Projection: Set and confirmed ☐ GSD95 ☐ HT 2.0

Remote Elevation to: ____ at: ____ m.

Horizontal Projection:

☒ Mapping Plane Zone: 3TM

☐ Single Point (Base) Ground Origin Pt. # ____

☐ Control Points Control File: ____

Points Used: ____

Adjustment Residuals: N. ____ m. E. ____ m.

Scale: ____ Rotation: ____

Check Point Number(s): 2531 to 2018

Check Point Residuals: N. 0.004 m. E. 0.001 m. Elev 0.003

Point Numbers observed from this base set up:

2416-2531

Field Representative: Ryder Kiehl

Weather ____ °C ____ kPa

GeoVerra

RTK OBSERVATION DATA SHEET

Job No. 222062 **Page** 5 **of** 9

Client: AEP **Date:** Oct 18, 2020

Base:

Antenna Type: R10 Serial Number: 5446483764

Height: 1.434 m. ____ ft ☒ Lvr of Ext. ☐ Cen of Bmpr ☐ Bot of Mnt ☐ ____

Base set at Point # 101 ☒ Known ☐ Autonomous (60 sec.)

Description: ASCM 37754

Base Lat: N. ____ Ground N. ____

Base Long: W. ____ Ground E. ____

☐ Height above Ellipse ____ m. ☐ Ground Elevation ____ m.

Rover: Antenna Type R6

Height: 2 m. ____ ft ☐ Cen of Bmpr ☐ Bot of Mnt

☐ Bot of Quick Release ☐ ____

Vertical Projection: Set and confirmed ☐ GSD95 ☐ HT 2.0

Remote Elevation to: ____ at: ____ m.

Horizontal Projection:

☒ Mapping Plane Zone: 3TM

☐ Single Point (Base) Ground Origin Pt. # ____

☐ Control Points Control File: ____

Points Used: ____

Adjustment Residuals: N. ____ m. E. ____ m.

Scale: ____ Rotation: ____

Check Point Number(s): 3000 to 8000

Check Point Residuals: N. 0.003 m. E. 0.006 m. Elev 0.000

Point Numbers observed from this base set up:

3000-3008

46550-46589

Field Representative: Ryder Kiehl

Weather ____ °C ____ kPa

GeoVerra

Toll Free: 1-800-465-6233
www.geoverra.com

JOB NO.: 222062 SURVEY DATE: Oct 18, 2020 PAGE: 6 OF 9

CLIENT : AEP PREPARED BY: Ryder Kiehl

L.S: ______ SECTION: ______ TOWNSHIP: ______ RANGE: ______ W.____ M.

Highway 1A Bridge Length 170.95m Width 13.28m

Add 0.023 m to all Elevations to Related to Project Control

West
Chainage 170.95

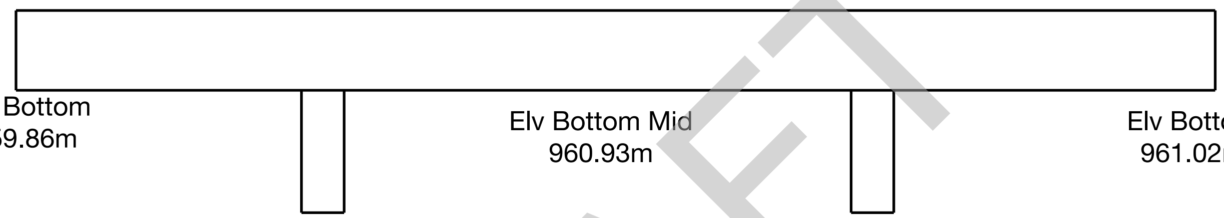
Ignore elvrail shots

East
Chainage 0

Elv Curb
963.06m

Elv Curb
964.17m

Elv Curb
964.20m



Elv Bottom
959.86m

Elv Bottom Mid
960.93m

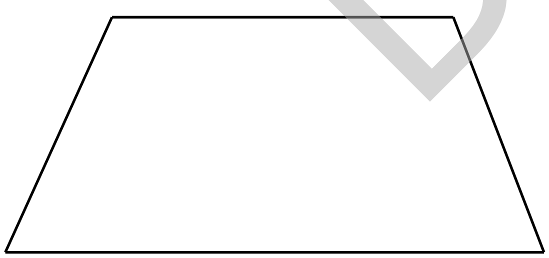
Elv Bottom
961.02m

Pillar 2
Ch119.75m

Pillar 1
Ch 51.80m

Pillar Side

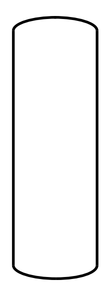
11.75m



18.40m

Pillarb shots taken near water level

Pillar Top

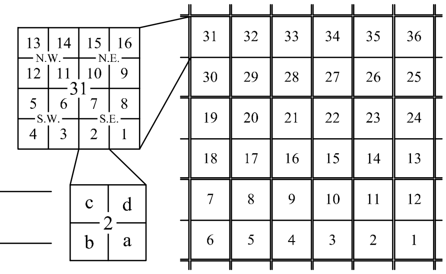


1.50m

Pillars have
curved fronts

GeoVerra

Toll Free: 1-800-465-6233
www.geoverra.com



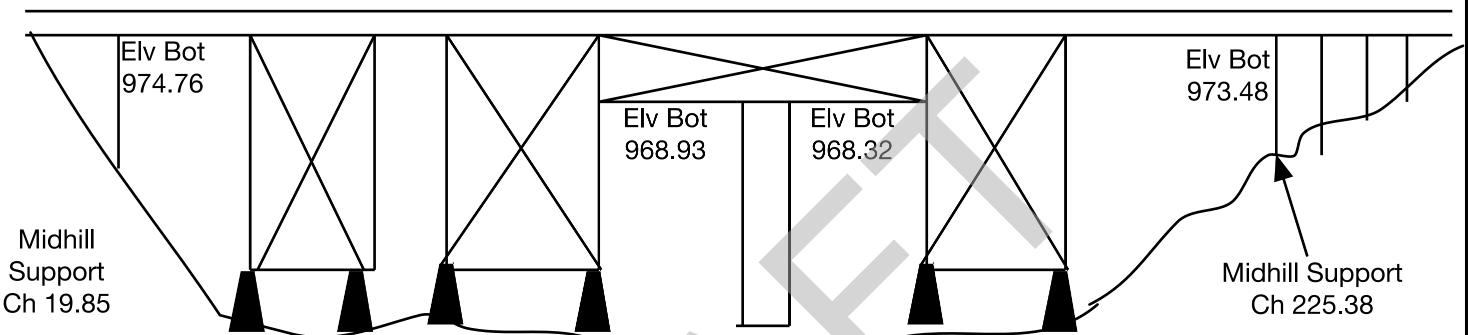
JOB NO.: 222062 SURVEY DATE: Oct 18, 2020 PAGE: 7 OF 9

CLIENT : AEP PREPARED BY: Ryder Kiehl

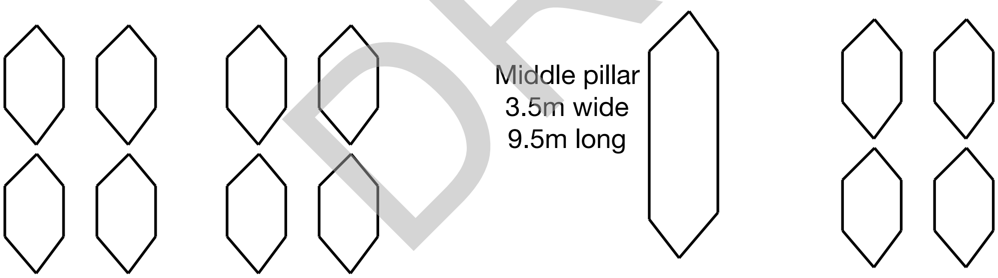
L.S: ______ SECTION: ______ TOWNSHIP: ______ RANGE: ______ W.____ M.

Rail Bridge South of Highway 1A Bridge Width 3.91m (use abut4 for width)

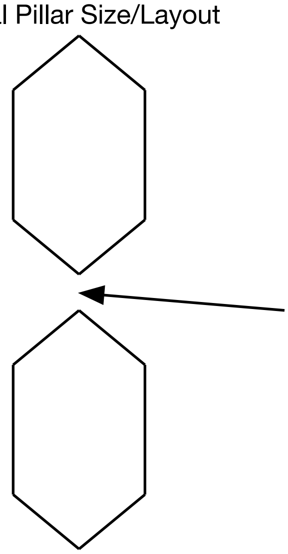
Note Add 0.023 m to all Elevations to relate to Project Control



Top View Pillars



Typical Pillar Size/Layout



NTS all distances in meters

GeoVerra

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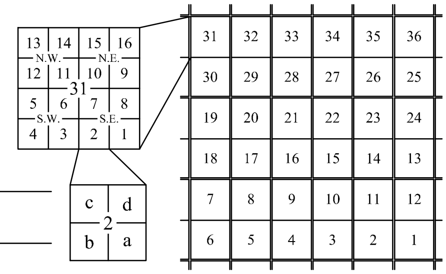
www.geoverra.com



JOB NO.: 222062 **SURVEY DATE:** Oct 18, 2020 **PAGE:** 8 **OF** 9

CLIENT : AEP **PREPARED BY:** Ryder Kiehl

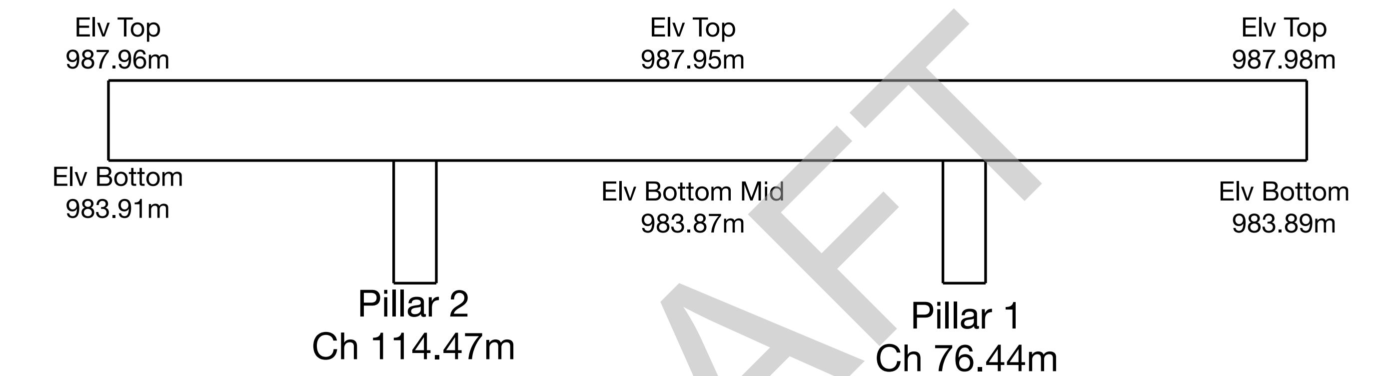
L.S: ______ **SECTION:** ______ **TOWNSHIP:** ______ **RANGE:** ______ **W.**____ **M.**

Rail Bridge on West end of project width 3.66m

Note Add 0.023 m to all Elevation to Related to All project Control

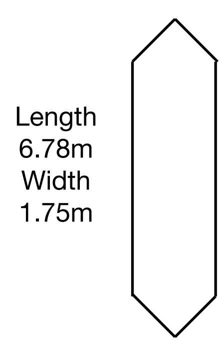
South
Chainage 152.97

North
Chainage 0



Pillar Top

Note pillars are tapered so the length and width vary top to bottom

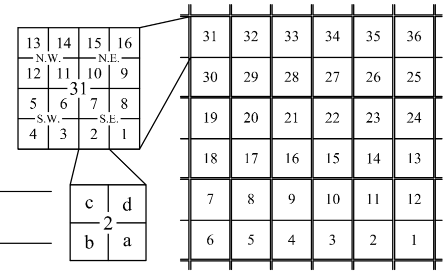


Pillars have pointed front/ back

Note lots of trees in the area, difficult to get shots through them.

GeoVerra

Toll Free: 1-800-465-6233
www.geoverra.com



JOB NO.: 222062 **SURVEY DATE:** Oct 18, 2020 **PAGE:** 9 **OF** 9

CLIENT : AEP **PREPARED BY:** Ryder Kiehl

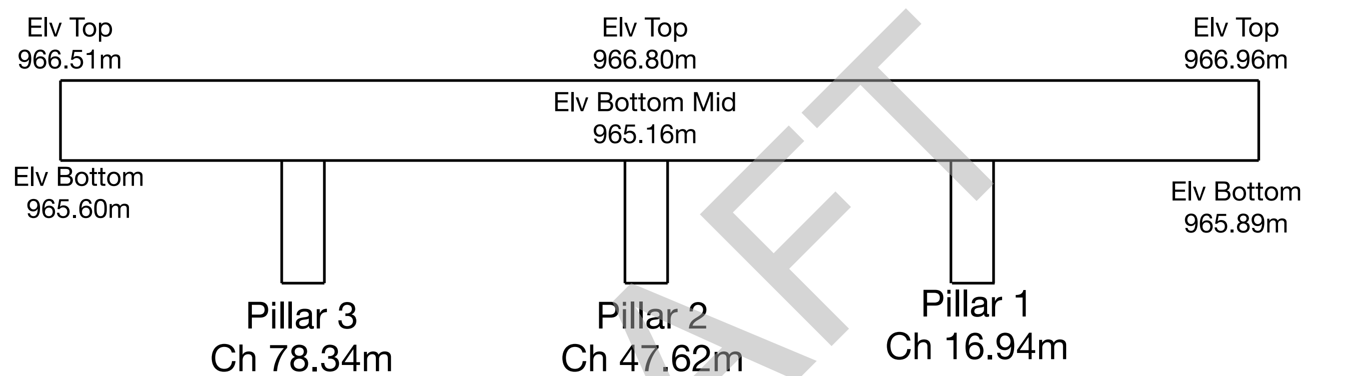
L.S: ____ **SECTION:** ____ **TOWNSHIP:** ____ **RANGE:** ____ **W.** ____ **M.**

Highway 752 Bridge Width 10.52m

Note Add 0.023 m Elevation to relate to Project Control

South
Chainage 89.16

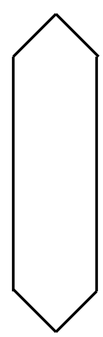
North
Chainage 0



Pillar Top

Note pillars are tapered so the length and width vary top to bottom

Length
11.33m
Width
1.33m



Pillars have pointed front/ back

Classification: Public

BRIDGE INFORMATION SHEET

Project: 222062

Cross Section: A2

Location: ATS NE 11-39-8-5 CN Railway Crossing

Surveyor: Greg Hebb

Overall Dimensions

Abutment to Abutment Span 152.97 m

Outside to Outside Width 3.66 m

Elevation Data

	Top Solid Wooden Deck	of Curb or Guard Rail	Low Chord
Left Abutment	988.00 m	983.91	m
Midspan	987.97 m	983.89	m
Right Abutment	987.97 m	983.93	m

Note: For arch type bridges, additional shots should be taken between abutments and midspan. Provide a sketch.

Pier Description

Number 2 Width 1.75 m

Type Concrete (i.e. pile bent, timber truss, concrete cylinder)

Nose Shape Hexagon (i.e. rectangular, circular, wedge)

Note: All elevations to be referenced to geodetic datum.

See Field Notes Diagram
File 222062 RK Oct18 2020 - Notes.pdf
Page 8 of 9

BRIDGE INFORMATION SHEET

Project: 222062

Cross Section: B3

Location: ATS NE 21-39-7-5 CP Railway Crossing

Surveyor: Greg Hebb

Overall Dimensions

Abutment to Abutment Span 258.58 m

Outside to Outside Width 3.91 m Abuttment Width

Elevation Data

	Top Solid Wooden Deck	of Curb or Guard Rail	Low Chord
Left Abutment	975.75 m	973.48	m
Midspan	976.74	m 968.34	m
Right Abutment	977.27 m	974.78	m

Note: For arch type bridges, additional shots should be taken between abutments and midspan. Provide a sketch.

Pier Description

Number 7 Width Varies m See Field Notes

Type Concrete (i.e. pile bent, timber truss, concrete cylinder)

Nose Shape Hexagon (i.e. rectangular, circular, wedge)

Note: All elevations to be referenced to geodetic datum.

See Field Notes Diagram
File 222062 RK Oct18 2020 - Notes.pdf
Page 7of 9

BRIDGE INFORMATION SHEET

Project: 222062

Cross Section: D11

Location: ATS NE 21-39-7-5 Highway 1A Crossing

Surveyor: Greg Hebb

Overall Dimensions

Abutment to Abutment Span 170.95 m

Outside to Outside Width 13.28 m

Elevation Data

Solid Top Top of Curb of Curb or Guard Rail		Low Chord	
Left Abutment	963.08 m	959.88	m
Midspan	964.19 m	960.95	m
Right Abutment	964.22 m	961.04	m

Note: For arch type bridges, additional shots should be taken between abutments and midspan. Provide a sketch.

Pier Description

Number 2 Width Varies m See Field Notes

Type Concrete (i.e. pile bent, timber truss, concrete cylinder)

Nose Shape Cylinder (i.e. rectangular, circular, wedge)

Note: All elevations to be referenced to geodetic datum.

See Field Notes Diagram
File 222062 RK Oct18 2020 - Notes.pdf
Page 6 of 9

BRIDGE INFORMATION SHEET

Project: 222062

Location: ATS NE 9-39-7-5

Seconfary Road Crossing

Cross Section: D11

Surveyor: Greg Hebb

Overall Dimensions

Abutment to Abutment Span 89.16 m

Outside to Outside Width 10.52 m

Elevation Data

	Top Solid	Top of Curb	of Curb or Guard Rail	Low Chord
Left	Abutment	966.98 m	965.91	m
Midspan		966.82 m	965.18	m
Right	Abutment	966.53 m	965.62	m

Note: For arch type bridges, additional shots should be taken between abutments and midspan. Provide a sketch.

Pier Description

Number 3 Width 1.33 m

Type Concrete (i.e. pile bent, timber truss, concrete cylinder)

Nose Shape Hexagon (i.e. rectangular, circular, wedge)

Note: All elevations to be referenced to geodetic datum.

See Field Notes Diagram
File 222062 RK Oct18 2020 - Notes.pdf
Page 9 of 9

CSRS-PPP 3.45.0 (2020-07-08)

01842880.20o
101

Data Start	Data End	Duration of Observations
2020-10-14 16:26:50.00	2020-10-14 22:50:50.00	6:24:00
Processing Time		**Product Type**
17:50:16 UTC 2020/11/16		NRCan/IGS Final
Observations	**Frequency**	**Mode**
Phase and Code	Double	Static

Elevation Cut-Off	Rejected Epochs	Fixed Ambiguities	Estimation Steps
7.5 degrees	0.00 %	90.11 %	10.00 sec

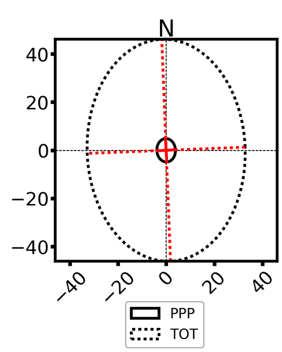
Antenna Model	APC to ARP	ARP to Marker
TRMR10 NONE	L1 = 0.128 m L2 = 0.120 m	H:1.660m / E:0.000m / N:0.000m

(APC = antenna phase center; ARP = antenna reference point)

Estimated Position for 01842880.20o

	Latitude (+n)	Longitude (+e)	Ell. Height
NAD83(CSRS) (2002.0)†	52° 22' 14.74365"	-114° 57' 39.84453"	949.727 m
SIG_PPP(95%)‡	0.004 m	0.003 m	0.013 m
SIG_TOT(95%)‡	0.037 m	0.026 m	0.028 m
A priori*	52° 22' 14.74586"	-114° 57' 39.90515"	949.159 m
Estimated –A priori	-0.068 m	1.147 m	0.568 m

Orthometric Height CGVD28 (HTv2.0)†	95% PPP Error Ellipse (mm) semi-major: 5 mm semi-minor: 4 mm semi-major azimuth: -3° 38' 18.85"	95% TOT Error Ellipse (mm) semi-major: 46 mm semi-minor: 33 mm semi-major azimuth: -2° 44' 19.64"	UTM (North) Zone 11
966.015 m (click for height reference information)			5804233.124 m (N) 638807.030 m (E) Scale Factors 0.99983651 (point) 0.99968778 (combined)



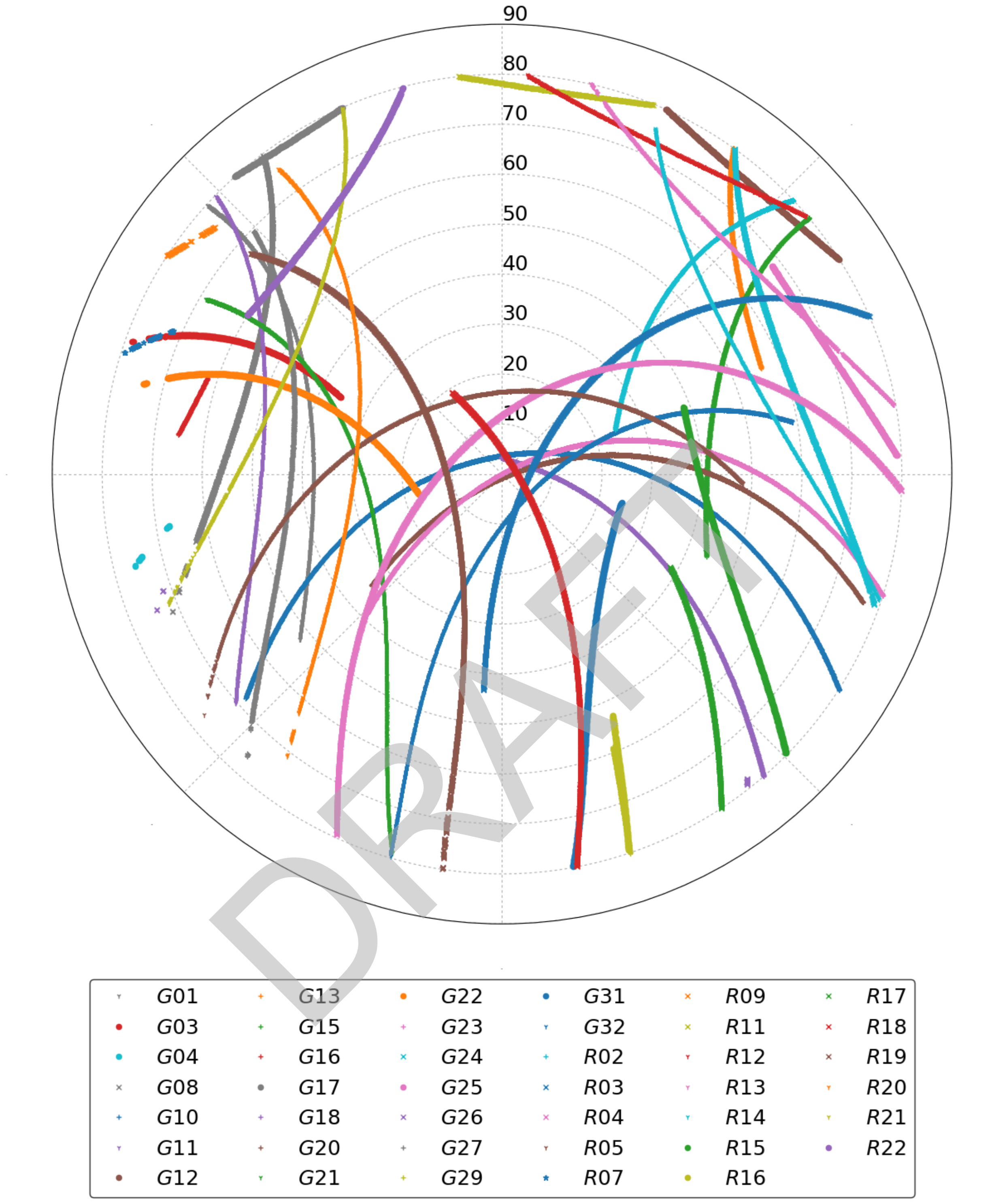
*(Coordinates from RINEX header used as a priori position)

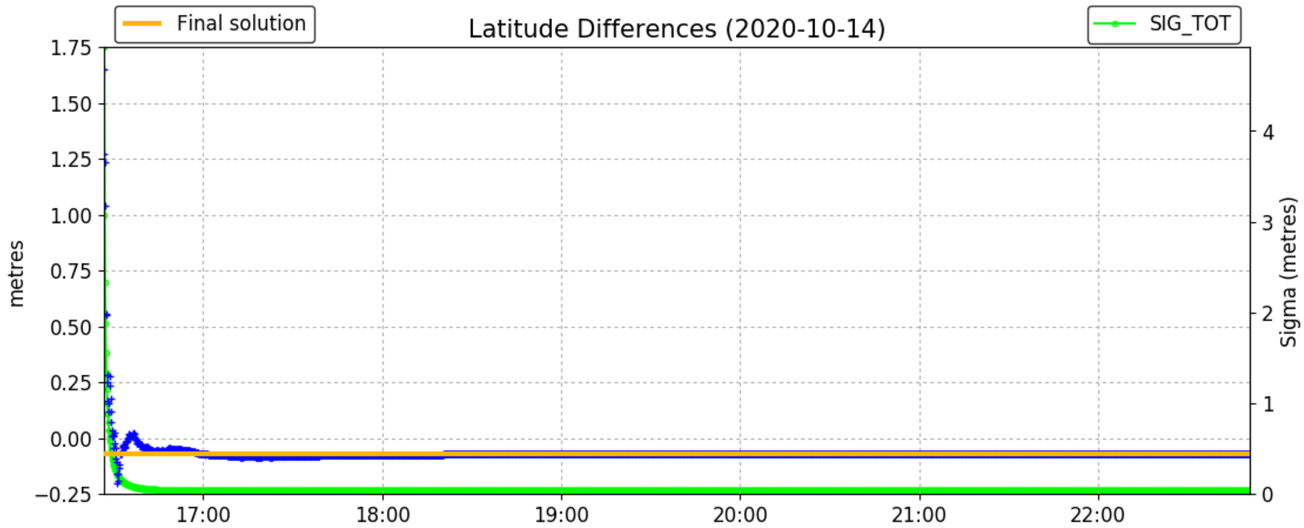
†(Epoch transformation using velocity grid NAD83v70VG (click for documentation))

‡SIG_PPP indicates PPP-derived uncertainties, SIG_TOT incorporates uncertainties from epoch transformation

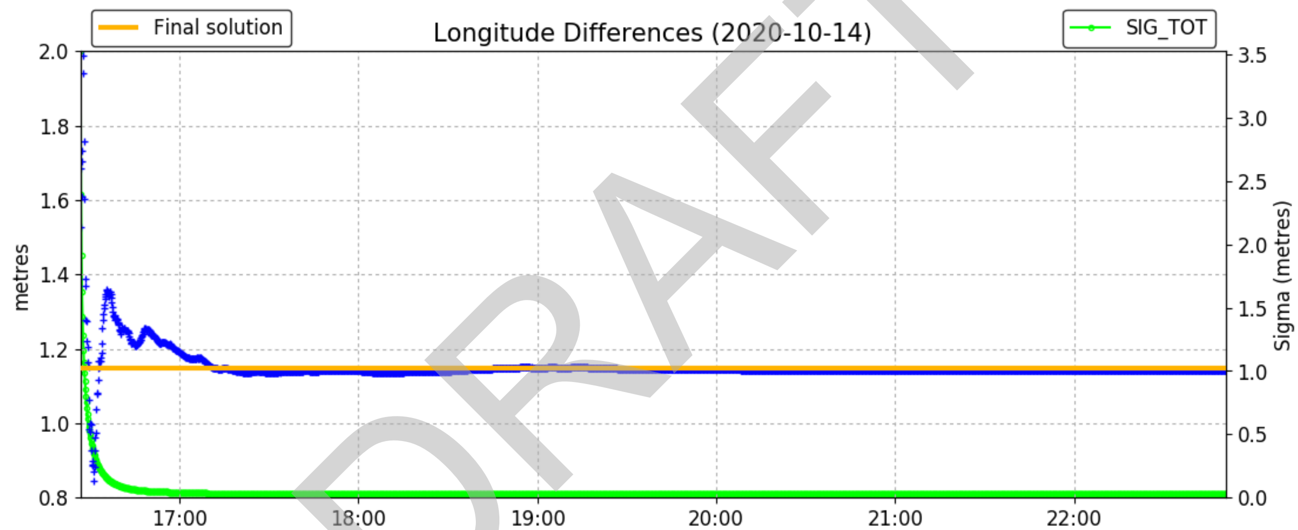
Classification: Public

Satellite Sky Distribution



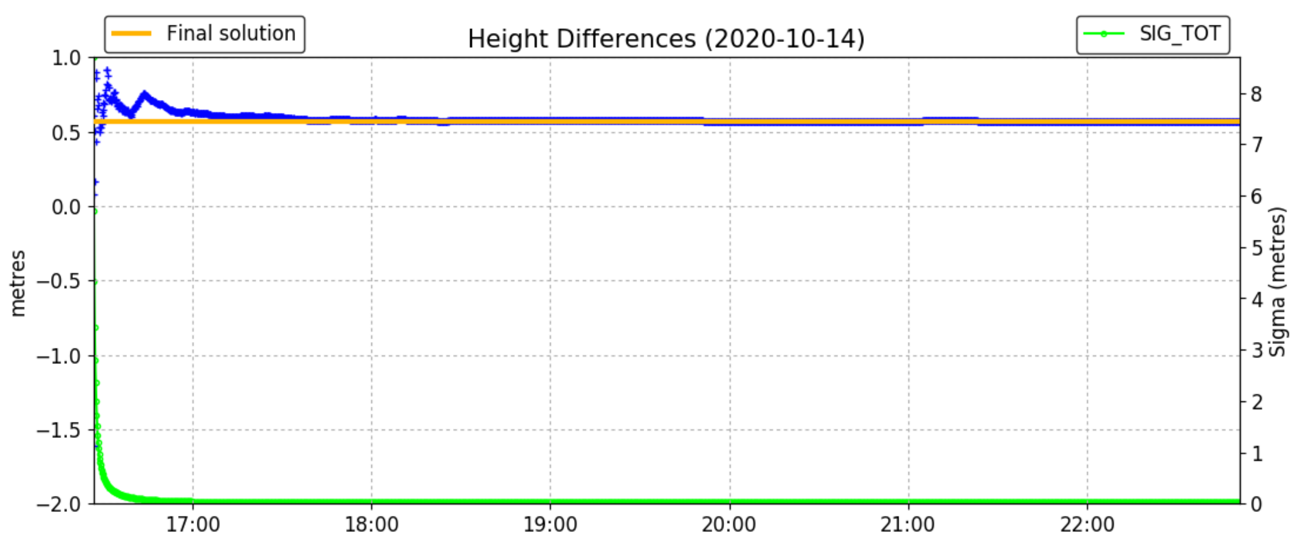


Latitude Differences (2020-10-14)
Final solution
SIG_TOT
metres
Sigma (metres)
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
0
1
2
3
4
17:00
18:00
19:00
20:00
21:00
22:00

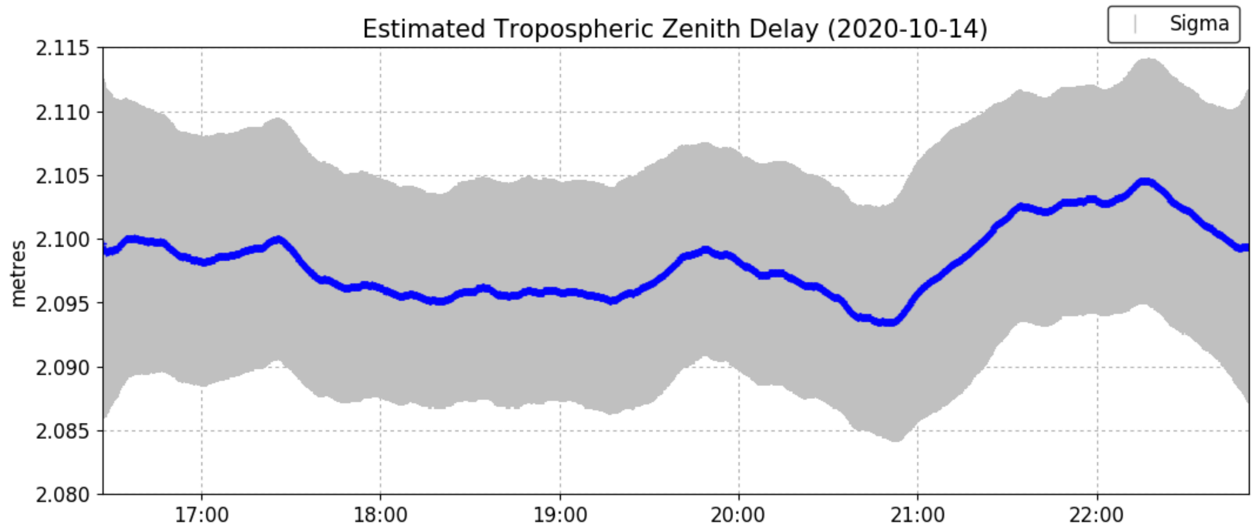


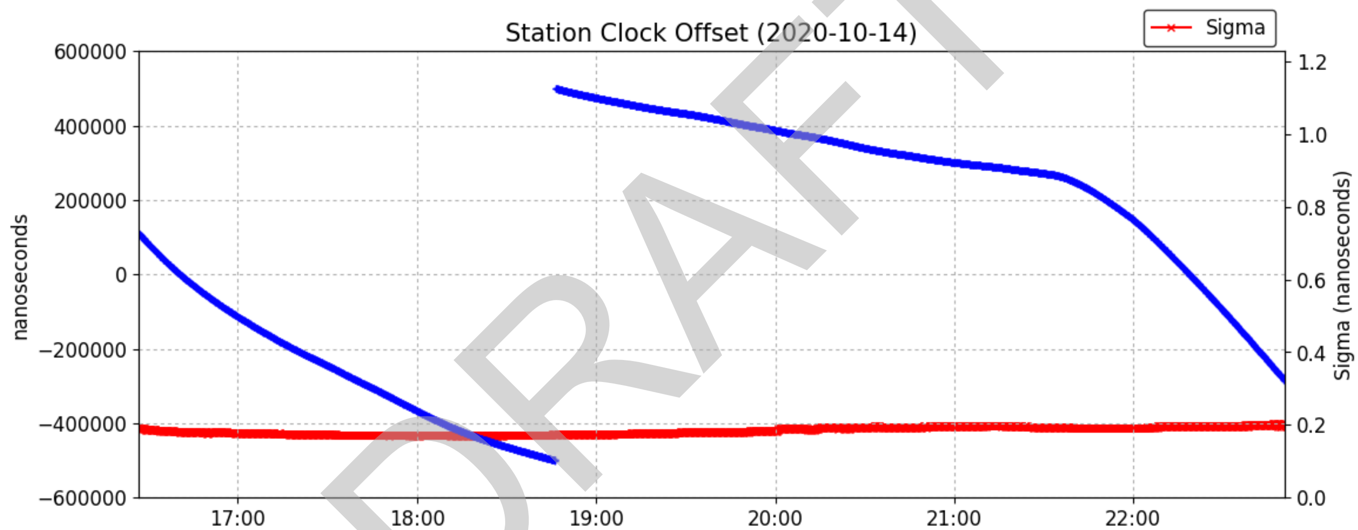
Longitude Differences (2020-10-14)
Final solution
SIG_TOT
metres
Sigma (metres)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
17:00
18:00
19:00
20:00
21:00
22:00

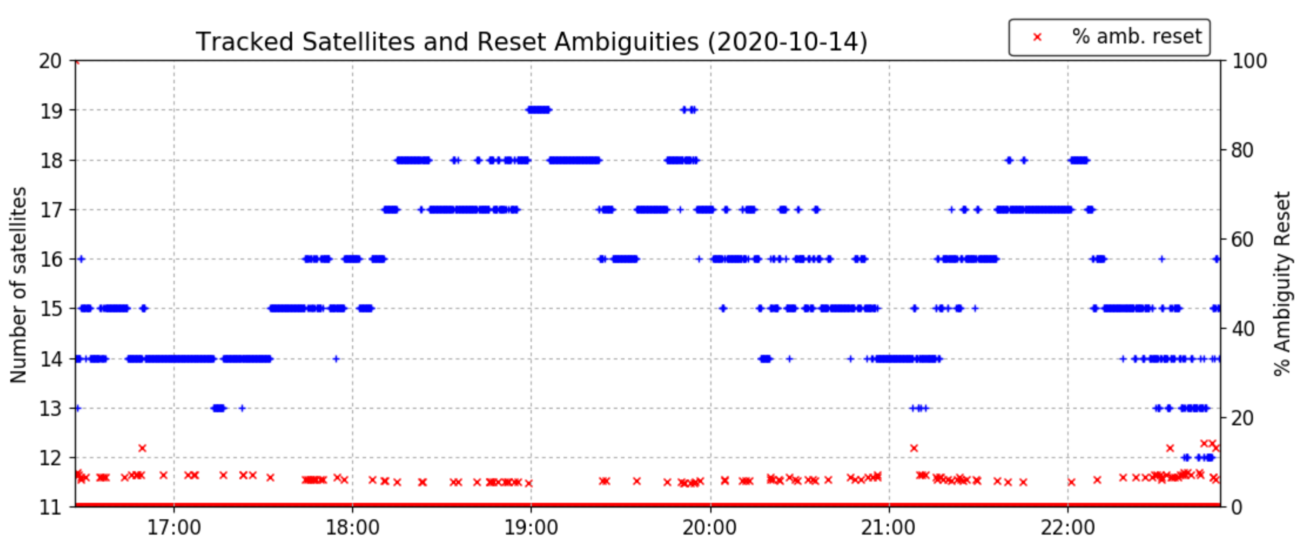
DRAFT



Height Differences (2020-10-14)
Final solution
SIG_TOT
metres
Sigma (metres)
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
8
7
6
5
4
3
2
1
0
17:00
18:00
19:00
20:00
21:00
22:00

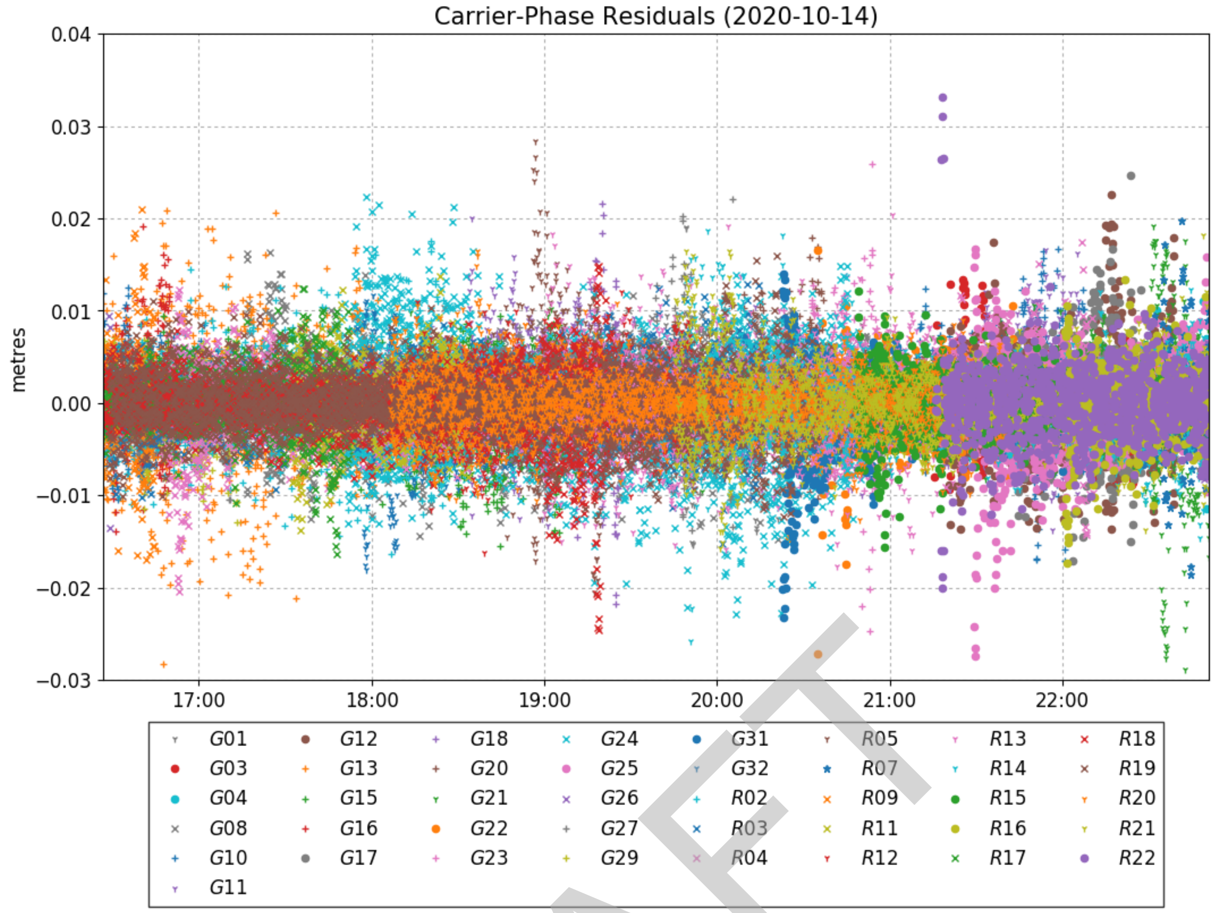


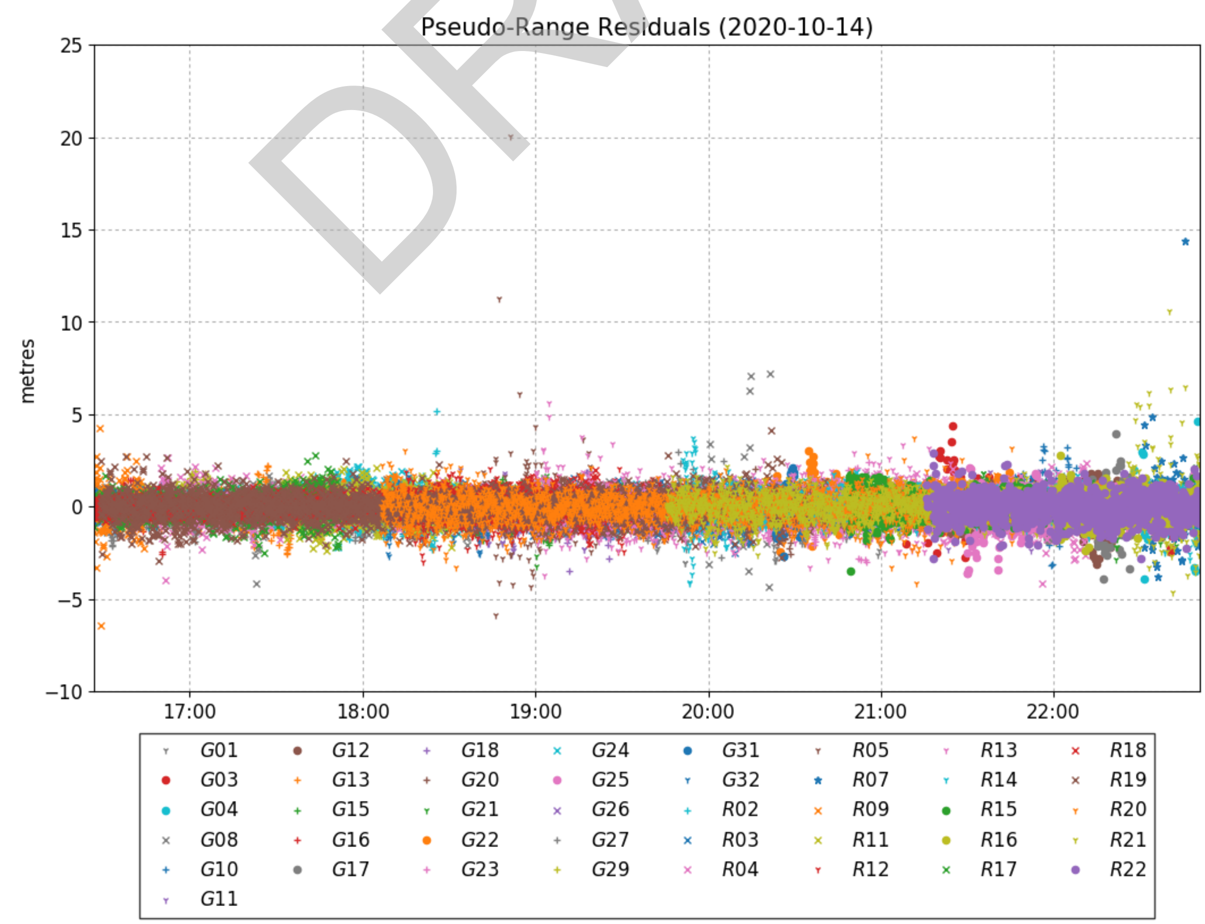


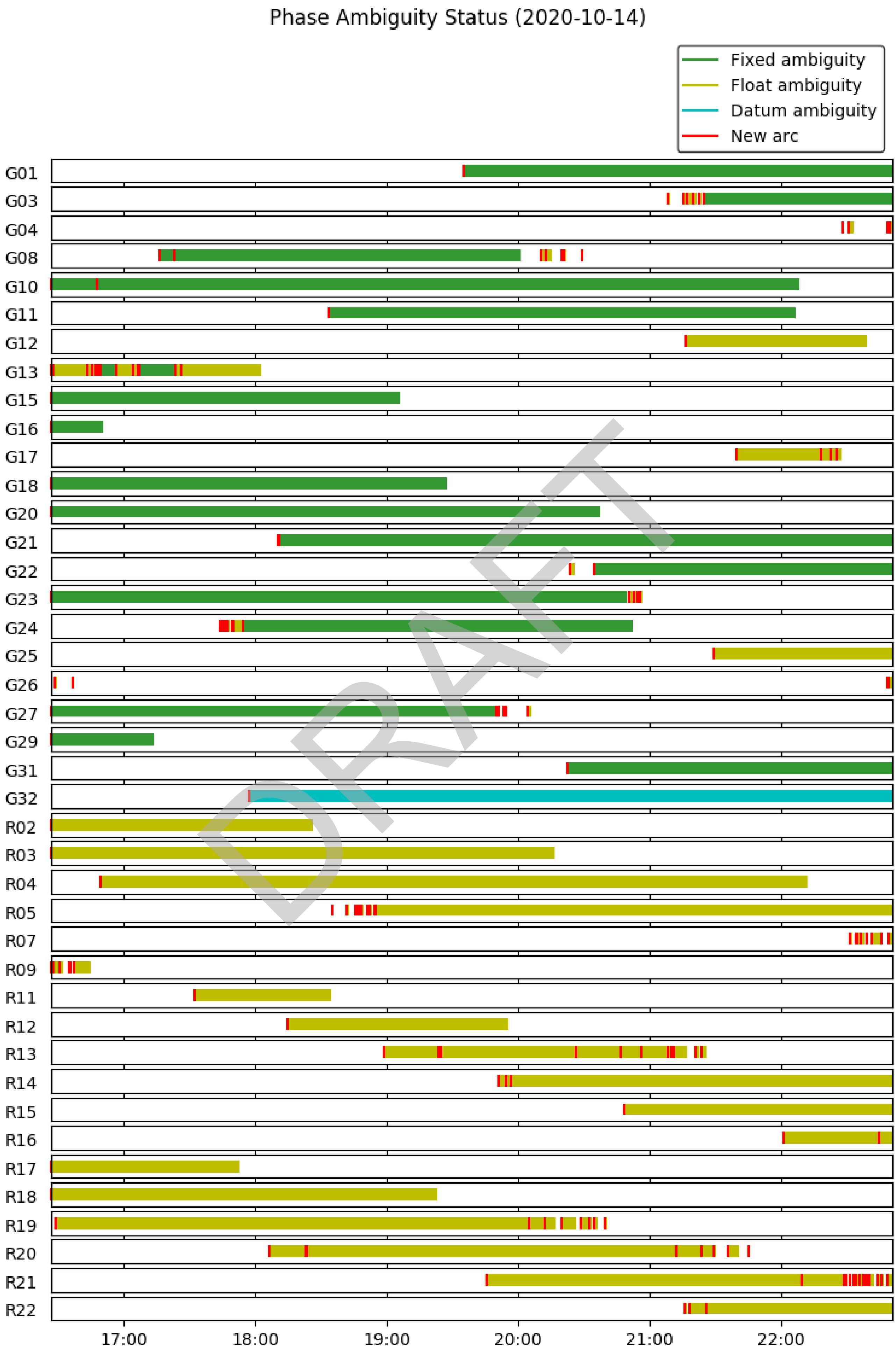


DRAFT

Classification: Public


Carrier-Phase Residuals (2020-10-14)
metres
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
17:00
18:00
19:00
20:00
21:00
22:00
G01 G03 G04 G08 G10 G11
G12 G13 G15 G16 G17
G18 G20 G21 G22 G23
G24 G25 G26 G27 G29
G31 G32 R02 R03 R04
R05 R07 R09 R11 R12
R13 R14 R15 R16 R17
R18 R19 R20 R21 R22


Pseudo-Range Residuals (2020-10-14)
metres
25
20
15
10
5
0
−5
−10
17:00
18:00
19:00
20:00
21:00
22:00
G01 G03 G04 G08 G10 G11
G12 G13 G15 G16 G17
G18 G20 G21 G22 G23
G24 G25 G26 G27 G29
G31 G32 R02 R03 R04
R05 R07 R09 R11 R12
R13 R14 R15 R16 R17
R18 R19 R20 R21 R22



Phase Ambiguity Status (2020-10-14)
Fixed ambiguity
Float ambiguity
Datum ambiguity
New arc
G01
G03
G04
G08
G10
G11
G12
G13
G15
G16
G17
G18
G20
G21
G22
G23
G24
G25
G26
G27
G29
G31
G32
R02
R03
R04
R05
R07
R09
R11
R12
R13
R14
R15
R16
R17
R18
R19
R20
R21
R22
17:00
18:00
19:00
20:00
21:00
22:00
DRAFT

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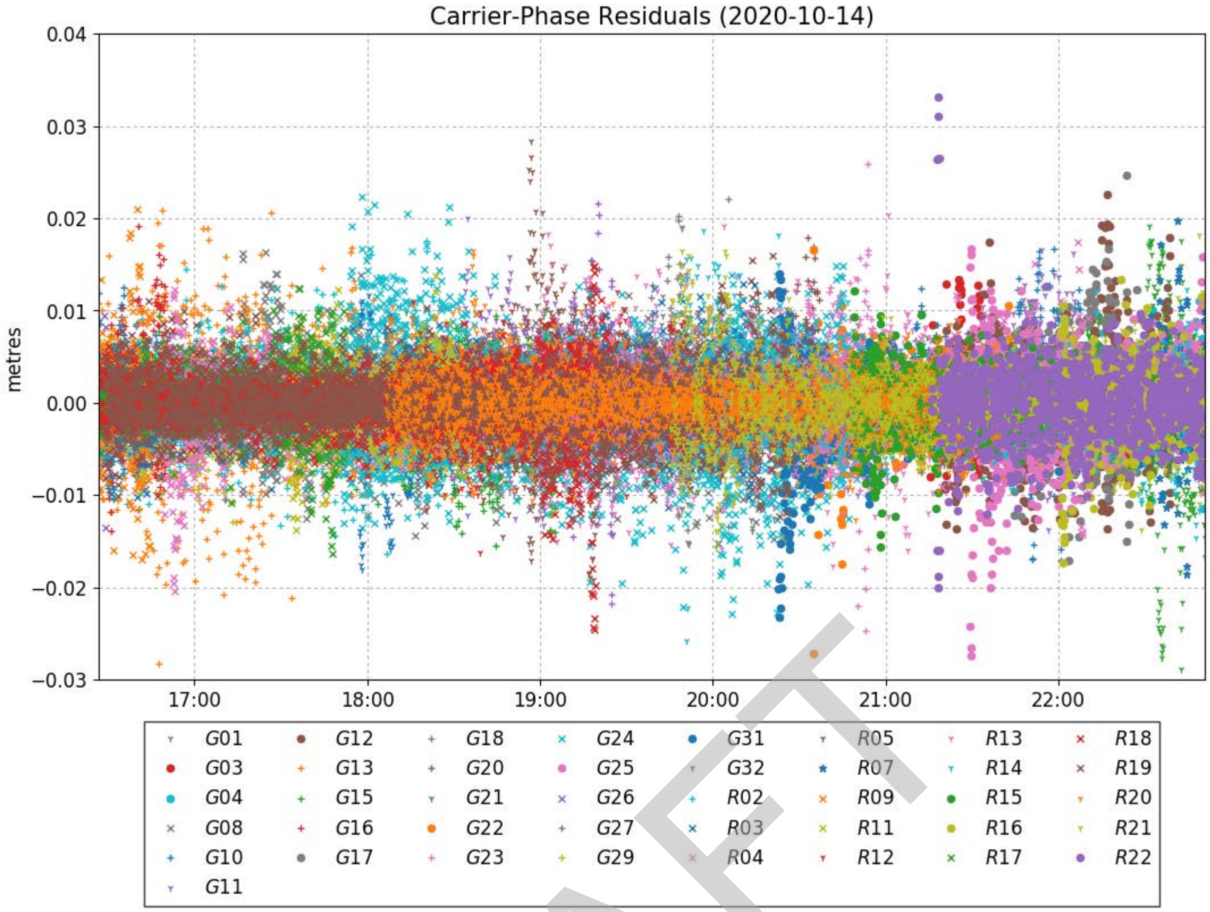
Canadian Geodetic Survey
Surveyor General Branch
Natural Resources Canada
Government of Canada
588 Booth Street, Room 334
Ottawa, Ontario K1A 0Y7
Phone: 343-292-6617
Email: nrcan.geodeticinformation-informationgeodesique.rncan@canada.ca

Natural Resources Canada   Ressources naturelles Canada   Canada


Carrier-Phase Residuals (2020-10-14)
metres
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
17:00
18:00
19:00
20:00
21:00
22:00
G01
G03
G04
G08
G10
G11
G12
G13
G15
G16
G17
G18
G20
G21
G22
G23
G24
G25
G26
G27
G29
G31
G32
R02
R03
R04
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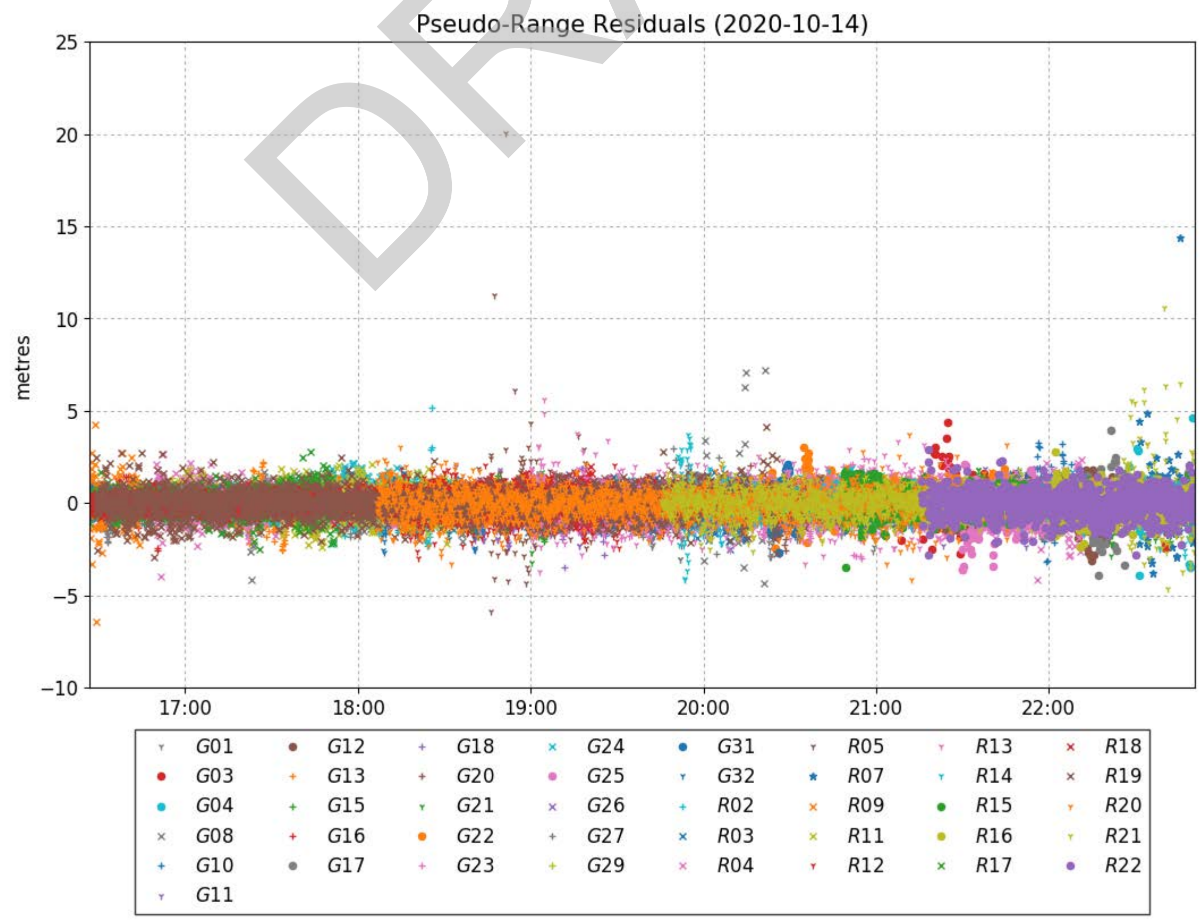
R19
R20
R21
R22


Pseudo-Range Residuals (2020-10-14)
metres
25
20
15
10
5
0
−5
−10
17:00
18:00
19:00
20:00
21:00
22:00
G01
G03
G04
G08
G10
G11
G12
G13
G15
G16
G17
G18
G20
G21
G22
G23
G24
G25
G26
G27
G29
G31
G32
R02
R03
R04
R05
R07
R09
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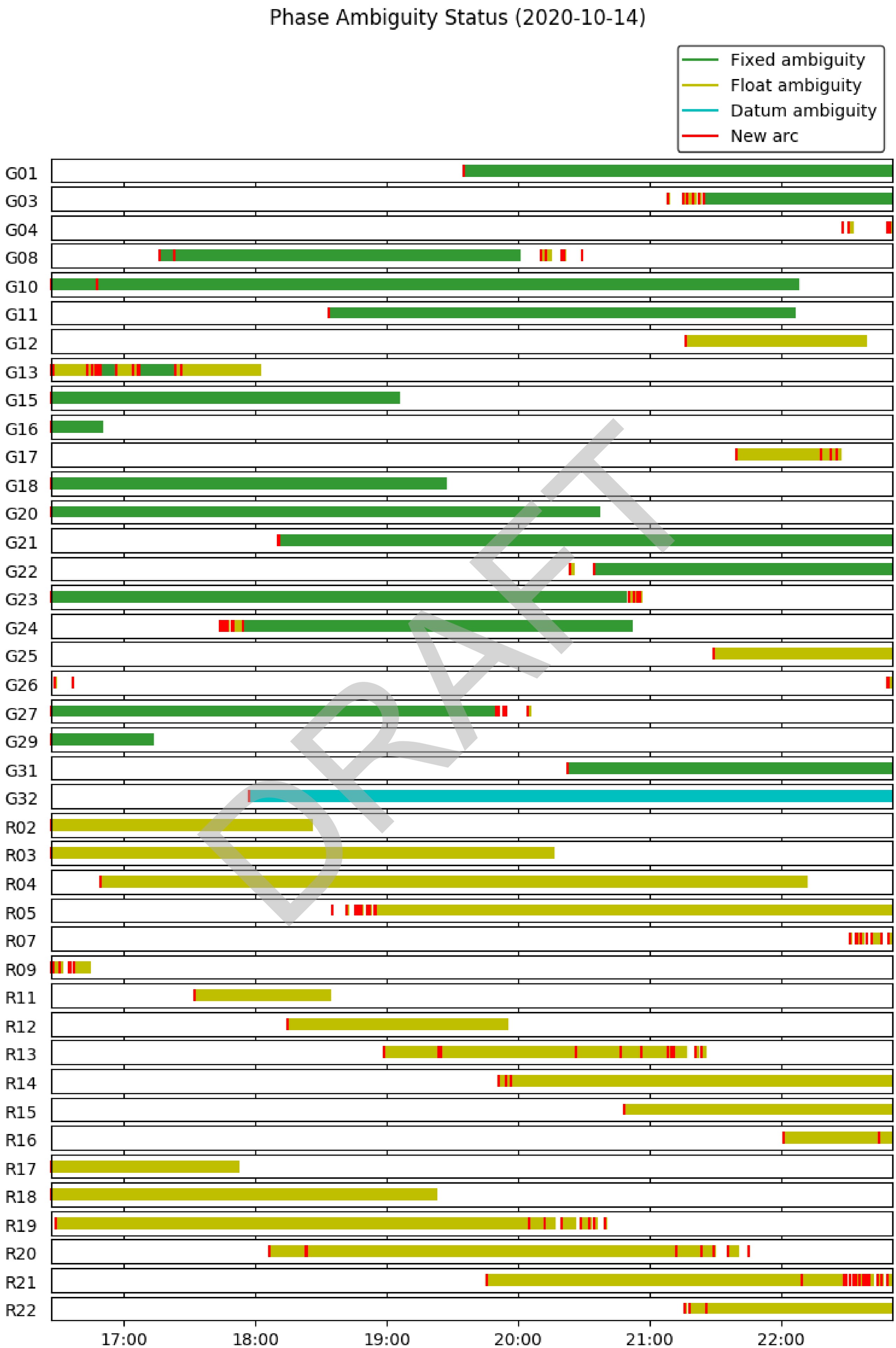
R19
R20
R21
R22


Phase Ambiguity Status (2020-10-14)
Fixed ambiguity
Float ambiguity
Datum ambiguity
New arc
G01
G03
G04
G08
G10
G11
G12
G13
G15
G16
G17
G18
G20
G21
G22
G23
G24
G25
G26
G27
G29
G31
G32
R02
R03
R04
R05
R07
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R11
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22:00
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Ottawa, Ontario K1A 0Y7
Phone: 343-292-6617
Email: nrcan.geodeticinformation-informationgeodesique.rncan@canada.ca

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APPENDIX A2
Survey Control and Ground Survey Equipment Specifications

Trimble R10

GNSS SYSTEM

A NEW LEVEL OF PRODUCTIVITY

Collect more accurate data faster and easier – no matter what the job or the environment, with the Trimble® R10 GNSS System. Built with powerful technologies integrated into a sleek design, this unique system provides Surveyors with a powerful way to increase productivity in every job, every day.

Trimble HD-GNSS Processing Engine

The advanced Trimble HD-GNSS processing engine provides markedly reduced convergence times as well as high position and precision reliability while reducing measurement occupation time. Transcending traditional fixed/float techniques, it provides a more accurate assessment of error estimates than traditional GNSS technology.

Trimble SurePoint

With Trimble SurePoint™ technology, advanced sensors onboard the Trimble R10 continuously stream pole tilt and heading information that is used to display an electronic level bubble on the Trimble controller screen, allowing surveyors to maintain focus where it matters most. Full tilt compensation allows the survey pole to be tilted up to 15° when measuring, allowing the Trimble R10 to capture points that would be inaccessible to other GNSS surveying systems.

Trimble 360 Receiver

Powerful Trimble 360 receiver technology in the Trimble R10 supports signals from all existing and planned GNSS constellations and augmentation systems. With two integrated Trimble Maxwell™ 6 chips, the Trimble R10 offers 440 GNSS channels.

Trimble CenterPoint RTX

Trimble CenterPoint® RTX delivers RTK level precision anywhere in the world without the use of a local base station or VRS network. Survey using satellite delivered, CenterPoint RTX corrections in areas where terrestrial based corrections are not available. When surveying over a great distance in a remote area, such as a pipeline or utility right of way, CenterPoint RTX eliminates the need to continuously move base stations or maintain connection to a cellular network.

Trimble xFill

Leveraging a worldwide network of Trimble GNSS reference stations and satellite datalinks, Trimble xFill® seamlessly fills in for gaps in your RTK or VRS connection stream. Maintain centimeter level accuracy beyond five minutes with a CenterPoint RTX subscription.

Smart, Versatile

A smart lithium-ion battery inside the Trimble R10 system delivers extended battery life and more reliable power. A built-in LED battery status indicator allows the user to quickly check remaining battery life.

The Trimble R10 system provides a number of communications options to support any workflow. Receive VRS corrections and connect to the Internet from the field with the integrated cellular modem. Using Wi-Fi, easily connect to the Trimble R10 system using a laptop or smartphone to configure the receiver without a Trimble controller.

The Complete Solution

Bring the power and speed of the Trimble R10 system together with trusted Trimble software solutions, including Trimble Access™ and Trimble Business Center.

Trimble Access field software provides specialized and customized workflows to make surveying tasks quicker and easier while enabling teams to communicate vital information between field and office in real time. Back in the office, users can seamlessly process data with Trimble Business Center software.

Key Features

- Cutting-edge Trimble HD-GNSS processing engine
- Precise position capture and full tilt compensation with Trimble SurePoint technology
- Trimble CenterPoint RTX provides RTK level precision anywhere without the need for a base station or VRS network
- Trimble xFill technology provides centimeter-level positioning during connection outages
- Advanced satellite tracking with Trimble 360 receiver technology
- Sleek ergonomic design for easier handling

PERFORMANCE SPECIFICATIONS		
MEASUREMENTS		
	Measuring points sooner and faster with Trimble HD-GNSS technology	
	Increased measurement productivity and traceability with Trimble SurePoint electronic tilt compensation	
	Worldwide centimeter level positioning using Trimble CenterPoint RTX satellite delivered corrections	
	Reduced downtime due to loss of radio signal with Trimble xFill technology	
	Advanced Trimble Maxwell 6 Custom Survey GNSS chips with 440 channels	
	Future-proof your investment with Trimble 360 GNSS tracking	
	Satellite signals tracked simultaneously:	GPS: L1C/A, L1C, L2C, L2E, L5 GLONASS: L1C/A, L1P, L2C/A, L2P, L3 SBAS: L1C/A, L5 (For SBAS satellites that support L5) Galileo: E1, E5A, E5B, E5 AltBOC BeiDou: B1, B2
	CenterPoint RTX, OmniSTAR® HP, XP, G2, VBS positioning	
	QZSS, WAAS, EGNOS, GAGAN, MSAS	
	Positioning Rates	1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz
POSITIONING PERFORMANCE[1]		
CODE DIFFERENTIAL GNSS POSITIONING		
	Horizontal	0.25 m + 1 ppm RMS
	Vertical	0.50 m + 1 ppm RMS
	SBAS differential positioning accuracy[2]	typically <5 m 3DRMS
STATIC GNSS SURVEYING		
High-Precision Static		
	Horizontal	3 mm + 0.1 ppm RMS
	Vertical	3.5 mm + 0.4 ppm RMS
STATIC AND FAST STATIC		
	Horizontal	3 mm + 0.5 ppm RMS
	Vertical	5 mm + 0.5 ppm RMS
REAL TIME KINEMATIC SURVEYING		
Single Baseline <30 km		
	Horizontal	8 mm + 1 ppm RMS
	Vertical	15 mm + 1 ppm RMS
Network RTK[3]		
	Horizontal	8 mm + 0.5 ppm RMS
	Vertical	15 mm + 0.5 ppm RMS
RTK start-up time for specified precisions[4]		2 to 8 seconds
TRIMBLE RTX™ TECHNOLOGY (SATELLITE AND CELLULAR/INTERNET (IP))		
CenterPoint RTX[5]		
	Horizontal	2 cm RMS
	Vertical	5 cm RMS
	RTX convergence time for specified precisions - Worldwide	< 15 min
	RTX QuickStart convergence time for specified precisions	< 1 min
	RTX convergence time for specified precisions in select regions (Trimble RTX Fast Regions)	< 1 min
TRIMBLE XFILL[6]		
	Horizontal	RTK[7] + 10 mm/minute RMS
	Vertical	RTK[7] + 20 mm/minute RMS

HARDWARE		
PHYSICAL		
Dimensions (W×H)	11.9 cm x 13.6 cm (4.6 in x 5.4 in)	
Weight	1.12 kg (2.49 lb) with internal battery, internal radio with UHF antenna, 3.57 kg (7.86 lb) items above plus range pole, controller & bracket	
Temperature[8]		
	Operating	−40° C to +65° C (−40° F to +149° F)
	Storage	−40° C to +75° C (−40° F to +167° F)
Humidity		100%, condensing
Ingress Protection		IP67 dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)
Shock and vibration (Tested and meets the following environmental standards)		
	Shock	Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
	Vibration	MIL-STD-810F, FIG.514.5C-1
ELECTRICAL		
	Power 11 to 24 V DC external power input with over-voltage protection on Port 1 and Port 2 (7-pin Lemo)	
	Rechargeable, removable 7.4 V, 3.7 Ah Lithium-ion smart battery with LED status indicators	
	Power consumption is 5.1 W in RTK rover mode with internal radio[9]	
Operating times on internal battery[10]		
	450 MHz receive only option	5.5 hours
	450 MHz receive/transmit option (0.5 W)	4.5 hours
	450 MHz receive/transmit option (2.0 W)	3.7 hours
	Cellular receive option	5.0 hours
COMMUNICATIONS AND DATA STORAGE		
Serial	3-wire serial (7-pin Lemo)	
USB v2.0	Supports data download and high speed communications	
Radio Modem	Fully Integrated, sealed 450 MHz wide band receiver/transmitter with frequency range of 403 MHz to 473 MHz, support of Trimble, Pacific Crest, and SATEL radio protocols:	
	Transmit power: 2 W	
	Range: 3–5 km typical / 10 km optimal[11]	
Cellular	Integrated, 3.5 G modem, HSDPA 7.2 Mbps (download), GPRS multi-slot class 12, EDGE multi-slot class 12, UMTS/HSDPA (WCDMA/FDD) 850/1900/2100MHz, Quad-band EGSM 850/900/1800/1900 MHz, GSM CSD, 3GPP LTE	
Bluetooth	Fully integrated, fully sealed 2.4 GHz communications port (Bluetooth®)[12]	
Wi-Fi	802.11 b,g, access point and client mode, WPA/WPA2/WEP64/WEP128 encryption	
USB v2.0	Supports data download and high speed communications	
External communication devices for corrections supported on	Serial, USB, TCP/IP and Bluetooth ports	
Data storage	4 GB internal memory; over seven years of raw observables (approx. 1.4 MB /day), based on recording every 15 seconds from an average of 14 satellites	
	CMR+, CMRx, RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1, RTCM 3.2 input and output	
	24 NMEA outputs, GSOF, RT17 and RT27 outputs	
WEBUI		
	Offers simple configuration, operation, status, and data transfer	
	Accessible via Wi-Fi, Serial, USB, and Bluetooth	
SUPPORTED TRIMBLE CONTROLLERS		
	Trimble TSC7, Trimble T10, Trimble TSC3, Trimble Slate, Trimble CU, Trimble Tablet Rugged PC	
CERTIFICATIONS		
	IEC 60950-1 (Electrical Safety); FCC OET Bulletin 65 (RF Exposure Safety); FCC Part 15.105 (Class B), Part 15.247, Part 90; PTCRB (AT&T); Bluetooth SIG; WFA IC ES-003 (Class B); Radio Equipment Directive 2014/53/EU, RoHS, WEEE; Australia & New Zealand RCM; Japan Radio and Telecom MIC	

Trimble R10 GNSS SYSTEM

1 Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. The specifications stated recommend the use of stable mounts in an open sky view, EMI and multipath clean environment, optimal GNSS constellation configurations, along with the use of survey practices that are generally accepted for performing the highest-order surveys for the applicable application including occupation times appropriate for baseline length. Baselines longer than 30 km require precise ephemeris and occupations up to 24 hours may be required to achieve the high precision static specification.
2 Depends on WAAS/EGNOS system performance.
3 Network RTK PPM values are referenced to the closest physical base station.
4 May be affected by atmospheric conditions, signal multipath, obstructions and satellite geometry. Initialization reliability is continuously monitored to ensure highest quality.
5 RMS performance based on repeatable in field measurements. Achievable accuracy and initialization time may vary based on type and capability of receiver and antenna, user's geographic location and atmospheric activity, scintillation levels, GNSS constellation health and availability and level of multipath including obstructions such as large trees and buildings.
6 Accuracies are dependent on GNSS satellite availability. xFill positioning without a Trimble CenterPoint RTX subscription ends after 5 minutes of radio downtime. xFill positioning with a CenterPoint RTX subscription will continue beyond 5 minutes providing the Trimble RTX solution has converged, with typical precisions not exceeding 6 cm horizontal, 14 cm vertical or 3 cm horizontal, 7 cm vertical in Trimble RTX Fast regions. xFill is not available in all regions, check with your local sales representative for more information.
7 RTK refers to the last reported precision before the correction source was lost and xFill started.
8 Receiver will operate normally to –40° C, internal batteries are rated to –20° C.
9 Tracking GPS, GLONASS and SBAS satellites.
10 Varies with temperature and wireless data rate. When using a receiver and internal radio in the transmit mode, it is recommended that an external 6 Ah or higher battery is used.
11 Varies with terrain and operating conditions.
12 Bluetooth type approvals are country specific.

Specifications subject to change without notice.

Contact your local Trimble Authorized Distribution Partner for more information

NORTH AMERICA
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10368 Westmoor Dr
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Trimble Germany GmbH
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Singapore PTE Limited
3 HarbourFront Place
#13-02 HarbourFront Tower Two
Singapore 099254
SINGAPORE

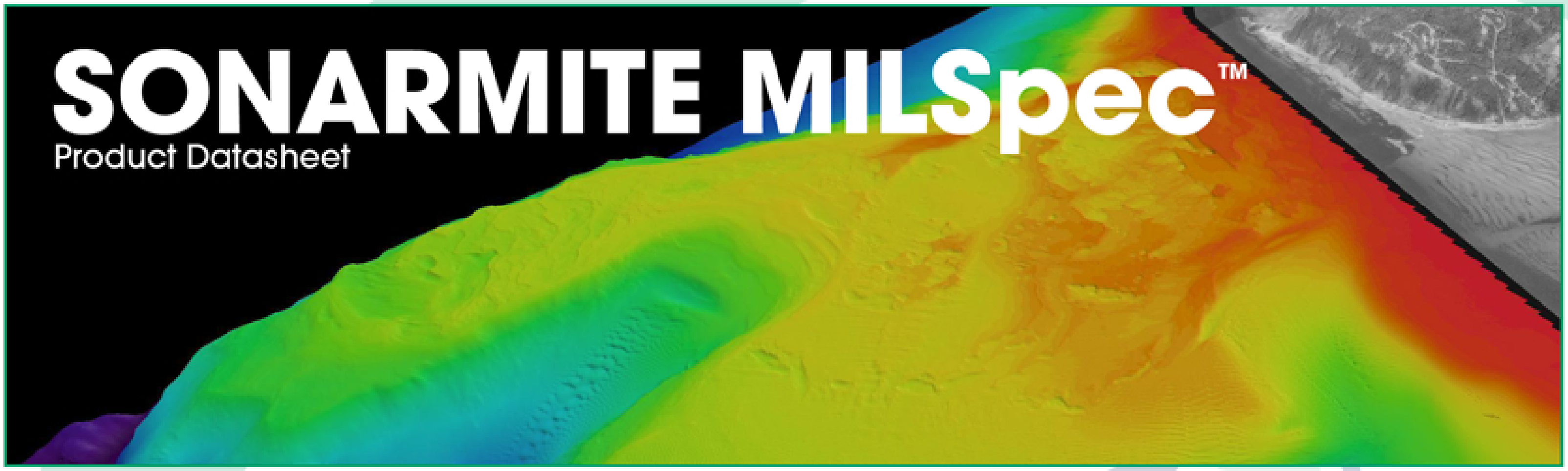
PN 022543-544K (12/19)

APPENDIX A3
Bathymetry Sonar Equipment Specifications

Seafloor

SONARMITE MILSpec™

Product Datasheet



ABOUT

The SonarMite MILSpec™ Echo Sounder is result of nearly two years research and development to further extend the boundaries of shallow water hydrographic surveying equipment. The introduction by Ohmex in 1997 of the SonarLite, the world's first truly portable echosounder system, has been a hard act to follow and it remains the portable instrument of choice in many survey companies around the world. The release of the SonarMite instrument marks the next stage introducing a series of equipment designed around the WinSTRUMENT concept using the latest portable computer integrated with new measurement technologies.

FEATURES

- Rugged, field-proven survey grade echosounder
- Bluetooth technology integrated with Windows Pocket PC devices
- Proven 'Smart' transducer design with QA output
- Internal rechargeable battery for all day use
- Easily integrated with other modern software & GPS technology

OPTIONS

- Data collection software
- Heave, Pitch and Roll measurements
- Sound velocimeter
- Portable mounting bracket
- Rugged shipping case
- Extended warranty

SPECS

ECHOSOUNDER

- Frequency: 200-KHz
- Beam width: 4-degrees
- Ping Rate: 6 Hz
- Depth Accuracy: 1cm /0.1% of depth
- Output Formats: NMEA, ASCII
- Range: 0.3m-75m
- I/O: Serial, Bluetooth
- Environmental: IP-65
- Power: Rechargeable 12V battery

PHOTOS

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APPENDIX B
Hydrologic Assessment Memorandum

Version 1.0
March 31, 2021 Matrix 31781-531

Mr. Kurt Morrison, M.Eng., P.Eng., CFM
ALBERTA ENVIRONMENT AND PARKS
Floor 11, Oxbridge Place
9820 - 106 St. NW
Edmonton, AB T5K 2J6

Subject: Rocky Mountain House Flood Hazard Study, Hydrologic Assessment

Dear Mr. Morrison:

1 INTRODUCTION

Matrix Solutions Inc. was retained by Alberta Environment and Parks (AEP) to assess and identify flood hazards along the North Saskatchewan River (NSR) and the Clearwater River through the Town of Rocky Mountain House and Clearwater County. These assessments are part of the continuing flood hazard mapping efforts of the Government of Alberta to identify, map, and document flood hazard areas in communities throughout Alberta. No similar study for this area was completed in the past. The purpose of the current study is to assess and identify flood hazards along a 13.4 km reach of the North Saskatchewan River and a 4.7 km reach of the Clearwater River near Rocky Mountain House, Alberta, in Clearwater County. Figure 1 shows the study area boundary.

The flood frequency estimates for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods with confidence intervals are required at key locations along the NSR and the Clearwater River within the study area. The key locations include:

- at the upstream study area boundary
- at the gauging station located on the NSR near Rocky Mountain House (05DC001)
- at the confluence location of the Clearwater River and the North Saskatchewan River
- at the upstream boundary of the Clearwater River study reach
- any other locations where significant peak inflows entered the Clearwater River and the North Saskatchewan River

This hydrology report has been prepared to support the flood hazard study by providing 2- to 1,000-year flood estimates. Hydrologic analysis conducted herein has been guided by the *Flood Hazard Identification Program Guidelines* (AENV 2011), the *Rocky Mountain House Hazard Study Terms of Reference* (AEP 2020), and the *Guidelines for Determining Flood Flow Frequency, Bulletins 17B and 17C* (USGS 1982, 2018).

The estimated flood frequencies will be used as model input data for hydraulic modelling and flood inundation mapping. A detailed description of the flood frequency analysis methodology and the flood frequency estimates are provided herein.

2 PROJECT SETTING

Figure 2 depicts the NSR and Clearwater River Basins with locations of some key gauging stations. The NSR begins in the ice fields of Banff and Jasper National Parks and generally flows east toward the Alberta-Saskatchewan boundary. The total area of the NSR Basin from its headwaters in the glaciers of Jasper and Banff National Parks on the eastern slopes of the Rocky Mountains to the prairie landscape along the Alberta-Saskatchewan boundary is about 57,000 km^2. Within Alberta, the Brazeau, Nordegg, Ram, Clearwater, Sturgeon and Vermilion rivers are the major tributaries to the North Saskatchewan River. Flows in the North Saskatchewan River are regulated at two locations: the Brazeau Dam on the Brazeau River since 1961 and the Bighorn Dam on the North Saskatchewan River since 1972. These are hydroelectric facilities operated by TransAlta. The operations of the dam increase winter flows and reduce maximum discharges during summer months. Flows on the NSR in the Rocky Mountain House area is affected only by the operation of the Bighorn Dam. The drainage area of the NSR near Rocky Mountain House is 11,000 km^2 and located approximately 128 km downstream of the Lake Abraham (reservoir) created by the Bighorn Dam. The flows in this stretch of the river are not natural since 1972 and need to be naturalized for flood frequency estimates since the flood frequency estimates methodology generally requires naturalized flows.

The Clearwater River is a tributary of the NSR, and its confluence is located upstream of the Town of Rocky Mountain House. Most of the Clearwater River watershed is located within Clearwater County and it covers part of the Rocky Mountains and the Foothills extending to the Banff National Park. The drainage area of the Clearwater River at its confluence with the NSR is approximately 3,220 km^2.

The Town of Rocky Mountain House and Clearwater County are located within the study reach and have several stormwater outfalls that discharge to the NSR. As a result, summer storm events may result in temporarily relatively high contribution to total flow in the NSR; however, since flooding in the NSR is generally governed by snowmelt runoff events, the likelihood of these events occurring simultaneously is very low and thus the contribution of stormwater outfalls was not investigated further for this study.

3 AVAILABLE STREAMFLOW RECORDS

Recorded historical streamflow data is required to derive flood frequency estimates associated with various return periods. In addition, recorded water levels of a reservoir are required to generate naturalized flows along a river affected by upstream dam operation. A select number of these stations, which have data as early as 1913, are considered key hydrometric stations for the open water hydrology assessment and are provided in Table A and presented on Figure 2.

TABLE A Key Hydrometric Stations

Station Name and ID	Gross Drainage Area (km^2)	Data Period
Lake Abraham near Nordegg (05DC009)	3,890	1972-2012
North Saskatchewan River below Bighorn Plant (05DC010)	3,890	1972-2019
North Saskatchewan River near Saunders (05DC002)	5,160	1915-1923; 1952-1978
North Saskatchewan River near Rocky Mountain House (05DC001)	11,000	1913-1930; 1944- 2020
Ram River near the mouth (05DC006)	1,860	1967-2019
Clearwater River near Rocky Mountain House (05DB001)	3,220	1914 – 1931; 1944 – 1975
Clearwater River near Dovercourt (05DB006)	2,250	1975-2020
Clearwater River above Limestone Creek (05DB003)	1,340	1959-1992
Prairie Creek near Rocky Mountain House (05DB002)	844	1922-1925; 1951-2020

Recorded streamflow data at the WSC stations are available at the WSC database up to 2018. No data is available for the year 2017. Preliminary data at WSC stations at various locations along the Clearwater River for 2017 and 2019 to 2020 and on the NSR for the 2017 and 2019 were obtained from AEP for this study and are subject to change.

In 1975, the WSC station on the Clearwater River near Rocky Mountain House (05DB001) was moved upstream to a location on the Clearwater River near Dovercourt (05DB006). Prairie Creek enters the Clearwater River between these two WSC stations. The drainage area (844 km^2) of the Prairie Creek near Rocky Mountain House (05DB002) plus drainage area (2,250 km^2) of the Clearwater River basin above 05DB006 accounts for 95% of the drainage area of the Clearwater River above 05DB001 (3,220 km^2). As a result, recorded flows covering a period from 1976 to 2019 at both locations were amalgamated at the downstream WSC station (05DB001) to generate a set of streamflow data at this location. The complete streamflow data set (recorded up to 1975 and computed for the period from 1976 to 2019) was used in flow frequency analysis to estimate flood frequencies associated with various return periods at the WSC station on the Clearwater River near Rocky Mountain House (05DB001).

Reported data for 2017, 2019 and 2020 at the Prairie Creek and Clearwater River gauging stations are preliminary and may be subject to change. The largest recorded flood event in the Clearwater River upstream of Prairie Creek occurred in 2005 with a magnitude of 938 m^3/s (WSC 05DB006) and a magnitude of 1,256 m^3/s in the Clearwater River downstream of Prairie Creek in 1915 (WSC 05DB001).

The largest flood event in the NSR near Rocky Mountain House was in 1914 with a magnitude of 4,110 m^3/s.

4 HYDROLOGIC ANALYSIS

The hydrologic analysis was undertaken to recommend 2- to 1,000-year return period instantaneous flood estimates for the North Saskatchewan River and Clearwater River to be used for subsequent hydraulic modelling and flood inundation mapping. The recorded/estimated flow data on the Clearwater River were considered as natural flows as no man-made structure that can affect the flows is located on this river. The recorded/estimated flow data on the NSR near Rocky Mountain House prior to 1972 were considered natural. The Bighorn Dam commenced its operation in August 1972 and the recorded flow data since September 1972 needed to be naturalized by removing the effect of operation of the dam from the recorded flows downstream. Appendix A provides a detailed methodology of determining the naturalized daily flow data covering the period from September 1972 to December 2019.

4.1 Data Series Preparation

The recorded streamflow data at various locations along the NSR and Clearwater River was used to carry out flood frequency estimates. The annual maximum instantaneous discharge data series is required for such an analysis. However, annual maximum instantaneous discharge data covering the period of record are not always available and data for the missing periods are estimated based on a relationship between the annual maximum daily discharge and maximum instantaneous discharge data for the coincident flood events. The generation of maximum instantaneous discharge data series for the Clearwater and the NSR is described herein.

4.1.1 Clearwater River near Rocky Mountain House (05DC001)

The historical recorded streamflow on the Clearwater River near Rocky Mountain (05DB001) is available from 1914 to 1975 with missing periods 1932 to 1943. In 1975, the gauge was moved upstream to a location on the Clearwater River near Dovercourt (05DB006). Prairie Creek enters the Clearwater River between these two gauging sites. Flows on Prairie Creek have been recorded from 1922 to 2020 with missing periods from 1926 to 1950 at the WSC station, Prairie Creek near Rocky Mountain House (05DB002). As such, the recorded flow data at the Clearwater River near Dovercourt (05DB006) and on Prairie Creek near Rocky Mountain House (05DB002) were used to extend the streamflow data at the Clearwater River near Rocky Mountain House gauging station (05DB001). The gauging stations were chosen to extend the data series at the WSC station (05DB001) due to the availability of data and the proximity of the gauging stations. Recorded annual maximum daily discharges and maximum instantaneous discharges for the three gauging stations are provided in Appendix B (Tables B1 and B2).

In order to extend the flow data series at the WSC station, Clearwater River near Rocky Mountain House (05DB001), the following relationship was used.

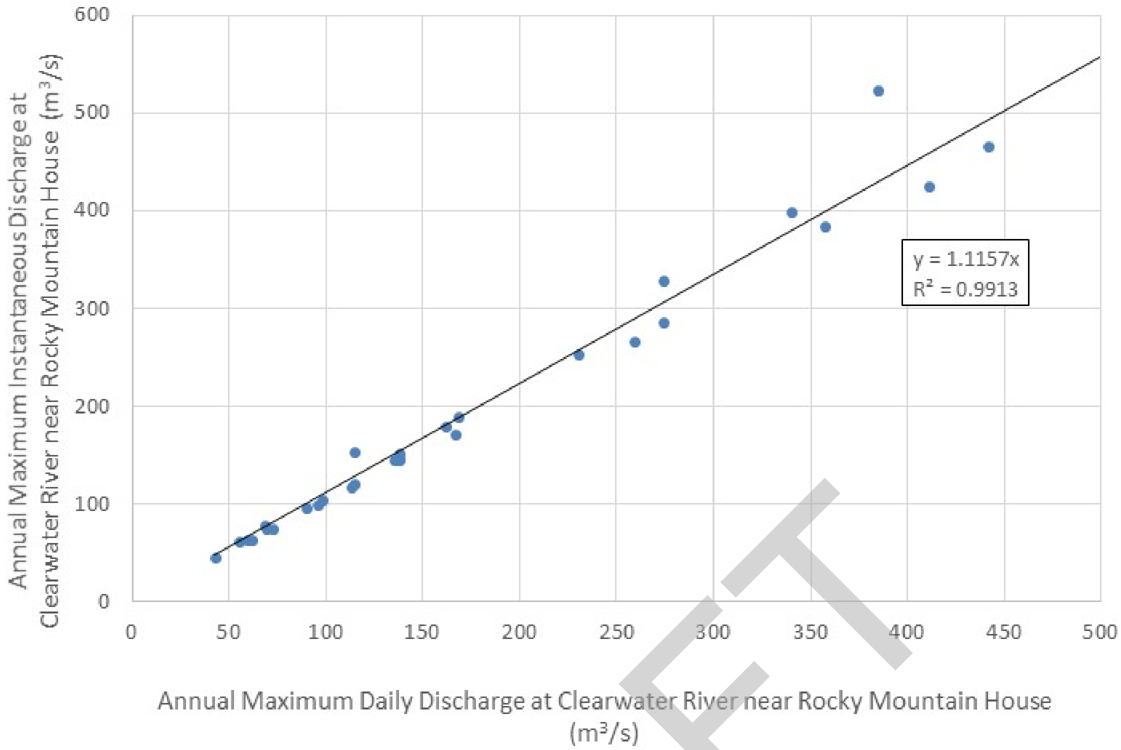
$$Q_{05DB001} = \{Q_{05DB006} + Q_{05DB002}\} * \{DA_{05DB001} / (DA_{05DB006} + DA_{05DB002})\}$$

where: $Q_{05DB001}$ = daily discharge at Clearwater River near Rocky Mountain House (m^3/s)
$Q_{05DB006}$ = daily discharge at Clearwater River near Dovercourt (m^3/s)
$Q_{05DB002}$ = daily discharge at Prairie Creek near Rocky Mountain House (m^3/s)
$DA_{05DB001}$ = drainage area at Clearwater River near Rocky Mountain House (km^2)
$DA_{05DB006}$ = drainage area at Clearwater River near Dovercourt (km^2)
$DA_{05DB002}$ = drainage area at Prairie Creek near Rocky Mountain House (km^2)

Once the daily data set series was extended at the WSC station, Clearwater River near Rocky Mountain House (05DB001) for the period of record of 1976 to 2020, the annual maximum daily discharge data was extracted from the data set series. The annual maximum instantaneous discharge record is needed for the flood frequency analysis to derive the flood frequencies with various return periods. However, the maximum instantaneous discharge record is often incomplete and will need to be derived from available data in some years. For those years where maximum instantaneous discharge data at the Clearwater River near Rocky Mountain House station (WSC 05DB001) is missing, estimates were derived based on a linear correlation between the available recorded coincident maximum instantaneous discharges and the maximum daily discharges at the Clearwater River near Rocky Mountain House gauging station (05DB001). A total of 29 data points was used in deriving the relationship between the maximum instantaneous discharges and maximum daily discharges. As shown on Graph A, the following relationship was derived to extend the maximum instantaneous discharge data series for the Clearwater River near Rocky Mountain House (05DB001):

$$Q_{05DB001\_I} = 1.1157 Q_{05DB001\_M}$$

where: $Q_{05DB001\_I}$ = maximum instantaneous discharge at Clearwater River near Rocky Mountain House (m^3/s)
$Q_{05DB001\_M}$ = maximum daily discharge at Clearwater River near Rocky Mountain House (m^3/s)
R^2 = index of determination, 0.9728 for this relationship



GRAPH A Relationship between Annual Maximum Daily Discharges and Maximum Instantaneous Discharges at Clearwater River near Rocky Mountain House (05DB001)

Table B2 (Appendix B) presents the extended annual maximum instantaneous discharge data series containing 94 data points adopted for flood frequency analysis. The extended annual maximum instantaneous discharge data series contains flows ranging from 45.3 m^3/s to 1,238 m^3/s. Figure B1 (Appendix B) shows the annual maximum daily discharges and annual maximum instantaneous discharges hydrographs. Table B summarizes the statistical parameters of the complete maximum instantaneous discharge data set.

TABLE B Summaries of Statistical Parameters of Maximum Instantaneous Discharge of the Clearwater River near Rocky Mountain House (05DB001)

Parameters	Normal Data Series	Log-transformed Data
Years of Record	94	94
Mean (m^3/s)	194.4	2.17
Maximum Discharge (m^3/s)	1,238	3.093
Minimum Discharge (m^3/s)	45.3	1.656
Standard Deviation (m^3/s)	185	0.303
Coefficient of Variation	0.95	0.14
Coefficient of Skewness (minimum, maximum, actual)	1.9, 2.48, 3.39	0.28, 1.18, 0.57

Extreme high and low events were evaluated to determine whether they should be considered as outliers. Standard outlier analysis was conducted following the *Bulletin 17B* detection procedure (McCuen 2004).

This analysis (Table C) confirmed that the extreme low observations belong to the same population as the remainder of the data series. The extreme high observation was slightly above the Detection Criteria ($Y_h > Y_{oh}$), resulting in an outlier. The largest instantaneous discharge (1,238 m^3/s) was marginally higher than the threshold flow of 1,176 m^3/s and was determined to be an outlier; however, based on a review of the flood recorded in nearby WSC stations, it was identified that an extreme flood actually happened and was included in the flow frequency analysis.

TABLE C Outlier Analysis for Clearwater River near Rocky Mountain House

Peak Event	Record Length	Outlier Test Deviates (K_o)[1]	Logarithm of Flow (Y_h)	Mean of Logarithm Transformed Flow Data	Standard Deviation of Logarithm Transformed Flow Data	Detection Criteria (Y_{oh})	Outlier (Yes/No)
1915 (extreme high)	94	2.996	3.093	2.170	0.303	3.070	May be an outlier
1975 (extreme low)			1.656			1.270	No

1 (McCuen 2004)

4.1.2 North Saskatchewan River near Rocky Mountain House (05DC001)

The derived naturalized daily flows data series, as described in Appendix A, was used to compute the naturalized annual maximum daily discharges for the period from September 1972 to December 2019. The annual maximum daily discharges at the NSR near Rocky Mountain House (05DC001) for the period from 1972 to 2019 were combined with the recorded annual maximum daily natural discharges covering the period from 1914 to 1972. This was done to generate an extended annual naturalized maximum daily discharges at the WSC station near Rocky Mountain House (05DC001) covering a period from 1914 to 2019 with a missing period from 1931 to 1943 and 1945 to 1951, since no recorded flow data is available for this period. This complete annual naturalized maximum daily discharges can be used to determine the annual maximum instantaneous discharges (for missing years during pre-regulation and all years during post-regulation) using a relationship between the maximum instantaneous discharges and maximum daily discharges during the pre-regulation period (1914 to summer of 1972) under the assumption that the same relationship exists during pre-regulation (natural) and post-regulation periods (naturalized flow conditions). The annual maximum instantaneous discharges covering the period from 1914 to 2019 can then be used for flood frequency estimates.

The annual maximum instantaneous discharge record is needed for the flood frequency analysis to derive the flood frequencies for various return periods. However, the annual maximum instantaneous discharge record is often incomplete and needs to be derived from available data in some years. For those years where maximum instantaneous discharge data at the NSR near Rocky Mountain House station (05DC001) is missing, estimates were derived based on a linear correlation between the available recorded coincident maximum instantaneous discharge and the maximum daily discharge at the gauging station.

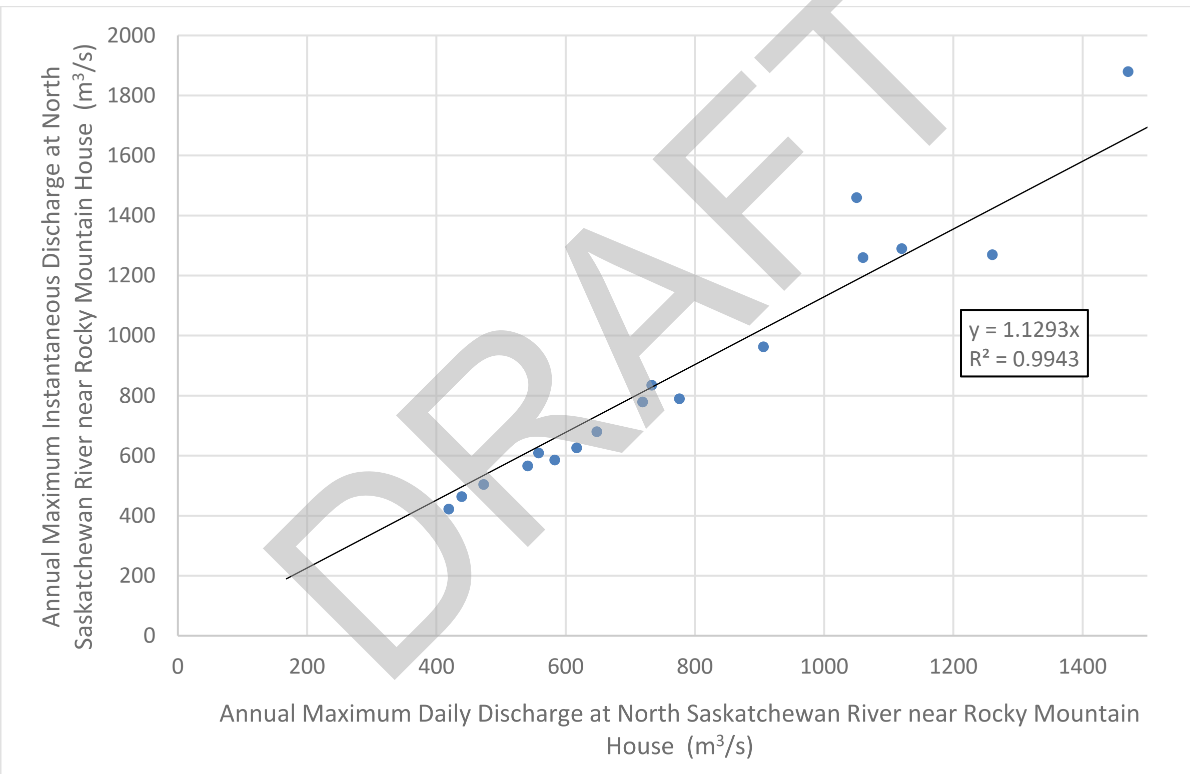
A total of 18 data points for the pre-regulation period was used in deriving the relationship between the maximum instantaneous discharges and maximum daily discharges. As shown on Graph B, the following relationship was used in estimating the naturalized maximum instantaneous discharge data series and the missing gauged data prior to 1972 at the North Saskatchewan River near Rocky Mountain House (05DC001):

$$Q_{05DC001\_I} = 1.1293 Q_{05DC001\_M}$$

where: $Q_{05DC001\_I}$ = maximum instantaneous discharge at North Saskatchewan River near Rocky Mountain House (m^3/s)

$Q_{05DC001\_M}$ = maximum daily discharge at North Saskatchewan River near Rocky Mountain House (m^3/s)

R^2 = index of determination, 0.9852 for this relationship



GRAPH B Relationship between Annual Maximum Daily Discharge and Annual Maximum Instantaneous Discharge at North Saskatchewan River near Rocky Mountain House (05DC001) for the Pre-Regulation Period

Tables C1 and C2 (Appendix C) present the extended annual maximum instantaneous discharge data series containing 86 data points adopted for flood frequency analysis. The extended maximum instantaneous discharge data series contains flows ranging from 358 m^3/s to 4,100 m^3/s. Figure C1 (Appendix C) shows the annual maximum daily discharges and annual instantaneous discharges hydrographs. Table D summarizes the statistical parameters of the complete maximum instantaneous discharge data set.

TABLE D Summaries of Statistical Parameters of Naturalized Maximum Instantaneous Discharge of the North Saskatchewan River near Rocky Mountain House (05DC001)

Parameters	Normal Data Series	Log-transformed Data Series
Years of Record	86	86
Mean (m^3/s)	832.6	2.87
Maximum Discharge (m^3/s)	4,100	3.61
Minimum Discharge (m^3/s)	358	2.55
Standard Deviation (m^3/s)	541	0.197
Coefficient of Variation	0.65	0.07
Coefficient of Skewness (minimum, maximum, actual)	1.3, 2.28, 3.39	0.14, 1.26, 1.168

Extreme high and low events were evaluated to determine whether they should be considered outliers. Standard outlier analysis was conducted following the *Bulletin 17B* detection procedure (McCuen 2004). This analysis (Table E) confirmed that the extreme low observations belong to the same population as the remainder of the data series.

TABLE E Outlier Analysis of Naturalized Maximum Instantaneous Discharge of the North Saskatchewan River near Rocky Mountain House (05DC001)

Peak Event	Record Length	Outlier Test Deviates (K_o)[1]	Logarithm of Flow (Y_h)	Mean of Logarithm Transformed Flow Data	Standard Deviation of Logarithm Transformed Flow Data	Detection Criteria (Y_{oh})	Outlier (Yes/No)
1915 (extreme high)	86	2.966	3.614	2.867	0.197	3.453	May be an outlier
2009 (extreme low)			2.554			2.281	No

1 (McCuen 2004)

The extreme high observation was slightly above the Detection Criteria ($Y_h > Y_{oh}$), resulting in an outlier. The largest instantaneous discharge (4,100 m^3/s) was higher than the threshold flow of 2,840 m^3/s and was determined to be an outlier; however, based on a review of the flood recorded in nearby WSC stations, it was identified that an extreme flood happened and was included in the flow frequency analysis.

5 FLOW FREQUENCY ANALYSIS

Standard statistical analysis of the generated annual maximum instantaneous discharges for the WSC station, the Clearwater River near Rocky Mountain House (05DC001) and the generated maximum instantaneous discharges for the WSC station, NSR near Rocky Mountain House (05DC001) were completed as a part of the flow frequency analysis. Different theoretical probability distributions to the observed data sets were tested for their suitability for the subject data set, and the most suitable theoretical distribution for each data set was selected based on comparing visual goodness of fit curves against the observed data and comparing results of statistical goodness of fit tests. The goodness of fit of each distribution, as applied to a flood series, was compared through the Kolmogorov-Smirnov (K-S) test, Anderson-Darling Test, and Least Squares Method.

Various 2 parameter and 3 parameter theoretical probability distributions were tested. These distributions include: Normal, log Normal, 3-parameter log Normal, Pearson Type III, log Pearson Type III, Extreme Value 1 (EV1), Exponential, Weibull, Gamma and Gumbel extreme value distributions. Hydrological Frequency Analysis (Hyfran) Plus Version 1.2 software and the Microsoft Excel based tool created for City of Calgary Frequency Analysis (AMEC 2014) were used to compute flood frequency estimates and to perform goodness of fit testing. Best fitting curve methods considered include method of moments and method of maximum likelihood. The Cunnane positioning formula was used to plot data points for visualization purposes.

The flood frequency analysis completed as part of this study followed the *Guidelines for Determining Flood Frequency, Bulletin 17B* (USGS 1982) and *Bulletin 17C* (USGS 2018). The guidelines provide a procedure for computing flood flow frequency including accounting for historic flood information, zero flows, low and high outliers, and methods to estimate population parameters. Log-Pearson type III is recommended as the basic distribution for defining the annual floods series and recommended use of a weighted average of the station skew and a regional skew.

The guidelines in Bulletin 17C improve on Bulletin 17B by addressing major limitations. Bulletin 17C introduces a standardized Multiple Grubbs-Beck test to identify influential low flood outliers. A new recommended method for estimating regional skew is introduced in Bulletin 17C using the Bayesian Weighted Least Squares/Bayesian Generalized Least Squares method, which supersedes the regional skew coefficient map in Bulletin 17B. And it uses the new Expected Moments Algorithm (EMA) to extend the method of moments so that it can better handle lower outlier adjustments, regional skew information, and historical information. Regional skew estimates were developed to address the complexities of the EMA but are not available in Alberta. Therefore, only the station skewness and theoretical limits were used in this study.

In the absence of regional skew coefficients, flood frequency estimates following 17B guidelines are identical to those from the regular log Pearson Type III distribution based on the method of moments.

5.1 Flood Frequency Estimates for Clearwater River

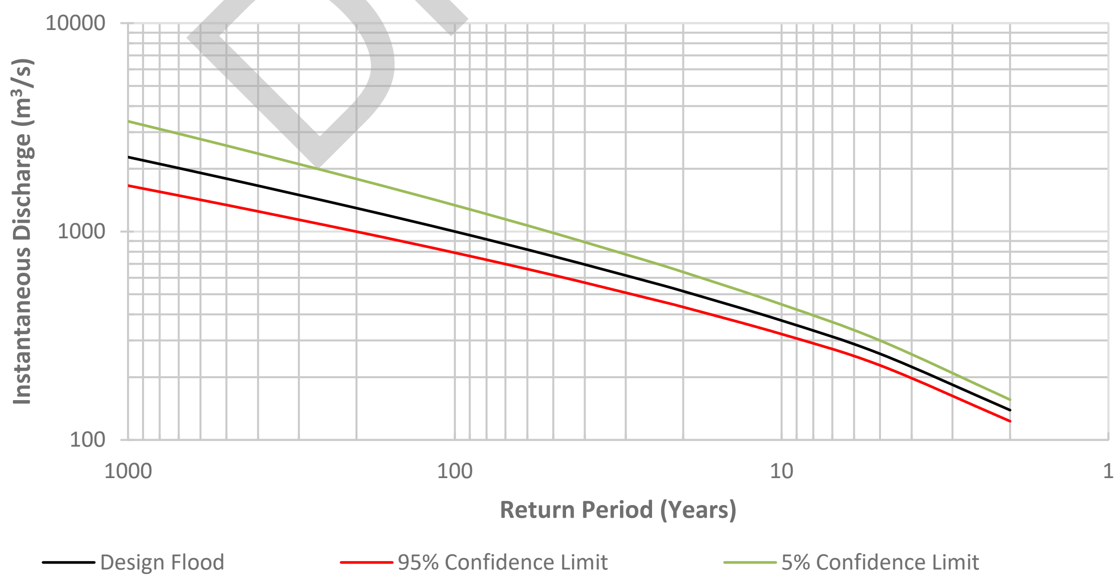
Figures B2 and B3 (Appendix B) illustrate the fitted distributions to the maximum instantaneous discharge data and show the summary of statistical goodness of fit test results. The overall rank of the log Pearson Type III distribution is 1 out of 10 distributions. A visual inspection of various frequency distributions to the flow data and goodness of fit also indicates that the log Pearson Type III distribution has the most representative fit to the recorded data. Therefore, the log Pearson Type III distribution has been selected to represent the flood frequencies for the Clearwater River near Rocky Mountain House (05DB001).

Table F presents the complete set of flood frequency estimates recommended for adoption for the flood risk mapping study within the Clearwater River study reach; Graph C presents the flood frequency curve for the log Pearson Type III distribution with 95% confidence limits.

TABLE F Flood Frequency Estimates at Clearwater River near Rocky Mountain House (05DB001)

Return Period (years)	Annual Probability of Exceedance	Flood Discharge[1] (m^3/s)	95% Confidence Limits
2	0.5	139	123 -156
5	0.2	259	228 – 300
10	0.1	374	322 – 447
20	0.05	517	434 – 639
35	0.029	658	540 - 837
50	0.02	761	618 – 985
75	0.013	895	733 – 1,161
100	0.01	1,000	791 – 1,337
200	0.005	1,295	999 – 1,788
350	0.003	1,584	1,243 – 2,186
500	0.002	1,794	1,341 – 2,584
750	0.0013	2,065	1,555 – 2,982
1,000	0.001	2,276	1,661 – 3,380

[1]Rounded to nearest whole number.



GRAPH C Flood Frequency Curve for Clearwater River near Rocky Mountain House (05DB001)

Given that the preliminary flow data is provisional and may be subject to change, the flood frequency analysis was repeated with this data excluded. After rounding to the nearest whole number, the flood frequency estimates were not much different due to the absence of large flood events post-2018.

Given the short modelling reach along the Clearwater River, the recommended flood frequencies in Table F will be used along the entire modelling reach.

5.2 Flood Frequency Estimates for North Saskatchewan River Near Rocky Mountain House

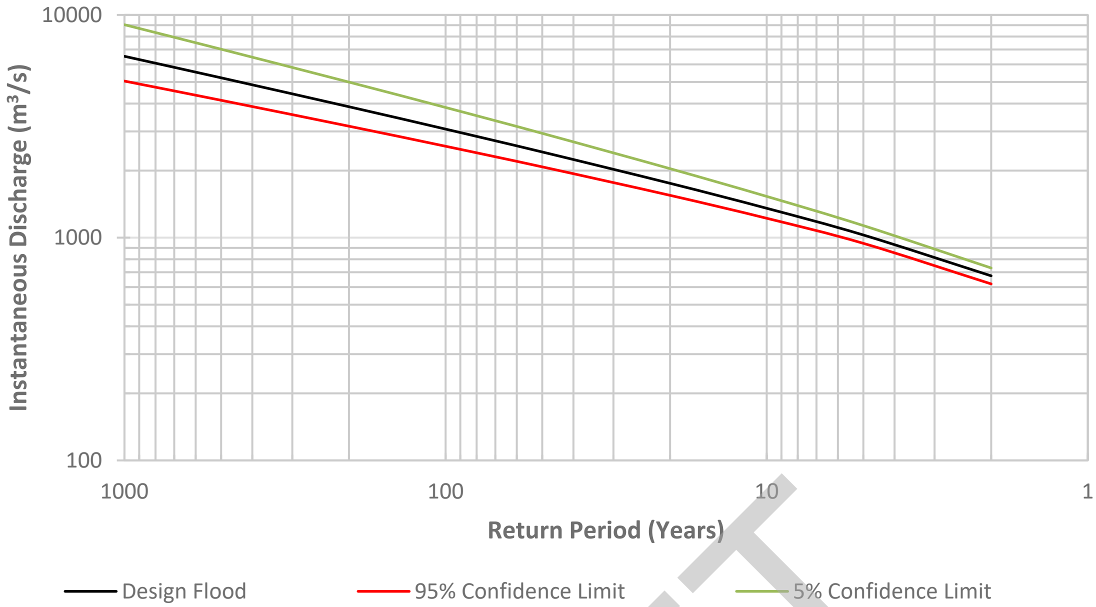
Figures C2 and C3 (Appendix C) illustrate the fitted distributions to the maximum instantaneous discharge data and show the summary of statistical goodness of fit test results. Based on the ranking of ten different distributions, the log Pearson Type III distribution and the 3-parameter log Normal distribution are both equivalently ranked as the most suitable distributions. However, a visual inspection of various frequency distributions to the flow data and goodness of fit indicates that the log Pearson Type III distribution has the most representative fit to the recorded data. Therefore, the log Pearson Type III distribution has been selected to represent the flood frequencies for the NSR near Rocky Mountain House (05DC001).

Table G presents the complete set of flood frequency estimates at the NSR near Rocky Mountain House (05DC001); Graph D presents the flood frequency curve for the log Pearson Type III distribution with 95% confidence limits.

TABLE G Naturalized Flood Frequency Estimates at North Saskatchewan River near Rocky Mountain House (05DC001)

Return Period (years)	Annual Probability of Exceedance	Flood Discharge[1] (m^3/s)	95% Confidence Limits
2	0.5	674	620 – 731
5	0.2	1,028	943 – 1,133
10	0.1	1,355	1,222 – 1,532
20	0.05	1,754	1,549 – 2,041
35	0.029	2,137	1,814 – 2,491
50	0.02	2,425	2,079 – 2,940
75	0.013	2,776	2,326 – 3,391
100	0.01	3,072	2,573 – 3,842
200	0.005	3,871	3,166 – 4,994
350	0.003	4,613	3,652 – 6,005
500	0.002	5,220	4,138 – 7,016
750	0.0013	5,890	4,593 – 8,027
1,000	0.001	6,520	5,047 – 9,037

[1] Rounded to nearest whole number.



GRAPH D Naturalized Flood Frequency Curve for North Saskatchewan River near Rocky Mountain House (05DC001)

Given that the preliminary flow data is provisional and may be subject to change, the flood frequency analysis was repeated with this data excluded. After rounding to the nearest whole number, the flood frequency estimates were not much different due to the absence of large flood events post-2018.

6 RECOMMENDED FLOOD FREQUENCY ESTIMATES

The upstream boundary of the study area is located about 8.7 km upstream of the WSC station NSR near Rocky Mountain House (05DC001) and the downstream boundary is located 4.7 km from this WSC station. The Clearwater River, a major tributary to the NSR, enters the river about 1.7 km upstream of the WSC station.

The WSC station, the Clearwater River near Rocky Mountain House (05DB001) is located about 2.8 km upstream of its confluence with the NSR, and the upstream boundary of the study area along the Clearwater River is located about 1.9 km upstream of the WSC station.

Due to the short distance between the upstream boundary and the WSC station on the Clearwater River as well as its confluence with the NSR, the flood frequency estimates at the WSC station, Clearwater River near Rocky Mountain House (05DB001) can be used at the upstream boundary for hydraulic modelling purposes and also at its confluence with the NSR.

Due to the short distance between the upstream boundary and the WSC station, the flood frequencies at the upstream boundary of the study area along the NSR are computed by subtracting the corresponding flood frequencies of the Clearwater River from the flood frequencies of the NSR near Rocky Mountain House. This is based on the assumption that the instantaneous maximum discharges in the Clearwater River are coincident with those in the NSR.

Table H presents the complete set of flood frequencies recommended for adoption for the flood risk mapping study and will be used in hydraulic modelling.

TABLE H Flood Frequency Estimates for Hydraulic Modelling

Return Period (years)	Flood Frequency Estimates at the Upstream Boundary on the NSR	Flood Frequency Estimates at the Upstream Boundary on the Clearwater River (m^3/s)	Flood Frequency Estimates on the NSR Downstream of the Confluence of the Clearwater River (m^3/s)
2	535	139	674
5	769	259	1,028
10	981	374	1,355
20	1,237	517	1,754
35	1,479	658	2,137
50	1,664	761	2,425
75	1,881	895	2,776
100	2,072	1,000	3,072
200	2,576	1,295	3,871
350	3,029	1,584	4,613
500	3,426	1,794	5,220
750	3,825	2,065	5,890
1,000	4,244	2,276	6,520

Note: Naturalized flood frequency estimates in the NSR and natural flood frequency estimates in the Clearwater River.

6.1 Potential Effects of Climate Change

This section provides a summary of a qualitative interpretation of climate and hydrologic projections obtained from the scientific literature that would be pertinent to evaluating future changes in flood hazards in the study area.

Though occasional summer storms produce large summer flood peaks, flooding on the NSR is largely dominated by spring snowmelt. From a climate change perspective, changes to winter and spring conditions are most likely to affect the hydrologic response of the NSR and Clearwater River watersheds; however, significant uncertainty exists in quantifying the hydrologic response and any potential impact on flood magnitude and timing due to the complex nature and inherent uncertainty in projecting climate change.

Several studies have been conducted for assessing the climate change effects on river flows in western Canada and findings of some of the available documents are briefly discussed herein. Golder (2008) assessed potential changes in the water yield from the NSR basin in Alberta under forecasted future climate conditions. Trend analyses across the basin suggested that there was an increasing trend in air temperature but the trends in monthly, seasonal, and annual precipitation data were not statistically significant. The study forecasted air temperature, precipitation, and water yield for the 2021-2050 period for twelve combinations of Global Climate models (GCMs) and future development scenarios, and the results were compared to the conditions that existed for the 1961-1990 baseline period. The study indicated that the changes in mean annual precipitation ranged from an 8% decrease to a 19% increase, depending on the GCM scenario combination. The predicted changes in annual water yield varied from a 23% decrease to a 15% increase.

Poitras et al. (2011) conducted a study on climate change effects and projected changes in average and extreme stream flows of ten major rivers in western Canada. They compared the results for the 2041-2070 period to the conditions that existed for the 1961-1990 baseline period. Mean and annual flows were projected to increase in all basins with a 17% increase in the NSR basin. Snowmelt events in the NSR basin were predicted to occur earlier and peak discharges were likely to increase by up to 20%.

Kienzle et al. (2012) conducted a climate change effects study in the Cline River watershed, located in the upper NSR basin. The study assessed a range of future climate conditions (2010–2039, 2040–2069, and 2070–2099) using the historical 1961–1990 period as a baseline condition. Increases in both high and low flow magnitudes and frequencies and large increases to winter and spring streamflow were predicted for all climate scenarios. Spring runoff and peak streamflow were projected to occur up to 4 weeks earlier than in the 1961–1990 baseline period.

DFO (2013) conducted a climate change effect assessment and indicated that annual temperatures in the prairies would increase for all seasons in the range of 0.8 to 5.4°C. Winter temperatures would increase more than summer temperatures. Minimum temperatures would increase at a higher rate than maximum temperatures. Spring runoff is expected to increase but occur earlier. Annual runoff may decrease. A general increase in annual precipitation was projected by 3 to 18%. Projections were more uncertain for the Saskatchewan River basin since both an increase and a decrease have been predicted. Higher precipitation is expected in winter compared to summer. During the summer months, streamflow in the Saskatchewan River basin could decrease by up to 50%.

Generally, climate change projections for Alberta generally predict an increase in annual temperatures and precipitation as well as increased intensity and frequency of extreme events (Alberta WaterPortal 2018). Though it is difficult to predict how these changes will interact and what impact that may have on future floods, potential scenarios have been identified based on these projected trends, as follows:

- An increase in winter precipitation would increase the snowpack and higher winter temperatures would result in increased and earlier snowmelt, thereby producing larger and earlier spring flood peaks.

- Warmer temperatures would increase the probability of extreme rainfall events, which could result in more extreme rain or snow events producing larger spring flood peaks (Sauchyn and Kulshreshtha 2008).

These scenarios take a conservative stance by assuming that annual increases in precipitation are experienced in the winter or during spring snowmelt and do not consider any increase in evaporation or sublimation losses resulting from increased temperatures. Climate science is not well-developed as of yet, particularly for infrequent events that cause flooding. Global climate models, and even regional climate models, are designed to predict general trends, not event style data (Natural Resources Canada 2019). As such, these models are not effective for quantifying future flooding characteristics. Given the uncertainty in quantifying the effect of climate change on estimated flood peaks for developing flood maps, Natural Resources Canada (2019) suggested several approaches that may be considered in climate change adaptation. These include: a) using a safety factor; b) carrying out sensitivity analysis; c) using a risk based approach; d) planning for adaptive designs; and e) managing residual risk during infrastructure operations (Natural Resources Canada 2019).

Natural Resources Canada has developed the Federal Flood Mapping Guidelines Series and has recently published the document, *Case Studies on Climate Change in Floodplain Mapping* (Natural Resources Canada 2018a). While this document identifies different approaches (including a qualitative approach such as adding a freeboard to the design flood level and quantitative approach through the use of a hydrologic model) applied in different Canadian jurisdictions, there is currently no standard methodology that has been adopted (Natural Resources Canada 2019). Current practices in British Columbia are governed by the Association of Professional Engineers and Geoscientists of British Columbia's *Legislated Flood Assessments in a Changing Climate in BC* (Natural Resources Canada 2018b). This document recommends increasing the design flow by up to 20% to account for uncertainties on future conditions. The province of Ontario does not prescribe a process to deal with climate change adaptation; Matrix is currently working with the Ontario Ministry of Natural Resources and Forestry to provide guidance on the inclusion of climate change resiliency in flood hazard assessments. The suggested approach may include sensitivity analysis and resiliency testing methods to account for the potential impacts of a changing climate.

7 CONCLUSIONS

Flood frequency estimates are required for the Rocky Mountain House flood hazard study. A WSC hydrometric gauging station, the NSR near Rocky Mountain House (05DC001) is located within the study area. However, due to flow regulation by the upstream Bighorn Dam since 1972, recorded flows are not in a natural state. As a result, recorded stream data were naturalized by removing the effect of the dam by conducting a water balance analysis and by routing flows through the NSR up to the WSC station location within the study area. The extended annual maximum instantaneous discharges covering a period of 1914 to 2019 consisting of 86 data points at the NSR near Rocky Mountain House (05DC001) were used for flow frequency analysis.

The recorded flows on the Clearwater River and Prairie Creek were considered as natural since no major structures are located on these watercourses. The extended annual maximum instantaneous discharges covering a period of 1914 to 2020 consisting of 94 data points at the Clearwater River near Rocky Mountain House (05DB001) were used for flow frequency analysis.

Following standard flow frequency analysis procedures, different theoretical probability distributions to the observed data sets were tested for their suitability for the subject data set. The most suitable theoretical distribution for each data set was selected based on comparing visual goodness of fit curves against the observed data and comparing results of statistical goodness of fit tests. It was concluded that log Pearson Type III distribution represents the annual maximum instantaneous discharges for both locations, the Clearwater River near Rocky Mountain House (05DB001) and the NSR near Rocky Mountain House (05DC001).

Due to the short distance between the upstream boundary and the WSC station on the Clearwater River as well as its confluence with the NSR, the flood frequency estimates at the WSC station, Clearwater River near Rocky Mountain House (05DB001) can be used at the upstream boundary of the Clearwater River for hydraulic modelling purposes.

Due to the short distance between the upstream boundary and the WSC station (05DC001) on the NSR, the flood frequencies at the upstream boundary of the study area along the NSR are computed by subtracting the corresponding flood frequencies of the Clearwater River (05DB001) from the flood frequencies of the NSR near Rocky Mountain House (05DC001) and can be used at the upstream boundary for hydraulic modelling. The flood frequency estimates at the WSC station (05DC001) can be considered as representative of the flood frequencies of the NSR just downstream of its confluence with the Clearwater River for hydraulic modelling purposes.

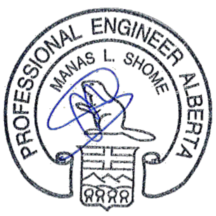
The flood frequency estimates reflect the most current data and methodologies available. Given the relatively short data record (in the range of 100 years of data), uncertainty exists for estimating flood frequencies with return periods greater than 200 years. The flood frequency estimates should be updated as more flood data become available.

8 CLOSURE

We trust that this letter report suits your present requirements. If you have any questions or comments, please call either of the undersigned at 403.237.0606.

Yours truly,

MATRIX SOLUTIONS INC.



Manas Shome, Ph.D., P.Eng.
Principal Water Resources Engineer

Reviewed by

Brandyn Coates, M.Eng., P.Eng.
Water Resources Engineer

EJ/cl
Attachments

PERMIT TO PRACTICE
MATRIX SOLUTIONS INC.
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RM APEGA ID #: 57054
DATE: 2021-Mar-31
PERMIT NUMBER: P005540
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

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VERSION CONTROL

Version	Date	Issue Type	Filename	Description
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V1.0	31-March-2021	Final	31781-531 LR 2021-03-31 final V1.0.docx	Issued as Final

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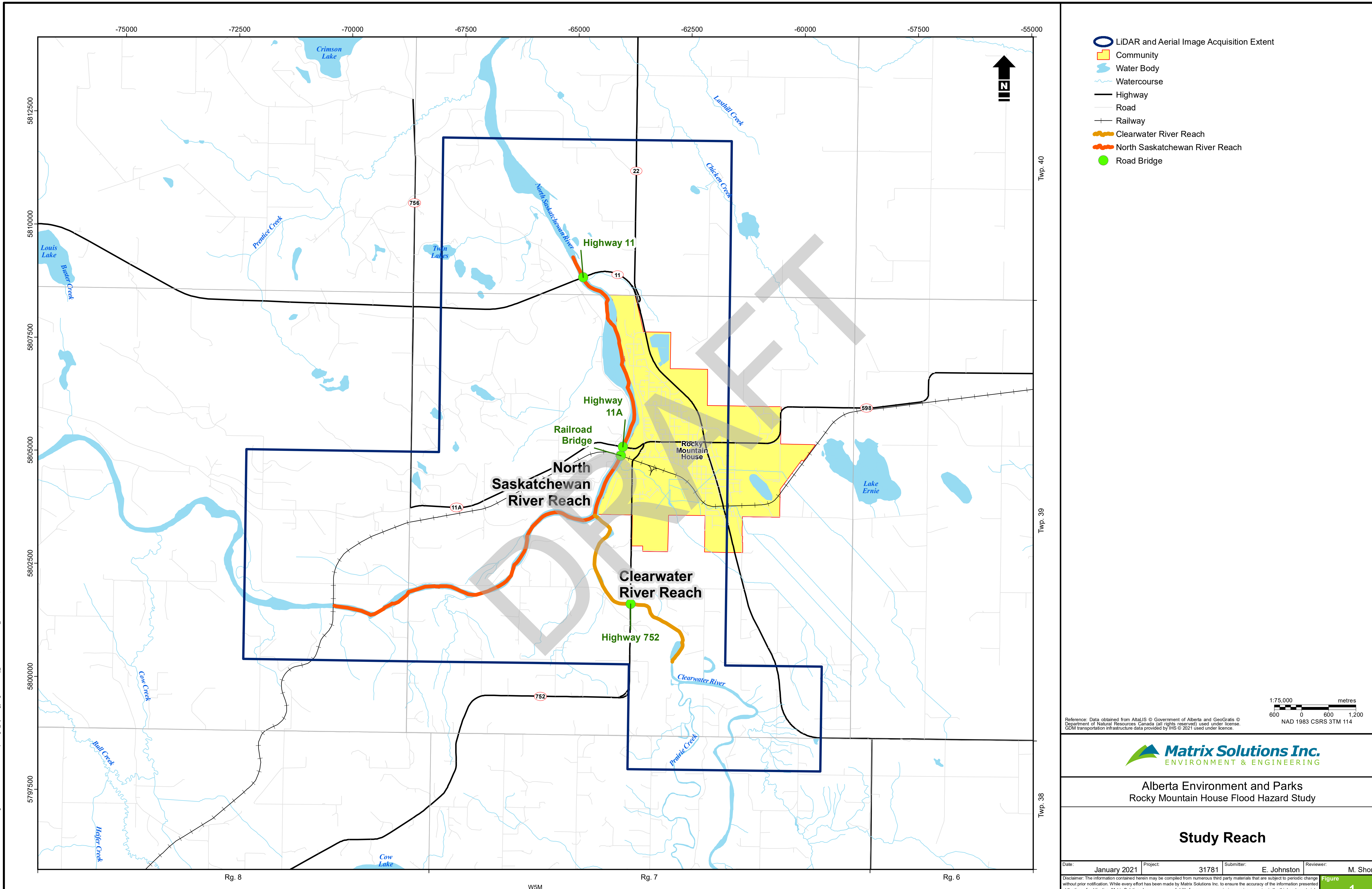

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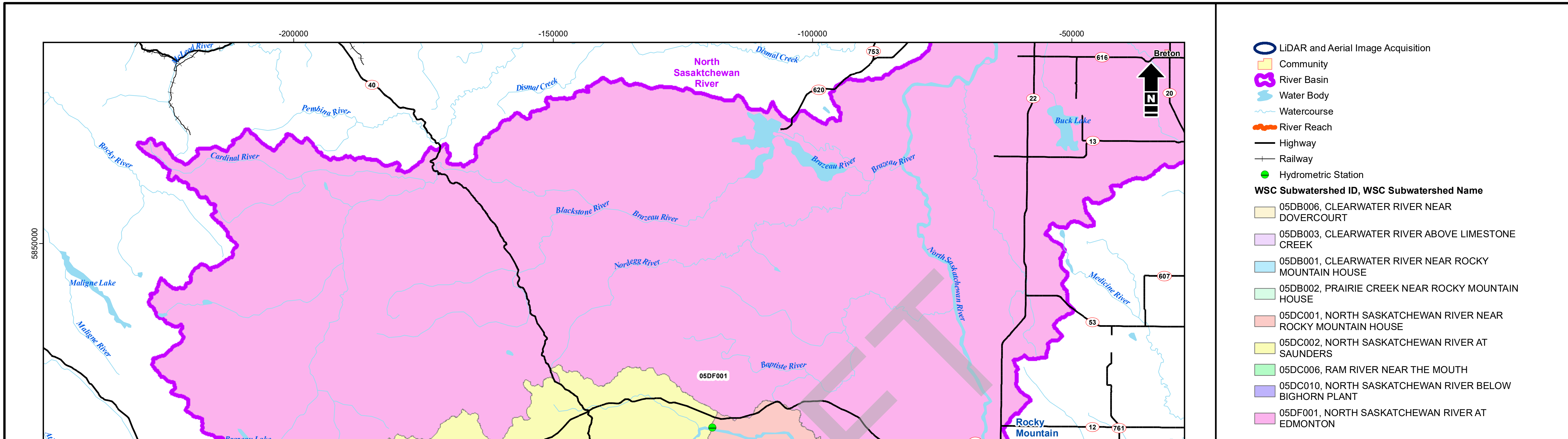

Station Number	Station Name	Total Gross Drainage Area (km ²)	Source
05DB001	Clearwater River Near Rocky Mountain House	3,220	WSC
05DB002	Prairie Creek Near Rocky Mountain House	844	WSC
05DB003	Clearwater River above Limestone Creek	1,340	WSC
05DB006	Clearwater River Near Dovercourt	2,250	WSC
05DC001	North Saskatchewan River Near Rocky Mountain House	11,000	WSC
05DC002	North Saskatchewan River near Saunders	5,160	WSC
05DC006	Ram River near the mouth	1,860	WSC
05DC009	Lake Abraham near Nordegg	3,890	WSC
05DC010	North Saskatchewan River below Bighorn Plant	3,890	WSC

1:750,000 Kilometers
7.5 0 7.5 15
NAD 1983 CSRS 3TM 114

Reference: Data obtained from AltaLIS © Government of Alberta used under licence.
GDM transportation infrastructure data provided by IHS © 2021 used under licence.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Alberta Environment and Parks
Rocky Mountain House Flood Hazard Study

North Saskatchewan River - Regional Hydrometric Stations

Date:	Project:	Submitter:	Reviewer:
January 2021	31781	E. Johnston	M. Shome

Figure 2

APPENDIX A
Naturalization of Flows of the North Saskatchewan River near Rocky Mountain House

Version 1.0
March 31, 2021 Matrix 31781-531

Mr. Kurt Morrison, M.Eng., P.Eng., CFM
ALBERTA ENVIRONMENT AND PARKS
Floor 11, Oxbridge Place
9820 – 106 St. NW
Edmonton, AB T5K 2J6

Subject: Rocky Mountain House Flood Hazard Study, Naturalization of Flows of the North Saskatchewan River near Rocky Mountain House

Dear Mr. Morrison:

1 INTRODUCTION

Matrix Solutions Inc. was retained by Alberta Environment and Parks (AEP) to assess and identify flood hazards along the North Saskatchewan River (NSR) and the Clearwater River through the Town of Rocky Mountain House and Clearwater County. These assessments are part of the continuing flood hazard mapping efforts of the Government of Alberta to identify, map, and document flood hazard areas in communities throughout Alberta. The purpose of the current study is to assess and identify flood hazards along a 13.4 km reach of the NSR and a 4.7 km reach of the Clearwater River near Rocky Mountain House in Clearwater County, Alberta. Flows on the NSR in the Rocky Mountain House area are affected by the operation of the Bighorn Dam since August 1972 and need to be naturalized for flood frequency estimates. Flows on the NSR before the operation of the dam (before August 1972) and recorded flows in all the tributaries have been assumed to be natural (unregulated) for this study. The drainage area of the NSR near Rocky Mountain House is 11,000 km^2 and located approximately 128 km downstream of the Bighorn Dam.

Matrix Solutions retained subconsulting services of Optimal Solutions Ltd. to assist in deriving naturalized flow data series on the NSR near the Rocky Mountain House gauging station location (05DC001) located within the study area. This report provides information on methodology, assumptions, and various types of data used in developing the daily naturalized discharge data series covering the period from September 1972 to December 2019.

1.1 Overview of the Bighorn Project

Flow regulation at the Bighorn Dam site on the NSR commenced in August 1972 and created Lake Abraham with a surface area of 50 km^2, the largest man-made lake in Alberta. The lake elevation level varies between 1,283.0 m and 1,321.5 m based on the Water Survey of Canada (WSC) gauging station, Lake Abraham near Nordegg (05DC009) daily recorded data. The lake level is controlled by varying the discharge through the power plant to the NSR. Outflows from this lake are reported at the WSC Station NSR below Bighorn Power Plant (05DC010). Flow regulation at the Bighorn Dam is typically dependent on reservoir inflows, water demand for power generation, and dam safety. TransAlta has established general operating plans for normal operations and flood action plans. However, actual operations often deviate from the plans partially due to uncertainties of inflow forecasting and monitoring and variability of water demand for power generation.

2 FLOW NATURALIZATION

The process of naturalizing historical flow records involves undoing the anthropogenic effects, such as storage and evaporative losses due to flow regulation by a dam and water consumptive uses due to flow diversion. This process will recreate the naturalized flow data series that would have occurred in the absence of such man-made activities. This is achieved by reversing the effects of storage change and flow diversions from the stream by starting from the most upstream control points and by moving reach by reach in a downstream progression. The River Basin Assessment Tools (RBAT), a computer program developed for Environment Canada/Prairie Provinces Water Board (PPWB; 2012) has been utilized in this study. The RBAT model has been used on similar studies for AEP in the past, which involved naturalization of flows on the Bow, Red Deer and Peace rivers. The RBAT model applies the Streamflow Synthesis and Reservoir Simulation (SSARR) hydrologic routing technique to route the calculated upstream naturalized flows to the downstream locations, where those are summed up with the estimates of local runoff. The routing equations are also applied on the recorded flows in order to calculate more accurately the local runoff between two adjacent control points.

The use of SSARR routing technique requires a relationship between discharges and travel time along various reaches between Bighorn Dam and the Rocky Mountain House WSC location. The RBAT model uses the Project Depletion Method to naturalize flows in any river basin and the general approach incorporated in the RBAT model is described below.

2.1 Project Depletion Method

Natural flows are river flows that would have been observed at selected locations in a river basin assuming there had been no human intervention by operation of large storage reservoirs or withdrawals. The most common approach to estimate natural flows is the Project Depletion Method, which is essentially aimed at ‘undoing’ the impacts of human intervention in a systematic way, reach by reach, in a downstream progression. The following section explains the calculation procedure on a small example shown on Figure A that has most of the elements found in complex river basins.

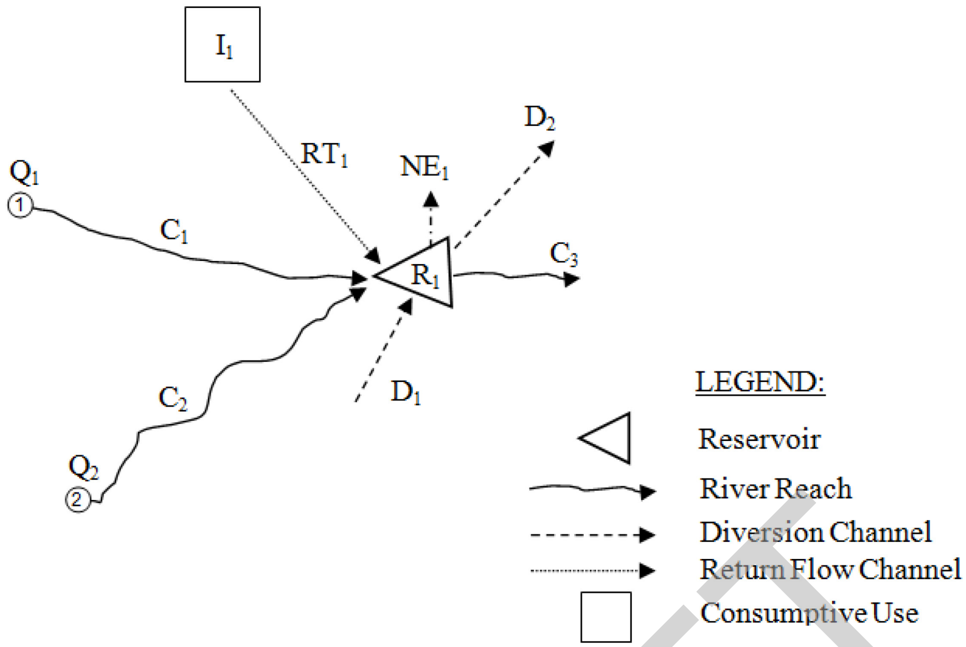

FIGURE A Sample Schematic for Calculation of Naturalized Flows

There are two river reaches with a reservoir R1 at their confluence. In this example, the naturalized flow is calculated at the reservoir site. There is one diversion (D1) and one return flow (RT1) into the reservoir, one diversion channel out of the reservoir (D2), and regulated outflow (Q_{C3}) from the reservoir into natural channel reach C3. The general approach to calculate naturalized flows at any location is to estimate local runoff that originates between the given location and the closest upstream locations at which natural flows had already been evaluated.

Denoting the naturalized flow at reservoir as QR1 and the local runoff between natural flows Q1, Q2, and the reservoir as LR, the naturalized flow at the reservoir site can then be calculated as:

$$Q_{R1} = Q_1 + Q_2 + LR \quad (1)$$

Consequently, the principal component of estimating naturalized flows is determination of the local runoff LR. Assuming Qr1 and Qr2 are the recorded flows at locations 1 and 2, LR for the reservoir in Figure A can be calculated using the following equation assuming average flow over time step *t*:

$$LR = Q_{C3} + Q_{D2} - Q_{RT1} - Q_{D1} + \Delta V/t - Q_{r1} - Q_{r2} \quad (2)$$

where:

- QC3 the recorded flow in channel C3
- QD1 flow in diversion channel D1
- QD2 flow in diversion channel D2
- QRT1 flow in return flow channel RT1
- ΔV/t reservoir storage change over time step *t*

Reservoir storage change is further evaluated using the starting and ending storage (*Vs* and *Ve*) for a time step, along with adjustments for net evaporation (evaporation minus precipitation) for a given time interval *t* (seconds). Note that the sign for net evaporation is reversed since the idea is to remove the effect of net evaporation (i.e., put the evaporation loss back in the river):

$$\frac{\Delta V}{t} = \frac{Ve - Vs}{t} + \frac{(E-P)[A(Ve)+A(Vs)]}{2t} \quad (3)$$

where:

V_e	volume at the end of time step *t* (m^3)
V_s	volume at the start of time step *t* (m^3)
P	total precipitation over time step *t* (m)
E	total evaporation from the reservoir surface over time step *t* (m)
$A(V_e)$	surface area (m^2) corresponding to the ending volume *Ve*
$A(V_s)$	surface area (m^2) corresponding to the starting volume *Vs*

To summarize, local runoff LR can, in general, be assessed by conducting a water balance calculation for a subcatchment which is delineated by the downstream point for which LR is evaluated and the upstream control points where recorded flow series are available. The general expression is:

$$LR = \sum_{i=1}^{m} Q_i - \sum_{j=1}^{n} Q_j + \sum_{k=1}^{l} \frac{\Delta V_k}{t} \quad (4)$$

where:

Q_i	average outflows (i=1,m) from a sub catchment within time step *t*
Q_j	average inflows (i=1,m) into a sub catchment within time step *t*

while the storage change term ΔV/t is summed up over all storage reservoirs in the sub-catchment area under consideration. Inflows and outflows into a subcatchment include all diversions and return flows into it, as well as diversions out of it. Normally, naturalized flows should be calculated at all on-stream reservoir locations, especially when reservoirs have sizeable live storage.

Equation (1) suggests that naturalized flows are first determined at upstream locations (e.g., locations 1 and 2 in the example on Figure A. The calculation then proceeds in the above manner for all requested locations in the river basin in a downstream progression, by simply adding the local runoff to the previously calculated naturalized flows at the immediate upstream nodes in the network.

It should be noted that if the length of the reaches C1 and C2 is associated with travel time that is longer than the calculation time step, the recorded outflows Qr1 and Qr2 in equation (2) should previously be routed before being used in equation (2). Once local runoff is calculated with routed recorded flows, it will be necessary to route the naturalized flows from the two upstream nodes before the local runoff is added to them to give naturalized flow at the downstream node R1.

The objective of the flow naturalization task is to estimate naturalized daily discharge under open water conditions on the NSR near Rocky Mountain House from September 1972 to December 2019 by removing the measurable effect imposed by the Bighorn Dam.

2.2 Data Requirements

Various types of data including recorded streamflow, climate data, water consumptive uses, and stage-storage, as well as stage-area relationships of the reservoir are normally required for flow naturalization. The water consumptive uses by other users such as municipal supplies, oil and gas extraction and agricultural activities along the NSR between the Bighorn Dam and the Rocky Mountain WSC gauging station would not have any measurable effect on annual peak flows compared to the effects caused by flow regulation by the dam. Consequently, the main activities in the naturalization of flows in this study involved removing the effects of storage change by using the recorded water levels at the WSC gauging station, the Lake Abraham near Nordegg (05DC009) and computed net evaporation. The different types of data used in the flow naturalization process included the following:

- historical recorded streamflow data for the NSR and its tributaries
- historical precipitation and evaporation data
- reservoir information including operations, water levels, and outflows

The recorded streamflow data at the following WSC stations (Table A) were used in the flow naturalization.

TABLE A Water Survey of Canada Hydrometric Gauging Stations

Station Name and ID	Gross Drainage Area (km^2)	Data Period
Lake Abraham near Nordegg (05DC009)	3,890	1972-2012
North Saskatchewan River below Bighorn Plant (05DC010)	3,890	1972-2019
North Saskatchewan River near Saunders (05DC002)	5,160	1915-1978
North Saskatchewan River near Rocky Mountain House (05DC001)	11,000	1913-1930; 1944- 2020
Clearwater River near Rocky Mountain House (05DB001)	3,220	1914 – 1931; 1944 – 1975
Clearwater River near Dovercourt (05DB006)	2,250	1975-2019
Prairie Creek near Rocky Mountain House (05DB002)	844	1922-1925; 1951-2020
Ram River near the mouth (05DC006)	1,860	1967-2019

The WSC database does not have streamflow data for 2017 and 2019. The preliminary streamflow data for these years have been obtained from AEP for this study and may be subject to change. The water level data at the Lake Abraham near Nordegg (05DC009) from 2012 to 2019 were obtained from TransAlta. The historical daily precipitation data covering the period from 1972 to 2019 in the Lake Abraham area was obtained from Alberta Agriculture and Forestry (AF 2020). Historical monthly evaporation data has been provided by AEP. Information on the reservoir operation rules, stage-area and stage-storage relationships was provided by TransAlta.

In addition, the naturalized flow computations using the SSARR routing method require continuous time series. It should be noted that the flows on NSR near the Rocky Mountain House and other WSC stations used in this study are gauged seasonally. For this reason, the missing data in winter months were filled using typical expected winter flows. This was done to enable continuous calculation, recognizing that the main purpose of this study is to estimate naturalized maximum daily discharges at the Rocky Mountain House WSC location in each of the years of record. The derived naturalized flow series should not be used for any low flow analysis since data records were not available at some of the key locations along the routing reaches of the NSR.

2.2.1 Routing Tables

The SSARR routing module in the RBAT model is a cascade of reservoir technique and requires routing characteristics of various modelled reaches in terms of discharge versus time of travel and the number of segments in a modelled reach. The routing tables used in Stantec (2005) were reviewed and adjusted for different length of the river reaches. The results were also confirmed using the downstream movement of observed (based on a review of recorded data) hydrograph peak flows downstream. Table B presents the routing tables used in this study.

TABLE B Routing Tables Along Various North Saskatchewan River Reaches

Bighorn to Ram River Confluence (86 km)		Ram River to Clearwater River (42 km)	
Flow (m^3/s)	Travel Time (hours)	Flow (m^3/s)	Travel Time (hours)
0.03	72.90	0.03	35.60
14.16	56.70	14.16	27.69
28.32	43.74	28.32	21.36
60.88	32.40	60.88	15.82
181.23	21.06	181.23	10.29
254.85	19.44	254.85	9.49
396.44	17.82	396.44	8.70
934.46	16.20	934.46	7.91
1614.06	14.58	1614.06	7.12
2973.27	12.96	2973.27	6.33

2.3 Flow Naturalization Process to the North Saskatchewan River

The modelling schematic of the NSR reaches and its tributaries is shown on Figure B, while the hydrometric stations and their years of available data are shown in Table A. As a part of the flow naturalization process, a water balance analysis was performed for Lake Abraham from September 1972 to December 2019 to compute naturalized flows. Changes in reservoir storage were computed using a) the reservoir water level data recorded at the WSC station 05DC009, b) discharge data recorded at the WSC station 05DC010, and c) precipitation and evaporation data as appropriate for the area.

The schematic diagram for flow naturalization is presented on Figure A1 in Appendix A. The main activities in the naturalization of flows involved removing the effects of storage change (as discussed above) and routing the recalculated reservoir inflow first to the confluence with the Ram River, where the Ram River tributary inflows were added to the routed flows. These routed flows were summed with the recorded flows of the Ram River at the mouth (05DC006), and the resulting flows were then routed to the confluence with the Clearwater River. The flows at Clearwater River near the Rocky Mountain House (05DB001) were then added to the routed daily flows, along with the remaining local runoff between the Bighorn Dam and Rocky Mountain House, which were calculated based on the flow records at the WSC station on the NSR near Rocky Mountain House (05DC001).

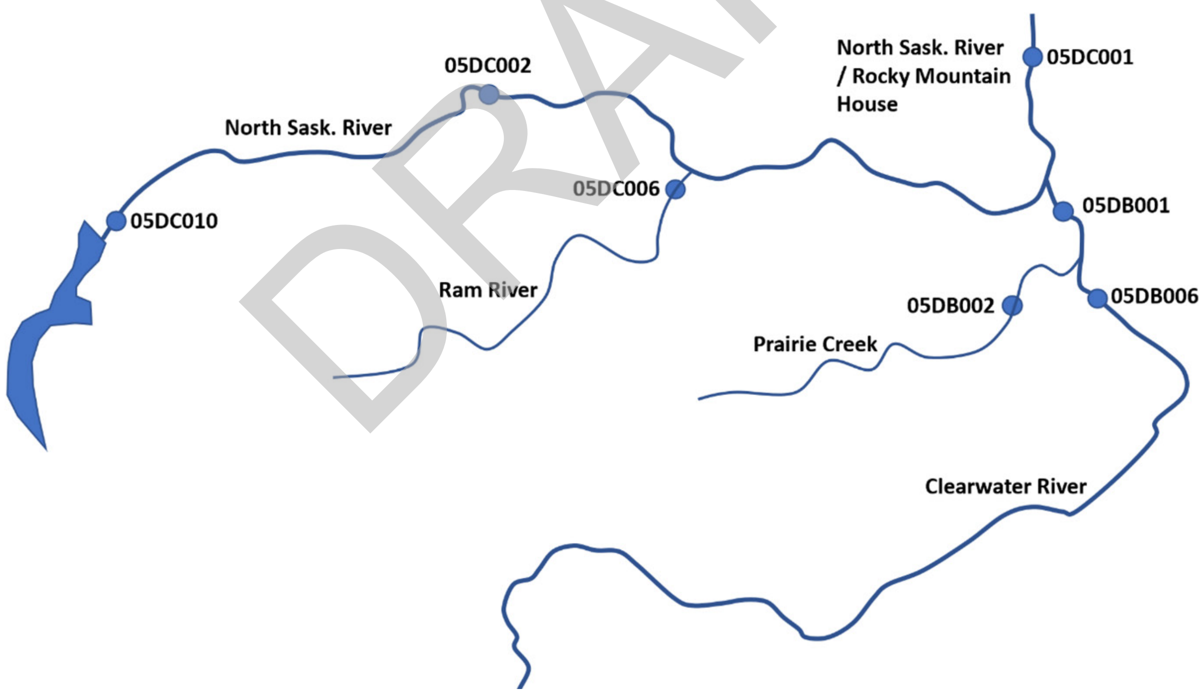

Figure B North Saskatchewan River Reaches and Tributaries and Locations of WSC Stations

Hydrologic routing was also required to calculate the local inflows between the Bighorn Dam and Rocky Mountain House, since the flows along the Ram and Clearwater rivers do not account for the entire local runoff. The procedure involved routing of the recorded outflows from the dam, which were then summed up with the flows of the Ram River near the mouth and routed down to the confluence with the Ram River, and finally added to the flows from the Clearwater River at the confluence. The resulting sum was subtracted from the recorded flows on NSR near Rocky Mountain House (05DC001). Both routing procedures for recorded flows (needed to calculate the local runoff) and the final naturalized flows were conducted by the RBAT model simultaneously as the calculation proceeds in the downstream progression.

The recorded flows at the Clearwater River at Rocky Mountain House (05DB001) were used as tributary inflow into the NSR until 1975. After that, the Prairie Creek flows (Station 05DB002) were added to the flows at the Clearwater River near Dover Station (05DB006) to represent total tributary daily flows into the NSR at the confluence covering a period from 1976 to 2019. The streamflow data from the NSR near Saunders (05DC002) were not used in this study since this station only has incomplete seasonal data, but the station location is provided since it was referenced in earlier studies from which the travel time versus flow relationships were retrieved.

2.4 Developed Naturalized Flow Data Series

Following the above-mentioned procedures, the RBAT model was used to route the daily flows through the NSR reaches on a daily time step basis. The comparison of daily regulated and naturalized flows at the WSC station on the NSR near the Rocky Mountain House (05DC001) for the period from 1972 to 2019 is shown on Figure A2 in Appendix A. Effects of river routing is highlighted on Figure C below for 1988 when the flows in the NSR has moderate levels while the total Ram River contribution is small..

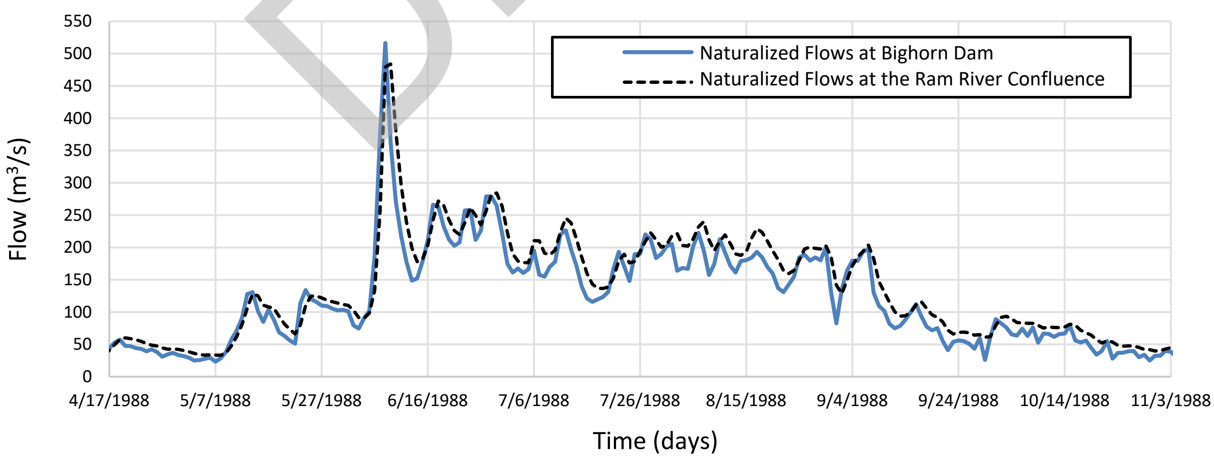

Figure C Naturalized Flows at Bighorn Dam and the Ram River Confluence during 1988

Similarly, typical comparison between naturalized and regulated flows below Bighorn Dam is shown on Figure D below.

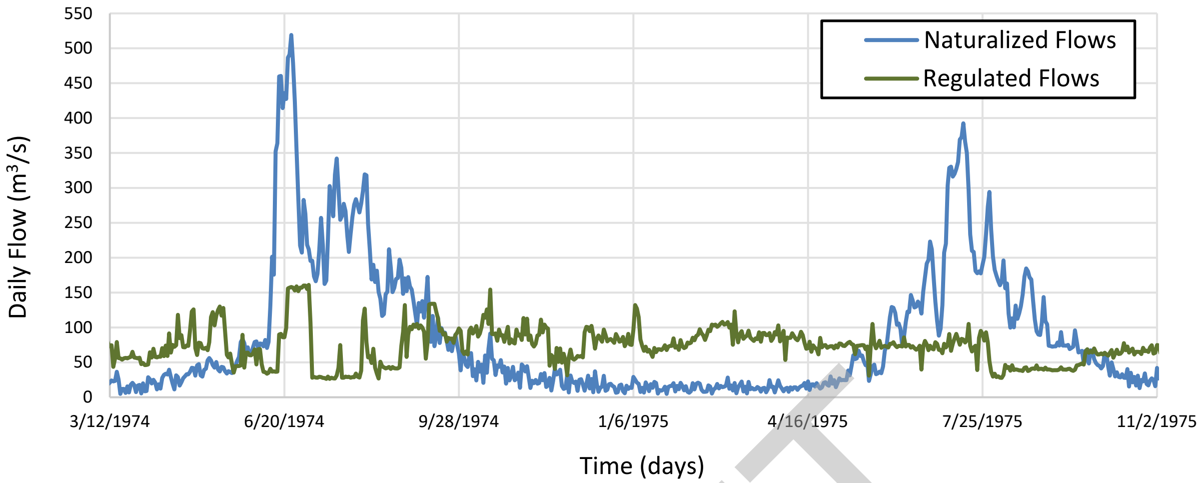

Figure D Comparison of Naturalized and Regulated Flows at Bighorn Dam

The derived naturalized daily discharge data series can be used to determine the naturalized annual maximum daily discharge for the period from 1973 to 2019 (annual maximum daily discharge in 1972 occurred before the operation of the dam). Figure A3 in Appendix A shows the naturalized maximum daily discharges covering the period from 1915 to 2019, where a slight downward trend (negative slope) can be seen. A similar trend has been noticed in the naturalized maximum daily flows at the WSC station on the NSR at Edmonton (05DF001) reported in the recently completed North Saskatchewan Flood Hazard Study from the Town of Devon through the City of Edmonton and Fort Saskatchewan (NHC 2020). The trend in the generated naturalized flow data series on the NSR near Rocky Mountain House (05DC001) is statistically insignificant based on the Mann-Kendall test performed in this study.

The average ratio of naturalized maximum daily discharges and recorded regulated maximum daily discharges covering the period from 1990 to 2019 is 1.5 with a median value of 1.4. No recorded maximum daily discharges from 1973 to 1989 is available. The ratio of computed naturalized maximum daily discharge and regulated maximum daily discharge (2,150 m^3/s) during the 2005 flood is 1.1 while the ratio of naturalized maximum daily discharge and regulated maximum daily discharge (1,650 m^3/s) during the 2013 flood is 1.3.

The annual maximum daily discharges at the NSR near Rocky Mountain House (05DC001) for the period from 1972 to 2019 can be combined to the recorded natural annual maximum daily discharges covering the period from 1914 to 1972 to generate a complete annual naturalized maximum daily discharges at the WSC station near Rocky Mountain House (05DC001). This complete annual naturalized maximum daily discharge data series can be used to determine the annual maximum instantaneous discharges (for missing years during pre-regulation and all years during post-regulation) using a relationship between the maximum instantaneous discharges and maximum daily discharges during pre-regulation period (1914 to summer of 1972). This is done under the assumption that the relationship between maximum instantaneous discharges and maximum daily discharges in the derived naturalized flow series for the post-regulation period is the same as the relationship that exists in natural flow series during pre-regulation. The derived maximum instantaneous discharges covering the period from 1914 to 2019 can then be used for flood frequency estimates.

3 CLOSURE

We trust that this letter report suits your present requirements. If you have any questions or comments, please call either of the undersigned at 780.989.8364.

Yours truly,

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MANAS L. SHOME
2021-Mar-31

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MS/cl
Attachments

PERMIT TO PRACTICE
MATRIX SOLUTIONS INC.
RM SIGNATURE: ____
RM APEGA ID #: 57054
DATE: 2021-Mar-31
PERMIT NUMBER: P005540
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

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VERSION CONTROL

Version	Date	Issue Type	Filename	Description
V0.1	27-Jan-2021	Draft	31781-531 LR 2021-01-28 draft V0.1.docx	Issued to client for review
V1.0	31-Mar-2021	Final	31781-531 LR 2021-03-31 final V1.0.docx	Issued to client

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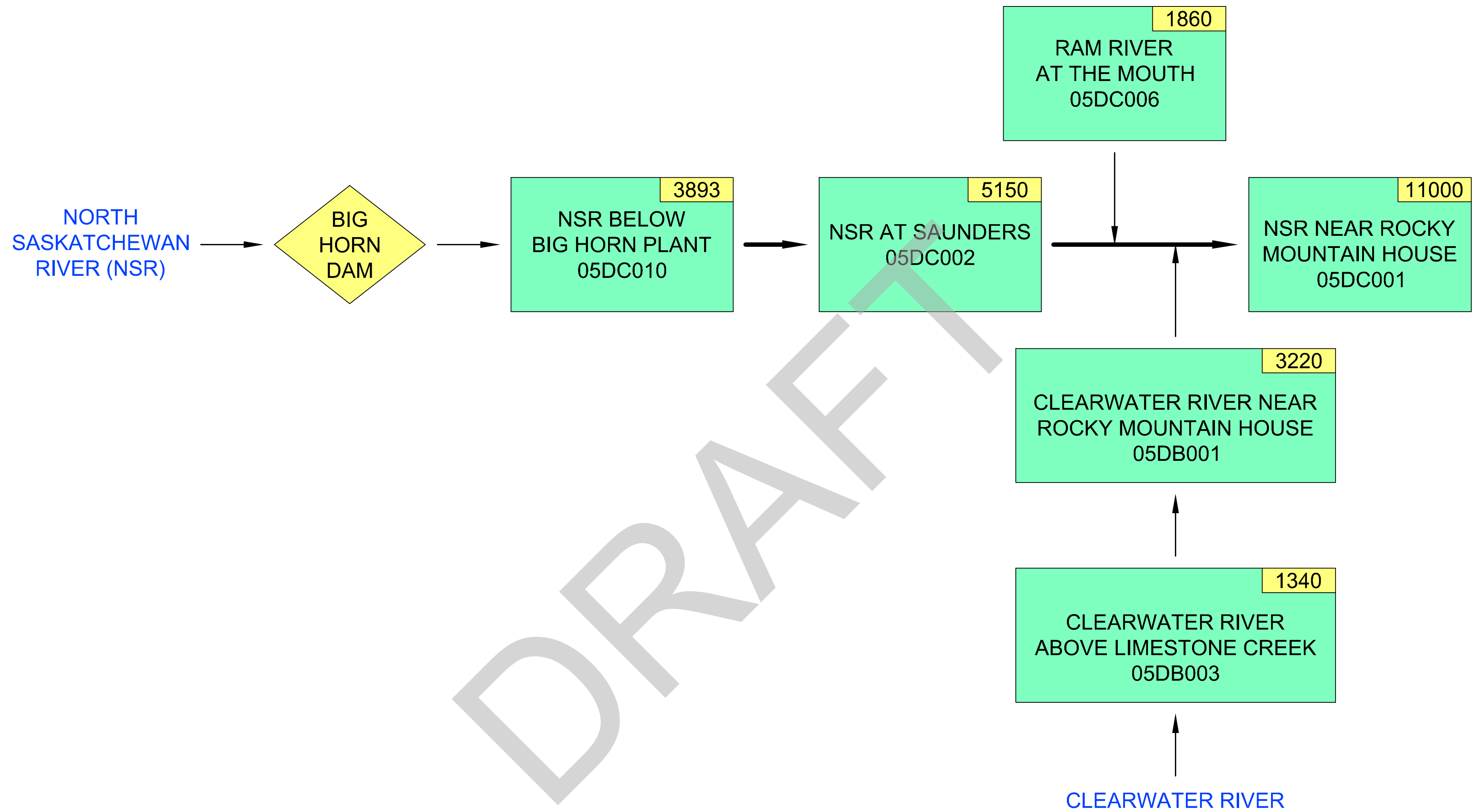

Matrix Solutions Inc.
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Alberta Environment and Parks
Rocky Mountain House Flood Hazard Study

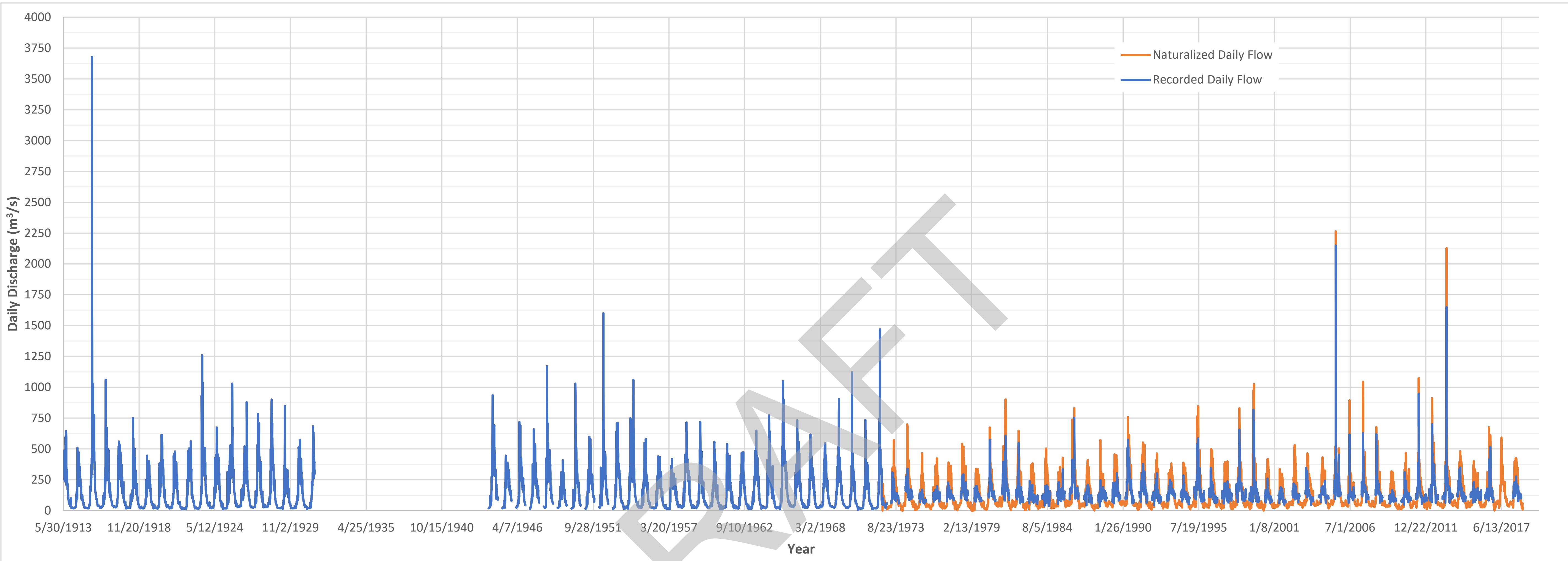
Schematic Diagram for Flow Naturalization

Date:	Project:	Submitter:	Reviewer:
January 2021	31781-SD-20	E. Johnston	M. Shome

Figure A1

Reference:

Comparison of Regulated and Natural Daily Discharge Hydrographs



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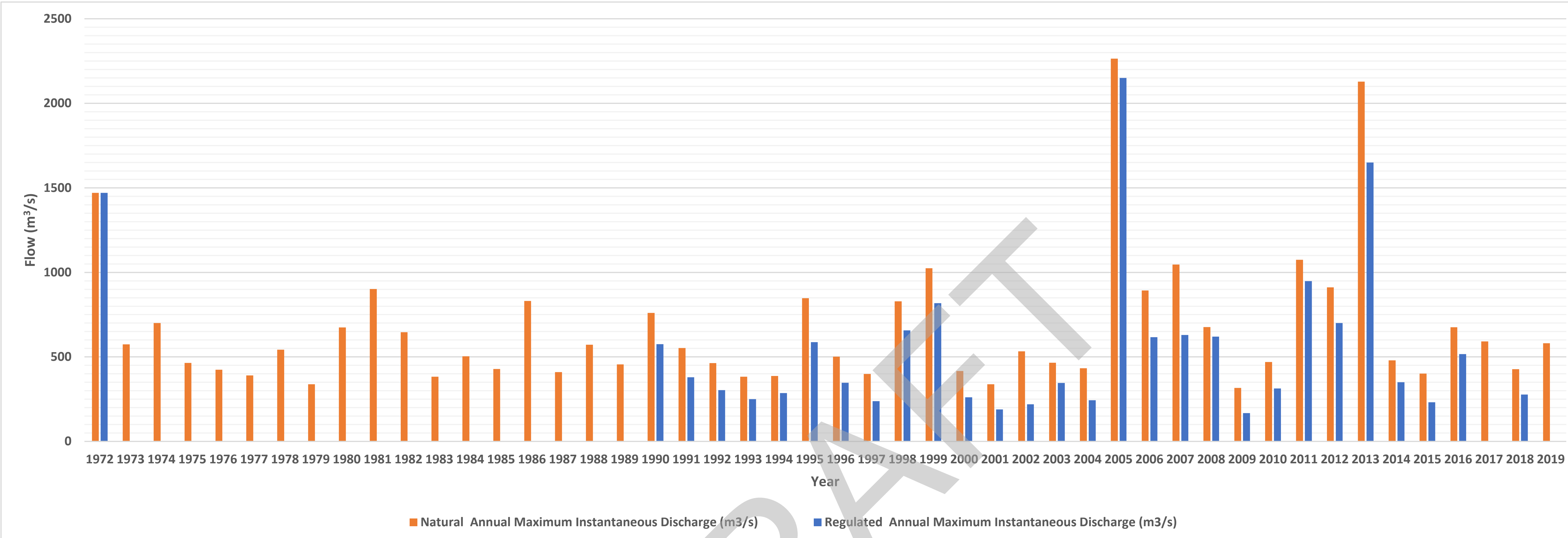
Rocky Mountain House Flood Hazard Study

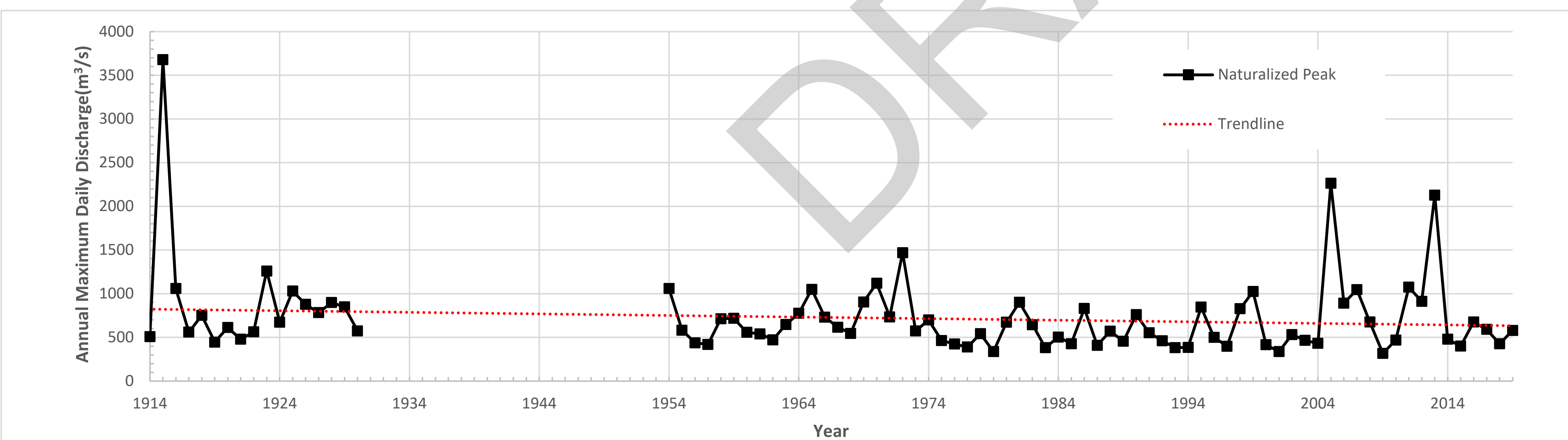
NORTH SASKATCHEWAN RIVER HYDROLOGIC ANALYSIS

Date:	Project:	Submitter:	Reviewer:
JANUARY 2021	31781-531	E. JOHNSTON	M. SHOME

Figure A2

Comparison of Regulated and Natural Annual Maximum Daily Discharge Hydrographs





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Rocky Mountain House Flood Hazard Study

NORTH SASKATCHEWAN RIVER HYDROLOGIC ANALYSIS

Date:	Project:	Submitter:	Reviewer:
JANUARY 2021	31781-531	E. JOHNSTON	M. SHOME

Figure A3

APPENDIX B
Results of Hydrologic Analysis – Clearwater River near Rocky Mountain House

TABLE B1: Recorded Annual Maximum Daily and Maximum Instantaneous Discharges for WSC Gauging Stations

Year	Clearwater River Near Dovercourt (05DB006)				Prairie Creek Near Rocky Mountain House (05DB002)				Clearwater River Near Rocky Mountain House (05DB001)			
	Annual Maximum Instantaneous Discharge (m³/s)	Date	Annual Maximum Daily Discharge (m³/s)	Date	Annual Maximum Instantaneous Discharge (m³/s)	Date	Annual Maximum Daily Discharge (m³/s)	Date	Annual Maximum Instantaneous Discharge (m³/s)	Date	Annual Maximum Daily Discharge (m³/s)	Date
1914	-	-	-	-	-	-	-	-	-	-	64.6	06--08
1915	-	-	-	-	-	-	-	-	-	-	1110	06--27
1916	-	-	-	-	-	-	-	-	-	-	221	06--20
1917	-	-	-	-	-	-	-	-	-	-	174	05--17
1918	-	-	-	-	-	-	-	-	-	-	119	06--15
1919	-	-	-	-	-	-	-	-	-	-	42.2	08--09
1920	-	-	-	-	-	-	-	-	-	-	178	05--09
1921	-	-	-	-	-	-	-	-	-	-	56.9	06--07
1922	-	-	-	-	-	-	15.4	08--17	75.3	08--17	72.5	08--17
1923	-	-	-	-	58.9	06--24	57.5	06--24	-	-	320	06--02
1924	-	-	-	-	-	-	11.8	05--03	153	05--01	115	05--01
1925	-	-	-	-	43.9	08--17	42.5	08--17	328	08--17	274	08--17
1926	-	-	-	-	-	-	-	-	-	-	233	09--02
1927	-	-	-	-	-	-	-	-	117	07--28	113	07--28
1928	-	-	-	-	-	-	-	-	267	06--19	259	06--19
1929	-	-	-	-	-	-	-	-	253	06--03	230	06--03
1930	-	-	-	-	-	-	-	-	-	-	66.3	06--11
1931	-	-	-	-	-	-	-	-	-	-	-	-
1944	-	-	-	-	-	-	-	-	-	-	231	06--15
1945	-	-	-	-	-	-	-	-	-	-	103	06--01
1946	-	-	-	-	-	-	-	-	-	-	144	06--23
1947	-	-	-	-	-	-	-	-	-	-	119	06--28
1948	-	-	-	-	-	-	-	-	-	-	289	05--24
1949	-	-	-	-	-	-	-	-	-	-	46.2	07--21
1950	-	-	-	-	-	-	-	-	-	-	137	06--15
1951	-	-	-	-	-	-	-	-	-	-	90.6	05--05

Year	Clearwater River Near Dovercourt (05DB006)				Prairie Creek Near Rocky Mountain House (05DB002)				Clearwater River Near Rocky Mountain House (05DB001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1952	-	-	-	-	94.3	06--24	86.1	06--24	425	06--24	411	06--24
1953	-	-	-	-	-	-	28.3	06--04	171	06--04	167	06--04
1954	-	-	-	-	94.6	08--27	94	08--26	385	08--26	357	08--26
1955	-	-	-	-	-	-	36.8	06--01	96.3	06--13	89.5	06--14
1956	-	-	-	-	-	-	8.41	04--16	-	-	53.8	06--21
1957	-	-	-	-	-	-	18.4	04--30	78.4	04--30	68.5	05--01
1958	-	-	-	-	-	-	17.9	07--02	104	07--02	98.3	07--02
1959	-	-	-	-	-	-	43.6	06--29	146	06--28	135	06--28
1960	-	-	-	-	-	-	22.5	05--19	63.7	07--03	62	07--02
1961	-	-	-	-	-	-	9.63	05--05	62.9	07--03	59.2	07--30
1962	-	-	-	-	17.4	05--16	17.1	05--16	62	05--21	55.5	05--21
1963	-	-	-	-	42.2	07--17	36.8	07--17	147	07--17	138	07--17
1964	-	-	-	-	109	05--08	90	05--08	189	05--07	168	05--07
1965	-	-	-	-	68.8	06--30	65.4	06--30	524	06--19	385	06--19
1966	-	-	-	-	32.3	07--04	29.7	07--04	180	07--04	162	07--05
1967	-	-	-	-	22	06--01	21.2	06--01	152	06--01	138	06--01
1968	-	-	-	-	22.5	07--21	20.4	07--22	74.2	07--21	69.4	07--22
1969	-	-	-	-	69.4	07--06	67.4	07--06	286	07--07	274	07--06
1970	-	-	-	-	70.5	06--17	64.8	06--17	399	06--17	340	06--17
1971	-	-	-	-	24.9	06--10	24	06--10	146	06--07	138	06--07
1972	-	-	-	-	116	06--26	102	06--26	467	06--26	442	06--26
1973	-	-	-	-	20.4	05--28	19.4	05--28	98.8	05--28	95.4	05--28
1974	-	-	-	-	23.5	05--21	23	05--20	121	06--18	115	06--18
1975	-	-	-	-	11.6	05--08	11.2	05--08	45.3	06--26	42.8	06--27
1976	55.8	08--09	50.7	08--11	11.6	08--09	9.77	08--17	-	-	-	-
1977	61.4	06--10	56.1	06--09	38.2	05--30	34	05--30	-	-	-	-
1978	111	06--07	106	06--07	22.4	06--01	19	06--01	-	-	-	-
1979	50.1	05--28	45.4	05--28	8.43	04--29	7.93	04--29	-	-	-	-

Year	Clearwater River Near Dovercourt (05DB006)				Prairie Creek Near Rocky Mountain House (05DB002)				Clearwater River Near Rocky Mountain House (05DB001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1980	94.1	06--18	87.2	06--05	28.1	06--06	27	06--06	-	-	-	-
1981	223	07--31	194	07--31	54.8	07--31	49.5	07--31	-	-	-	-
1982	77.9	07--05	73.3	07--06	-	-	41.2	07--06	-	-	-	-
1983	93.7	07--04	84.5	07--04	18.5	07--04	17.3	07--04	-	-	-	-
1984	66.9	06--10	65.1	06--10	26.1	06--10	25.3	06--10	-	-	-	-
1985	99.3	09--14	94.2	09--14	32.6	09--14	30.3	09--14	-	-	-	-
1986	158	07--18	136	07--18	112	07--19	104	07--19	-	-	-	-
1987	48.8	07--27	46.3	07--27	7.56	07--23	7.28	07--23	-	-	-	-
1988	75.3	06--09	68.5	06--09	14.4	08--18	13.3	08--18	-	-	-	-
1989	60.2	08--18	56.4	08--18	20.5	08--04	19.4	08--04	-	-	-	-
1990	341	06--03	274	06--03	64.4	06--13	59.9	06--13	-	-	-	-
1991	109	08--16	102	08--16	24.6	07--07	21.3	07--07	-	-	-	-
1992	85.2	07--10	82.7	07--10	20	07--10	18.8	07--10	-	-	-	-
1993	-	-	83.2	07--27	22.3	07--27	20.6	07--27	-	-	-	-
1994	67.9	06--08	65.5	06--08	31.9	06--09	29.8	06--09	-	-	-	-
1995	214	07--04	201	07--05	51.7	07--05	48.9	07--05	-	-	-	-
1996	65.6	06--10	60.2	06--10	19.8	06--02	19.2	06--02	-	-	-	-
1997	62.7	08--16	54.5	08--17	26.7	08--17	24.9	08--17	-	-	-	-
1998	-	-	151	06--30	55.4	07--02	50	07--02	-	-	-	-
1999	228	07--16	206	07--16	131	07--05	113	07--05	-	-	-	-
2000	75.2	07--11	71.3	07--11	35.5	07--11	33.7	07--11	-	-	-	-
2001	38.8	06--26	38.4	06--26	-	-	10.4	06--19	-	-	-	-
2002	64.1	06--17	61	06--18	12.5	05--16	12.2	05--16	-	-	-	-
2003	175	04--26	143	04--26	60.3	04--26	53.9	04--26	-	-	-	-
2004	50.3	07--05	49.9	07--05	27.8	09--04	25.7	09--04	-	-	-	-
2005	938	06--19	738	06--19	212	06--19	183	06--19	-	-	-	-
2006	161	06--16	126	06--17	38.1	06--16	33.5	06--17	-	-	-	-
2007	229	06--07	189	06--07	62.2	06--18	52.6	06--18	-	-	-	-

Year	Clearwater River Near Dovercourt (05DB006)				Prairie Creek Near Rocky Mountain House (05DB002)				Clearwater River Near Rocky Mountain House (05DB001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
2008	204	05--26	186	05--26	41.5	06--12	40.1	06--12	-	-	-	-
2009	43.6	07--16	42.4	07--16	12.4	07--10	11.8	07--10	-	-	-	-
2010	64.6	06--11	63.2	06--11	49.7	06--11	46.4	06--11	-	-	-	-
2011	200	06--18	187	06--20	85.9	06--18	79	06--18	-	-	-	-
2012	275	06--07	217	06--07	41.8	06--11	37.6	06--11	-	-	-	-
2013	587	06--21	509	06--22	85.5	06--22	81.2	06--22	-	-	-	-
2014	89	06--17	84.1	06--18	29.4	06--17	27.9	06--17	-	-	-	-
2015	46	09--22	41.8	09--22	6.5	09--08	6.11	09--08	-	-	-	-
2016	139	08--24	132	07--18	73.1	08--24	67.1	08--24	-	-	-	-
2017	-	-	89	06--15	-	-	24.1	05--26	-	-	-	-
2018	64.5	07--08	62.2	07--08	20.2	04--29	19.4	04--30	-	-	-	-
2019	-	-	111	06--29	-	-	31.5	06--29	-	-	-	-
2020	-	-	118	07--02	-	-	68.0	05--23	-	-	-	-

Note: Maximum Daily Discharge for 2017, 2019 and 2020 were derived from taking Daily Average from Hourly data available through AEP. It was determined that there was a good correlation between WSC and AEP daily maximum flow at WSC Stations 05DB006 and 05DB002.

TABLE B2: Annual Maximum Instantaneous and Recorded Annual Maximum Daily Discharges for WSC Gauging Station 05DB001

Year	Clearwater River Near Rocky Mountain House (05DB001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1914	72.1	-	64.6	06--08
1915	1238.4	-	1110	06--27
1916	246.6	-	221	06--20
1917	194.1	-	174	05--17
1918	132.8	-	119	06--15
1919	47.1	-	42.2	08--09
1920	198.6	-	178	05--09
1921	63.5	-	56.9	06--07
1922	75.3	08--17	72.5	08--17
1923	357	-	320	06--02
1924	153	05--01	115	05--01
1925	328	08--17	274	08--17
1926	260	-	233	09--02
1927	117	07--28	113	07--28
1928	267	06--19	259	06--19
1929	253	06--03	230	06--03
1930	74	-	66.3	06--11
1931	-	-	-	-
1944	257.7	-	231	06--15
1945	114.9	-	103	06--01
1946	160.7	-	144	06--23
1947	132.8	-	119	06--28
1948	322.4	-	289	05--24
1949	51.5	-	46.2	07--21
1950	152.9	-	137	06--15
1951	101.1	-	90.6	05--05
1952	425	06--24	411	06--24
1953	171	06--04	167	06--04
1954	385	08--26	357	08--26
1955	96.3	06--13	89.5	06--14
1956	60	-	53.8	06--21
1957	78.4	04--30	68.5	05--01
1958	104	07--02	98.3	07--02
1959	146	06--28	135	06--28
1960	63.7	07--03	62	07--02
1961	62.9	07--03	59.2	07--30

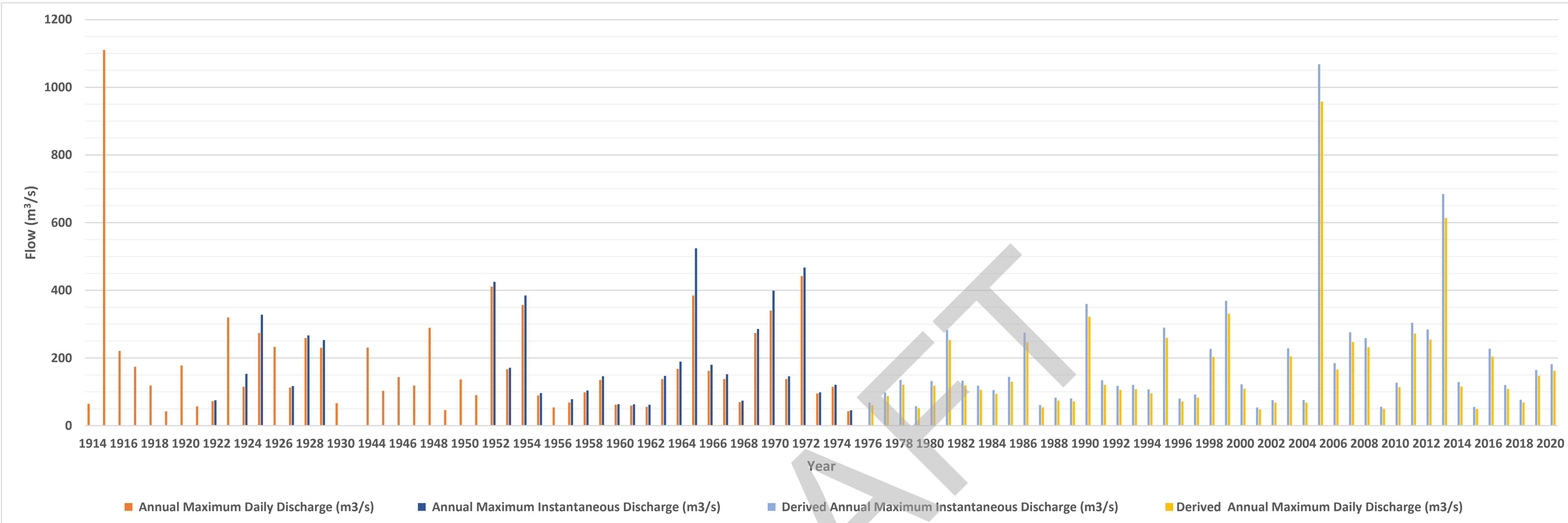
Year	Clearwater River Near Rocky Mountain House (05DB001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1962	62	05--21	55.5	05--21
1963	147	07--17	138	07--17
1964	189	05--07	168	05--07
1965	524	06--19	385	06--19
1966	180	07--04	162	07--05
1967	152	06--01	138	06--01
1968	74.2	07--21	69.4	07--22
1969	286	07--07	274	07--06
1970	399	06--17	340	06--17
1971	146	06--07	138	06--07
1972	467	06--26	442	06--26
1973	98.8	05--28	95.4	05--28
1974	121	06--18	115	06--18
1975	45.3	06--26	42.8	06--27
1976	*67.8*	-	-	-
1977	*97.9*	-	-	-
1978	*134.9*	-	-	-
1979	*57.8*	-	-	-
1980	*131.9*	-	-	-
1981	*282.5*	-	-	-
1982	*132.8*	-	-	-
1983	*118.1*	-	-	-
1984	*104.9*	-	-	-
1985	*144.4*	-	-	-
1986	*274.9*	-	-	-
1987	*60.7*	-	-	-
1988	*82.8*	-	-	-
1989	*80.3*	-	-	-
1990	*359.5*	-	-	-
1991	*134.3*	-	-	-
1992	*117.7*	-	-	-
1993	*120.4*	-	-	-
1994	*107.1*	-	-	-
1995	*289.9*	-	-	-
1996	*80*	-	-	-
1997	*92.1*	-	-	-
1998	*226.7*	-	-	-
1999	*368.9*	-	-	-
2000	*121.8*	-	-	-
2001	*53.8*	-	-	-

Year	Clearwater River Near Rocky Mountain House (05DB001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
2002	*75.8*	-	-	-
2003	*228.4*	-	-	-
2004	*75.5*	-	-	-
2005	*1068.4*	-	-	-
2006	*185*	-	-	-
2007	*275.9*	-	-	-
2008	*258.5*	-	-	-
2009	*55.9*	-	-	-
2010	*127.1*	-	-	-
2011	*303.9*	-	-	-
2012	*284.1*	-	-	-
2013	*684.7*	-	-	-
2014	*128.8*	-	-	-
2015	*55.2*	-	-	-
2016	*227.5*	-	-	-
2017	*120.6*	-	-	-
2018	*76.7*	-	-	-
2019	*164.8*	-	-	-
2020	*181.5*	-	-	-

Note:

1. 1914 to 1975 data are from the WSC Station 05DB001.
2. 1976 to 2020 (shown in Italic) are derived from WSC Stations 05DB006 and 05DB002.
3. The underlined values are based on Qi= 1.1157Qp.

Comparison of Annual Maximum Daily and Instantaneous Discharge Hydrographs



Notes
1. The 1914 to 1975 are WSC gauge data (05DB001)
2. The 1976 to 2020 data are derived from WSC gauge data (05DB006 and 05DB002)
3. The 2017, 2019 and 2020 are preliminary data from AEP.

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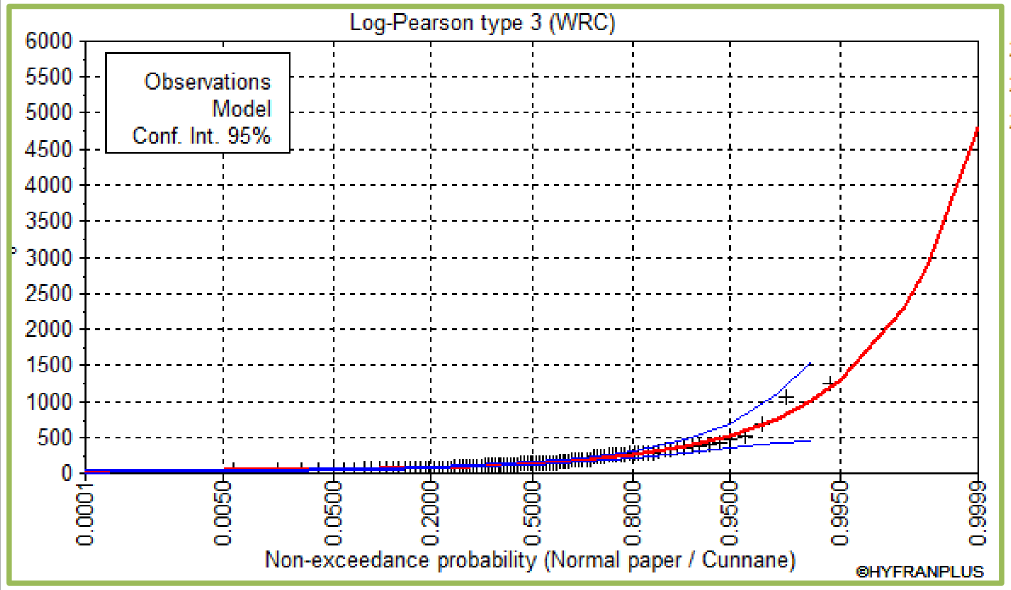
Alberta Environment and Parks
Rocky Mountain House Flood Hazard Study

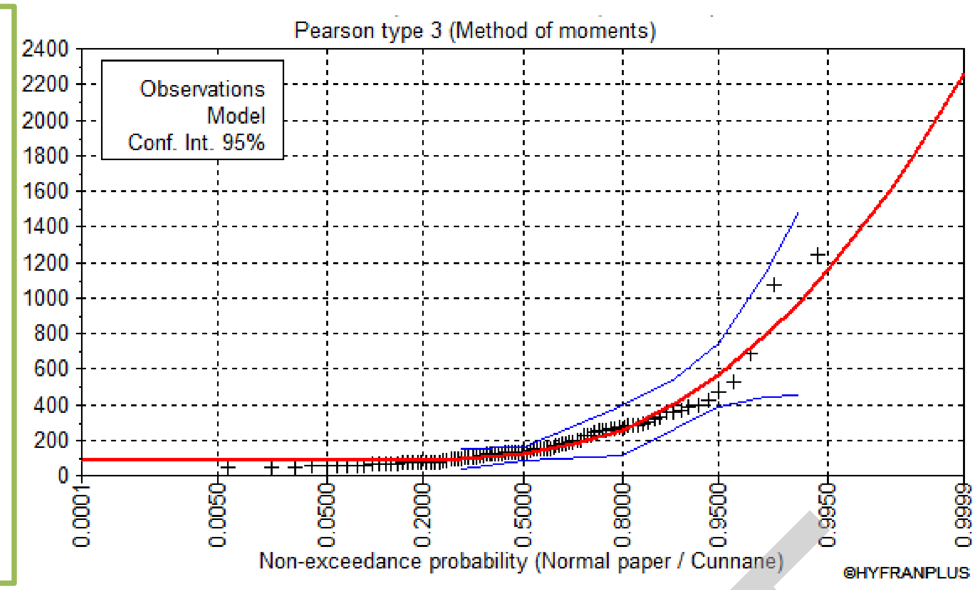
CLEARWATER RIVER
HYDROLOGIC ANALYSIS

Date:	Project:	Submitter:	Reviewer:
MARCH 2021	31781-531	E. JOHNSTON	M. SHOME

Figure
B1

F:\31781\531\2 - Open Water Hydrology Assessment\Report\Appendix A"





Distribution Type	Numerical Goodness-of-fit Tests from Spreadsheet			Average of Ranks	Ranking from Numerical Tests
	A-D Test	K-S Test	Least Squares Ranking		
Normal	10	10	10	10.00	10
Lognormal	4	2	6	4.00	2
Lognormal III	6	6	3	5.00	6
Exponential	3	3	7	4.33	4
Pearson III	5	5	2	4.00	2
Log Pearson III	1	1	1	1.00	1
Gumbel	7	7	9	7.67	8
GEV	2	4	8	4.67	5
Weibull	9	9	5	7.67	8
Gamma	8	8	4	6.67	7

Selected Distribution

1) Anderson-Darling Test (1952)

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\cdot[\ln F(X_i) + \ln(1 - F(X_{n-i+1}))]$$

H0= Data follows specified distribution
HA= Data does not follow the specified distribution

Distribution Type:	Critical Value at 10%	Critical Value at 5%	Critical Value at 1%	A2	Hypothesis	Rank (1 = best fit)
Normal	1.929	2.502	3.907	7.613	Reject H0	10
Lognormal	1.929	2.502	3.907	0.644	Accept H0	4
Lognormal III	1.929	2.502	3.907	1.408	Accept H0	6
Exponential	1.929	2.502	3.907	0.527	Accept H0	3
Pearson III	1.929	2.502	3.907	1.088	Accept H0	5
Log Pearson III	1.929	2.502	3.907	0.355	Accept H0	1
Gumbel	1.929	2.502	3.907	2.373	Accept H0	7
GEV	1.929	2.502	3.907	0.510	Accept H0	2
Weibull	1.929	2.502	3.907	4.463	Reject H0	9
Gamma	1.929	2.502	3.907	4.301	Reject H0	8

Least Squares Ranking

$$SE_j = \sqrt{\frac{1}{n - m_j}\sum_{i=1}^{n}(x_i - y_i)^2}$$

Distribution Type:	Standard Error	Rank
Normal	116	10
Lognormal	62	6
Lognormal III	44	3
Exponential	65	7
Pearson III	41	2
Log Pearson III	31	1
Gumbel	94	9
GEV	71	8
Weibull	61	5
Gamma	60	4

2) Kolmogorov-Smirnov Test (1933)

$$F_n(x) = \frac{1}{n}\cdot\left[\text{Number of observations} \le x\right] \qquad D_n = \sup_x |F_n(x) - F(x)|$$

H0= Data follows specified distribution
HA= Data does not follow the specified distribution

Distribution Type:	Critical Value at 10%	Critical Value at 5%	Critical Value at 1%	Dn	Hypothesis	Rank (1 = best fit)
Normal	0.126	0.140	0.168	0.210	Reject H0	10
Lognormal	0.126	0.140	0.168	0.066	Accept H0	2
Lognormal III	0.126	0.140	0.168	0.105	Accept H0	6
Exponential	0.126	0.140	0.168	0.069	Accept H0	3
Pearson III	0.126	0.140	0.168	0.102	Accept H0	5
Log Pearson III	0.126	0.140	0.168	0.059	Accept H0	1
Gumbel	0.126	0.140	0.168	0.128	Accept H0	7
GEV	0.126	0.140	0.168	0.070	Accept H0	4
Weibull	0.126	0.140	0.168	0.194	Reject H0	9
Gamma	0.126	0.140	0.168	0.190	Reject H0	8

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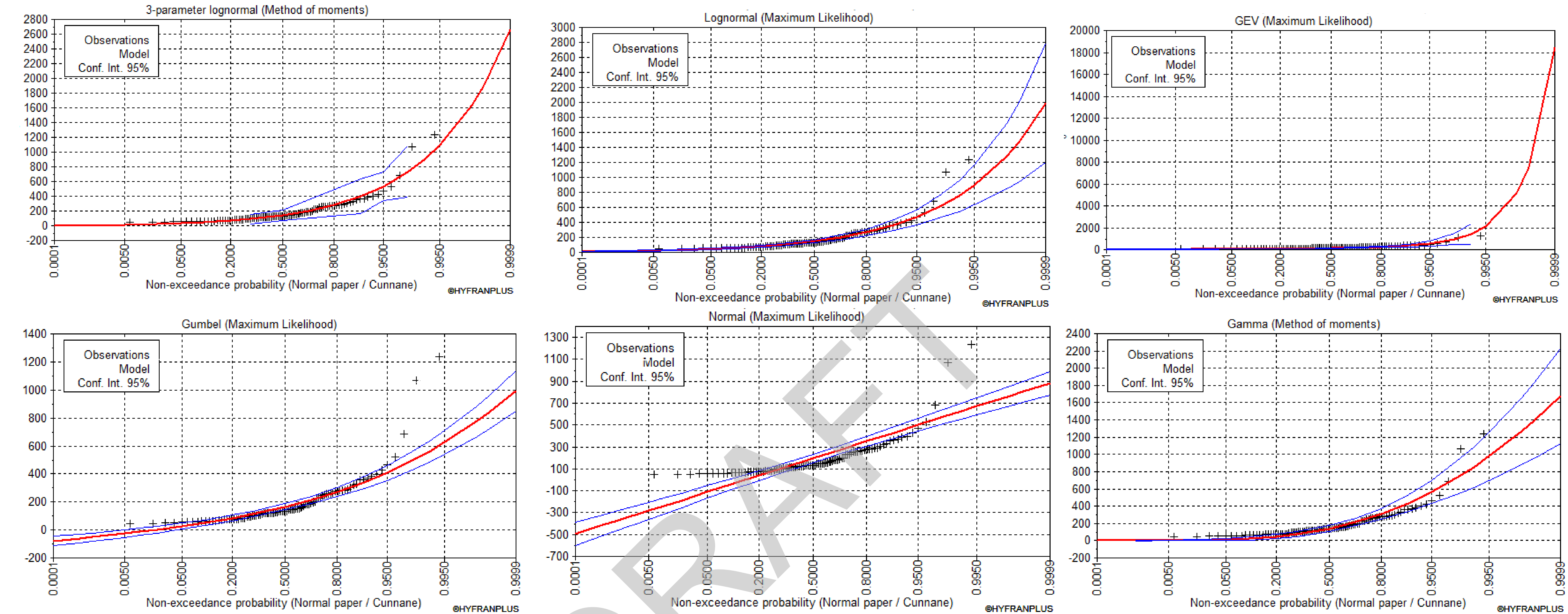
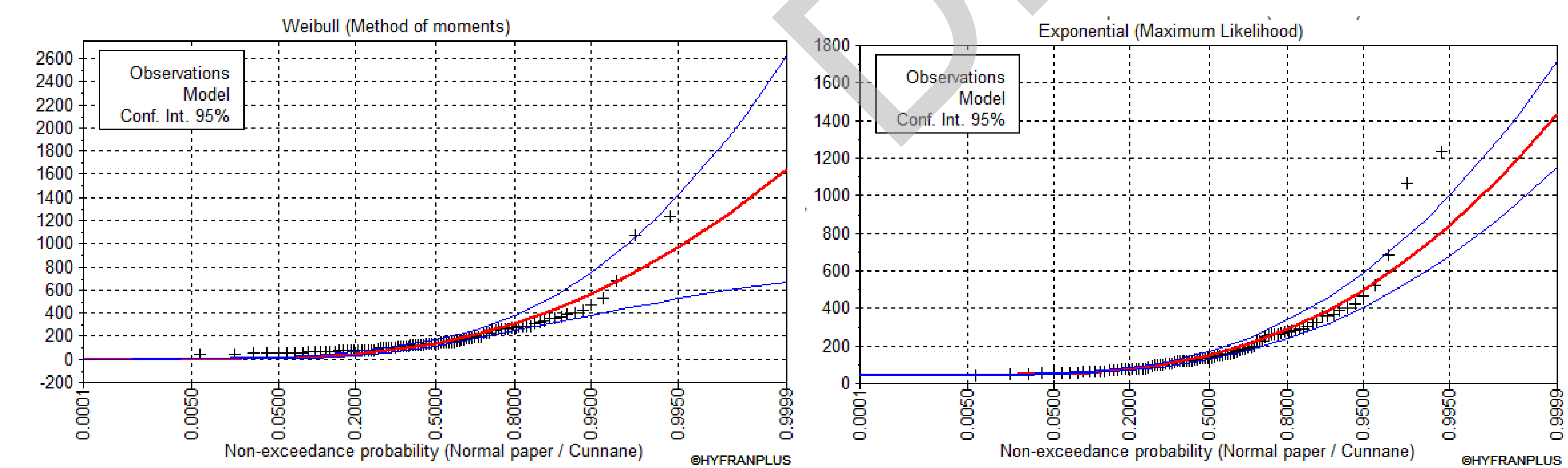
CLEARWATER RIVER
COMPARISON OF FREQUENCY DISTRIBUTIONS

Date:	Project:	Submitter:	Reviewer:
MARCH 2021	31781-531	E. JOHNSTON	M. SHOME

Figure B2





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CLEARWATER RIVER
COMPARISON OF FREQUENCY DISTRIBUTIONS

Date: MARCH 2021	Project: 31781-531	Submitter: E. JOHNSTON	Reviewer: M. SHOME

Figure B3

APPENDIX C
Results of Hydrologic Analysis – North Saskatchewan River near Rocky Mountain House

TABLE C1: Recorded Annual Maximum Daily and Maximum Instantaneous Discharges for WSC Gauging Station 05DC001

Year	North Saskatchewan River Near Rocky Mountain House (05DC001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1913	-	-	-	-
1914	-	-	510	06--07
1915	4110	06--27	3680	06--27
1916	-	-	1060	06--20
1917	-	-	561	06--03
1918	-	-	753	06--15
1919	-	-	447	06--23
1920	-	-	614	07--03
1921	-	-	479	06--26
1922	-	-	564	08--17
1923	1270	06--14	1260	06--14
1924	-	-	674	07--04
1925	-	-	1030	08--17
1926	-	-	878	09--02
1927	-	-	784	06--27
1928	-	-	900	06--23
1929	-	-	850	06--03
1930	-	-	575	07--16
1931	-	-	-	-
1944	971	06--15	-	-
1945	-	-	-	-
1946	-	-	-	-
1947	-	-	-	-
1948	-	-	-	-
1949	-	-	-	-
1950	-	-	-	-
1951	-	-	-	-
1952	1990	06--23	-	-
1953	742	07--15	-	-
1954	1260	08--25	1060	08--26
1955	586	07--19	583	07--19
1956	464	06--06	439	06--06
1957	422	06--09	419	06--09
1958	-	-	714	06--29
1959	779	06--27	719	06--27
1960	609	07--02	558	07--02
1961	566	06--08	541	06--08

Year	North Saskatchewan River Near Rocky Mountain House (05DC001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1962	504	08--06	473	08--06
1963	680	07--16	648	07--16
1964	790	06--19	776	06--19
1965	1460	06--18	1050	06--19
1966	835	07--04	733	07--04
1967	626	06--18	617	06--18
1968	-	06--28	547	07--11
1969	963	07--06	906	07--06
1970	1290	06--17	1120	06--17
1971	-	-	736	06--06
1972	1880	06--25	1470	06--26
1973	*348*	*05--28*		
1974	*351*	*06--26*		
1975	*191*	*07--18*		
1976	*212*	*08--11*		
1977	*244*	*05--30*		
1978	*323*	*07--12*		
1979	*214*	*05--27*		
1980	*679*	*06--05*		
1981	*633*	*07--25*		
1982	*554*	*07--06*		
1983	*250*	*04--26*		
1984	*241*	*10--06*		
1985	*360*	*09--14*		
1986	*773*	*07--18*		
1987	*246*	*07--08*		
1988	*262*	*06--09*		
1989	*334*	*08--17*		
1990	*594*	*06--03*	*575*	*06--03*
1991	*384*	*07--07*	*380*	*07--07*
1992	*324*	*07--10*	*304*	*07--10*
1993			*250*	*06--17*
1994	*324*	*06--09*	*286*	*06--08*
1995	*629*	*07--04*	*587*	*07--04*
1996	*377*	*06--02*	*347*	*06--02*
1997	*280*	*08--16*	*238*	*08--16*
1998	*683*	*06--30*	*657*	*06--30*
1999	*917*	*07--04*	*818*	*07--04*
2000	*301*	*07--05*	*261*	*07--11*
2001	*215*	*06--18*	*189*	*06--18*

Year	North Saskatchewan River Near Rocky Mountain House (05DC001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
2002	*251*	*05--30*	*220*	*05--30*
2003	*359*	*04--26*	*346*	*04--26*
2004	*276*	*09--04*	*244*	*09--04*
2005	*2420*	*06--19*	*2150*	*06--19*
2006			*617*	*06--16*
2007	*754*	*06--06*	*630*	*06--07*
2008	*758*	*05--25*	*620*	*05--25*
2009	*195*	*07--16*	*168*	*07--16*
2010	*339*	*06--11*	*313*	*06--11*
2011	*1170*	*06--17*	*949*	*06--17*
2012	*819*	*06--07*	*700*	*06--07*
2013	*1850*	*06--21*	*1650*	*06--21*
2014	*360*	*06--17*	*350*	*06--17*
2015	*235*	*06--09*	*232*	*06--09*
2016	*561*	*08--23*	*517*	*08--24*
2017				
2018	*295*	*07--05*	*277*	*07--05*
2019				

Notes:
1. 1914 to 1972 data are from the WSC pre-regulation record.
2. 1973 to 2019 (shown in Italic) are as reccorded from WSC (regulated flow).

TABLE C2: Annual Maximum Instantaneous and Recorded Annual Maximum Daily Discharges for WSC Gauging Station 05DC001

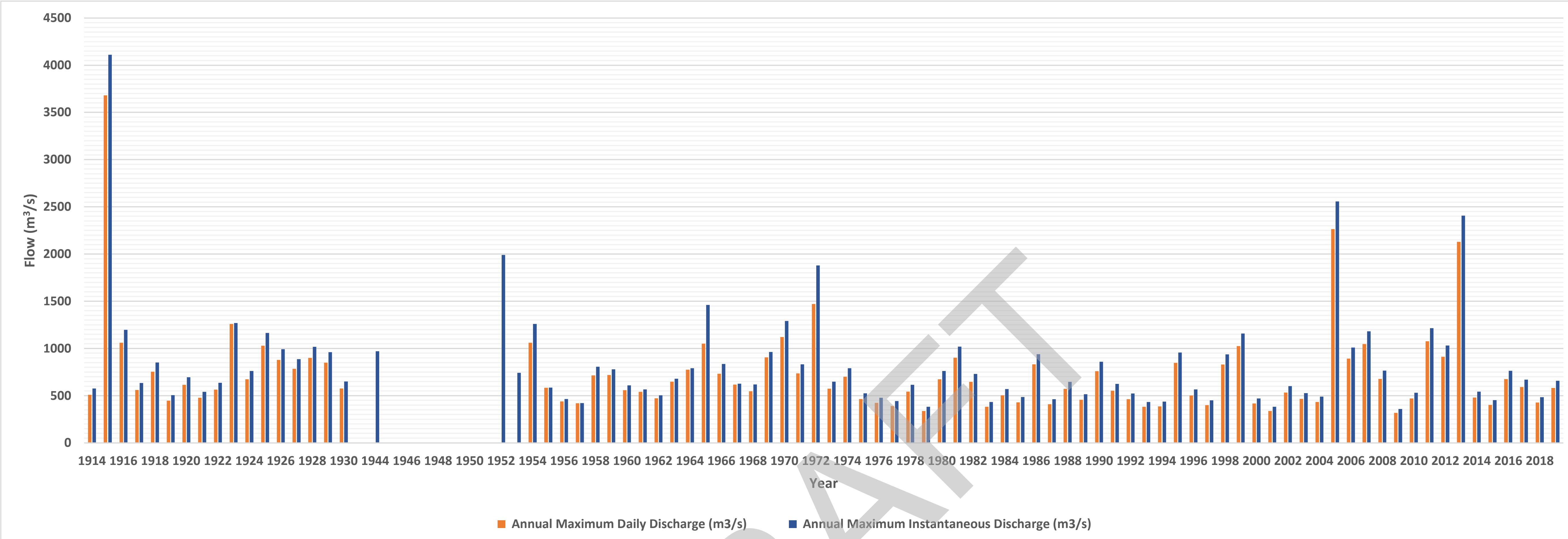
Year	North Saskatchewan River Near Rocky Mountain House (05DC001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1913	-	-	-	-
1914	576	-	510	06--07
1915	4110	06--27	3680	06--27
1916	1198	-	1060	06--20
1917	634	-	561	06--03
1918	851	-	753	06--15
1919	505	-	447	06--23
1920	694	-	614	07--03
1921	541	-	479	06--26
1922	637	-	564	08--17
1923	1270	06--14	1260	06--14
1924	762	-	674	07--04
1925	1164	-	1030	08--17
1926	992	-	878	09--02
1927	886	-	784	06--27
1928	1017	-	900	06--23
1929	961	-	850	06--03
1930	650	-	575	07--16
1931	-	-		-
1944	971	06--15		-
1945	-	-		-
1946	-	-		-
1947	-	-		-
1948	-	-		-
1949	-	-		-
1950	-	-		-
1951	-	-		-
1952	1990	06--23		-
1953	742	07--15		-
1954	1260	08--25	1060	08--26
1955	586	07--19	583	07--19
1956	464	06--06	439	06--06
1957	422	06--09	419	06--09
1958	807	-	714	06--29

Year	North Saskatchewan River Near Rocky Mountain House (05DC001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1959	779	06--27	719	06--27
1960	609	07--02	558	07--02
1961	566	06--08	541	06--08
1962	504	08--06	473	08--06
1963	680	07--16	648	07--16
1964	790	06--19	776	06--19
1965	1460	06--18	1050	06--19
1966	835	07--04	733	07--04
1967	626	06--18	617	06--18
1968	618	06--28	547	07--11
1969	963	07--06	906	07--06
1970	1290	06--17	1120	06--17
1971	832	-	736	06--06
1972	1880	06--25	1470	06--26
1973	*649*	-	*574*	*06--25*
1974	*791*	-	*700*	*06--26*
1975	*525*	-	*465*	*06--27*
1976	*479*	-	*424*	*06--28*
1977	*442*	-	*391*	*06--29*
1978	*614*	-	*543*	*06--30*
1979	*382*	-	*338*	*07--01*
1980	*762*	-	*674*	*07--02*
1981	*1019*	-	*902*	*07--03*
1982	*730*	-	*646*	*07--04*
1983	*433*	-	*383*	*07--05*
1984	*570*	-	*504*	*07--06*
1985	*485*	-	*429*	*07--07*
1986	*939*	-	*831*	*07--08*
1987	*463*	-	*410*	*07--09*
1988	*646*	-	*572*	*07--10*
1989	*515*	-	*456*	*07--11*
1990	*859*	-	*760*	*07--12*
1991	*625*	-	*553*	*07--13*
1992	*523*	-	*463*	*07--14*
1993	*433*	-	*383*	*07--15*
1994	*437*	-	*387*	*07--16*
1995	*957*	-	*847*	*07--17*
1996	*566*	-	*501*	*07--18*
1997	*451*	-	*399*	*07--19*
1998	*937*	-	*829*	*07--20*

Year	North Saskatchewan River Near Rocky Mountain House (05DC001)			
	Annual Maximum Instantaneous Discharge (m^3/s)	Date	Annual Maximum Daily Discharge (m^3/s)	Date
1999	*1158*	-	*1025*	*07--21*
2000	*471*	-	*417*	*07--22*
2001	*382*	-	*338*	*07--23*
2002	*602*	-	*533*	*07--24*
2003	*527*	-	*466*	*07--25*
2004	*489*	-	*433*	*07--26*
2005	*2558*	-	*2264*	*07--27*
2006	*1009*	-	*893*	*07--28*
2007	*1182*	-	*1046*	*07--29*
2008	*765*	-	*677*	*07--30*
2009	*358*	-	*317*	*07--31*
2010	*531*	-	*470*	*08--01*
2011	*1215*	-	*1075*	*08--02*
2012	*1031*	-	*912*	*08--03*
2013	*2406*	-	*2129*	*08--04*
2014	*542*	-	*480*	*08--05*
2015	*453*	-	*401*	*08--06*
2016	*764*	-	*676*	*08--07*
2017	*669*	-	*592*	*08--08*
2018	*483*	-	*427*	*08--09*
2019	*657*	-	*581*	*08--10*

Notes:
1. 1914 to 1972 data are from the WSC pre-regulation record.
2. 1973 to 2019 (shown in Italic) are from the results of the flow naturalizations.
3. The underlined values are based on Qi= 1.1293Qp.

Comparison of Annual Maximum Daily and Instantaneous Discharge Hydrographs



Notes
1. The 1913 to 1972 are WSC gauge data (05DC001)
2. The 1973 to 2019 data are modelled results from the flow naturalization

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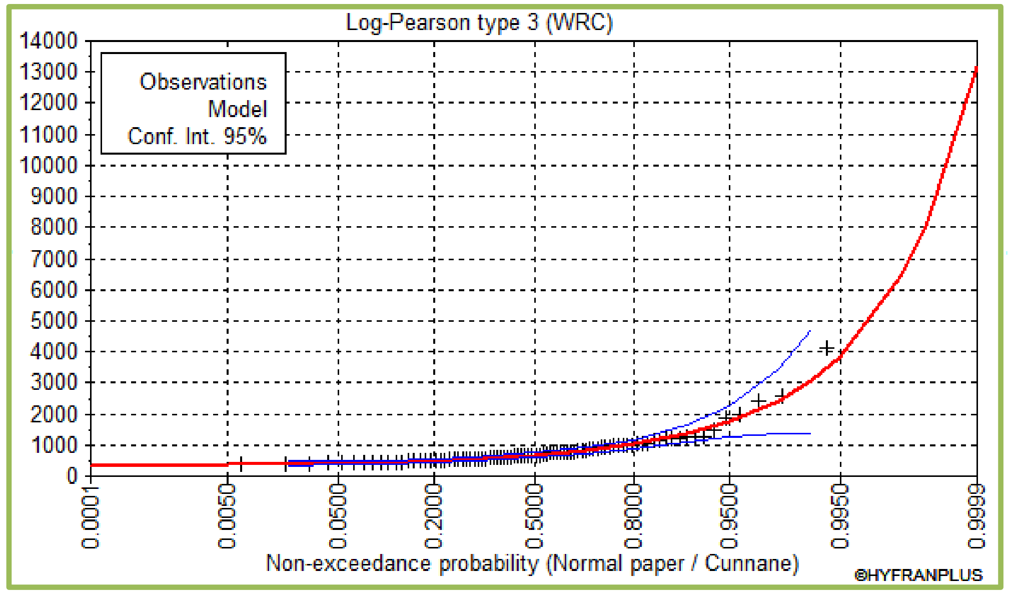
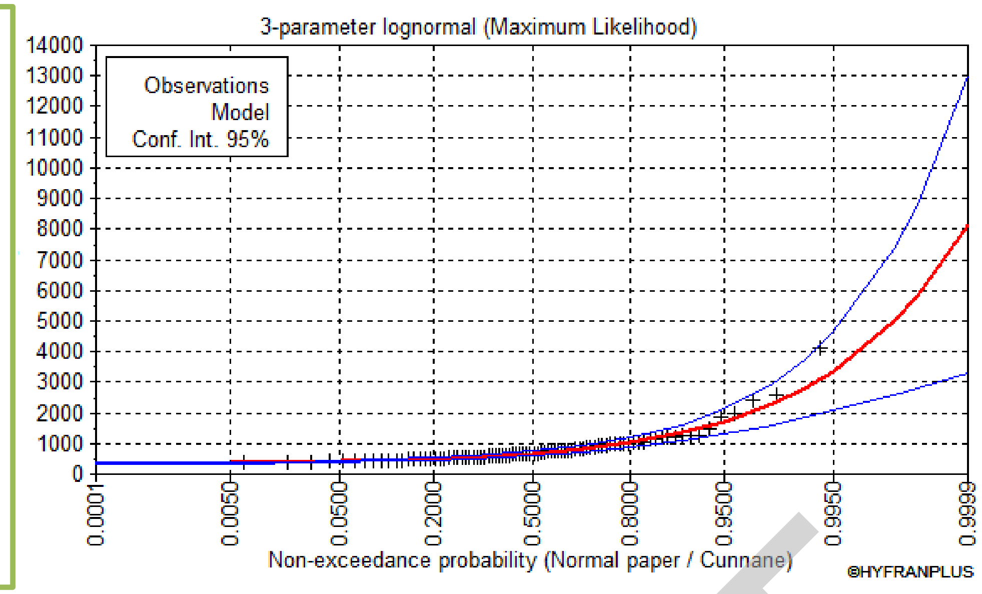
Rocky Mountain House Flood Hazard Study

NORTH SASKATCHEWAN RIVER HYDROLOGIC ANALYSIS

Date:	Project:	Submitter:	Reviewer:
MARCH 2021	31781-531	E. JOHNSTON	M. SHOME

Figure C1





Selected Distribution

Distribution Type	Numerical Goodness-of-fit Tests from Spreadsheet			Average of Ranks	Ranking from Numerical Tests
	A-D Test	K-S Test	Least Squares Ranking		
Normal	10	7	10	9.00	9
Lognormal	4	4	8	5.33	5
Lognormal III	1	1	4	2.00	1
Exponential	5	6	5	5.33	5
Pearson III	6	5	3	4.67	4
Log Pearson III	2	2	2	2.00	1
Gumbel	7	8	7	7.33	7
GEV	3	3	1	2.33	3
Weibull	9	10	9	9.33	10
Gamma	8	9	6	7.67	8

1) Anderson-Darling Test (1952)

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\cdot[\ln F(X_i) + \ln(1-F(X_{n-i+1}))]$$

H0= Data follows specified distribution
HA= Data does not follow the specified distribution

Distribution Type:	Critical Value at 10%	Critical Value at 5%	Critical Value at 1%	A2	Hypothesis	Rank (1 = best fit)
Normal	1.929	2.502	3.907	7.269	Reject H0	10
Lognormal	1.929	2.502	3.907	1.351	Accept H0	4
Lognormal III	1.929	2.502	3.907	0.181	Accept H0	1
Exponential	1.929	2.502	3.907	1.406	Accept H0	5
Pearson III	1.929	2.502	3.907	1.623	Accept H0	6
Log Pearson III	1.929	2.502	3.907	0.184	Accept H0	2
Gumbel	1.929	2.502	3.907	4.617	Reject H0	7
GEV	1.929	2.502	3.907	0.193	Accept H0	3
Weibull	1.929	2.502	3.907	5.705	Reject H0	9
Gamma	1.929	2.502	3.907	4.833	Reject H0	8

Least Squares Ranking

Distribution Type:	Standard Error	Rank
Normal	343	10
Lognormal	240	8
Lognormal III	132	4
Exponential	177	5
Pearson III	112	3
Log Pearson III	90	2
Gumbel	237	7
GEV	54	1
Weibull	252	9
Gamma	223	6

$$SE_j = \sqrt{\frac{1}{n-m_j}\sum_{i=1}^{n}(x_i - y_i)^2}$$

2) Kolmogorov-Smirnov Test (1933)

$$F_n(x) = \frac{1}{n}\cdot\left[\text{Number of observations} \le x\right] \qquad D_n = \sup_x |F_n(x) - F(x)|$$

H0= Data follows specified distribution
HA= Data does not follow the specified distribution

Distribution Type:	Critical Value at 10%	Critical Value at 5%	Critical Value at 1%	Dn	Hypothesis	Rank (1 = best fit)
Normal	0.132	0.147	0.176	0.191	Reject H0	7
Lognormal	0.132	0.147	0.176	0.087	Accept H0	4
Lognormal III	0.132	0.147	0.176	0.040	Accept H0	1
Exponential	0.132	0.147	0.176	0.108	Accept H0	6
Pearson III	0.132	0.147	0.176	0.107	Accept H0	5
Log Pearson III	0.132	0.147	0.176	0.054	Accept H0	2
Gumbel	0.132	0.147	0.176	0.191	Reject H0	8
GEV	0.132	0.147	0.176	0.057	Accept H0	3
Weibull	0.132	0.147	0.176	0.217	Reject H0	10
Gamma	0.132	0.147	0.176	0.204	Reject H0	9

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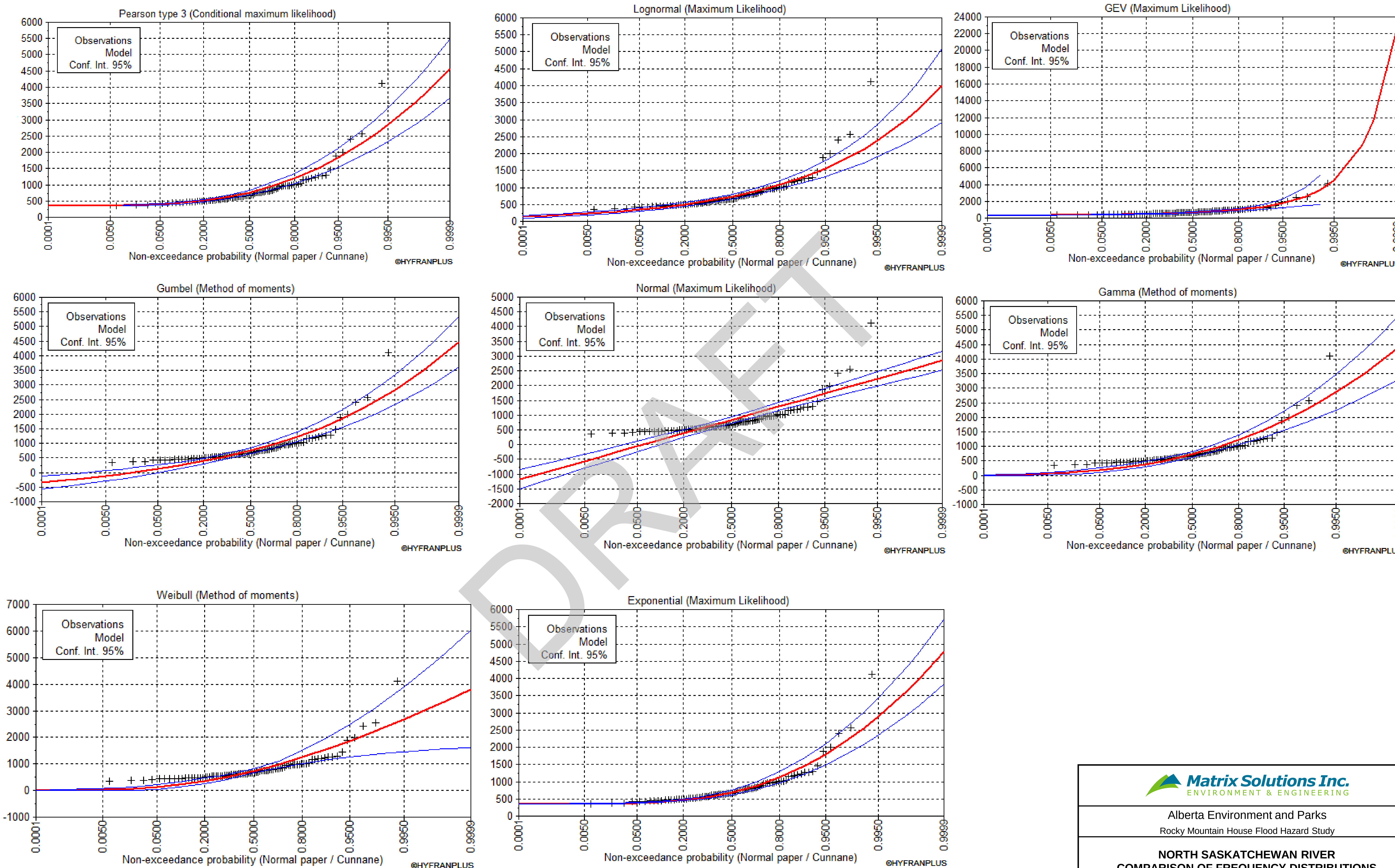
Rocky Mountain House Flood Hazard Study

NORTH SASKATCHEWAN RIVER
COMPARISON OF FREQUENCY DISTRIBUTIONS

Date: MARCH 2021 | Project: 31781-531 | Submitter: E. JOHNSTON | Reviewer: M. SHOME

Figure C2



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NORTH SASKATCHEWAN RIVER
COMPARISON OF FREQUENCY DISTRIBUTIONS

Date:	Project:	Submitter:	Reviewer:
MARCH 2021	31781-531	E. JOHNSTON	M. SHOME

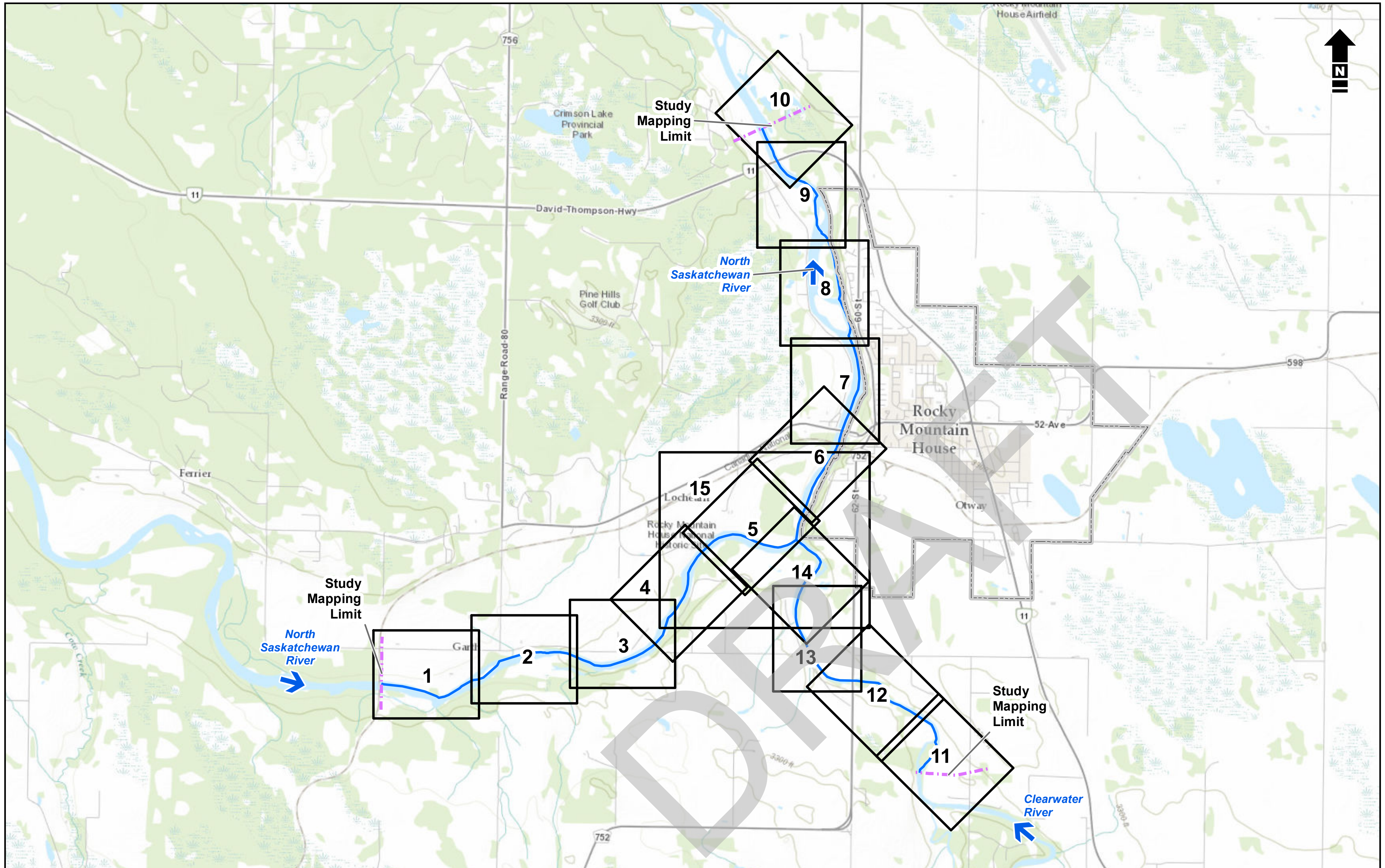
Figure C3

F:\31781\531\2 - Open Water Hydrology Assessment\Report\Appendix A

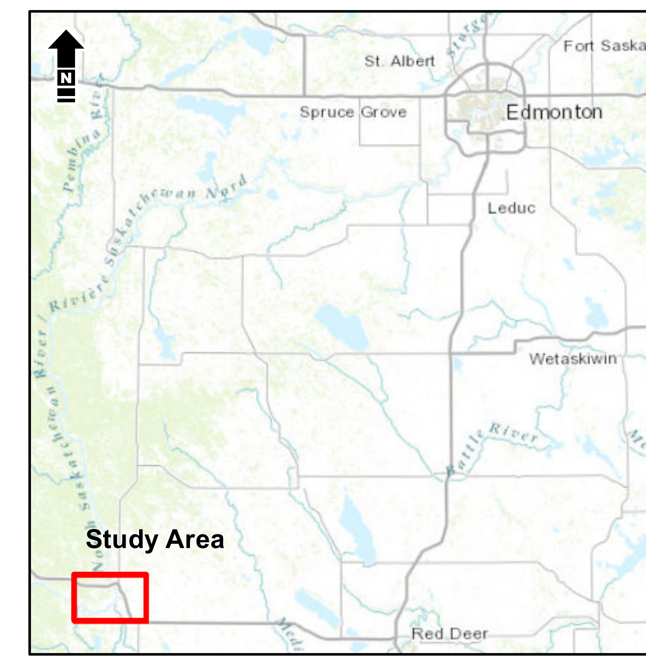
APPENDIX C
Flood Inundation Maps

Appendix C submitted under different cover

APPENDIX D
Floodway Criteria Maps



- Study Area
- Map Sheet
- Study Mapping Limit
- Municipal Boundary (Urban)
- Study Reach
- Flow Direction



1:65,000 kilometres
1.5 0 1.5 3
NAD 1983 CSRS 3TM 114

Notes:

1. Please refer to the accompanying Rocky Mountain House Flood Hazard Study for important information concerning these maps.

2. Within the flood inundation areas shown on this map, there may be isolated pockets of high ground. To determine whether or not a particular site is subject to flooding, reference should be made to the computed flood levels in conjunction with site-specific surveys where detailed definition is required.

3. Non-riverine and local sources of water have not been considered, and structures such roads or railways can restrict water flow and affect local flood levels. Channel obstruction, local stormwater inflow, groundwater seepage or other land drainage can cause flood levels to exceed those indicated on the map. Lands adjacent to a flooded area may be subject to flooding from tributary streams not indicated on the maps.

Definitions:

Flood Hazard Map - A flood hazard map is a specific type of flood map that identifies the area flooded for the 1:100 design flood, and divides that flood hazard area into floodway and flood fringe zones. Flood hazard maps can also show additional flood hazard information, including the incremental areas at risk for more severe floods like the 1:200 and 1:500 floods. Flood hazard maps are typically used for long-term flood hazard area management and land-use planning.

Design Flood - The design flood standard in Alberta is the 1:100 flood, which is a flood that has a 1% chance of being equaled or exceeded in any given year. The design flood is typically based on the 1:100 open water flood, but it can also reflect 1:100 ice jam flood levels or be based on a historical flood event. Different sized floods have different chances of occurring – for example, a 1:200 flood has a 0.5% chance of occurring in any given year and a 1:500 flood has a 0.2% chance of occurring in any given year – but only the 1:100 design flood is used to define the floodway and flood fringe zones on flood hazard maps.

Floodway - When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 1:100 design flood. When a flood hazard map is updated, the floodway will not get larger in most circumstances to maintain long-term regulatory certainty, even if the flood hazard area gets larger or design flood levels get higher.

Flood Fringe - The flood fringe is the area outside of the floodway that is flooded or could be flooded during the 1:100 design flood. The flood fringe typically represents areas with shallower, slower, and less destructive flooding, but it may also include “high hazard flood fringe” areas. Areas at risk of flooding behind flood berms may also be mapped as “protected flood fringe” areas.

High Hazard Flood Fringe - The high hazard flood fringe identifies areas within the flood fringe with deeper or faster moving water than the rest of the flood fringe. High hazard flood fringe areas are likely to be most significant for flood maps that are being updated, but they may also be included in new flood maps.

Protected Flood Fringe - The protected flood fringe identifies areas that could be flooded if dedicated flood berms fail or do not work as designed during the 1:100 design flood, even if they are not overtopped. Protected flood fringe areas are part of the flood fringe and do not differentiate between areas with deeper or faster moving water and shallower or slower moving water.

References:

Data obtained from AltaLIS © Government of Alberta and GeoBase® used under license.

Aerial imagery acquired by OGL Engineering on September 4, 2020 for Alberta Environment and Parks.

Additional Base Mapping available ESRI Base Mapping and Imagery Services.
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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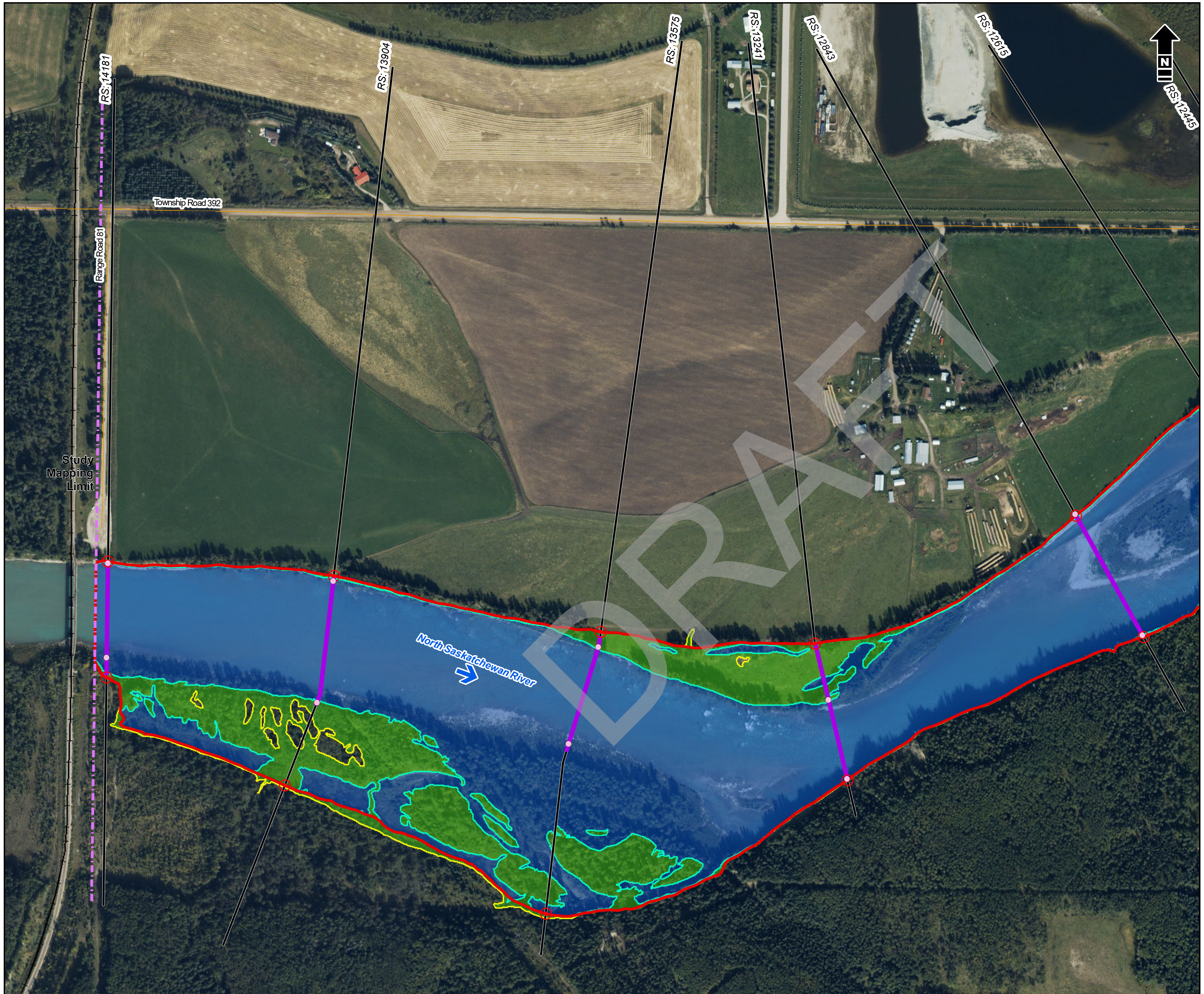
Rocky Mountain House Flood Hazard Study

Floodway Criteria Index Map

Date:	Project:	Submitter:	Reviewer:
January 2022	31781	P. Rogers	M. Shome

Sheet INDEX



Bridge
Culvert
Cross Section Line
Study Mapping Limit
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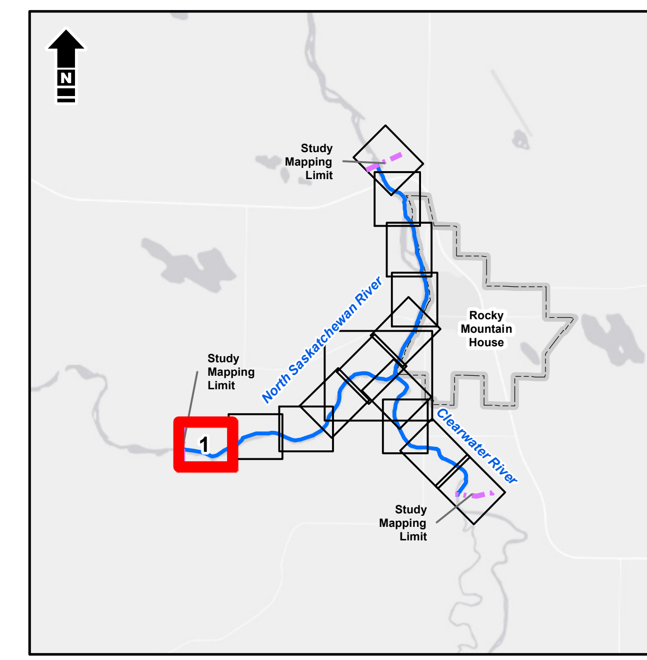
Major Road
Local Road
Railway
Flow Direction
Bank Station
Proposed Floodway Station
Proposed Floodway Boundary
100 Year Inundation - ≥1 m/s Velocity
100 Year Inundation Extent - ≥1 m Depth
100 Year Inundation Extent



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1:5,000 metres
50 0 50 100
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Floodway Criteria Map

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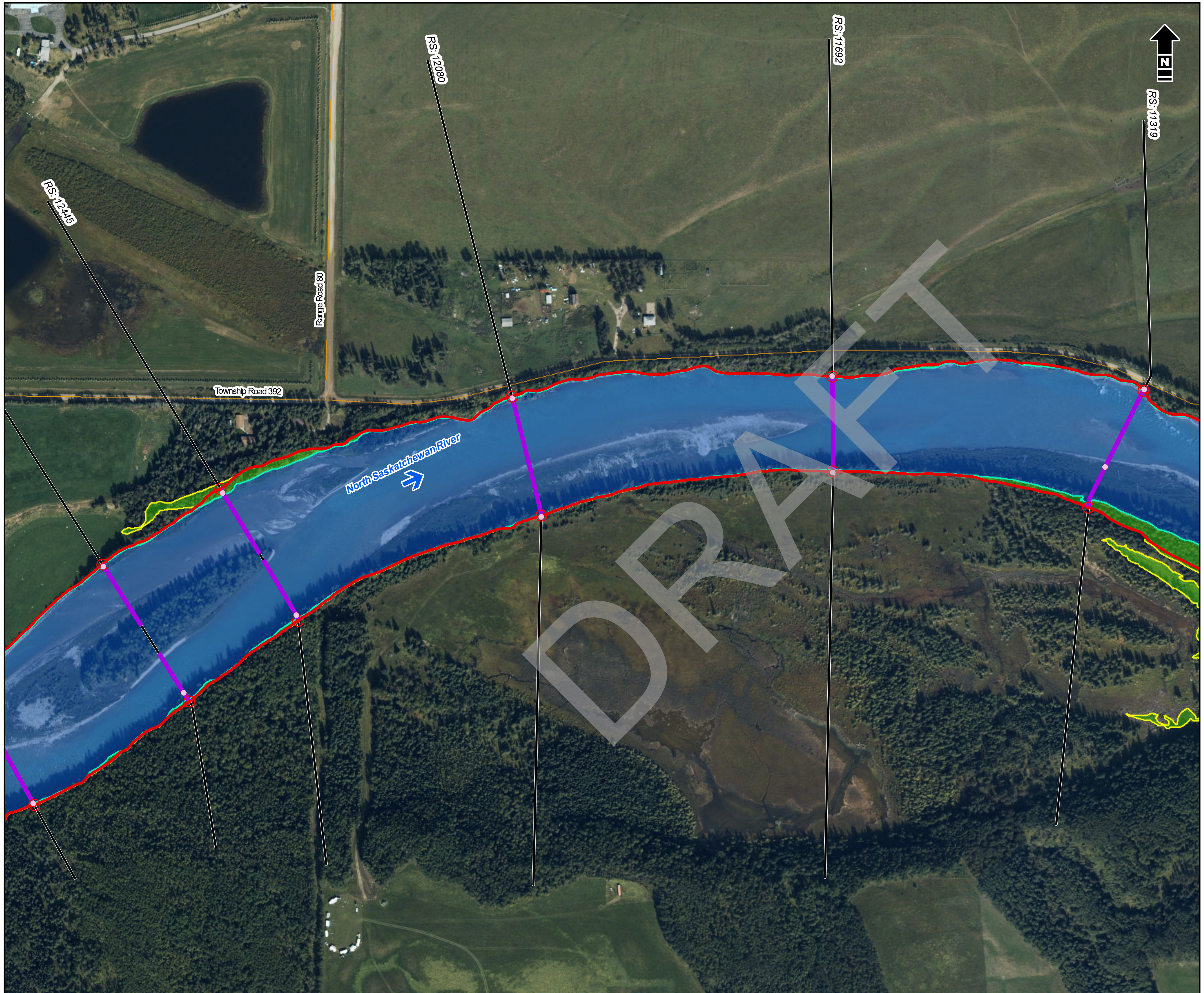
March 2022	31781	P. Rogers	M. Shome



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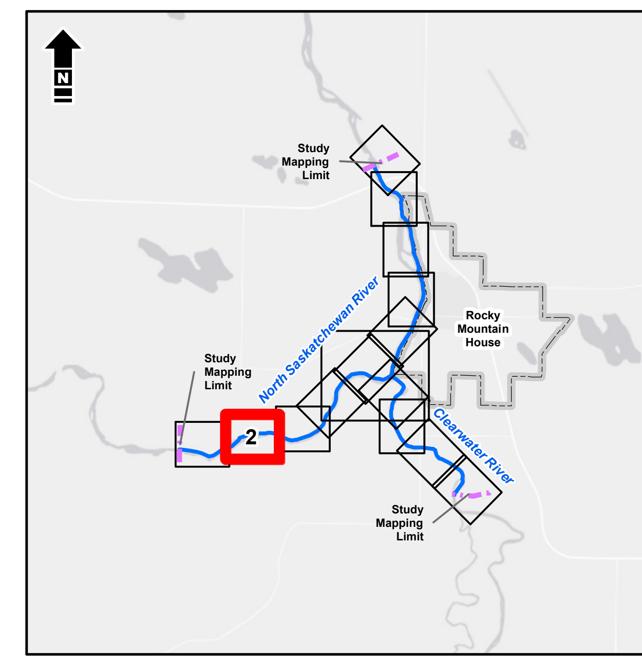

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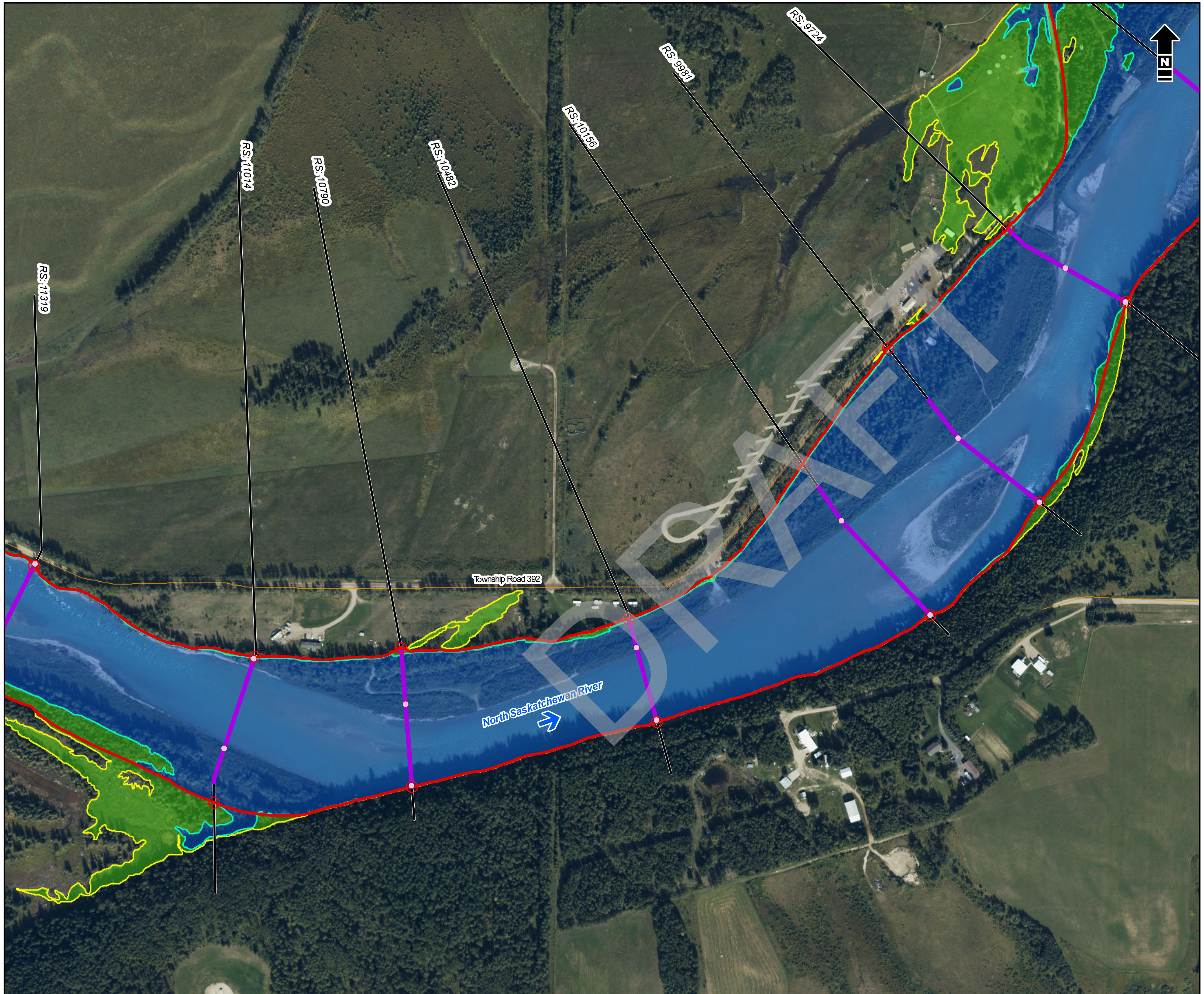

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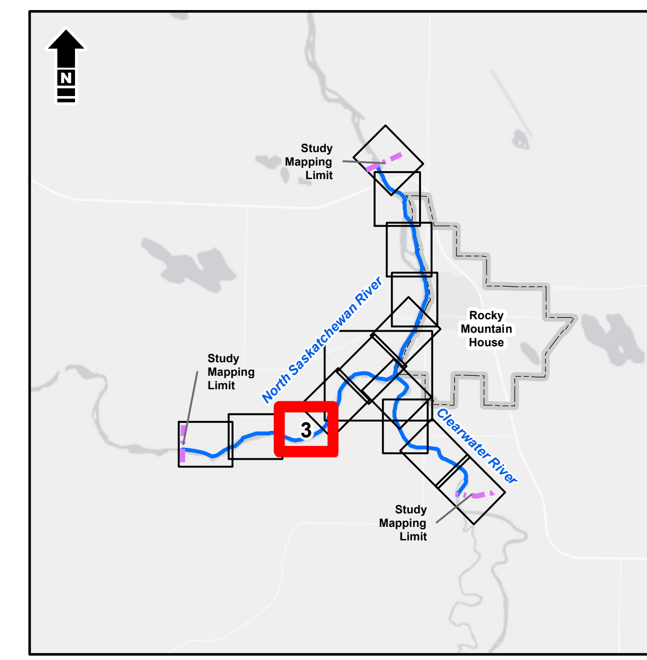

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Rocky Mountain House Flood Hazard Study

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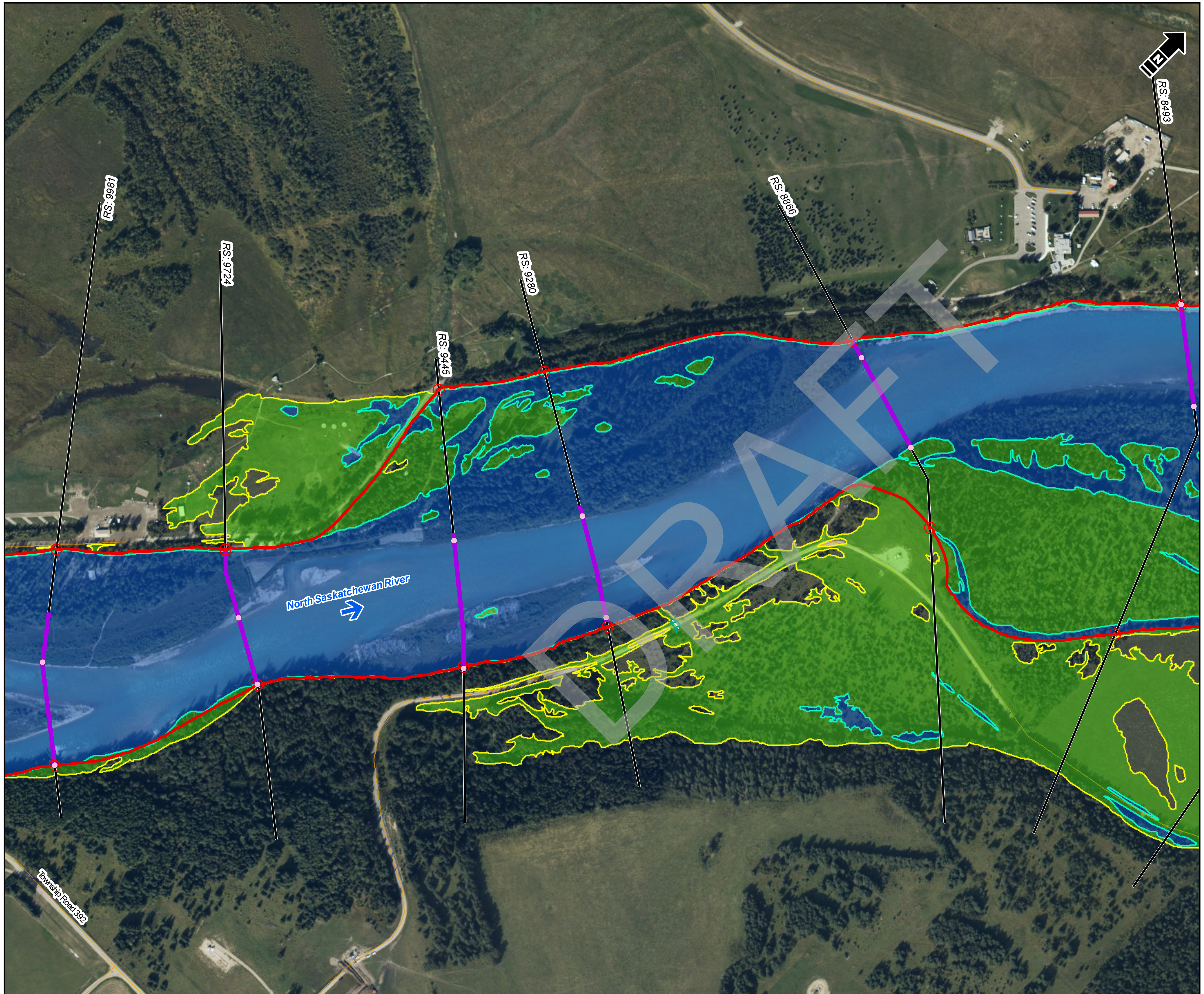

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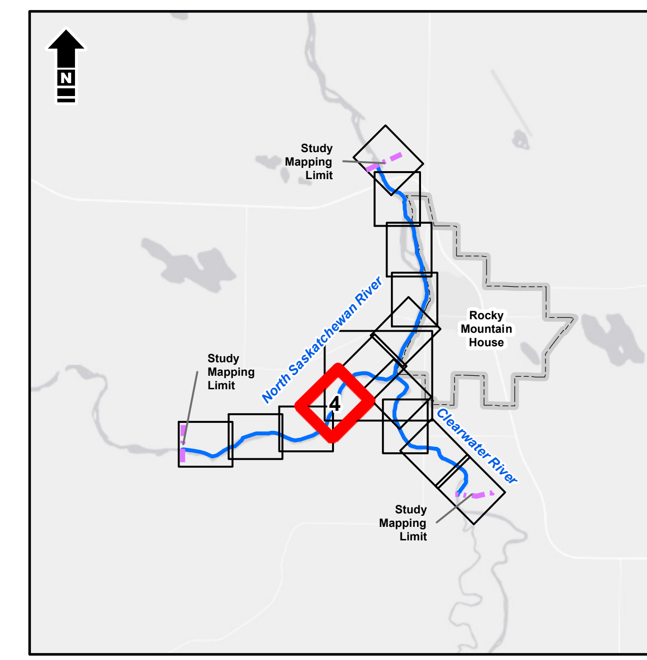

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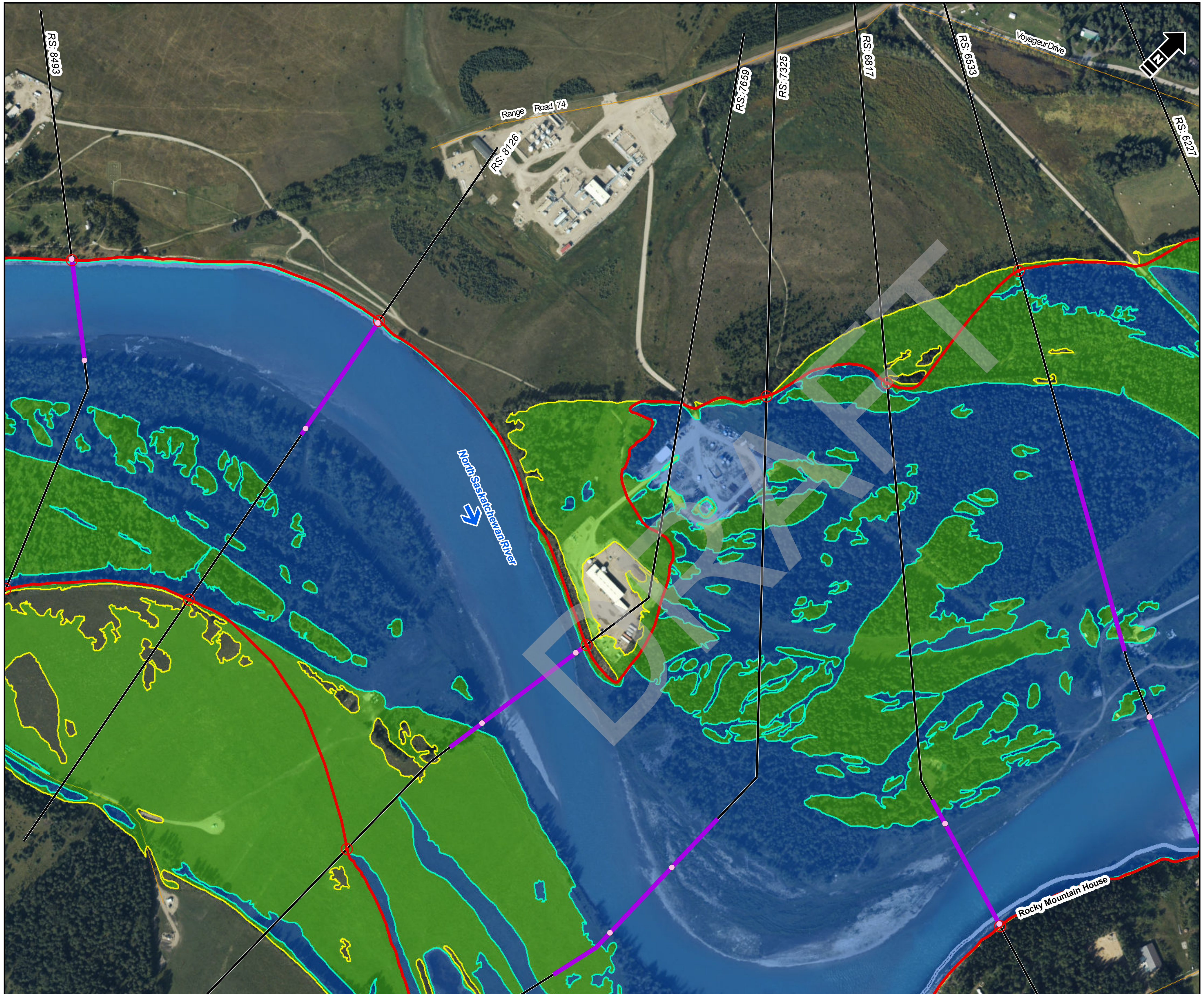

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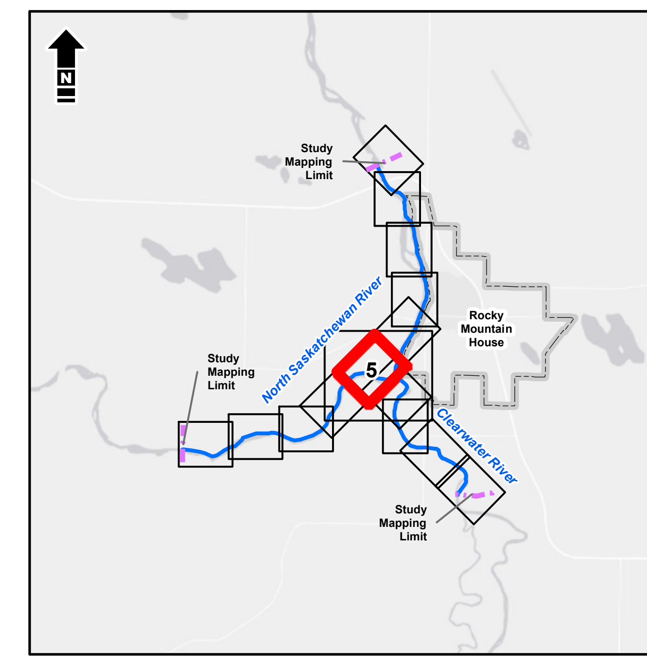

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Rocky Mountain House Flood Hazard Study

Floodway Criteria Map

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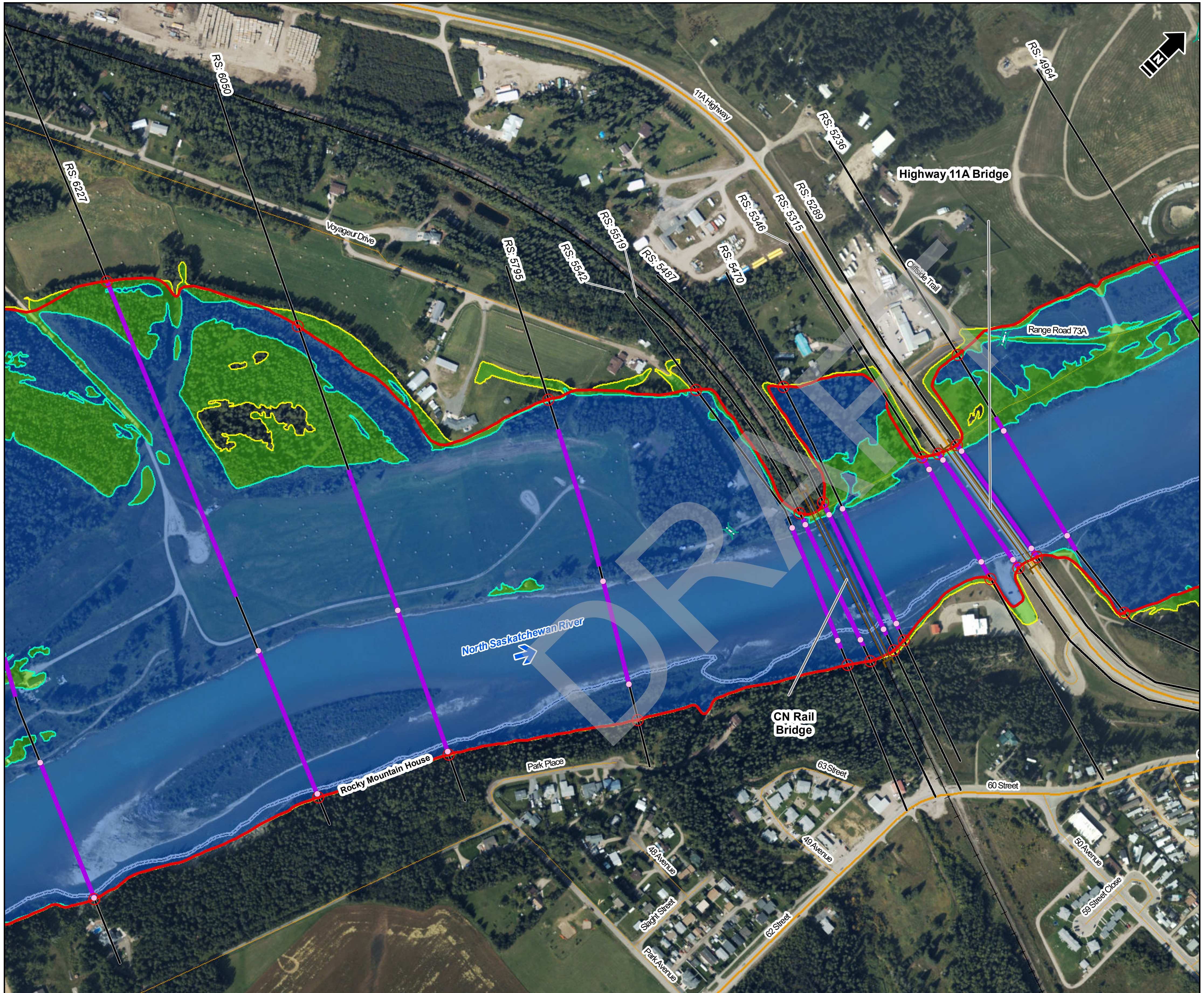

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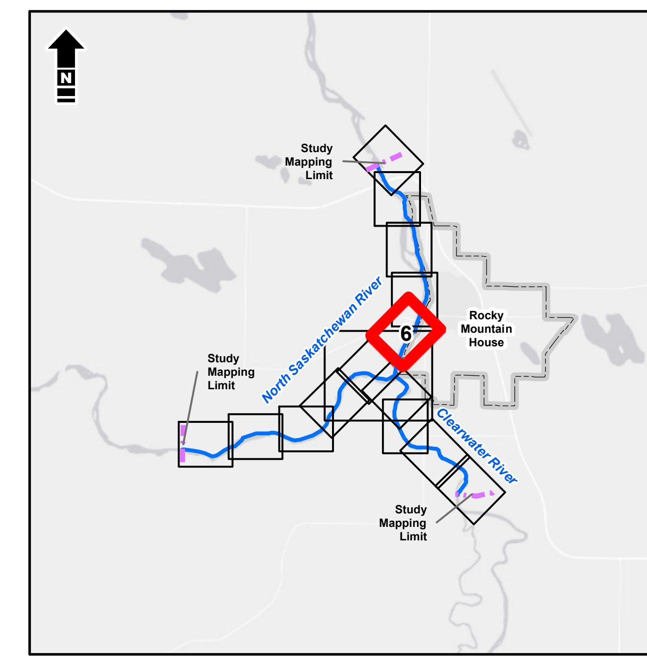

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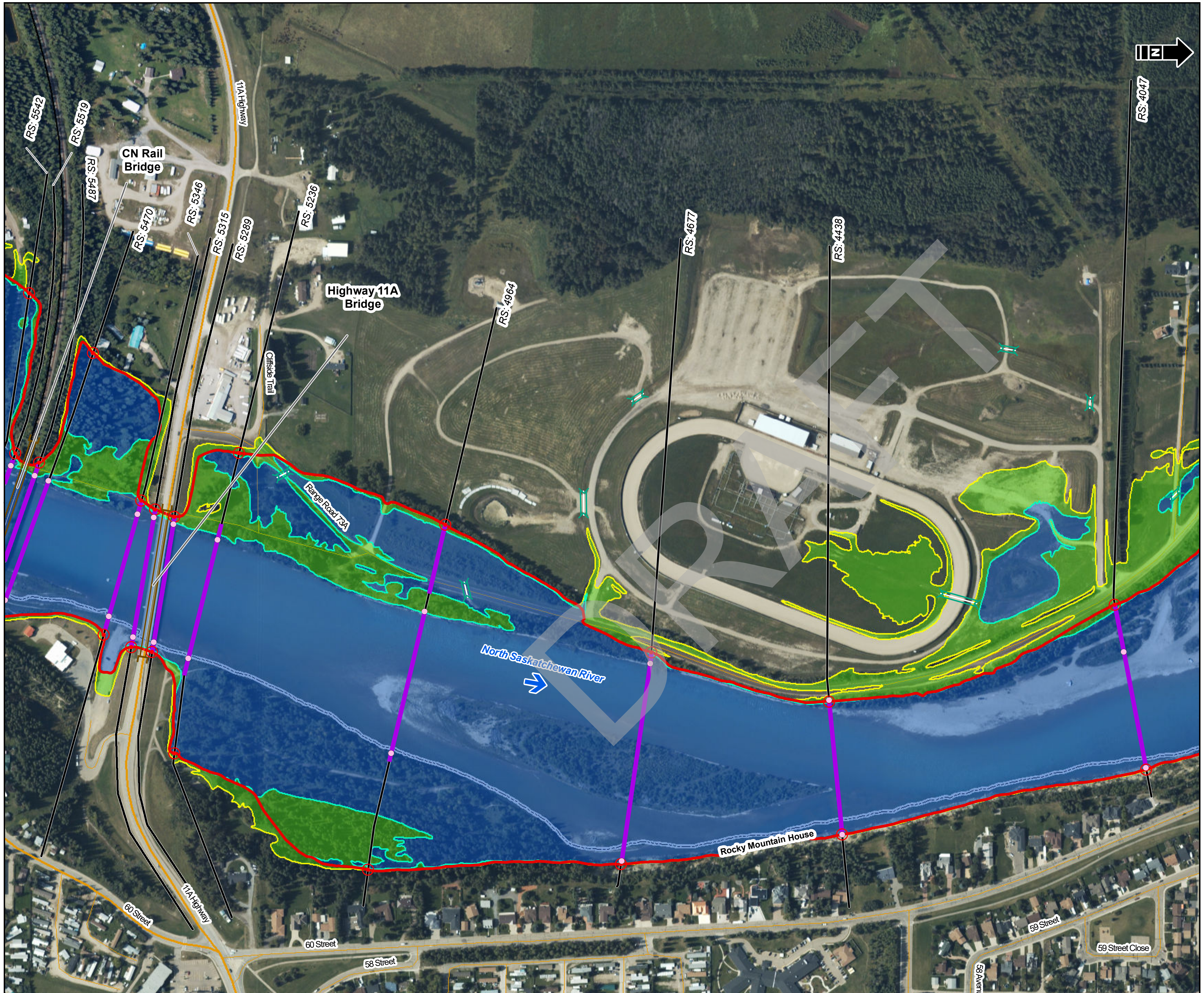

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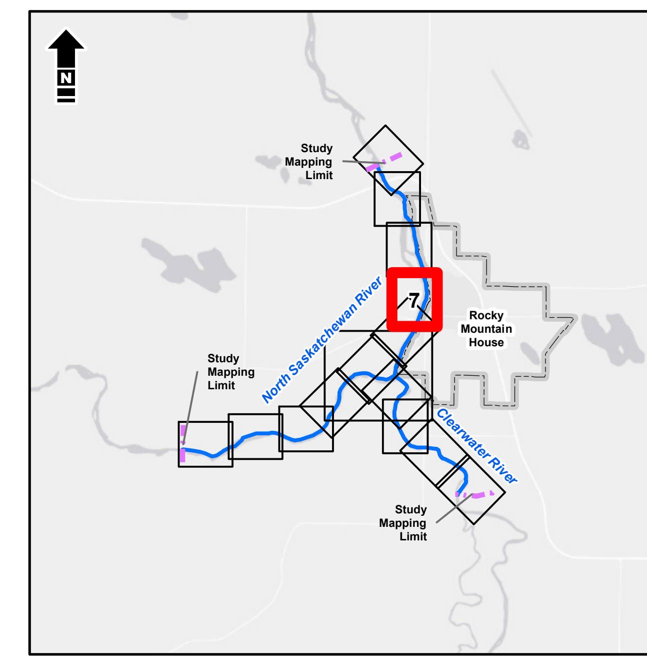

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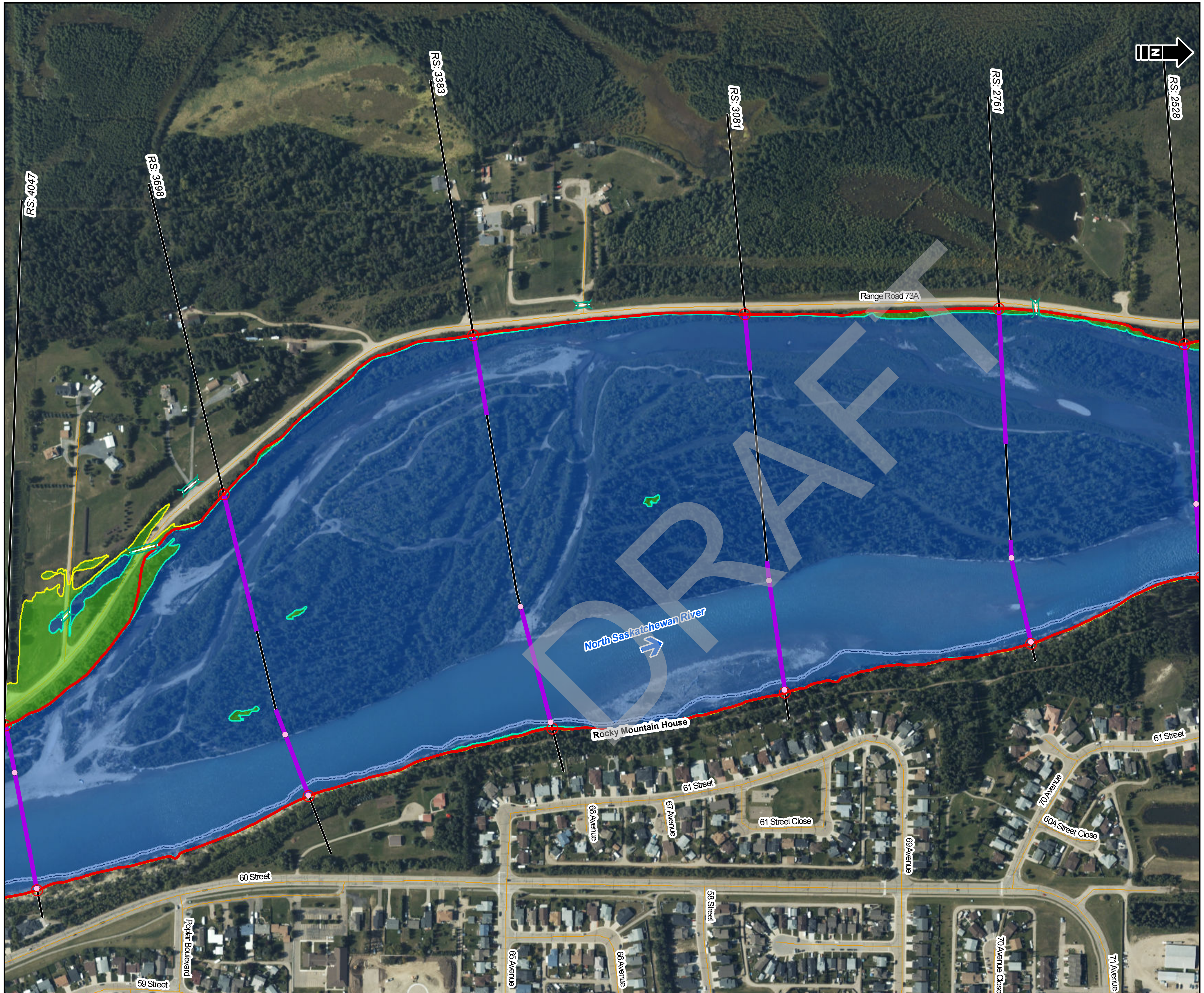

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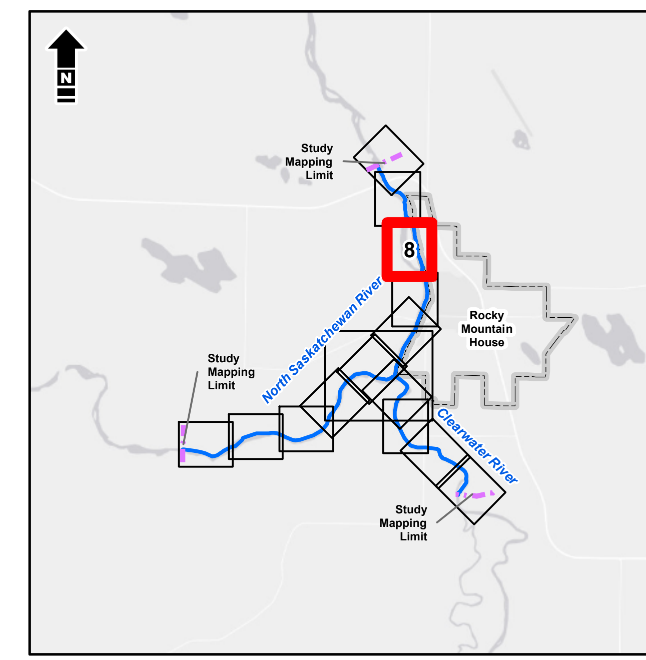

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Rocky Mountain House Flood Hazard Study

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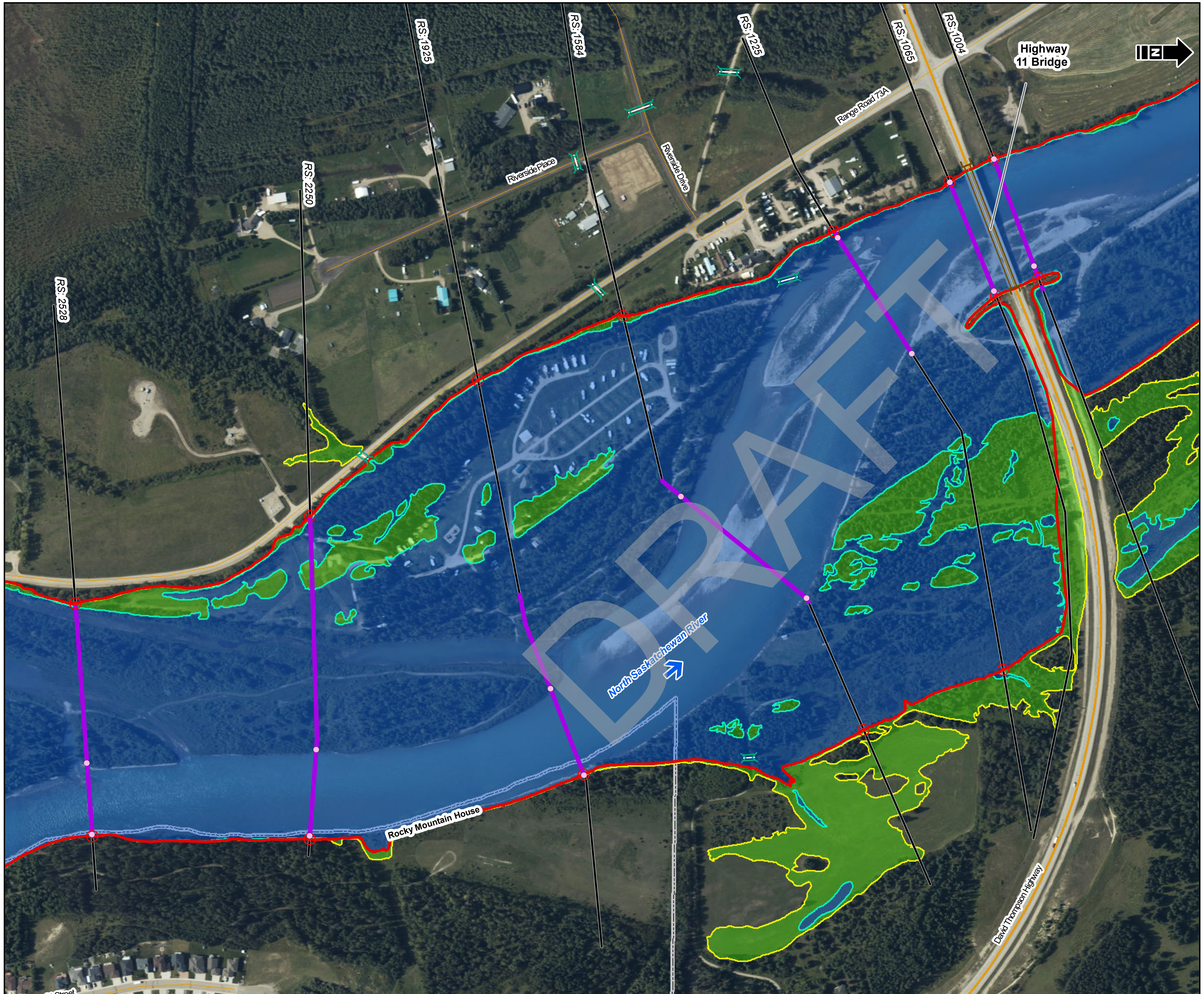

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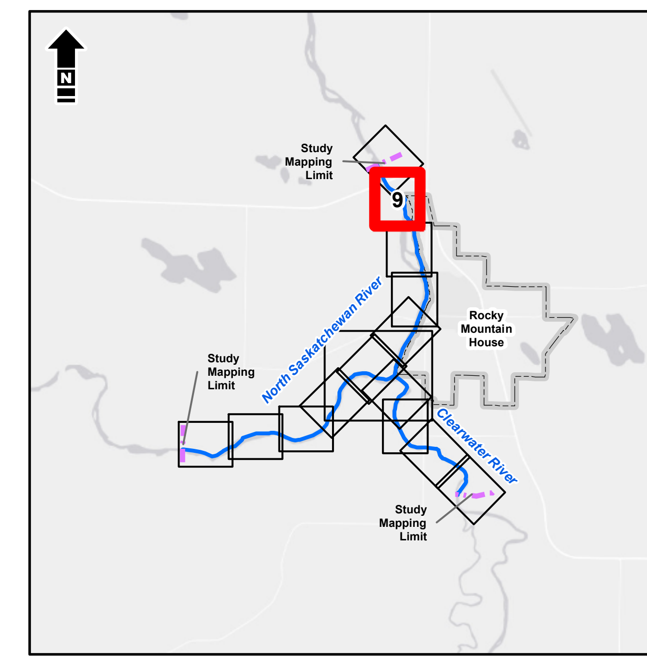

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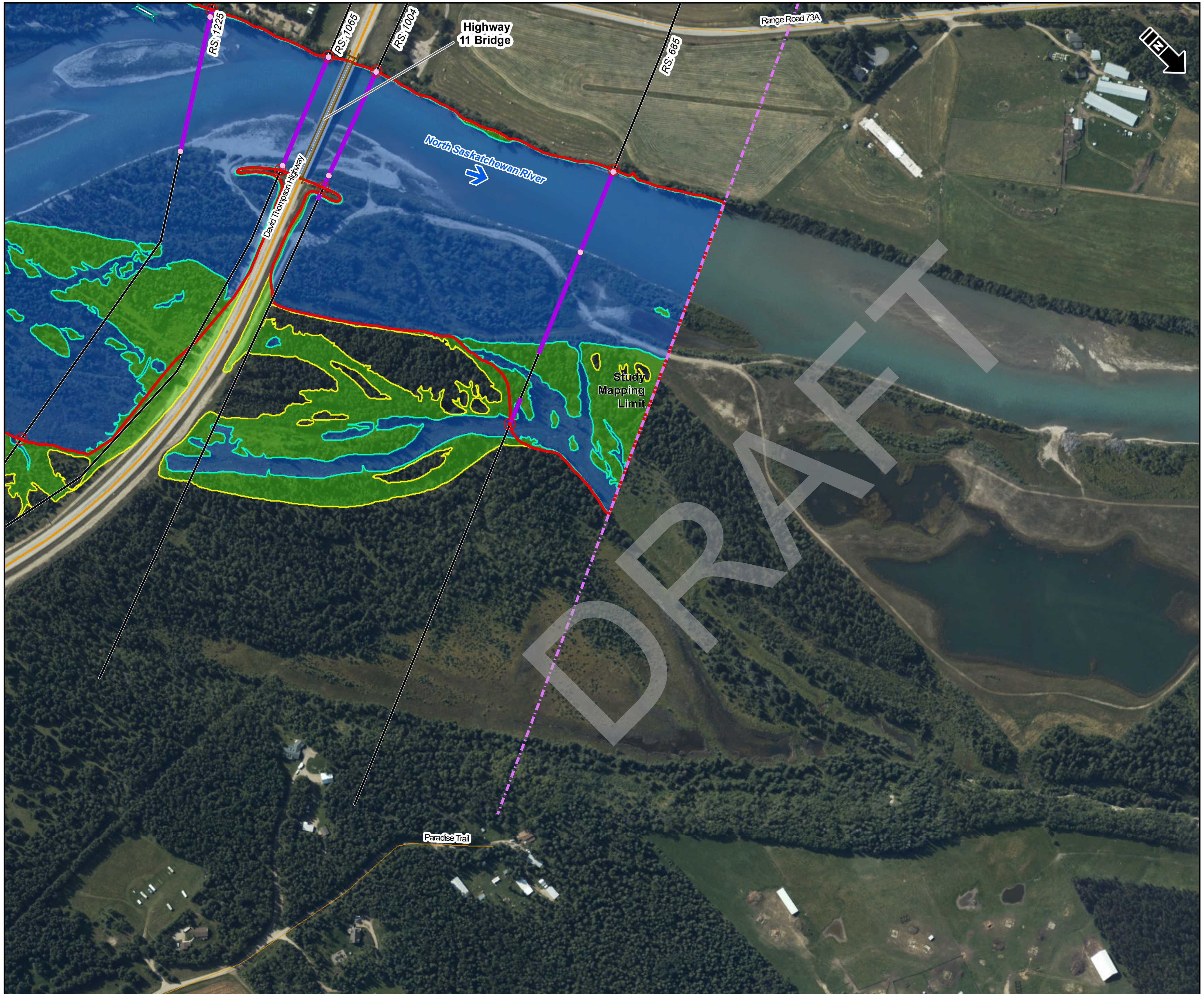

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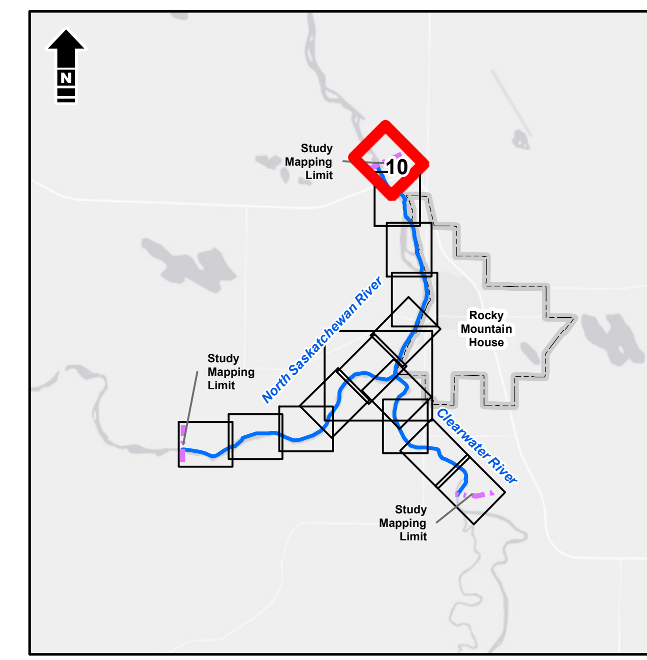
100 Year Inundation Extent - ≥1 m Depth
100 Year Inundation Extent



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Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community.

1:5,000 metres
50 0 50 100
NAD 1983 CSRS 3TM 114

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Alberta

Alberta Government
Rocky Mountain House Flood Hazard Study

Floodway Criteria Map

Date:	Project:	Submitter:	Reviewer:
March 2022	31781	P. Rogers	M. Shome

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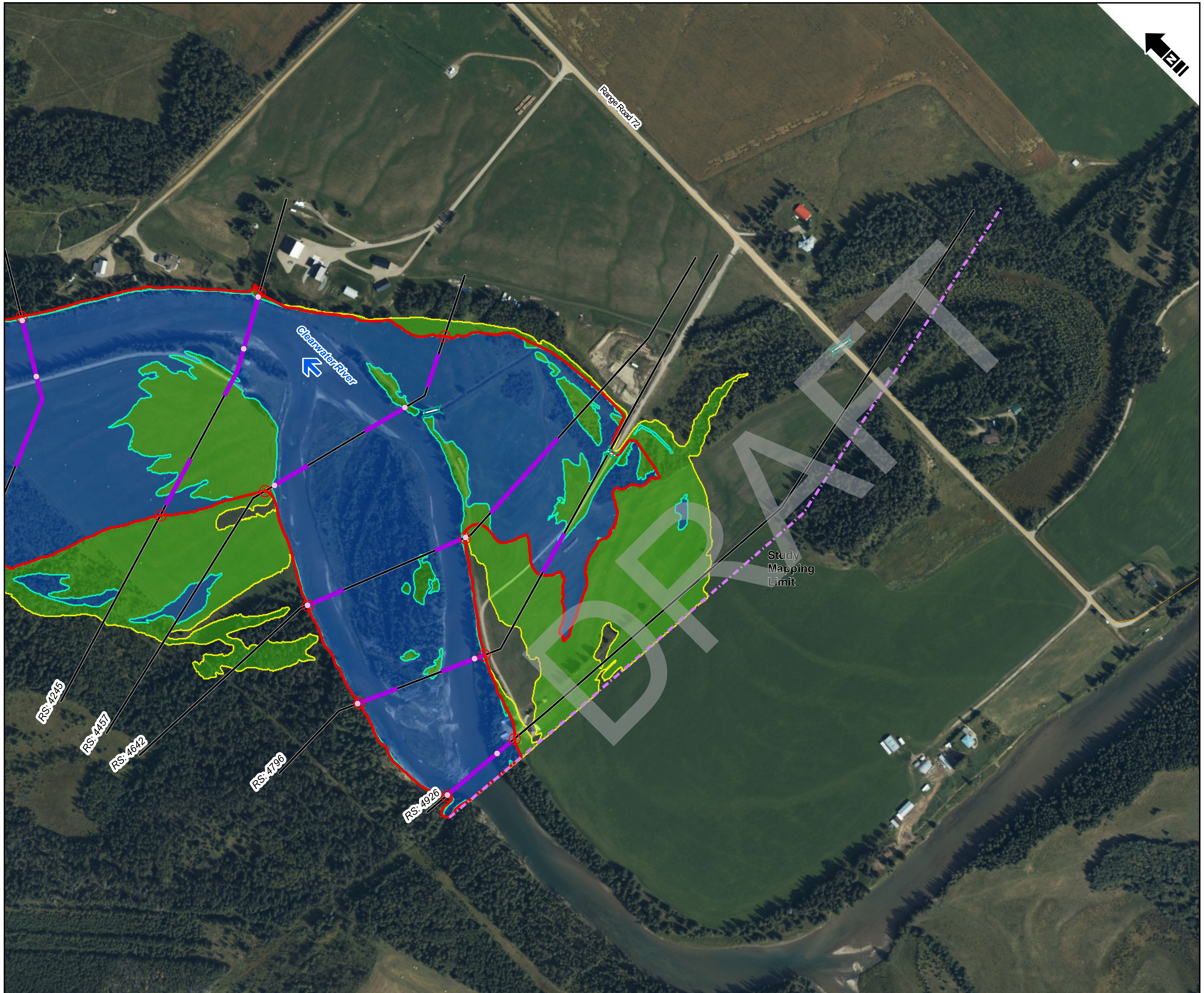
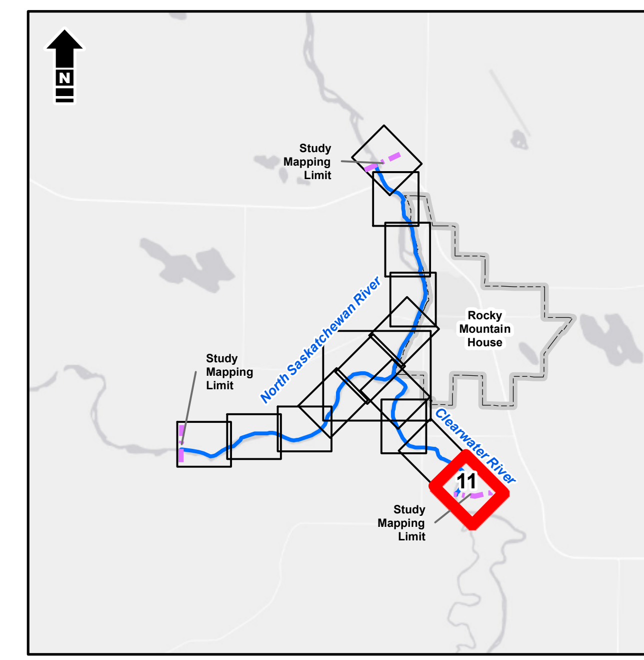


Bridge
Culvert
Cross Section Line
Study Mapping Limit
Municipal Boundary (Urban)
Major Road
Local Road
Railway
Flow Direction
Bank Station
Proposed Floodway Station
Proposed Floodway Boundary
100 Year Inundation - ≥1 m/s Velocity
100 Year Inundation Extent - ≥1 m Depth
100 Year Inundation Extent



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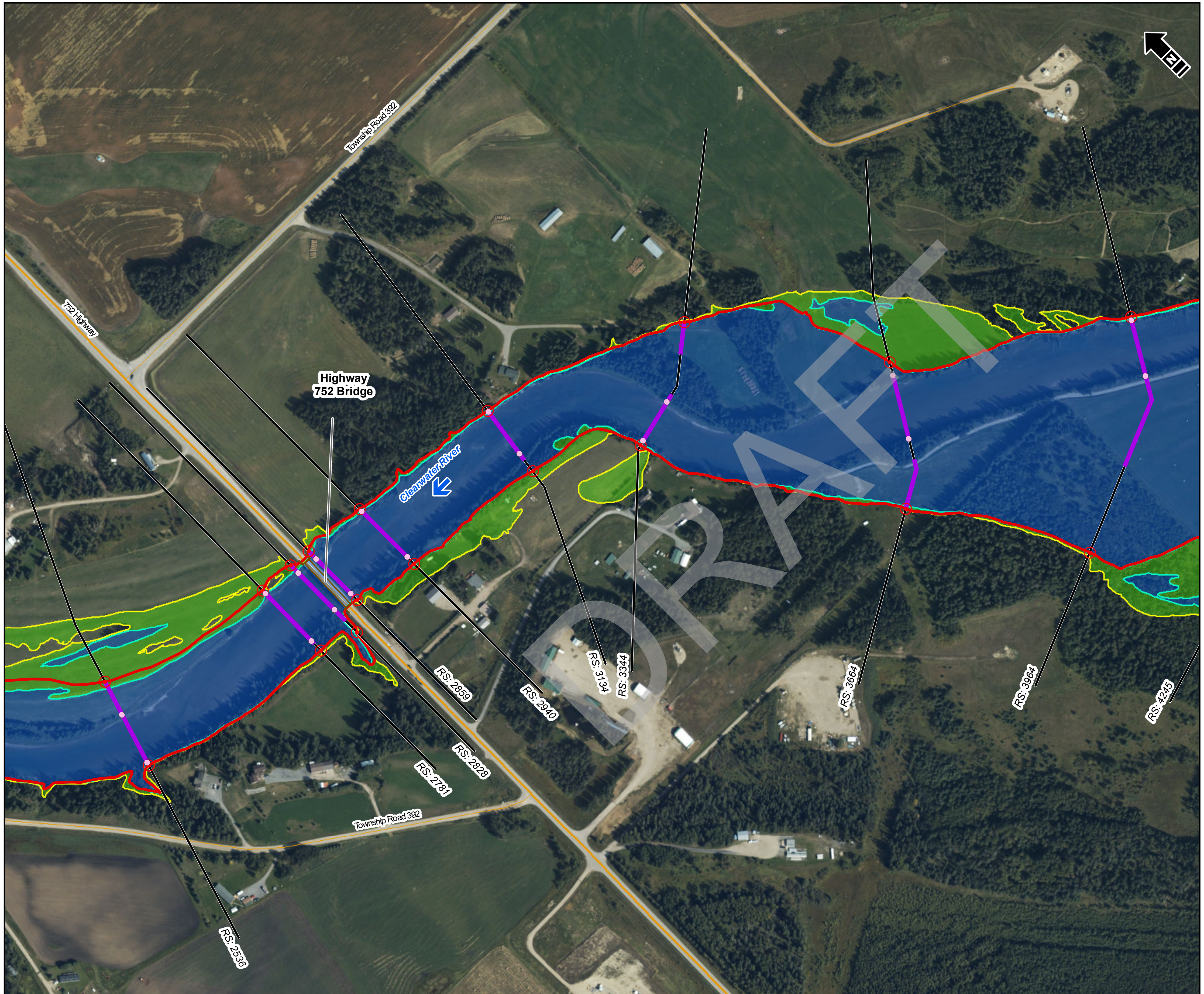

Bridge
Culvert
Cross Section Line
Study Mapping Limit
Municipal Boundary (Urban)
Major Road
Local Road
Railway
Flow Direction
Bank Station
Proposed Floodway Station
Proposed Floodway Boundary
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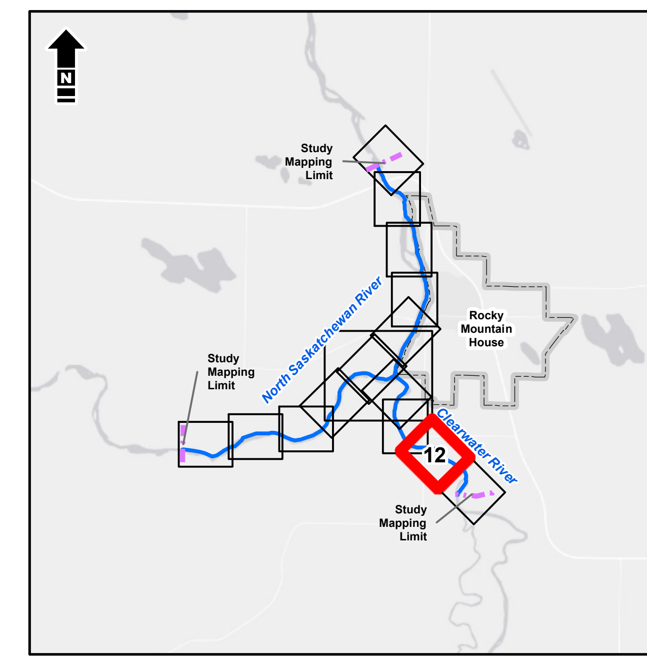
100 Year Inundation Extent - ≥1 m Depth
100 Year Inundation Extent



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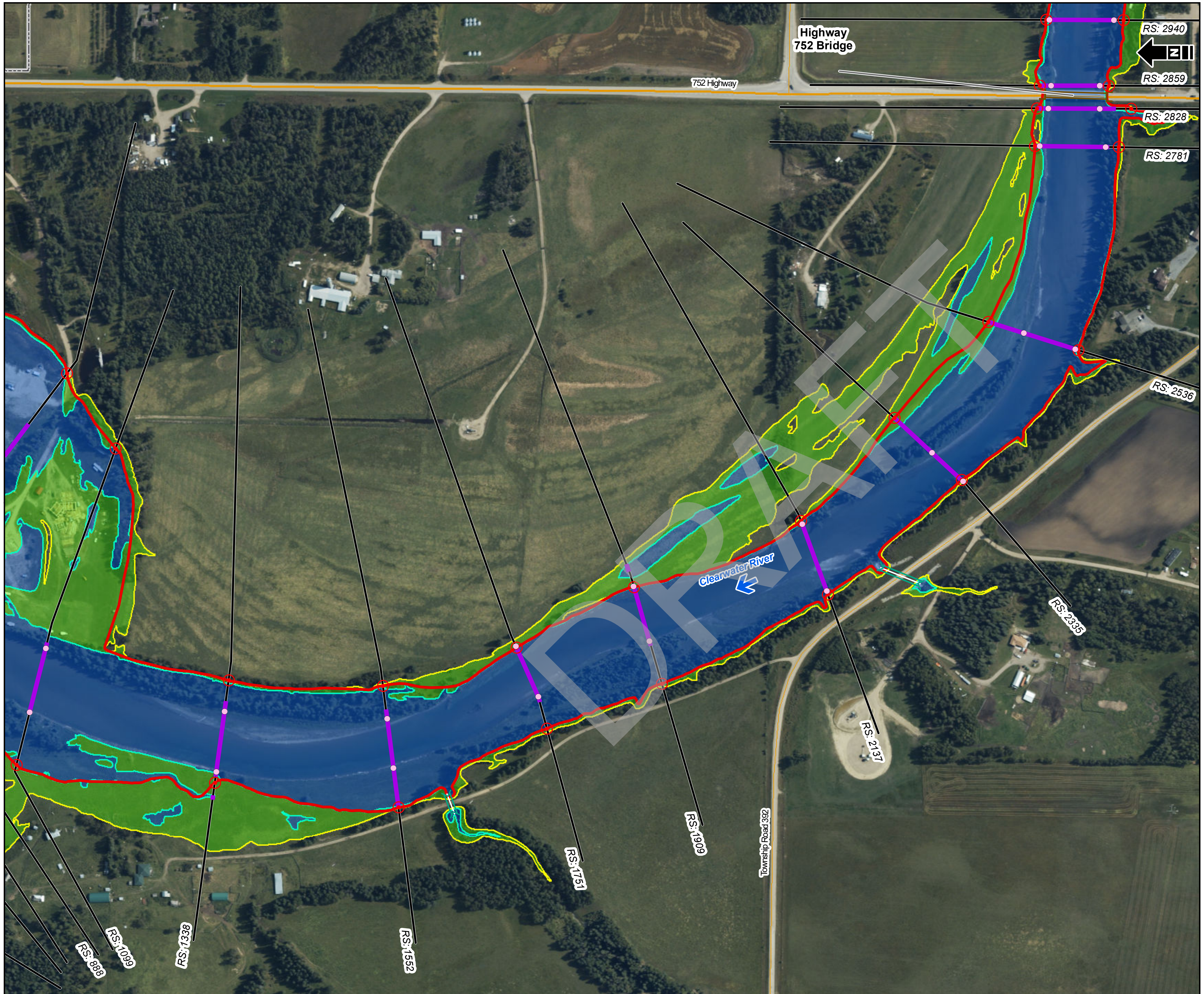
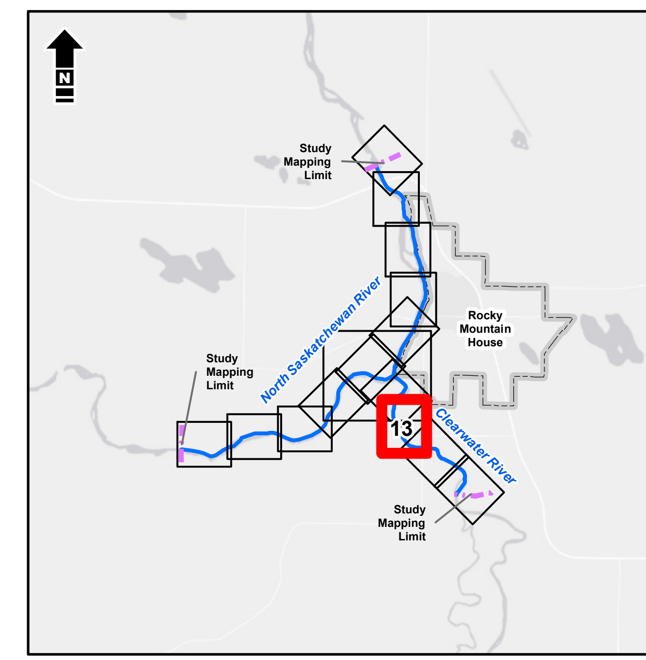


Bridge
Culvert
Cross Section Line
Study Mapping Limit
Municipal Boundary (Urban)
Major Road
Local Road
Railway
Flow Direction
Bank Station
Proposed Floodway Station
Proposed Floodway Boundary
100 Year Inundation - ≥1 m/s Velocity
100 Year Inundation Extent - ≥1 m Depth
100 Year Inundation Extent



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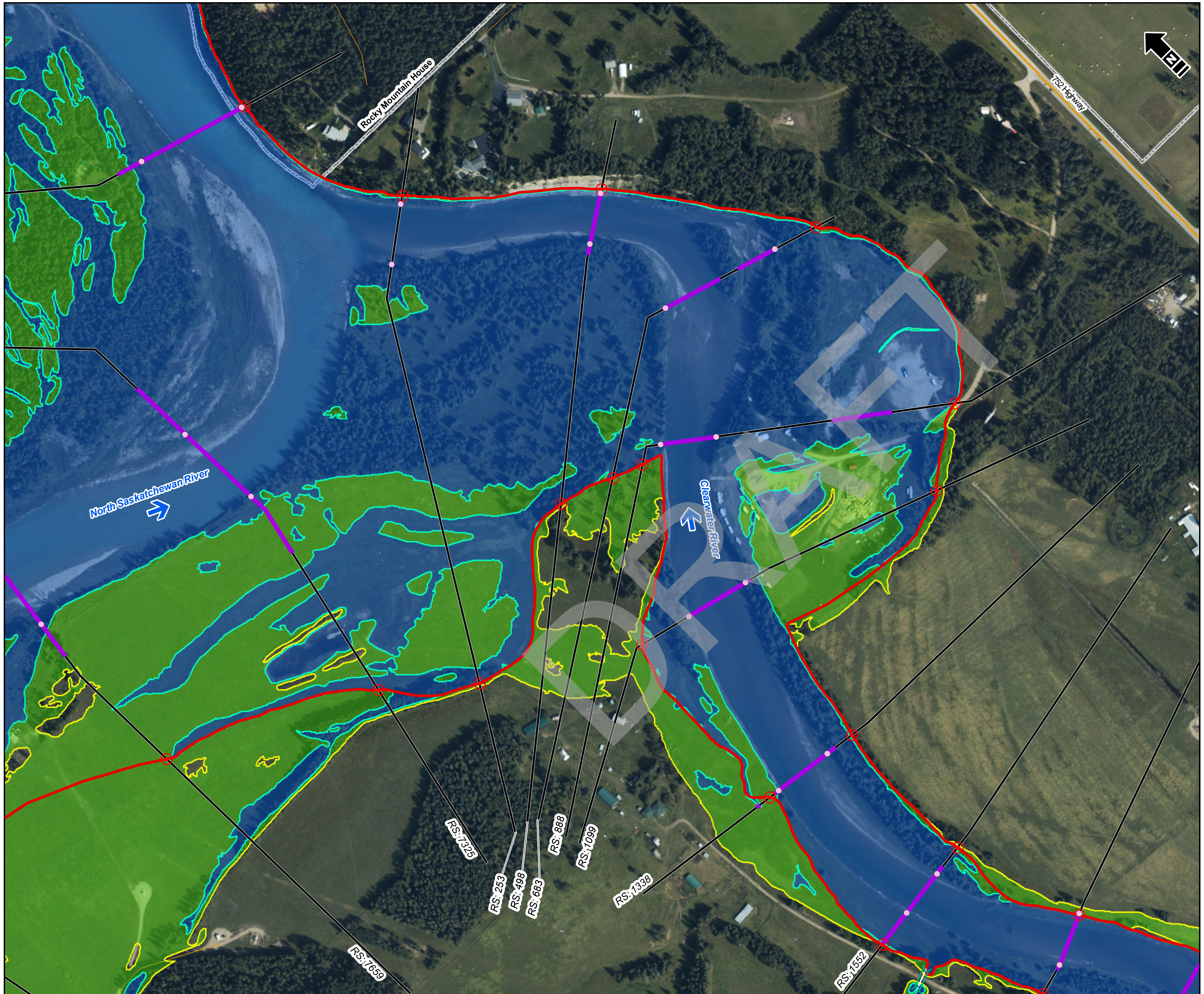
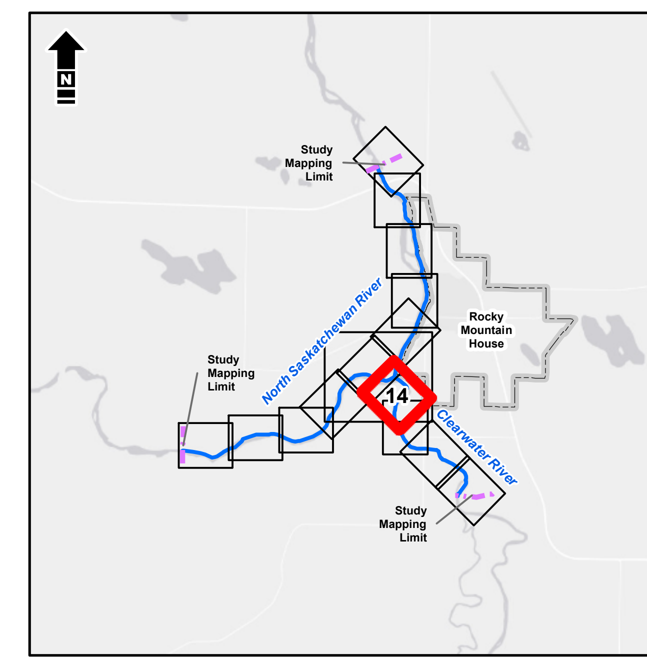


Bridge
Culvert
Cross Section Line
Study Mapping Limit
Municipal Boundary (Urban)
Major Road
Local Road
Railway
Flow Direction
Bank Station
Proposed Floodway Station
Proposed Floodway Boundary
100 Year Inundation - ≥1 m/s Velocity
100 Year Inundation Extent - ≥1 m Depth
100 Year Inundation Extent



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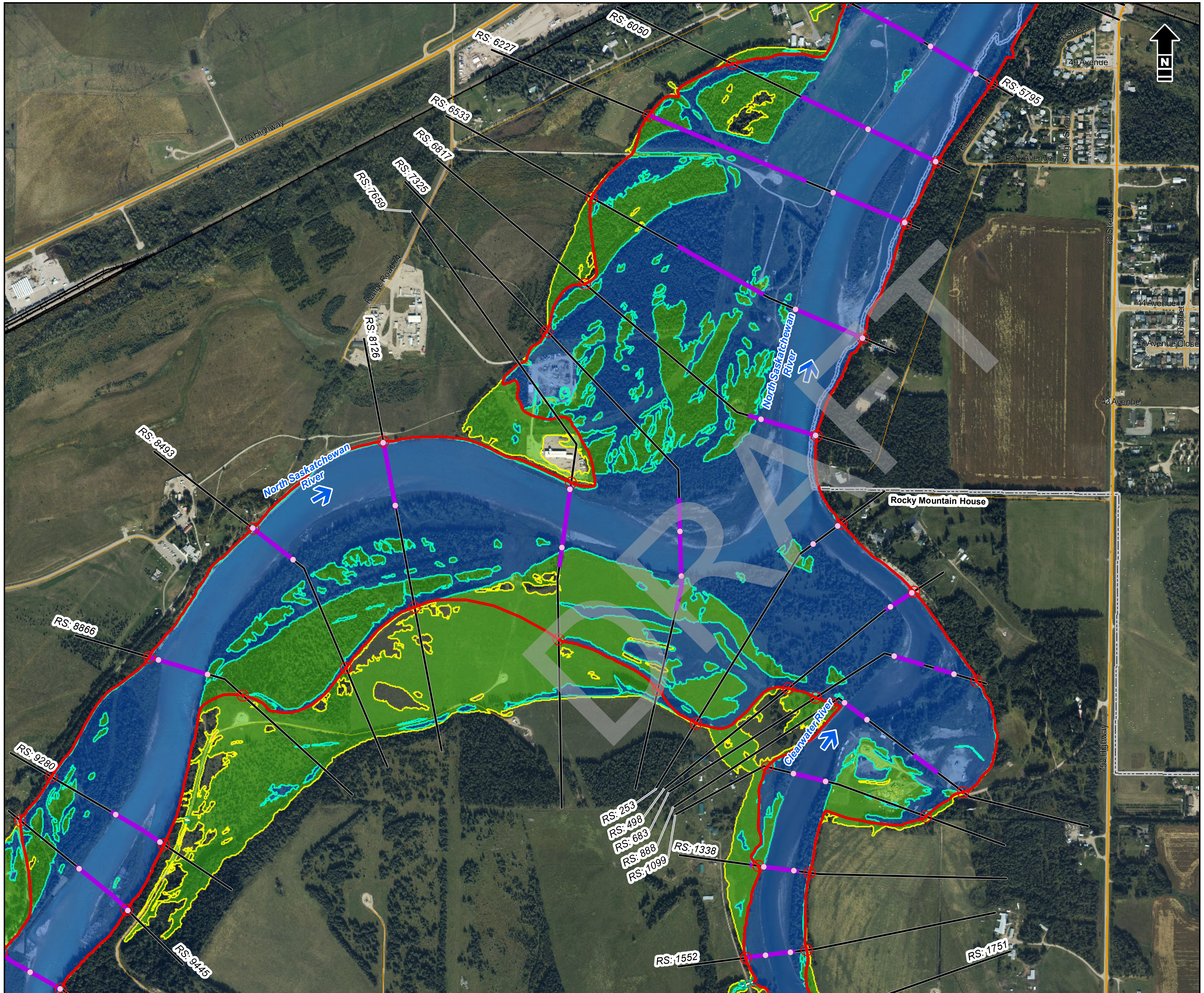

Bridge
Culvert
Cross Section Line
Study Mapping Limit
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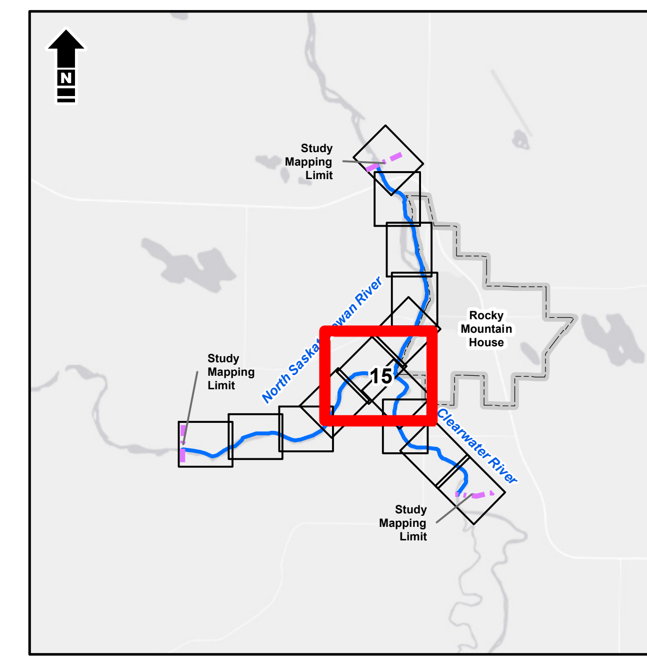
100 Year Inundation Extent



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1:10,000 metres
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Rocky Mountain House Flood Hazard Study

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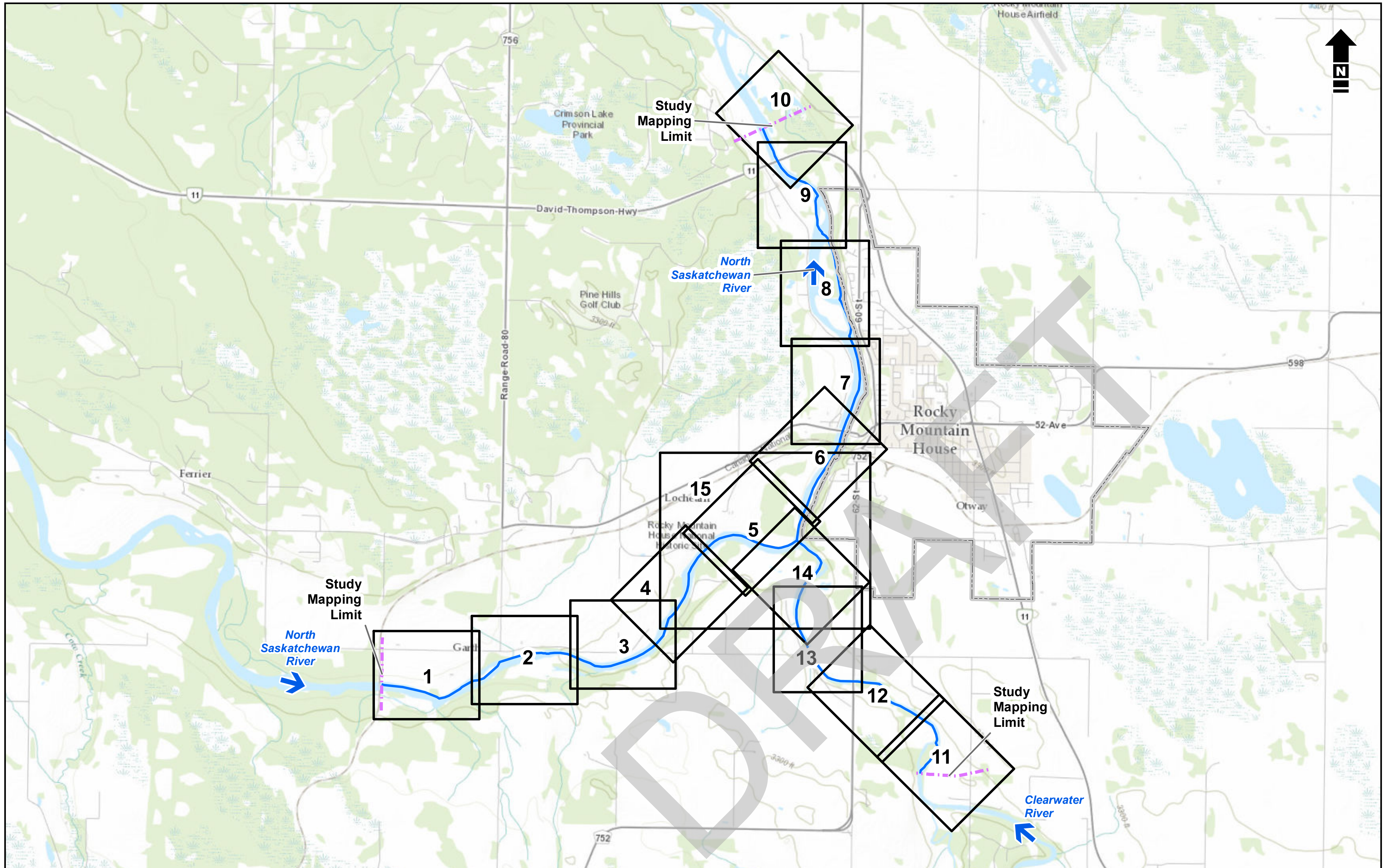
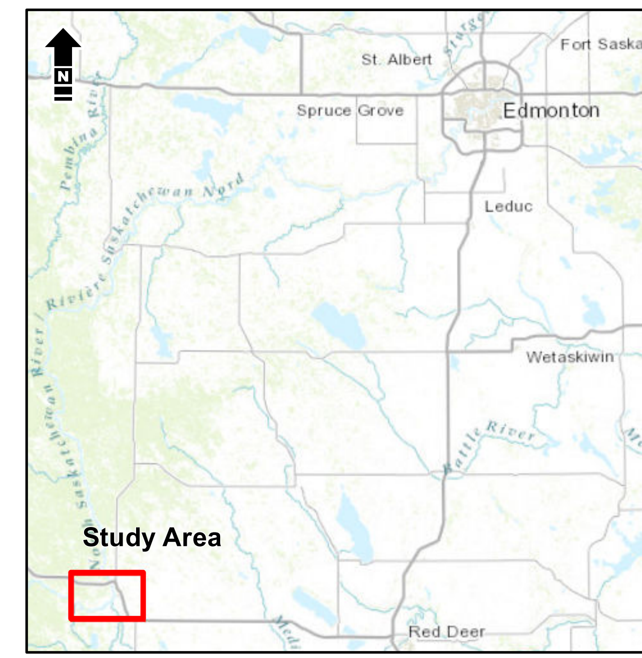
APPENDIX E
Flood Hazard Maps



Study Area
Map Sheet
Study Mapping Limit
Municipal Boundary (Urban)
Study Reach
Flow Direction



1:65,000
kilometres
1.5 0 1.5 3
NAD 1983 CSRS 3TM 114

Notes:

1. Please refer to the accompanying Rocky Mountain House Flood Hazard Study for important information concerning these maps.

2. Within the flood inundation areas shown on this map, there may be isolated pockets of high ground. To determine whether or not a particular site is subject to flooding, reference should be made to the computed flood levels in conjunction with site-specific surveys where detailed definition is required.

3. Non-riverine and local sources of water have not been considered, and structures such roads or railways can restrict water flow and affect local flood levels. Channel obstruction, local stormwater inflow, groundwater seepage or other land drainage can cause flood levels to exceed those indicated on the map. Lands adjacent to a flooded area may be subject to flooding from tributary streams not indicated on the maps.

Definitions:

Flood Hazard Map - A flood hazard map is a specific type of flood map that identifies the area flooded for the 1:100 design flood, and divides that flood hazard area into floodway and flood fringe zones. Flood hazard maps can also show additional flood hazard information, including the incremental areas at risk for more severe floods like the 1:200 and 1:500 floods. Flood hazard maps are typically used for long-term flood hazard area management and land-use planning.

Design Flood - The design flood standard in Alberta is the 1:100 flood, which is a flood that has a 1% chance of being equaled or exceeded in any given year. The design flood is typically based on the 1:100 open water flood, but it can also reflect 1:100 ice jam flood levels or be based on a historical flood event. Different sized floods have different chances of occurring – for example, a 1:200 flood has a 0.5% chance of occurring in any given year and a 1:500 flood has a 0.2% chance of occurring in any given year – but only the 1:100 design flood is used to define the floodway and flood fringe zones on flood hazard maps.

Floodway - When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 1:100 design flood. When a flood hazard map is updated, the floodway will not get larger in most circumstances to maintain long-term regulatory certainty, even if the flood hazard area gets larger or design flood levels get higher.

Flood Fringe - The flood fringe is the area outside of the floodway that is flooded or could be flooded during the 1:100 design flood. The flood fringe typically represents areas with shallower, slower, and less destructive flooding, but it may also include "high hazard flood fringe" areas. Areas at risk of flooding behind flood berms may also be mapped as "protected flood fringe" areas.

High Hazard Flood Fringe - The high hazard flood fringe identifies areas within the flood fringe with deeper or faster moving water than the rest of the flood fringe. High hazard flood fringe areas are likely to be most significant for flood maps that are being updated, but they may also be included in new flood maps.

Protected Flood Fringe - The protected flood fringe identifies areas that could be flooded if dedicated flood berms fail or do not work as designed during the 1:100 design flood, even if they are not overtopped. Protected flood fringe areas are part of the flood fringe and do not differentiate between areas with deeper or faster moving water and shallower or slower moving water.

References:

Data obtained from AltaLIS © Government of Alberta and GeoBase® used under license.

Aerial imagery acquired by OGL Engineering on September 4, 2020 for Alberta Environment and Parks.

Additional Base Mapping available ESRI Base Mapping and Imagery Services.
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

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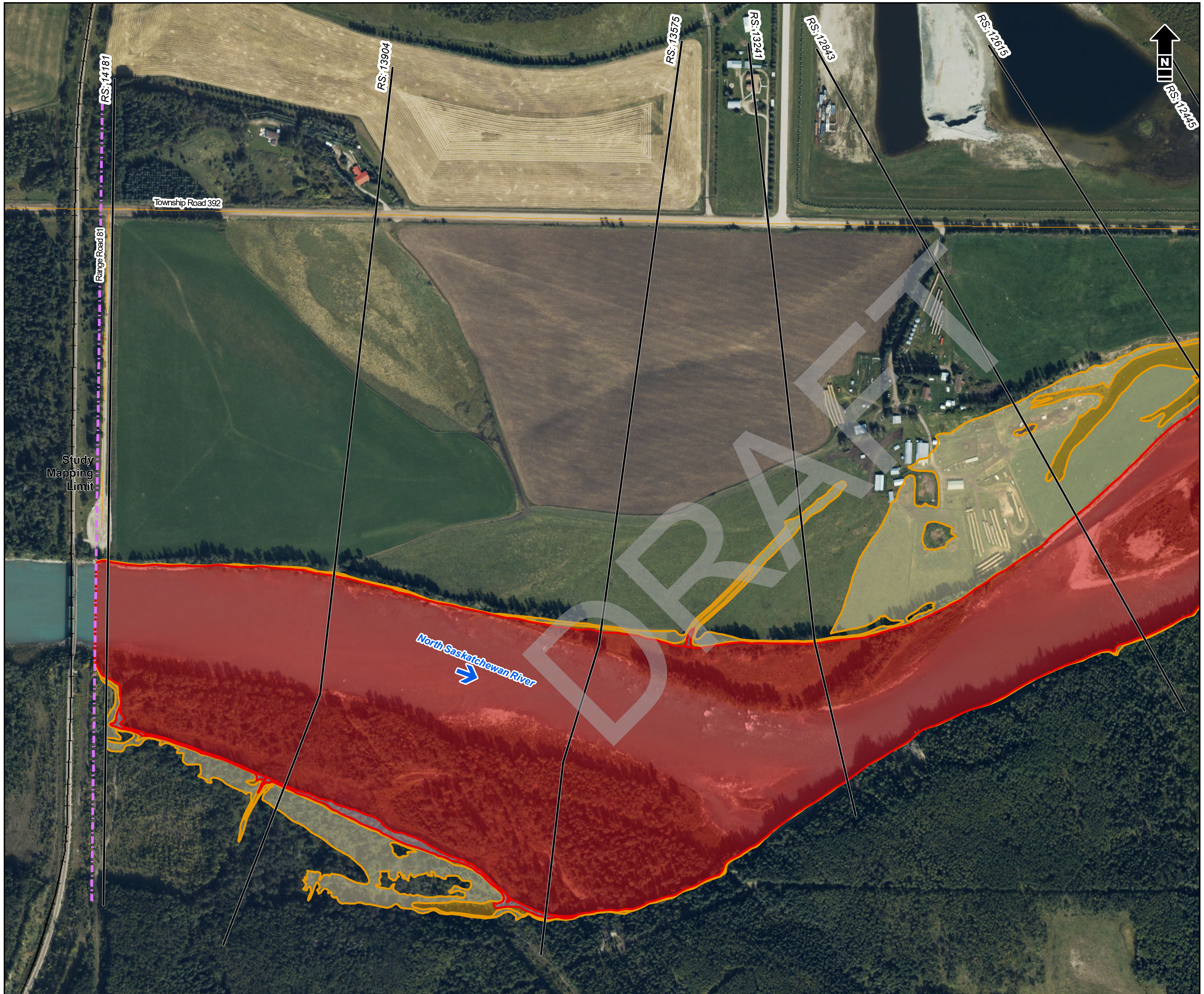
Rocky Mountain House Flood Hazard Study

Governing Design Flood Hazard Index Map

Date: January 2022	Project: 31781	Submitter: P. Rogers	Reviewer: M. Shome

Sheet INDEX



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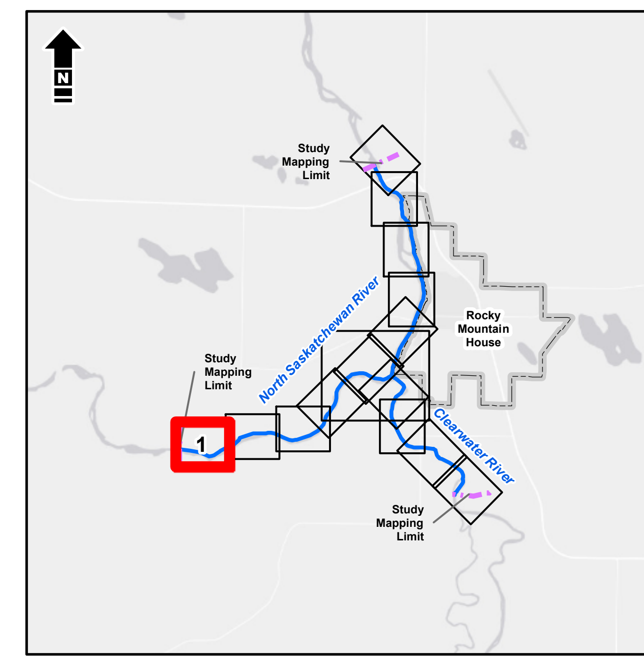
- Culvert
- Cross Section Line
- Study Mapping Limit
- Municipal Boundary (Urban)
- Major Road
- Local Road
- Railway
- Flow Direction
- Floodway
- Flood Fringe
- High Hazard Flood Fringe
- 200-Year Flood Inundation Extent
- 500-Year Flood Inundation Extent



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1:5,000 metres
50 0 50 100
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Rocky Mountain House Flood Hazard Study

Governing Design Flood Hazard Map

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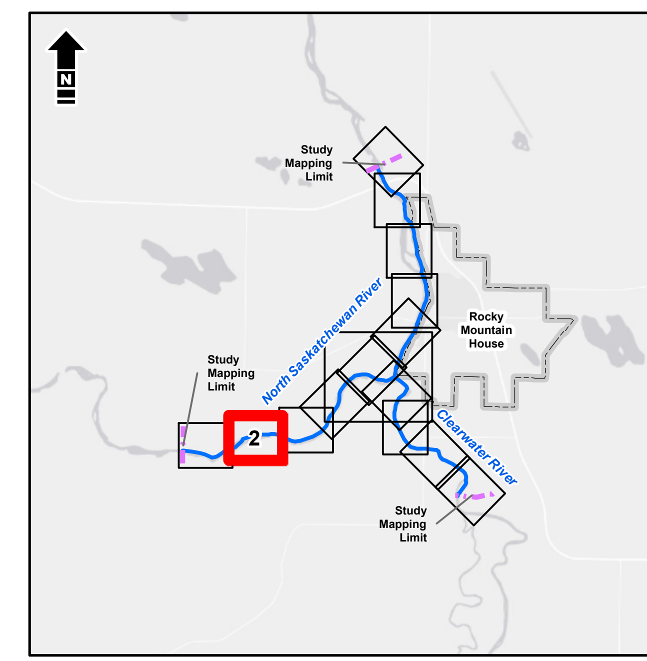

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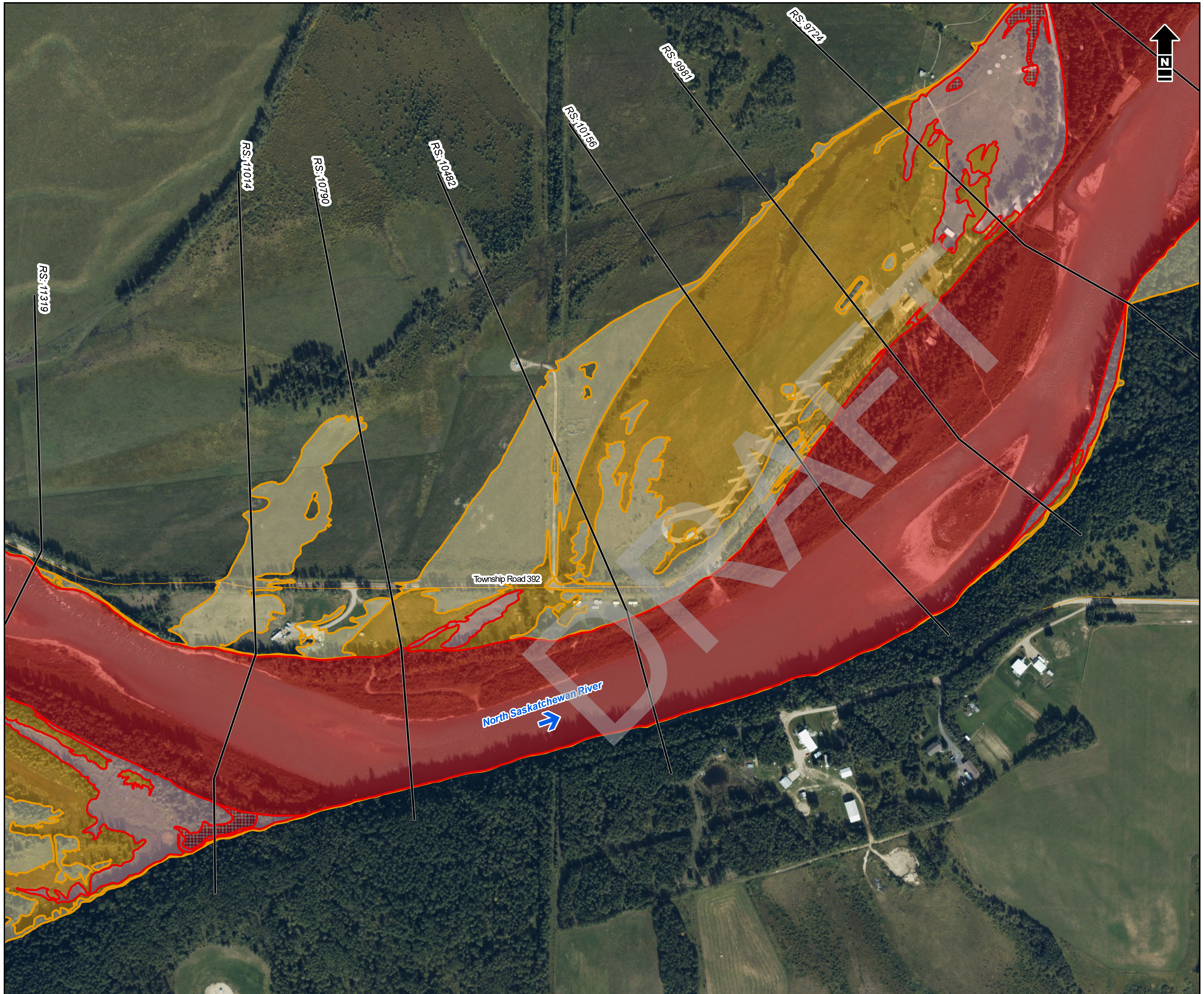

Bridge
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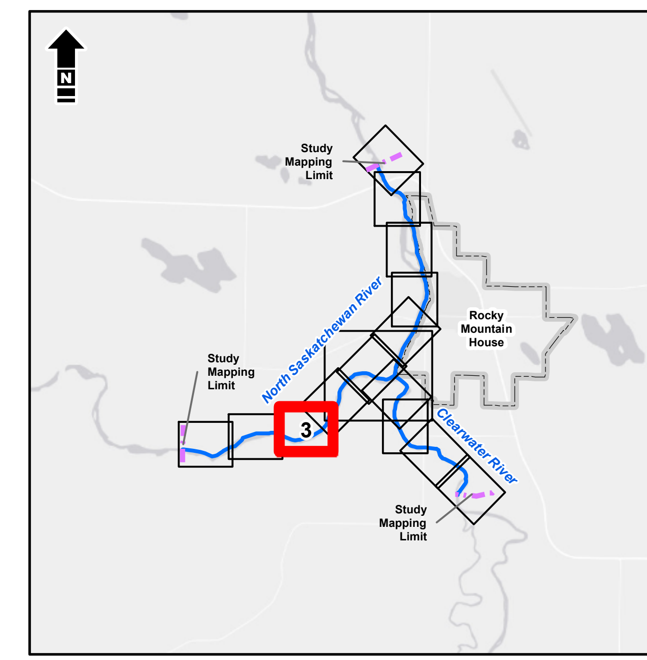

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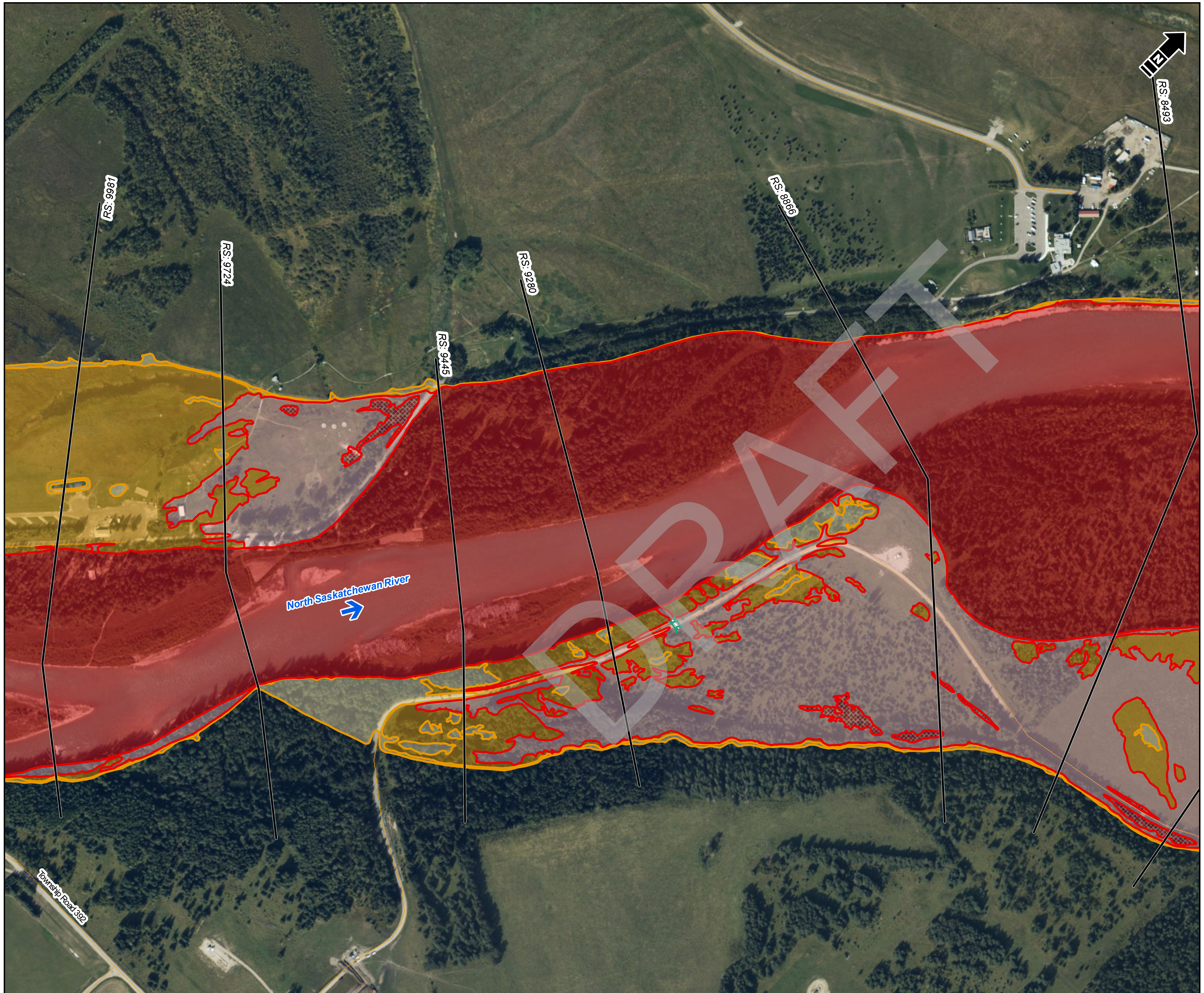

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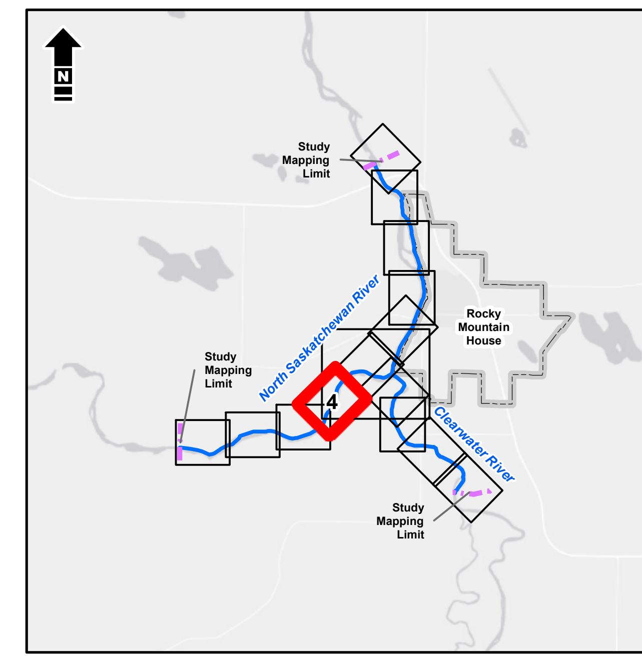

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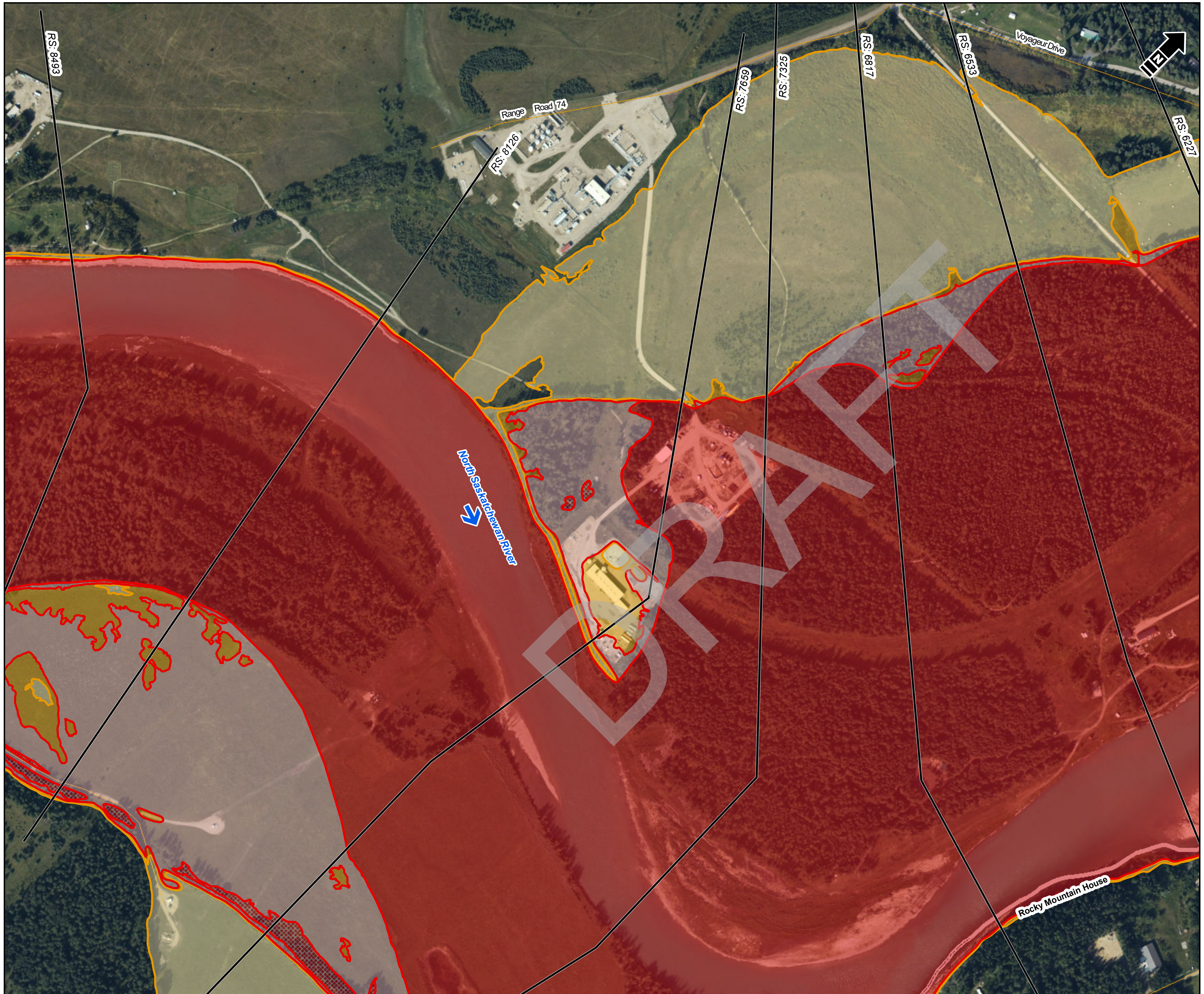

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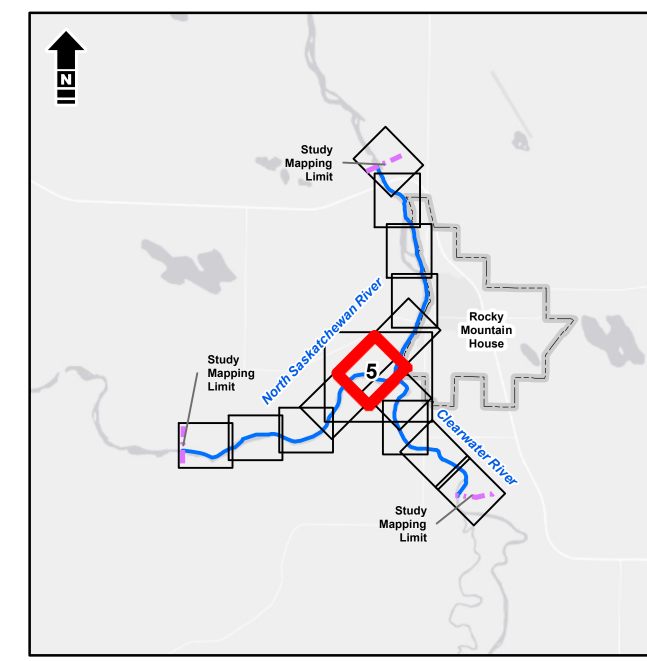

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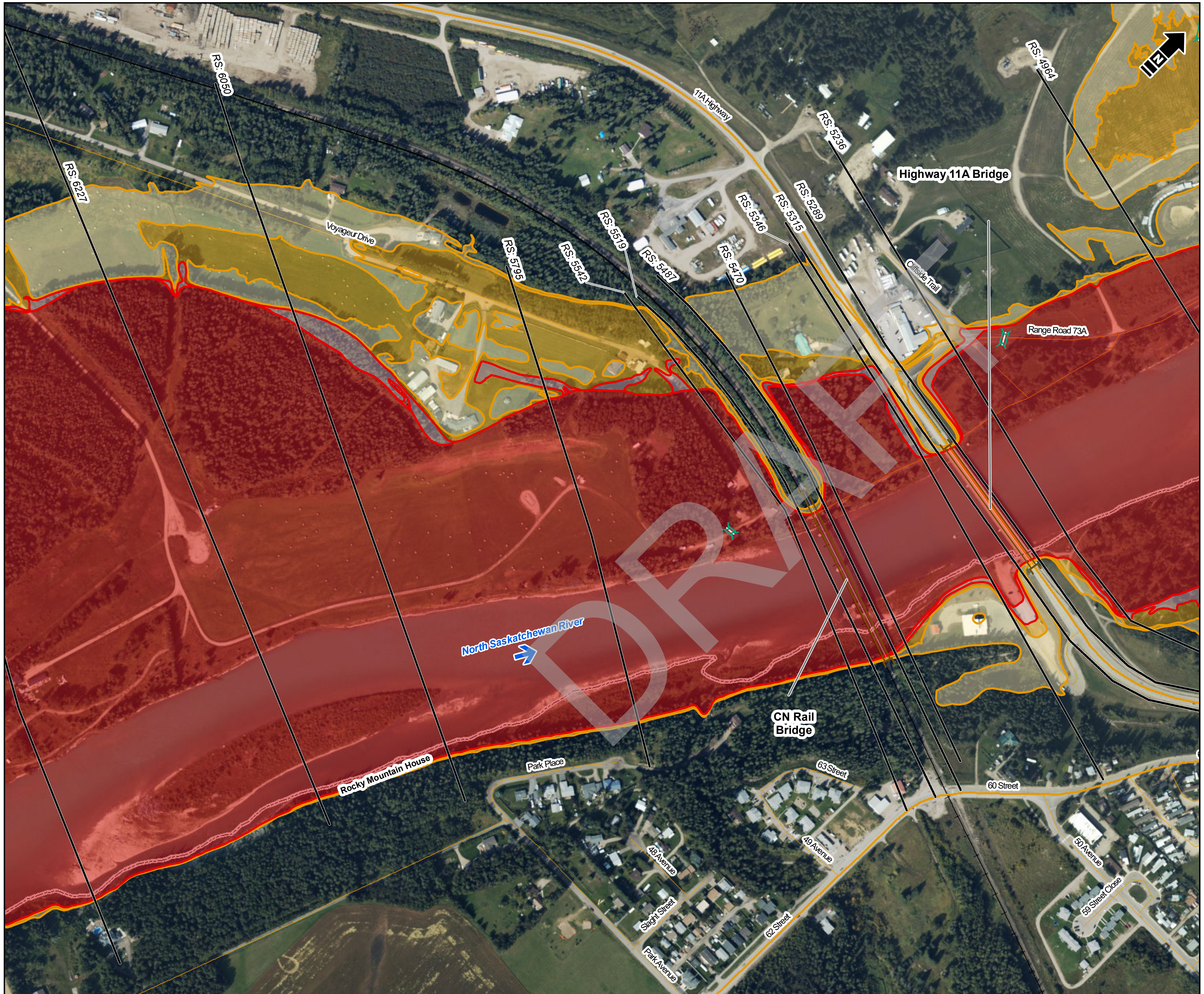

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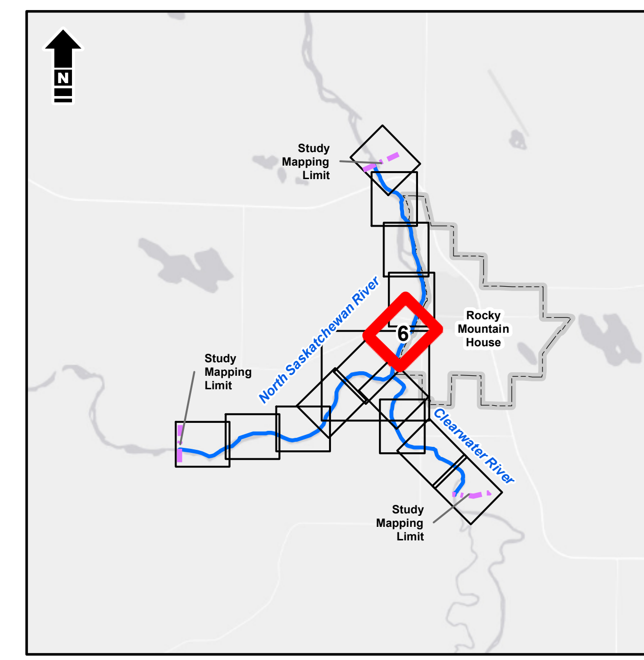

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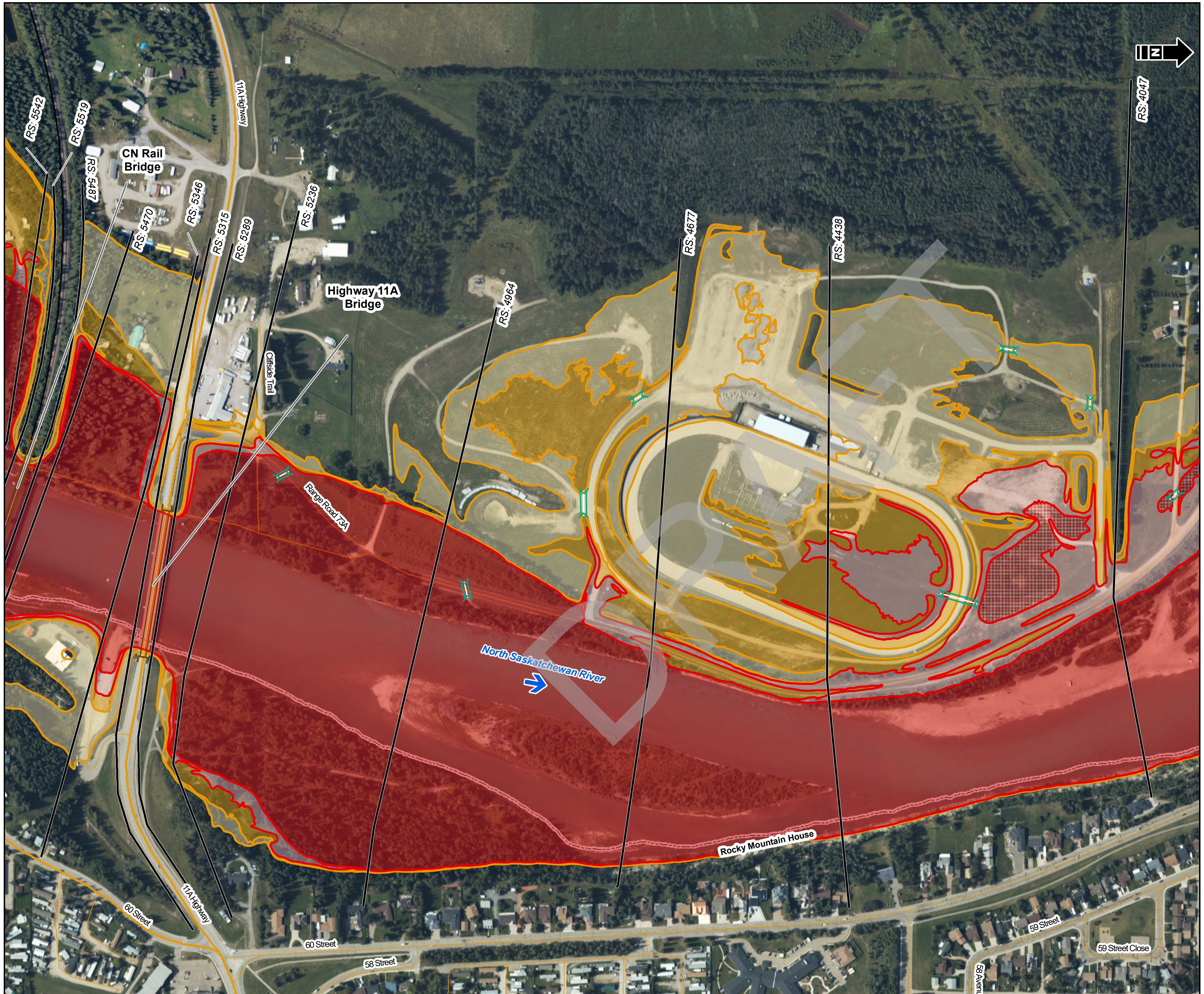

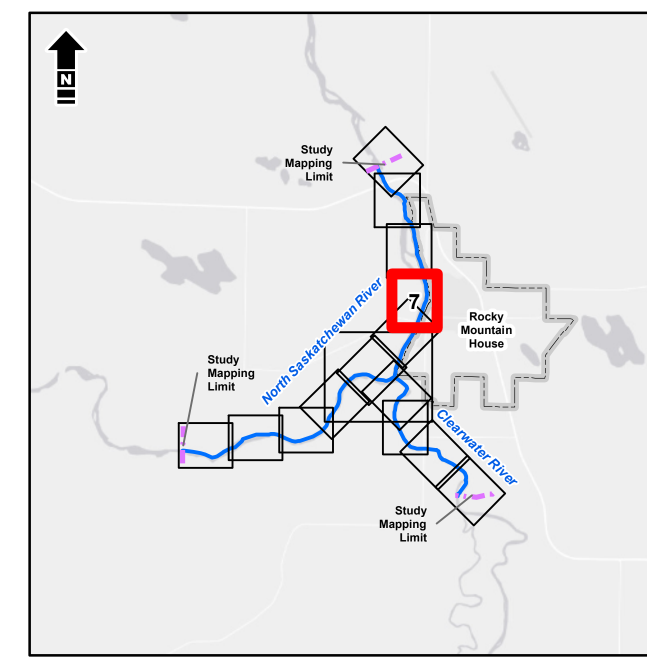

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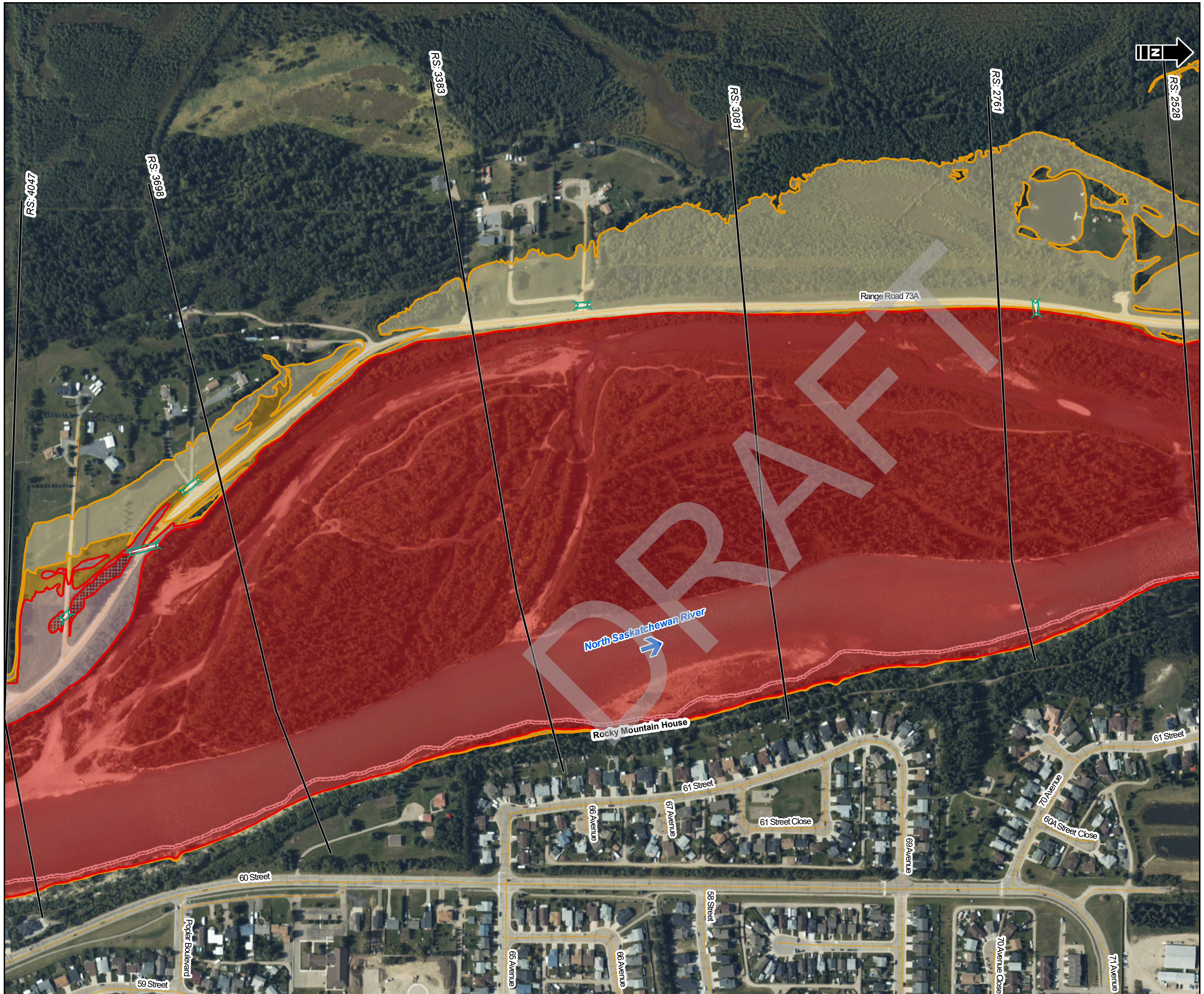

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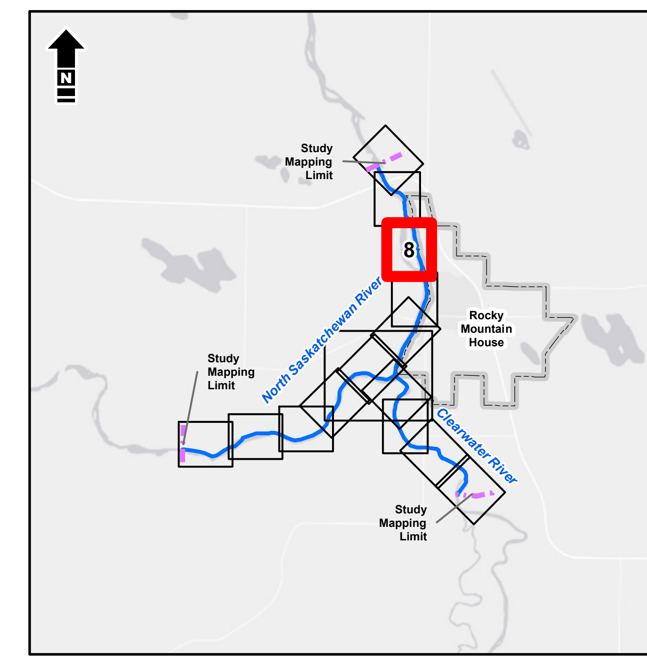

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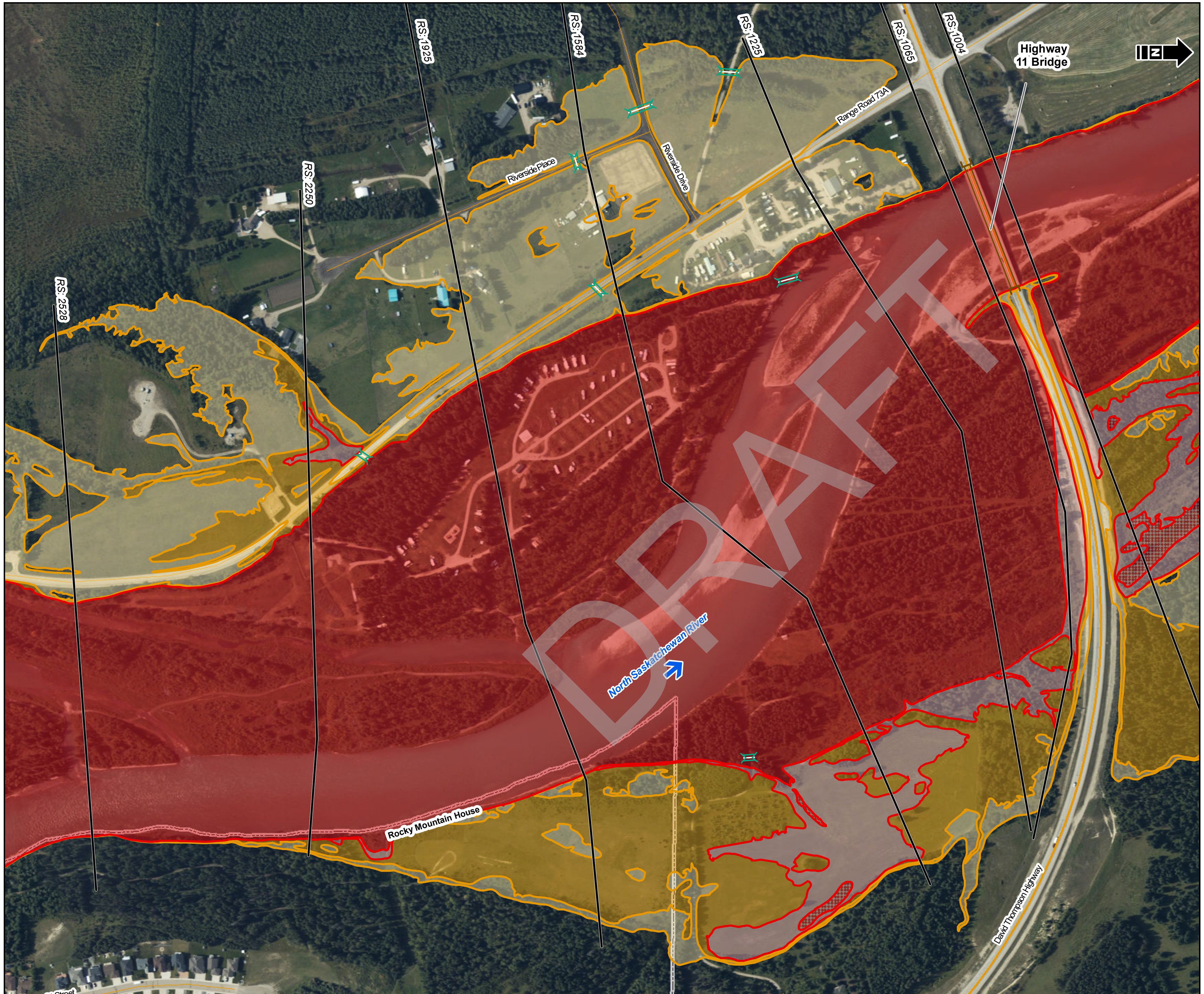

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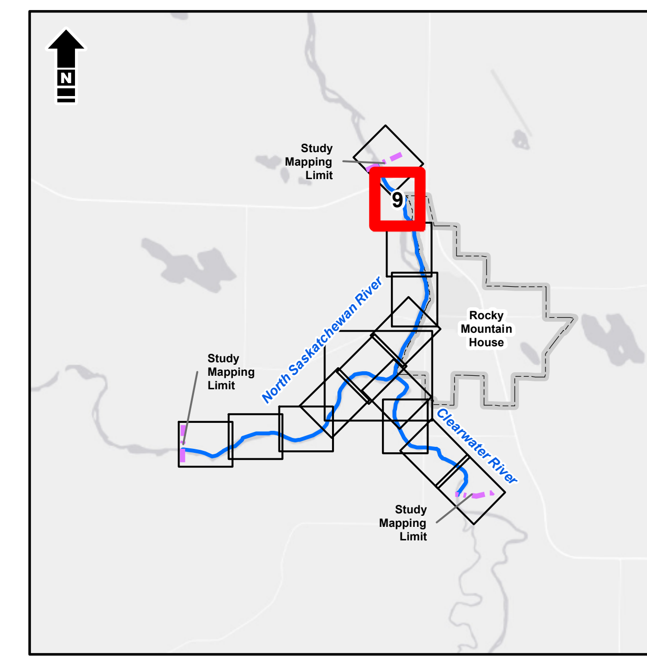

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Date:	Project:	Submitter:	Reviewer:
March 2022	31781	P. Rogers	M. Shome

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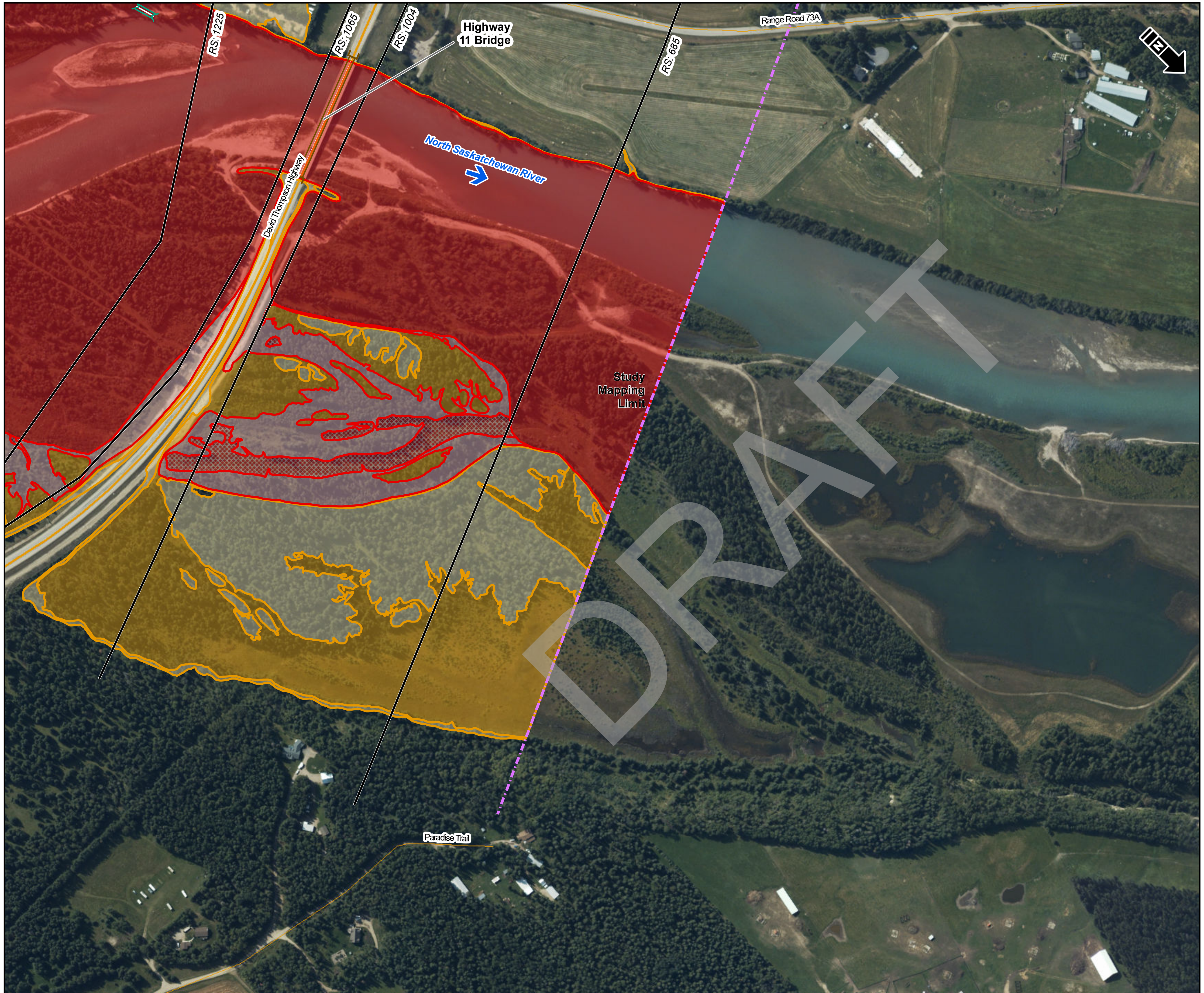
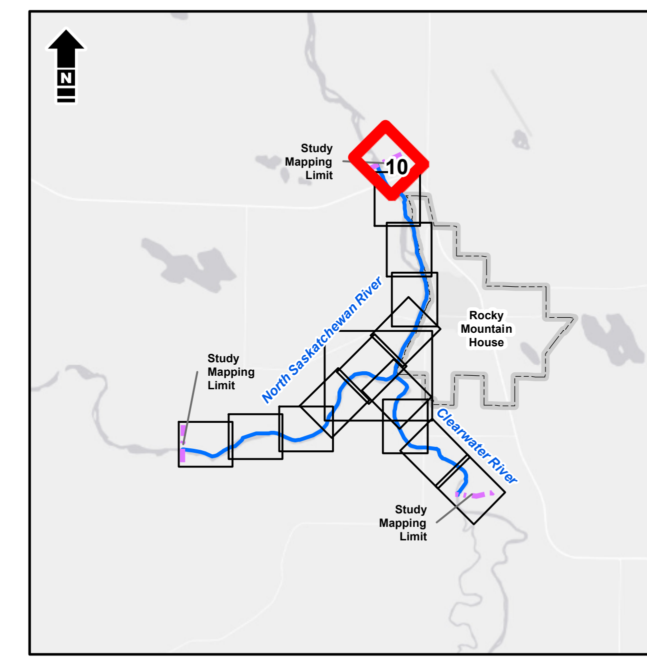


Bridge
Culvert
Cross Section Line
Study Mapping Limit
Municipal Boundary (Urban)
Major Road
Local Road
Railway
Flow Direction
Floodway
Flood Fringe
High Hazard Flood Fringe
200-Year Flood Inundation Extent
500-Year Flood Inundation Extent



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1:5,000 metres
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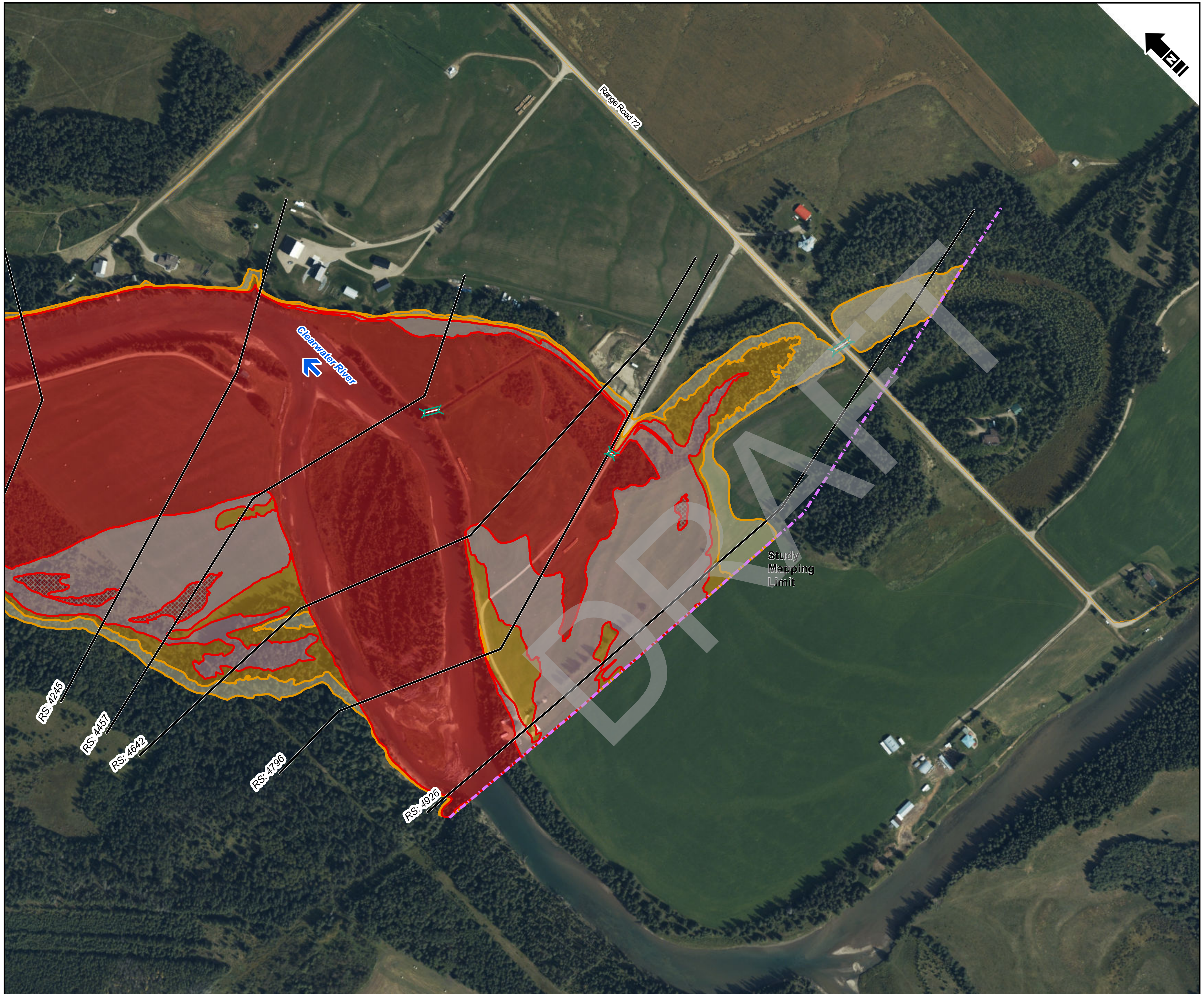

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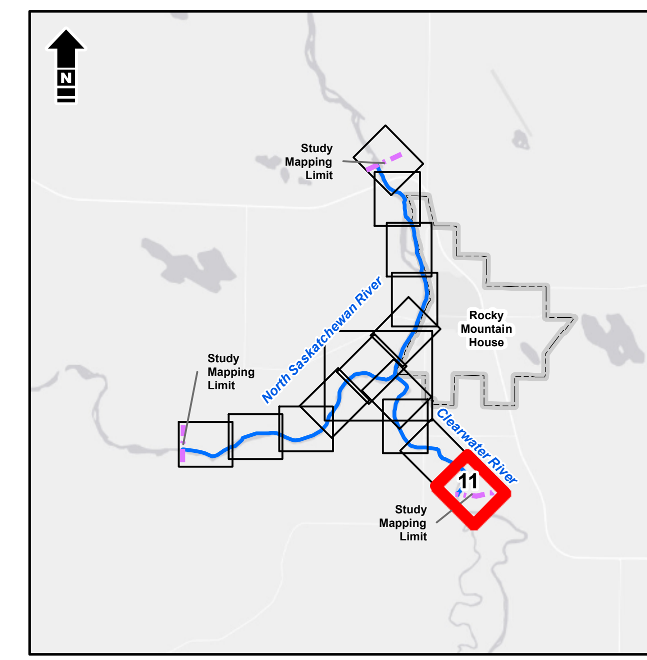

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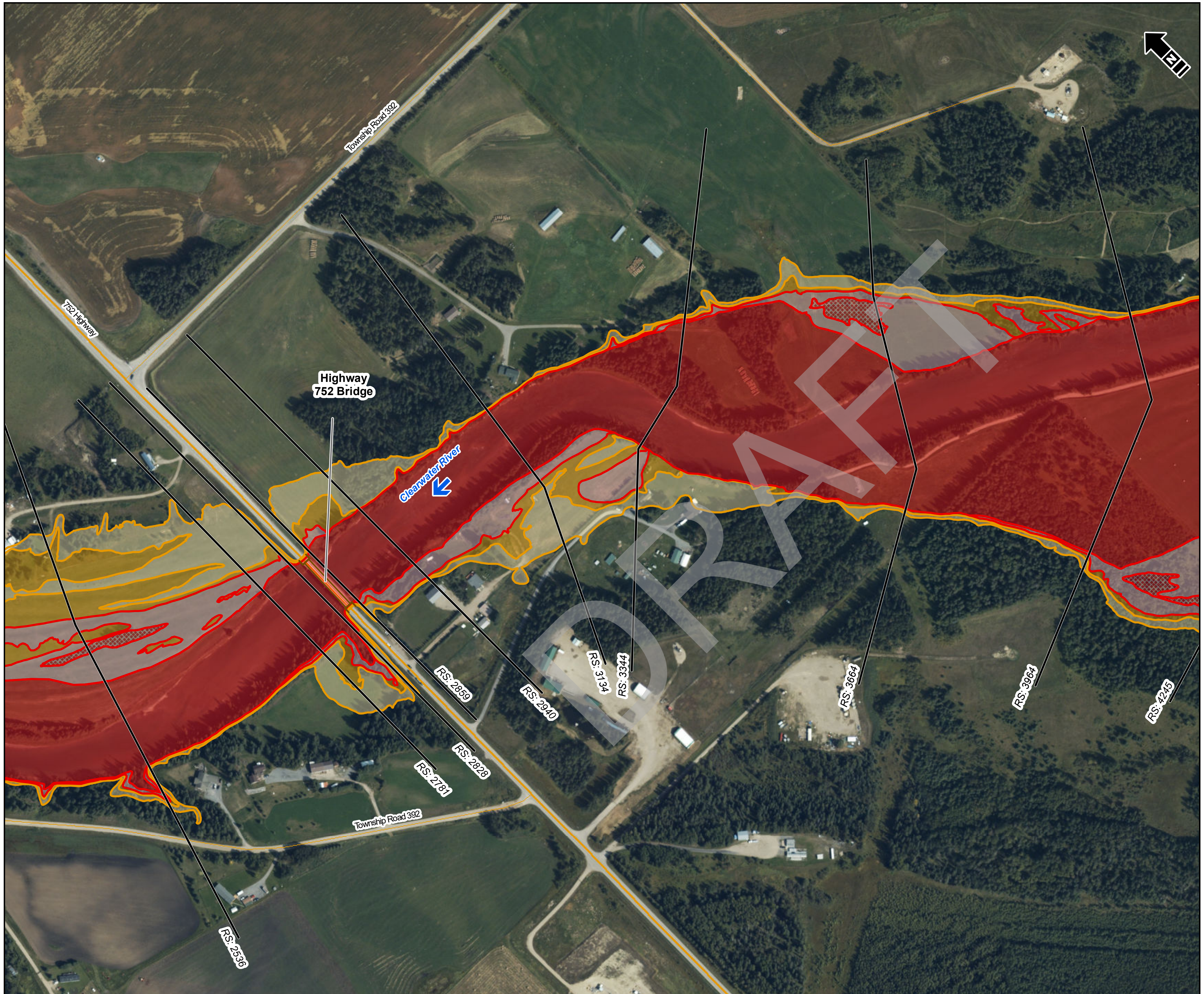

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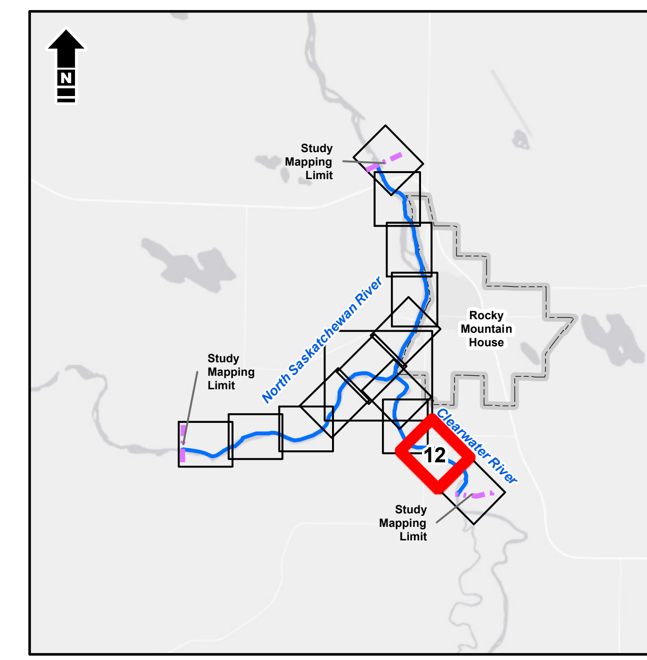

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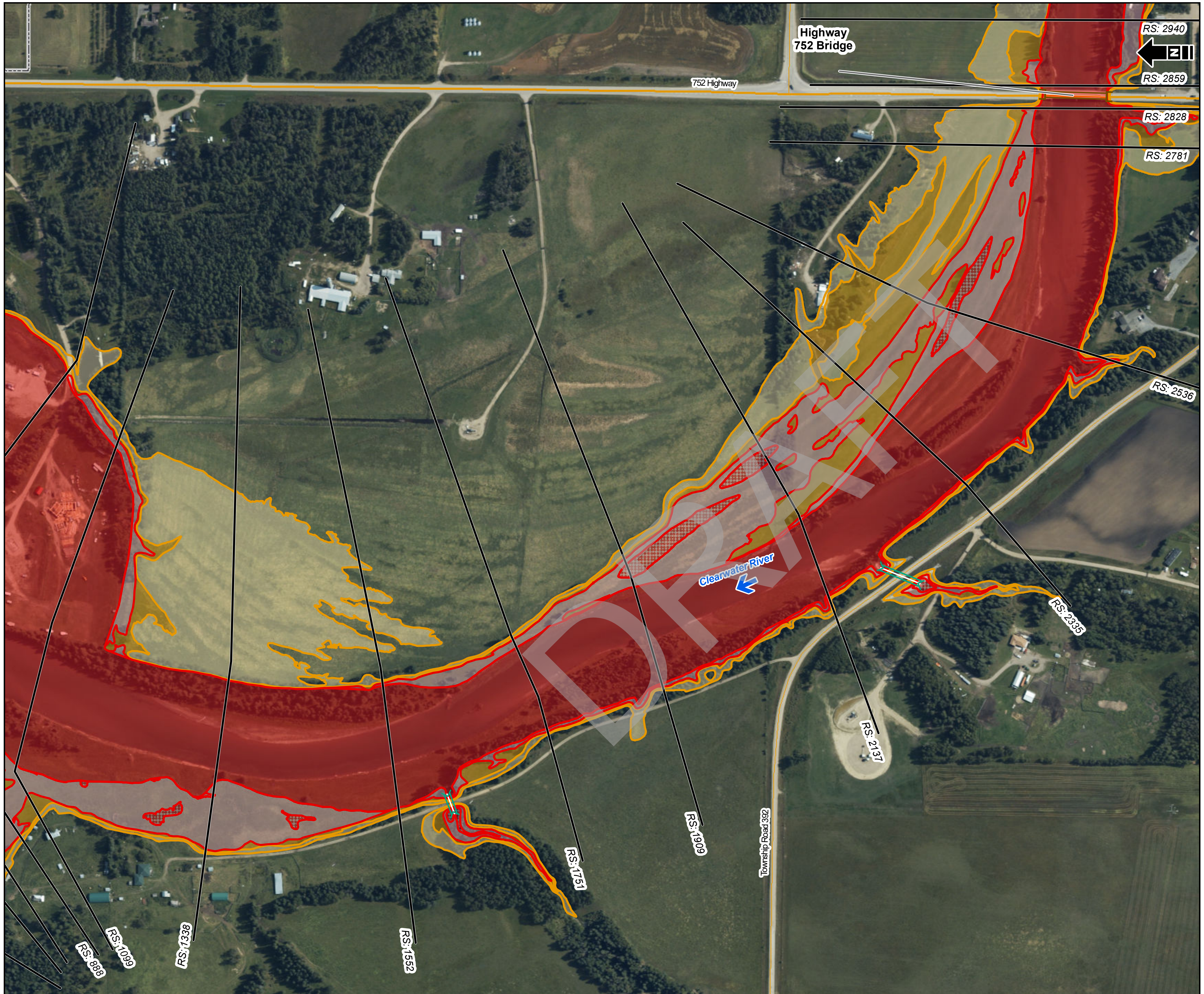

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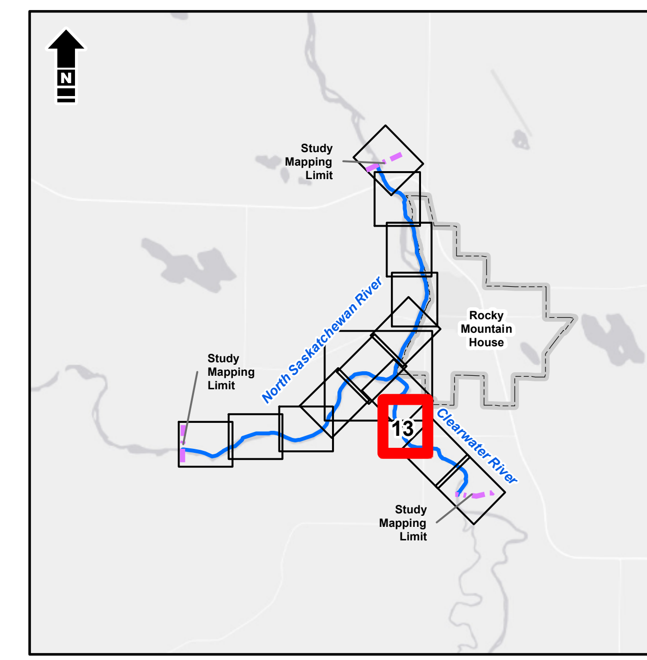

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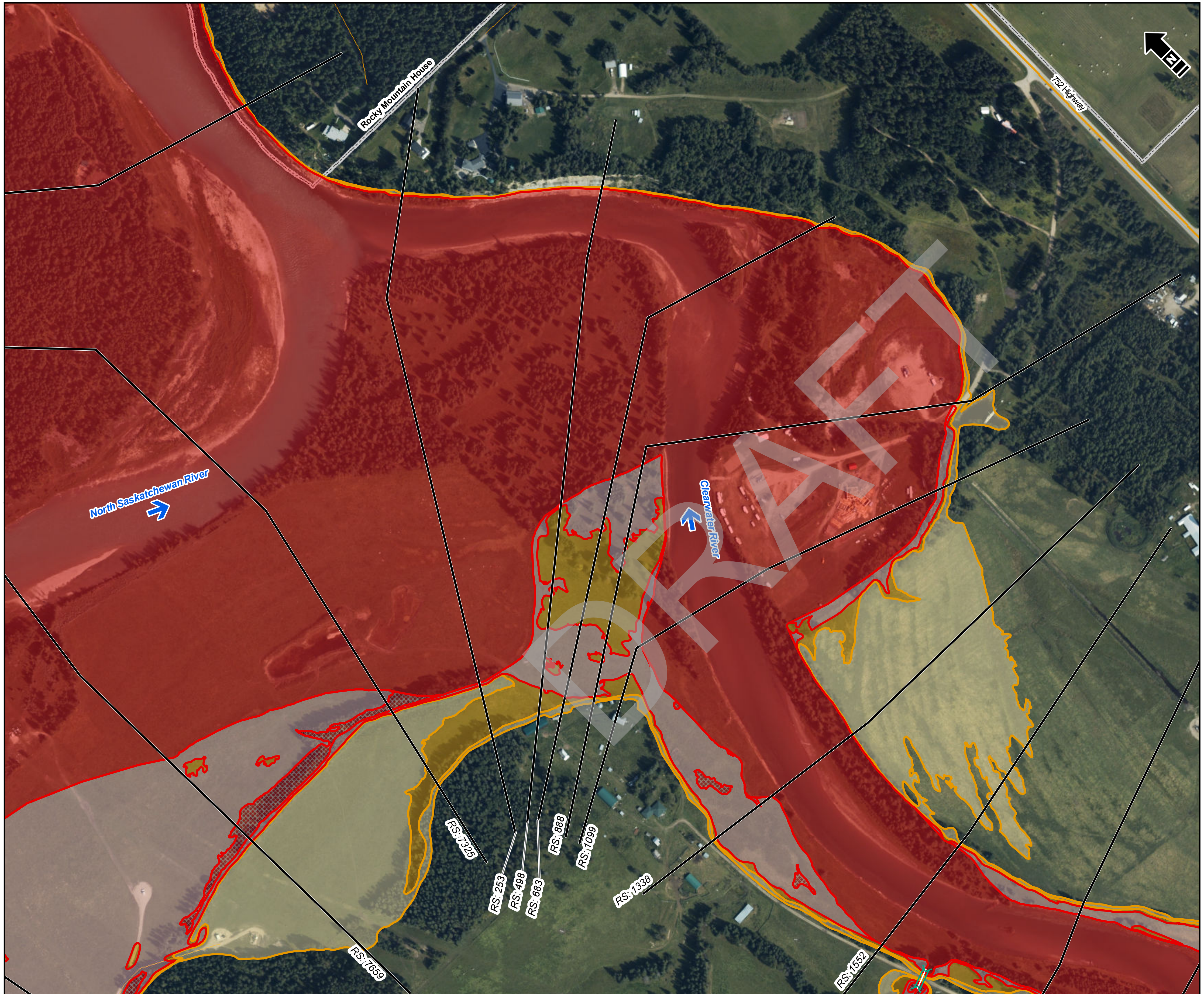

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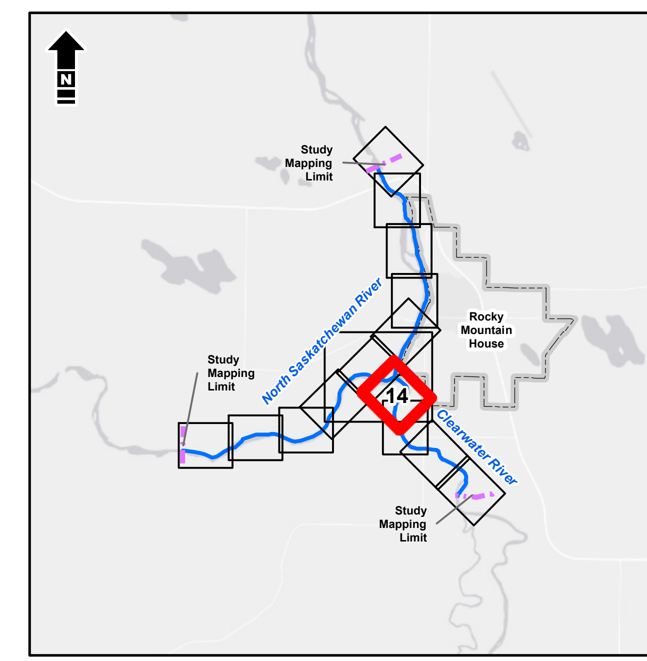

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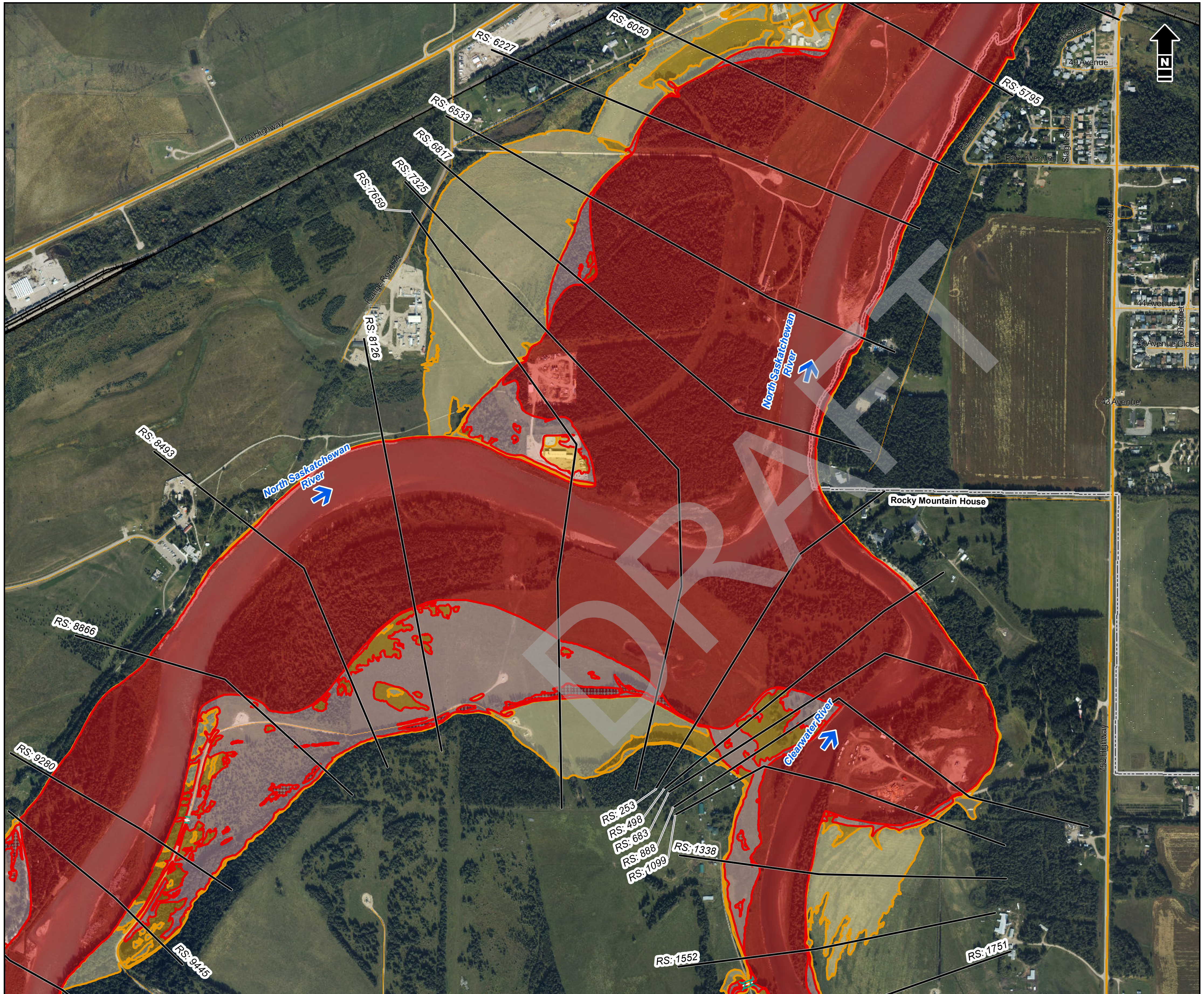

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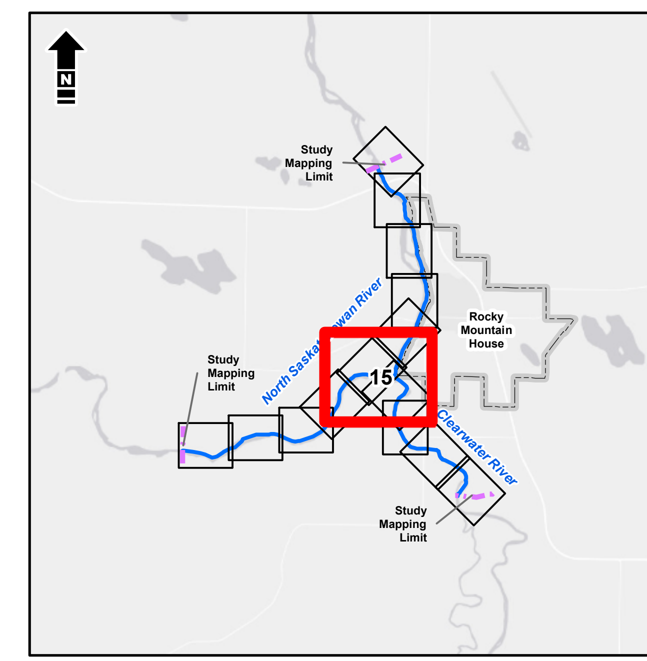

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