BARR

Kinuso Flood Study

Main Report

Prepared for
Alberta Environment and Protected Areas
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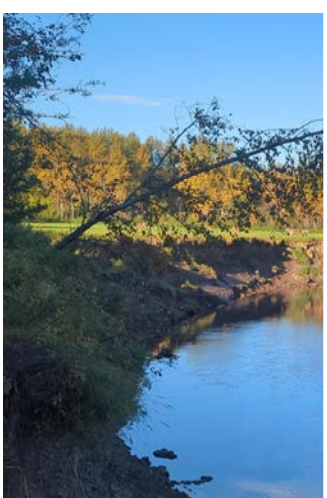

Executive Summary

Alberta Environment and Protected Areas (EPA) retained Barr Engineering and Environmental Science Canada Ltd. (Barr) in March 2024 to conduct the Kinuso Flood Study (the study). The primary purpose of the study is to assess and identify river and flood hazards along over 23 km of the Swan River near the Hamlet of Kinuso. The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancing public safety and reducing future flood damages by identifying river and flood hazards. This project includes working with the Swan River First Nation (SRFN). Project stakeholders include the Government of Alberta, Big Lakes County, and the public.

This report documents the methodology and results for all components of the study which are listed below:

- Survey and base data collection
- Open water hydrology assessment
- Open water hydraulic modelling
- Open water flood inundation mapping
- Design flood hazard mapping

The total length of Swan River for the Kinuso study reach is approximately 23.7 km, although the study extends considerably into the adjacent floodplain. The survey was completed in the summer and fall of 2024. The hydraulic features in this study are summarized in Table ES–1. The downstream model boundary in HEC-RAS was extended beyond the study area to enable the specification of reliable downstream boundary conditions.

Table ES–1 Summary of Survey Features

Features	Swan River	Floodplain	Total
Cross Sections	157	0	157
Bridges	2	3	5
Culverts	0	14	14
Flood Control Structure (FCS)	1		1

A site visit of the study reach was completed on May 14 and 15, 2024. In May 2024, hydraulic structures and the floodplain were surveyed, and cross-sections were surveyed between September 7 and 19, 2024.

A hydrology assessment was completed to provide the flood peak discharge estimates for the study area as inputs to the HEC-RAS model.

A 2D HEC-RAS hydraulic model was developed for the study area. The HEC-RAS model setup for the study area was initially informed by supplementary approximate two-dimensional modelling, excluding channel bathymetry, bridges, and culverts in the geometry.

Swan River has a rich history of highwater mark (HWM) data available within the study area. EPA has collected HWM data since 1979, with eight significant events with HWMs before 2024. Additionally, a high flow event was observed during the 2024 survey season, and HWMs were collected.

A composite roughness value was used to characterize Swan River below the banks. For low flow conditions, a calibrated channel bed Manning's n value of 0.04 was used, and a calibrated channel bank Manning's n value of 0.045 was used. For flood conditions, a calibrated channel bed Manning's n value of 0.035 was used, and a calibrated channel bank Manning's n value of 0.045 was used. The Manning's n values for the floodplain areas were estimated and selected based on the land use types.

The calibrated model was used to simulate the water surface profiles for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year flood events in the study area.

The model sensitivity was evaluated for the 100-year flood event. The results of the sensitivity analysis show that variations of the channel and floodplain roughness values have small impacts on the simulated water levels along the Swan River within the study area. Changes in the energy slope at the downstream boundary also have had small impacts on the simulated flood levels for approximately 3.0 km upstream of the downstream boundary.

The fully 2D HEC-RAS model produces a continuous water surface of directly inundated areas for each simulated flood event. Directly inundated areas were mapped where there is a direct connection between the main river channel and inundated areas on the floodplains. This includes areas where inundation is caused by topographic or structural overtopping points as well as backwater flooding. The 1,000-year flood does not overtop the flood berm east of Kinuso. However, the areas protected by this flood berm on the downstream side of it were mapped accordingly. Flood inundation and hazard maps were prepared for the study reach using ArcGIS.

Based on the simulation results, multiple rural residences within Big Lakes County and Swan River First Nations will be impacted from flooding in as low as the 35-year return period flood event. In addition to the above residences, one large commercial or residential establishment will be impacted by flooding southeast of HWY 2 and HWY 33.

The floodway was defined based on the 1 m depth, 1 m/s velocity, and main channel criteria with some professional judgment. The results of the design flood hazard mapping are the delineation of floodway and flood fringe zones, including high hazard flood fringe areas. Based on the flood hazard maps, no residential or commercial properties are situated within the floodway zone within the study area.

Acknowledgements

The study was completed by the Government of Alberta under the provincial Flood Hazard Identification Program, which aims to enhance public safety and reduce future flood damages through the identification of river and flood hazards. The study was co-funded by the Government of Canada through the federal Flood Hazard Identification and Mapping Program.

Barr Engineering and Environmental Science Canada Ltd. (Barr) acknowledges the contributions of the following staff of Alberta Environment and Protected Areas (EPA):

- Mr. Muhammad Durrani, EPA's project manager for the study, coordinated the participation from EPA and provided technical advice and guidance for the overall project and review of this report.
- Mr. Peter Onyshko, EPA's technical advisor for the study, provided technical review and guidance, particularly for the hydrology assessment, hydraulic modelling methodology, and inundation mapping.

Barr also acknowledges the following staff from SRFN and Kinosayo Museum for providing information for this study:

- Ms. Kaly Twin (Swan River First Nation)
- Mr. Todd Bailey (Swan River First Nation)
- Mr. David Reynolds (Big Lakes County)
- Mrs. Pat Olansky (Big Lakes County)
- Mrs. Jennifer Churchill (Kinosayo Museum)
- Mr. George Johnson (Kinosayo Museum)

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- Mr. Tom MacDonald was the senior advisor and reviewer for this study.
- Dr. Omid Mohseni, senior hydrologist, was responsible for open water hydrology assessment.
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- Dr. Christian Frias, senior hydraulic modeler, was responsible for the review of the hydraulic model and provided guidance to Mr. Paul Orban and Mrs. Kinda Chakas.
- Mr. Paul Orban, hydraulic modeler support for the study, was involved in the site visit and assisted with construction and simulation of the HEC-RAS model.
- Mrs. Kinda Chakas, hydraulic modeler for the study, was involved in construction and the simulation of the HEC-RAS model.

- Mr. Eddie Anderson, Senior GIS specialist, was responsible for preparing the flood inundation maps and flood hazard maps for this report.
- Mrs. Emily Cristobal, GIS specialist, prepared the flood inundation maps and flood hazard maps for this report.
- Mr. Carmen Orosz (of Core Geomatics Inc.), field survey lead for this study, was responsible for field survey and Swan River cross section data collection.
- Mr. Mark Miller (of Core Geomatics Inc.), survey project manager, was responsible for survey coordination and data QA/QC.
- Mr. Doug West (of Trout Hydrography Inc.), field survey lead for this study, was responsible for hydraulic structure data collection.

Kinuso Flood Study

March 31, 2025

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Abbreviations

1D	One-dimensional
2D	Two-dimensional
3TM	three-degree Transverse Mercator
AEP	Alberta Environmental Protection & Annual Exceedance Probability
ASCM	Alberta Survey Control Monuments
Barr	Barr Engineering and Environmental Science Canada Ltd.
CGVD28	Canadian Geodetic Vertical Datum of 1928
CORE	Core Geomatics Inc.
CSRS	Canadian Spatial Reference System
DTM	Digital Terrain Model
EPA	(Alberta) Environment and Protected Areas
FCS	Flood Control Structure
FHIP	Flood Hazard Identification Program
GNSS	Global Navigation Satellite System
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HWM	Highwater Mark
HWY	Highway
LiDAR	Light Detection and Ranging
LOB	Left Overbank
LSL	Lesser Slave Lake
LSWC	Lesser Slave Watershed Council
NAD83	North American Datum of 1983
Rd	Road
ROB	Right Overbank
RS	River Station
RR	Range Road
RTK	Real-Time Kinematic
SRFN	Swan River First Nation
SWE-LIA	Shallow Water Equations – Local Inertia
TIN	Triangulated Irregular Network
TROUT	Trout Hydrography Inc.
TWP Rd	Township Road
USACE	The U.S. Army Corps of Engineers
WSC	Water Survey Canada
WSEL	Water Surface Elevation

1 Introduction

1.1 Study Background

Alberta Environment and Protected Areas (EPA) retained Barr Engineering and Environmental Science Canada Ltd. (Barr) in March 2024 to conduct the Kinuso Flood Study (the study). The primary purpose of the study is to assess and identify river and flood hazards in the vicinity of the Hamlet of Kinuso, through the Swan River First Nation reserve and Big Lakes County. The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancing public safety and reducing future flood damages by identifying river and flood hazards. This project includes working with the Swan River First Nation (SRFN). Project stakeholders include the Government of Alberta, Big Lakes County, and the public.

This report documents the methodology and results for all components of the study which are listed below:

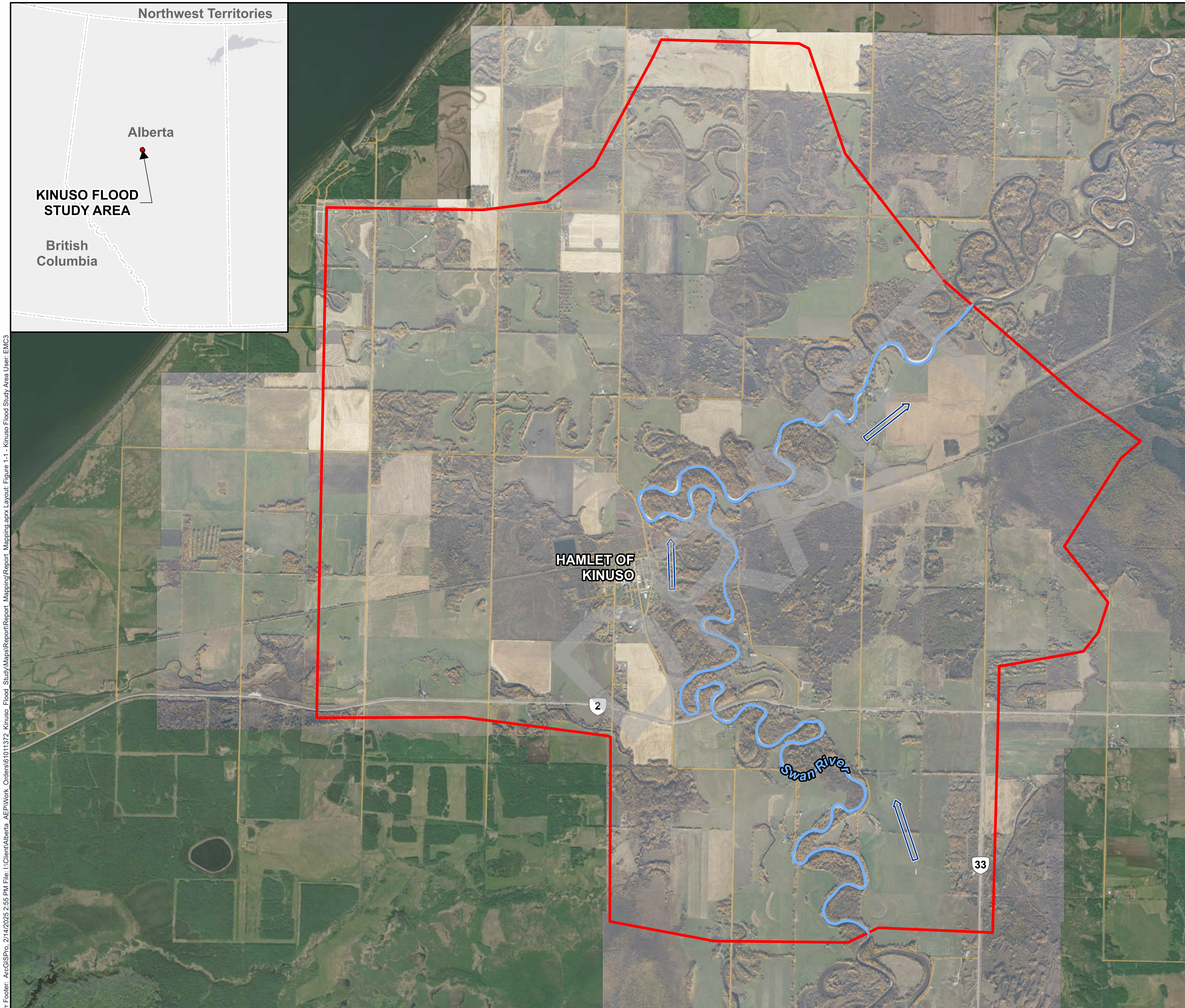
- Survey and base data collection
- Open water hydrology assessment
- Open water hydraulic modelling
- Open water flood inundation mapping
- Design flood hazard mapping

1.2 Study Objectives

The overall goal of the Kinuso Flood Study is to enhance public safety and support the assessment and identification of flood hazards in the study area. The study results are intended to reduce potential future flood damages and associated disaster assistance costs, to mitigate flood impacts by informing land use planning decisions, and for emergency preparation.

1.3 Study Area and Reach

The Swan River drains an area of approximately 3,000 km^2 (LSWC, 2009), originating from the Swan Hills and flowing north to its terminus at Swan Point on Lesser Slave Lake (LSL), about 12 km northeast of the Hamlet of Kinuso. Figure 1-1 shows the project location, the study extent, and the overall watershed area of the Swan River at the Water Survey of Canada (WSC) hydrometric station 07BJ001, where flood frequency estimates are required for the open water hydrology assessment.



LEGEND

- STUDY AREA
- FLOW DIRECTION
- SWAN RIVER
- SECONDARY HIGHWAY
- LOCAL ROAD

N

0 1 2

KILOMETRES

SCALE: 1:50,000

REFERENCES

ORTHOPHOTO IMAGERY ACQUIRED BY OGL ENGINEERING FOR ALBERTA ENVIRONMENT AND PROTECTED AREAS: OGL ENGINEERING (2023). ESRI IMAGERY SOURCED BY MAXAR (2023).

BASE DATA FROM ALBERTA ENVIRONMENT AND PROTECTED AREAS.

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

Alberta

Canada

KINUSO STUDY AREA

KINUSO FLOOD STUDY

ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 1-1

BARR

2 Survey and Base Data Collection

A site reconnaissance was conducted by representatives from EPA, Barr, and Trout Hydrography Inc. (TROUT) on May 14 and 15, 2024. The site visit was informed by a preliminary hydraulic model which showed significant inundation on the floodplain, required additional survey of structures located in the immediate floodplain. The site visit involved the following:

- Reviewed and confirmed the preliminary survey plan
- Confirmed the locations and numbers of channel cross sections and hydraulic structures to be surveyed
- Visited the important hydraulic structures (mostly culverts) for hydraulic modelling on the floodplain to include in the survey plan
- Familiarized with the study area

Barr retained TROUT and CORE Geomatics Inc. (CORE) to complete the survey of Swan River and surrounding floodplain hydraulic structures. A survey of cross sections and other base data was completed in two periods, Spring 2024 and Fall 2024. It is noted that during the survey season, two large events occurred, one of which resulted in highwater marks used in model high flow calibration. During the cross section survey, low flow was observed and subsequently was used in low flow calibration. The objective of the survey program was to survey channel cross sections and hydraulic structures along the study reach (on the main channel of Swan River and on its floodplain) to support the development of a HEC-RAS hydraulic model.

Survey data was collected at 157 cross sections and for 19 hydraulic structures.

The survey scope included the following:

- survey of channel cross sections and hydraulic structures (on the main channel of Swan River and on its floodplain)
- measurement of discharge and water surface profile

2.1 Survey Procedures and Methodology

The survey equipment and procedures used in collecting the topographic, bathymetric, and structure data for this study included a Real-time Kinematic (RTK) Global Navigation Satellite Systems (GNSS) and Trimble R10 GNSS receivers.

The proposed locations of all cross sections were identified in a digital georeferenced vector format. The survey crew utilized them on the data collectors to guide the survey. A georeferenced survey plan was uploaded into the data collector to aid the surveyor in maintaining precise spacing and alignment of cross sections along each study reach.

A SonTek FlowTracker2® Acoustic Doppler Velocimeter (ADV), in combination with a top-set wading rod, was used to conduct discharge measurements on Swan River.

2.1.1 Coordinate System and Datum

Horizontal positions were referenced to the local three-degree Transverse Mercator (3TM) projection of the Canadian Spatial Reference System (CSRS) North American Datum of 1983 (NAD83), which has a central meridian of 114°W. Orthometric heights are based on the Canadian Geodetic Vertical Datum of 1928 (CGVD28) and the HTv2.0 geoid model.

2.1.2 Control Network

A control network was established from local Alberta Survey Control Monuments (ASCMs) and GNSS surveying to provide a spatial reference for the survey program. Table 2-1 summarizes the comparison between the survey and published ASCM coordinates and elevations.

Table 2-1 Comparison Between Surveyed and Published ASCMs

ASCM No.	Published Values			Surveyed Values			Residuals (Surveyed Minus Published)		
	N (m)	E (m)	H (m)	N (m)	E (m)	H (m)	N (m)	E (m)	H (m)
733154	6131043.381	-86364.048	590.938	6131043.381	-86364.048	590.927	0.000	0.000	-0.011
				6131043.333	-86364.098	591.002	-0.048	-0.050	0.064
143560	6133503.097	-88019.403	587.455	6133503.097	-88019.403	587.455	0.000	0.000	0.000
				6133503.225	-88020.097	587.786	0.128	-0.694	0.331
98764	6137370.55	-91154.965	584.978	6137370.551	-91154.965	584.982	0.001	0.000	0.004
				6137370.230	-91155.288	583.970	-0.320	-0.323	-1.008
33019	6139297.544	-94908.505	580.767	6139297.540	-94908.505	580.759	-0.004	0.000	-0.008
				6139297.544	-94908.507	579.864	0.000	-0.002	-0.903

Note: N=Northing; E=Easting; H=Elevation. Green cells: May 2024 Survey by TROUT; Blue cells: September 2024 Survey by CORE.

Barr further compared CORE's survey of ASCMs to those collected by the independent LiDAR verification survey in Fall 2023 (shared to Barr by EPA). Table 2-2 shows that data collected by the independent LiDAR verification survey in Fall 2023 generally agrees well with those from CORE, with the largest difference being 5.3 cm (range: 1.9 cm to 5.3 cm).

Table 2-2 Comparison between CORE's survey of ASCMs to independent LiDAR verification survey

ID	Type of benchmark	Published Elevation (m)	Fall 2023 survey (m)	EPA Difference (survey-pub., m)	CORE Difference (survey-pub., m)
07BJ001	WSC	N/A	591.023	N/A	N/A
733154	ASCM	590.938	590.965	0.027	0.064
143560	ASCM	587.455	587.733	0.278	0.331
98764	ASCM	584.978	583.951	-1.027	-1.008
33019	ASCM	580.767	579.828	-0.939	-0.903

Note: WSC=Water Survey Canada

2.2 River Cross Section Survey

Cross-section locations were selected to ensure adequate representation of the channel geometry in the hydraulic model. During the planning process for the survey, each cross section was assigned a number in an effort to organize the cross sections sequentially on each reach. However, cross section lines and associated survey points shown in Appendix A are labelled according to their river stationing (RS).

The Trimble RTK GNSS receivers used for the survey of cross sections are accurate to ±0.02 m (when the GNSS receiver is mounted to a tripod with a clear view of the sky and sufficient satellites to accurately establish the receiver position). The overall expected accuracy of ground-based survey points is ±0.05 m, except in areas with dense vegetation or steep banks where the satellite coverage is poor.

A total of 157 cross sections were surveyed with an average spacing of 150 m. Survey point data has been assembled and provided as part of the digital file submission. All cross sections along Swan River were surveyed by wading the channel and walking the banks. CORE ensured they surveyed enough details at each cross section to properly define the channel's geometry during the hydraulic modelling. Figure 2-1 shows a schematic view of the cross section survey completed.

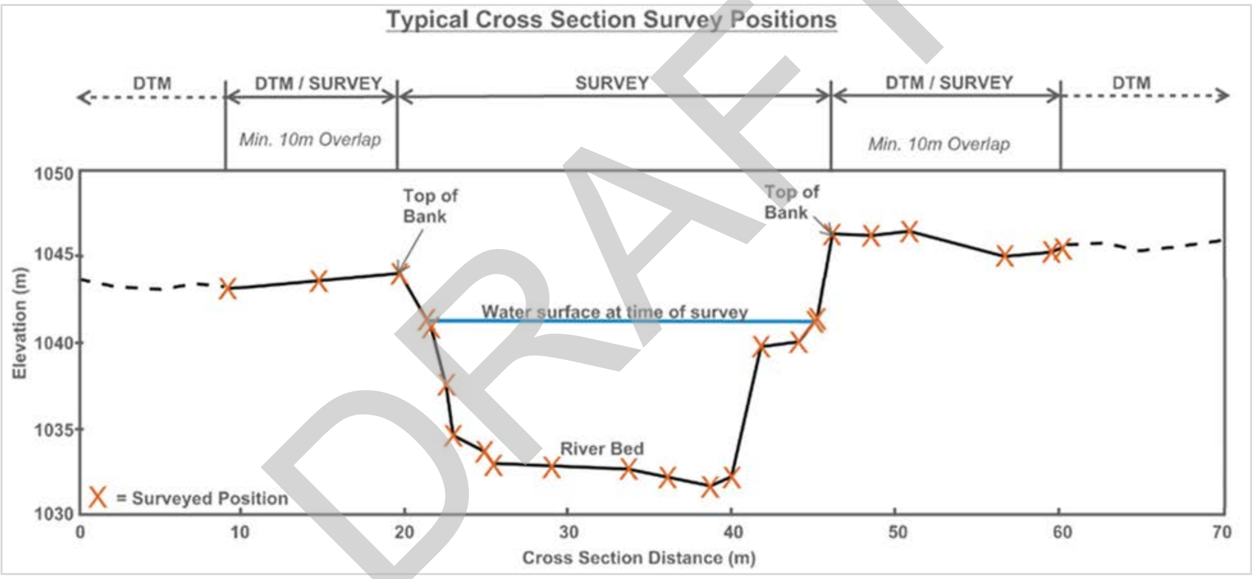


Figure 2-1 Schematic View of Cross-Section Survey

It is noted that the survey of Swan River was extremely challenging as banks stayed generally saturated and unstable during the survey, which made it difficult to climb. However, CORE managed to complete the survey of proposed cross sections as planned, with a longer than anticipated field campaign.

2.3 Discharge and Water Level Profile

The CORE survey crew collected discharge at two locations and water surface elevations at each cross section on Swan River for the purpose of low flow model calibration. Table 2-3 provides a summary of the discharge measurement data. Corresponding discharge from the WSC Station 07BJ001 (Swan River near Kinuso) is also included in Table 2-3 for comparison.

Table 2-3 Discharge Measurement Summary

River	Date	Discharge Measurement Location	Measured Discharge (m^3/s)	WSC Station 07BJ001 Discharge (m^3/s)
Swan River	09/14/2024	Swan River at approximately RS 14,400 m	3.38	3.67
	09/16/2024	Swan River at approximately RS 7,300 m	3.46	3.22

2.4 Hydraulic Structures

Table 2-4 summarizes the hydraulic structures in the study reach. A total of five bridges and 14 culvert crossings were identified and surveyed within the study area. Hydraulic structure locations are shown in Appendix A. Survey data for these structures has been assembled and provided as part of the digital study file; bridge and culvert details are provided in Appendix B.

Table 2-4 Summary of Hydraulic Structures

Location	Structure Type	Description	Corresponding Figure Number in Appendix B
Floodplain	Culvert	HWY 2 E1 Culvert	B1
Floodplain	Culvert	TWP Rd. 731A Culvert	B2
Floodplain	Culvert	HWY 2 W Culvert	B3
Floodplain	Culvert	HWY 2 E2 Culvert	B4
Floodplain	Culvert	Range Rd. 102 S Culvert	B5
Floodplain	Culvert	Range Rd. 102 N Culvert	B6
Floodplain	Culvert	5 St. Culvert	B7
Floodplain	Culvert	Railway Ave Culvert	B8
Floodplain	Culvert	Range Rd. 101A N Culvert	B9
Floodplain	Culvert	Railway Range Rd. 100 Culvert	B10
Floodplain	Culvert	Range Rd. 100 Culvert	B11
Floodplain/Strawberry Creek	Culvert	Unnamed Rd. Kinuso NW Culvert	B12
Floodplain	Culvert	HWY 2 Mid Culvert	B13
Floodplain	Culvert	Range Rd. 101 A S Culvert	B14
Floodplain/Eula Creek	Bridge	Railway E Bridge	B15
Swan River	Bridge	Swan River Railway Bridge	B16
Floodplain	Bridge	Railway NE Kinuso Bridge	B17

Location	Structure Type	Description	Corresponding Figure Number in Appendix B
Floodplain/Strawberry Creek	Bridge	Railway NW Bridge	B18
Swan River	Bridge	Swan River HWY 2 Bridge	B19

Data collected at each bridge includes:

- Length of span (corner points, abutment to abutment)
- Width of bridge (corner points, outside to outside)
- Top of curb or solid guard rail elevations
- Low chord elevations
- Number and width of piers
- Location of piers and the distance of each pier relative to the left abutment
- Type of piers (e.g., concrete, pile bent, steel column)
- Shape of piers (e.g., round nose, wedge, circular)
- Top of road surface profile
- Photographs of the bridge (as available)

Data collected at each culvert includes:

- Number of culverts
- Barrel length
- Culvert opening dimensions
- Upstream and downstream invert elevations
- Culvert type (e.g., corrugated steel pipe, concrete box, timber-framed)
- Culvert shape (e.g., circular, arch, elliptical, square, rectangular)
- Entrance condition (e.g., projecting from fill, mitered to conform to slope)
- Top of roadway profile
- Photographs of the culvert (as available)

2.5 Flood Control Structures

In collaboration with EPA and local authorities, Barr has confirmed that there is one official flood control structure (FCS) within the study area (Appendix C). This flood control structure consists of an earthen berm located on the east side of Kinuso. This berm is approximately 919 m long and was constructed in 1983 to prevent the Swan River from flooding into Kinuso.

2.6 Other Features

2.6.1 Site Photographs

Appendix D provides reach representative ground-level and drone-captured photographs obtained during the 2024 survey program, along with the profile views of cross section and water level surveys. The location, time, and other metadata information are embedded in the electronic images included as part of the digital file submission.

2.6.2 Aerial Imagery

Aerial imagery was acquired for EPA by OGL Engineering Ltd. on October 8th, 2023. Fully processed orthophoto mosaics were provided to Barr by EPA on September 27, 2024.

2.6.3 LiDAR Data

LiDAR topographic data was collected by LSI in October 2023 and provided by EPA to Barr on July 16, 2024. This dataset was verified by EPA to meet or exceed a vertical accuracy of ± 15 cm at 95%, on hard, flat, open (non-vegetated) surfaces, using independently collected survey data. The horizontal spatial reference system was 3TM 114, NAD83 (CSRS), Epoch 2002 and the vertical datum was CGVD28.

2.6.4 Other Base Mapping Data

In addition to the datasets mentioned above, other base mapping data were obtained to support modelling and mapping for the study, including road network, hydrography, administrative boundaries, topographic maps, interim 1 m LiDAR (bare-earth digital elevation model (DEM) and bare-earth hillshade) and 2022 SPOT6 1.5 m RBG imagery (provided to Barr by EPA on April 5, 2024), and Alberta Township System (ATS) grids within the study area.

3 Open Water Hydrology Assessment

This section provides a summary of the open water hydrology assessment for the study. A more detailed assessment of open water hydrology is provided in Appendix E.

3.1 Flooding History

3.1.1 General Information

The Swan River drains an area of approximately 3,000 km^2 (LSWC, 2009), originating from the Swan Hills and flowing north to its terminus at Swan Point on Lesser Slave Lake (LSL), about 12 km northeast of the Town of Kinuso (Figure 3-1). The river has a tortuously meandering channel pattern and is incised within a delta deposit and floodplain. The channel is perched, and ground elevation generally drops away from the river, particularly in the east and northeast of Kinuso. Significant channelization of the Swan River is evident downstream of Kinuso, with five previous meanders eliminated by cutoffs constructed in 1983 and 1984. The Swan River slope within the study area is quite gentle (~0.005 m/m).

3.1.2 Open Water Floods

Swan River has a detailed and rich history of flooding within the last century. Since 1961 there have been eight events on the Swan River exceeding the 10-year event of 470 m^3/s. Based on the available flow data, there are years where flooding occurred several times, but the significant recent flooding was in June 2018 and July 2024. As described further in Section 4.1.2, HWM data has been provided by EPA for eight events since 1979.

3.1.3 Ice Jam Floods

No ice jam flood information was found on Swan River within the study area.

3.2 Open Water Flood Frequency Analysis

A flood frequency analysis was carried out to determine estimates of flood frequencies for a range of return periods up to 0.1% annual exceedance probability (AEP). Details on the flood frequency analysis are provided in the Technical Memorandum on Open Water Hydrology Assessment in Appendix E.

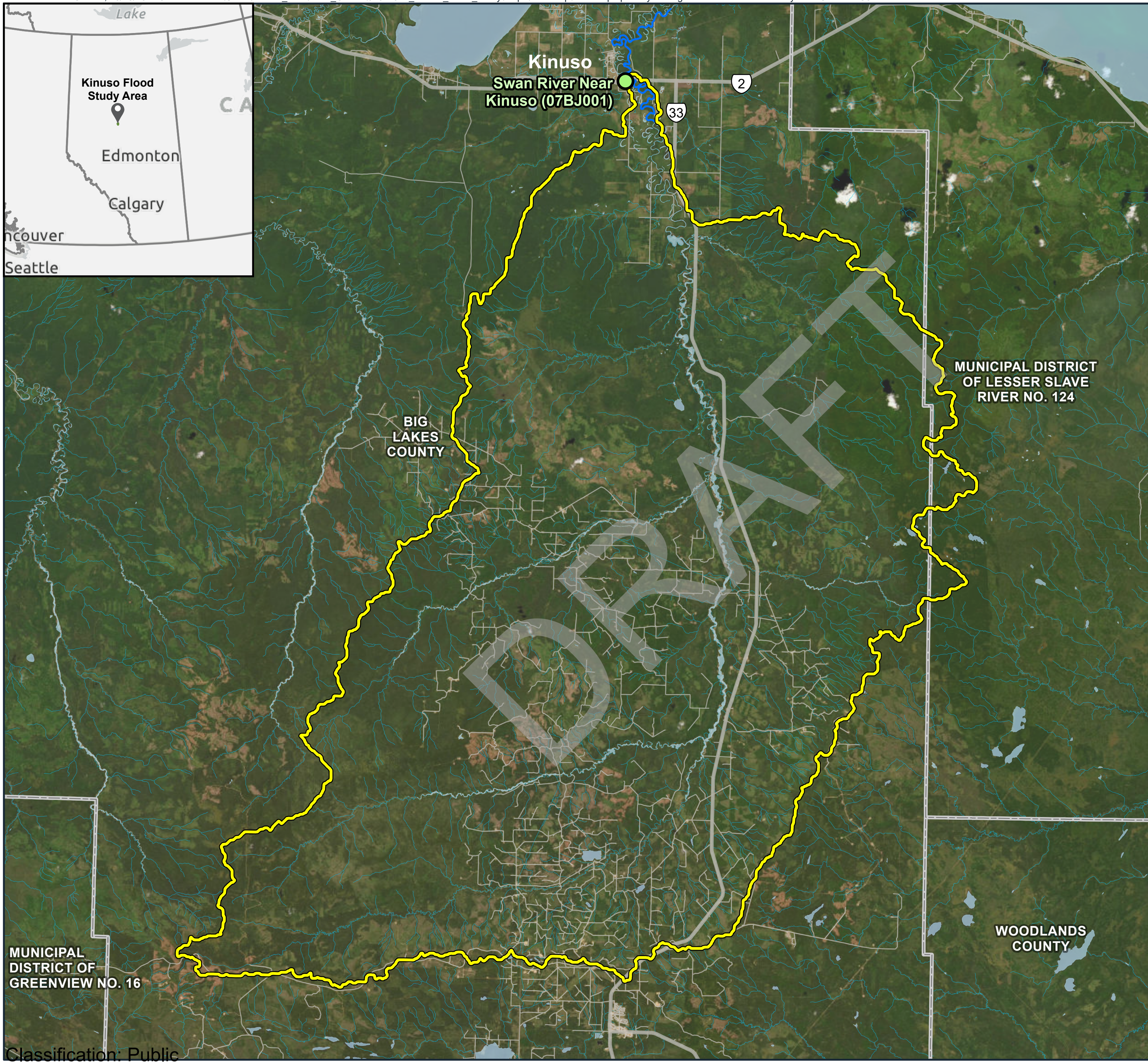
3.2.1 Flood Frequency Flow Estimates

There is a Water Survey of Canada (WSC) hydrometric station on the Swan River near Kinuso at the Highway 2 Bridge (07BJ001). The drainage area of the WSC gauge is 1,902 km^2 based on the delineated watershed area for this study. The gauging station has monitoring data over two periods. The gauge was first established in 1915 and operated only until 1917 (i.e., 3 years), for which no instantaneous annual peak flow is available. The gauge was then reestablished in 1961 and has remained in operation to the present time. Due to the presence of a significant gap between two monitoring periods and to ensure consistency in the peak flow data, the recorded data from 1961 to 2024 was used for flood frequency analysis and generating flood hydrographs.

Flood frequency analysis was performed for the Swan River near Kinuso using annual instantaneous peak flows from the WSC hydrometric station on the Swan River near Kinuso at the Highway 2 Bridge (07BJ001). Given the robustness of the Bulletin 17C method in flood frequency analysis, Barr recommended the Bulletin 17C results in generating flood hydrographs for the two-dimensional (2D) hydraulic model of the Swan River in the Kinuso Flood Study. Table 3-1 summarizes the recommended flood frequencies for use in the hydraulic modelling.

Table 3-1 Final Flood Frequency Estimate Recommended to be Used in the Hydraulic Model

AEP	Computed Peak Flow (m^3/s)
1:2	232
1:5	373
1:10	470
1:20	564
1:35	639
1:50	687
1:75	740
1:100	778
1:200	870
1:350	943
1:500	990
1:750	1,044
1:1,000	1,082



LEGEND

- Watershed Boundary
- WSC Hydrometric Gauge
- Kinuso River Centreline
- NHN Flow Line
- Waterbody
- Other Road
- Primary Road
- Municipal Boundary

Notes:
Watershed boundary for WSC gauge 07BJ001 (Swan River near Kinuso) was obtained from Alberta Flow Estimation Tool for Ungauged Watershed (afetuw.alberta.ca) and is based on a coarse digital elevation model.

References
Roads and Waterbodies: Altalis, all rights reserved.
Coordinate System: NAD 1983 CSRS 3TM 114.
National Hydro Network (NHN): Government of Canada.
Imagery: ESRI (2023).

0 5 10
Kilometers

Scale: 1:380,000

Study Area Watershed
Kinuso Flood Study
Alberta Environment and Protected Areas

FIGURE 3-1

Classification: Public

3.3 Hydrograph Generation for Flood Scenarios

Given the unique nature of the floodplain topography around Kinuso and the anticipated challenges with modelling and mapping realistic flood extents, EPA considered deviating from its standard steady-state or quasi-steady-state modelling approach to avoid any overly conservative prediction of the inundated areas. An unsteady state hydraulic model requires an inflow hydrograph as an upstream boundary condition to the hydraulic model. As a result, additional hydrologic analysis was completed to develop appropriate hydrographs for all modelled flood scenarios. Two methods of analysis were used for developing the inflow hydrographs. The first method (Method 1) was based on the use of a pattern hydrograph and a critical duration for the flood hydrographs observed in the Swan River near Kinuso. The second method was the USACE balanced hydrographs. Both methods incorporated some variation of flood volume frequency analysis of the daily flow data recorded at the WSC gauge near Kinuso. Both methods also used the 1996 flood hydrograph recorded at the WSC gauge as the pattern hydrograph for developing flood hydrographs with different AEPs. The 1996 flood is the highest recorded flood on the WSC gauge on the Swan River near Kinuso. The peaks of the resulting flood hydrographs were further adjusted to match the results of the flood frequency analysis on the instantaneous peak flows. After further evaluation, it was determined that the flood hydrographs developed using Method 1 appear to be more suitable for the flood mapping study. Therefore, it is recommended to use the hydrographs developed using Method 1 for the 2D model of Kinuso Flood Study. For more details on each method and developed hydrographs, see Appendix E.

4 Open Water Hydraulic Modelling

The following sections describe the methodology and results of the open water hydraulic modelling component. The scope of this component includes a summary of available data and stream/valley features in the study area, hydraulic model setup, hydraulic model calibration and validation, selection of Manning's *n* roughness values, sensitivity analysis, and generation of open water flood frequency profiles. The results of this component are used in the flood inundation mapping, flood hazard identification, and governing design flood hazard mapping components.

4.1 Available Data

The data available to develop and calibrate the hydraulic model are described below.

4.1.1 Digital Terrain Model

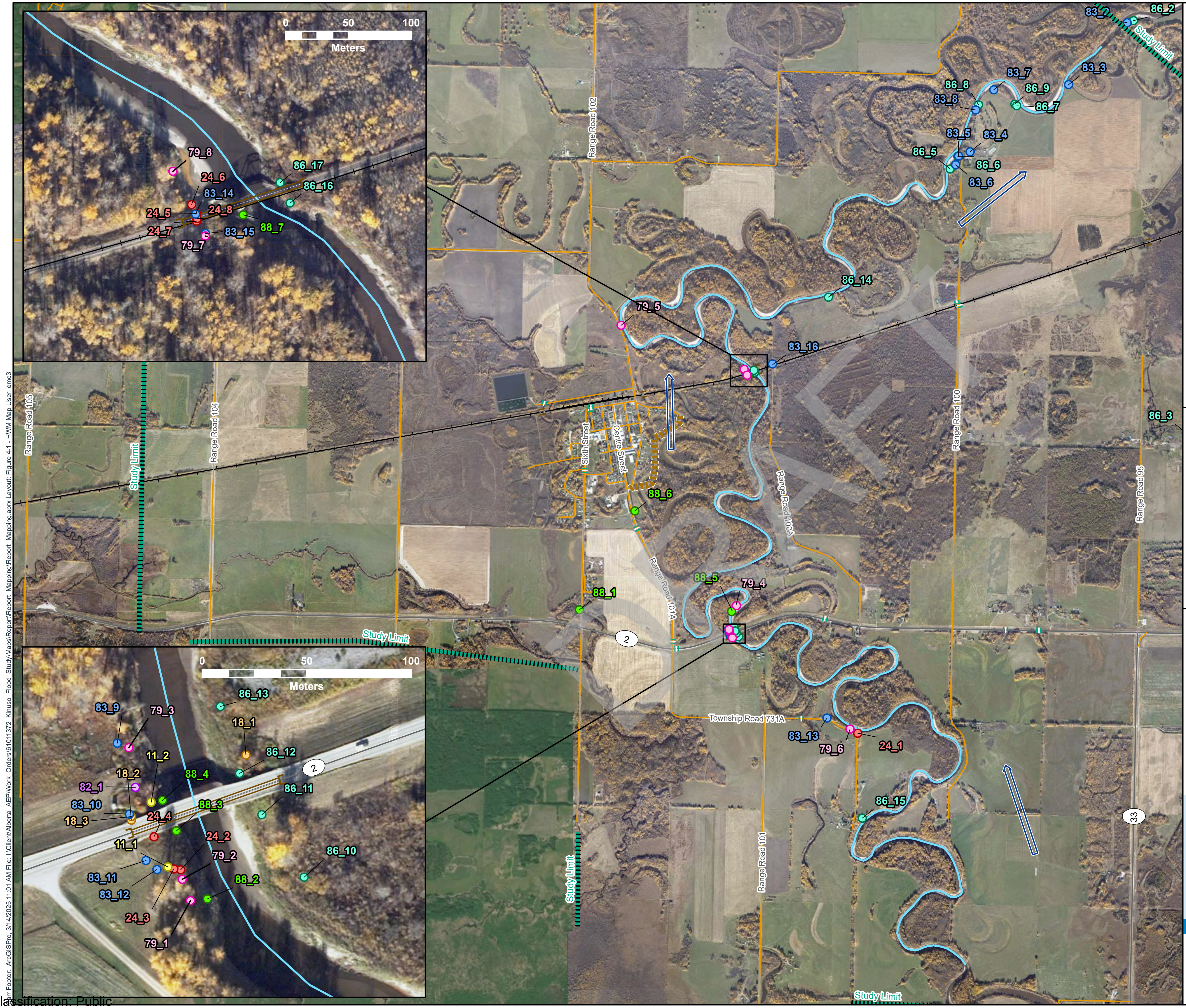
Digital Terrain Model (DTM) data was provided by EPA for this study. The DTM was derived from a survey-verified high-accuracy Light Detection and Ranging (LiDAR) remote sensing data set acquired by LSI in October 2023.

4.1.2 Highwater Marks

There is a strong history of highwater mark (HWM) data available along the study reach of Swan River. EPA provided HWM reports dating from 1979 to 2024. Table 4-1 summarizes the past flood events and number of HWM collected. The locations of the highwater marks used are shown in Figure 4-1.

Table 4-1 Swan River HWM Summary

Date	Peak Flow (m3/s)	Number of Highwater Marks
07/02/1979	362	8
08/04/1982	200	1
06/26/1983	571	13
07/19/1986	332	13
07/07/1988	654	6
06/25/2011	582	2
06/13/2018	637	3
07/27/2024	475	8



LEGEND

- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- STREAM CENTERLINE

HIGHWATER MARK YEAR

- 1979
- 1982
- 1983
- 1986
- 1988
- 2011
- 2018
- 2024

0 1 2
KILOMETRES
SCALE: 1:33,000

REFERENCES

ORTHOPHOTO IMAGERY ACQUIRED BY OGL ENGINEERING FOR ALBERTA ENVIRONMENT AND PROTECTED AREAS: OGL ENGINEERING (2023). ESRI IMAGERY SOURCED BY MAXAR (2023).

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

Alberta
Canada

KINUSO HWM
KINUSO FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS

FIGURE 4-1

BARR

4.1.3 Gauge Data and Rating Curve

There is a WSC hydrometric station on the Swan River near Kinuso (07BJ001) within the study at the Highway 2 bridge. The rating curve was obtained from WSC on September 16, 2024. This rating curve was created in 2018 as version 26 and has since been updated in 2024. In addition to the derived rating, the measured data was also sourced from WSC. The derived rating curve and associated measured data are shown in Figure 4-2.

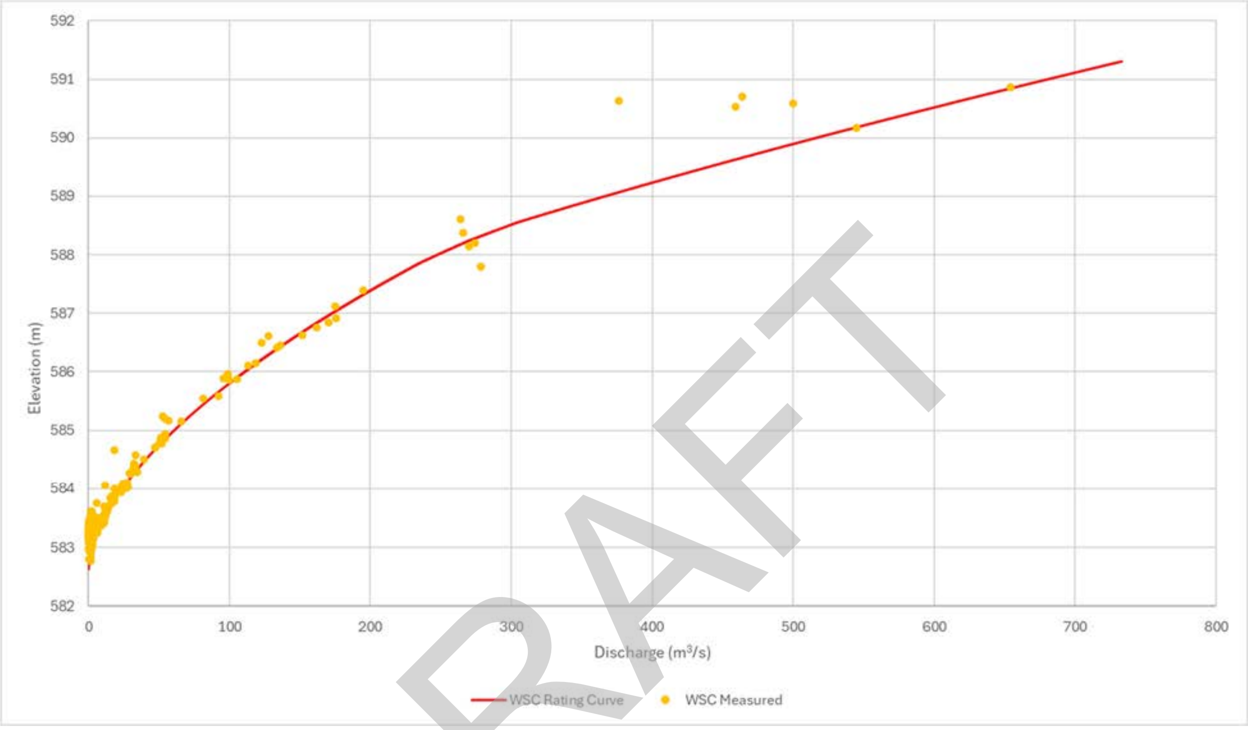


Figure 4-2 Swan River near Kinuso (07BJ001) Rating Curve and Measured Data

4.1.4 Flood Photography

EPA provided aerial photography from 1983, 1986, and 1988. The 1983 photography is the most intensive, with numerous pictures of channel and floodplain conditions. Key locations include the Highway 2 bridge, railway bridge, and several erosion sites.

4.2 River and Valley Features

4.2.1 General Description

The Swan River flows northward through the boreal forest of Alberta and eventually empties into Lesser Slave Lake, which is part of the Athabasca River basin. The river has a tortuously meandering channel pattern and is incised within a delta deposit and floodplain. The channel is perched, and ground elevation generally drops away from the river, particularly in the east and northeast of Kinuso. Significant channelization of the Swan River is evident downstream of Kinuso, with five previous meanders eliminated by cutoffs constructed in 1983 and 1984.

4.2.2 Channel Characteristics

The Swan River channel is relatively deep, with steep channel banks. The channel bottom is dominated by soft sediment, and woody debris is common. The river itself has a high degree of meandering and is incised within the floodplain. Through the study reach, the channel characteristics remain relatively constant. The average channel width is approximately 35 m, and the overall reach average channel slope is 0.0005 m/m. The numerous oxbow lakes and meander scars within the study area provide evidence of the rivers near-constant lateral movement.

4.2.3 Floodplain Characteristics

The floodplain surrounding Swan River generally slopes down parallel from the perched river. Close to the river, oxbow lakes and dense brush dominate the floodplain. As the distance from the river increases, the land cover transitions to a mix of cultivated cropland and brush.

4.2.4 Anthropogenic Features

The Hamlet of Kinuso is located 233 km NW of Edmonton in Big Lakes County, alongside the Swan River First Nation. A total of 19 hydraulic structures (e.g. bridges, culverts) have been documented within the study reach. Two of these structures are located on the Swan River, while the remaining are located within the floodplain. Details on these hydraulic structures are provided in Appendix B.

4.3 Model Construction

4.3.1 Methodology

The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center-River Analysis System (HEC-RAS) computer program (Version 6.6, September 2024) was used to calculate the flood levels along the study reach. HEC-RAS can perform one-dimensional (1D), two-dimensional (2D), or combined 1D and 2D hydraulic calculations for a network of channels and hydraulic structures. Previous EPA investigations of Swan River flood potential in the Kinuso area indicated that the channel is perched within a delta and that 1D modelling may not be able to adequately define flood levels or resolve flood extents through the floodplain when the Swan River overtops its banks. Therefore, a full 2D model was selected for the following reasons:

- The Swan River channel is highly meandering, and flood flows will likely utilize multiple flow paths on the floodplains on both sides of the stream with many ineffective flow areas. This complex, overland flood flow can be handled more accurately using a 2D model than a 1D model. Additionally, the 2D model will estimate the flood flow depths and velocities more accurately for mapping purposes and will create better delineation between the flood fringe and floodway.
- A fully 2D model will eliminate or greatly reduce the chance of profile crossings at locations where ineffective flow areas would be activated due to overtopping of roads, levees, or flood control structures. This is particularly important for this study as there are numerous oxbow lakes and distributary channels on both sides of the Swan River that might be activated during high flows.
- Depending on the location of highwater marks, a 2D modelling approach for the floodplain will allow more accurate highwater mark calibration for individual points on the floodplain.

4.3.2 Model Setup

4.3.2.1 Model Domain

Using a single geometry file to simulate floods of various return periods is generally desirable. Therefore, the model domain needs to be defined to cover the inundation extents of the largest flood event to be simulated. The model domain extent was defined considering the simulation results of a supplemental rough HEC-RAS 2D model, which was set up based on the LiDAR DEM without the inclusion of the channel bathymetry, to provide conservative water level estimates. Figure 4-3 shows the model domain.

4.3.2.2 2D Model Mesh

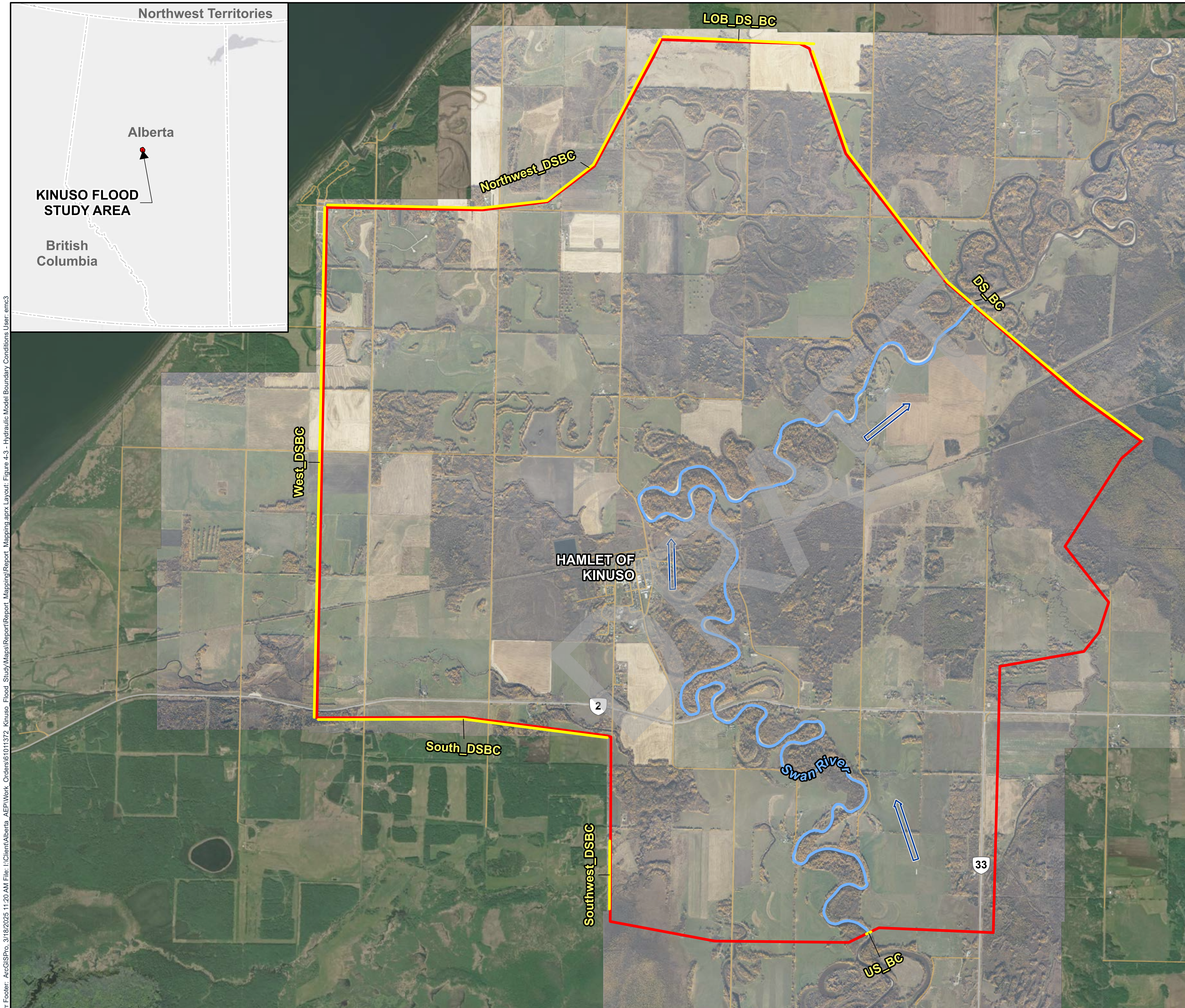
A refined mesh system was utilized in the model with a base cell size of 10 m in the channel. Three breaklines were used in the model–a channel centerline and two banklines–to ensure computation accuracy for the main channel and properly capture the banks in the model. Moreover, extra attention was paid to transition the mesh smoothly to coarser mesh sizes on the floodplain. The largest cell size on the outer floodplain in the 2D model is 30 m × 30 m. Local refinements along key structures, side channels, ponds, and high grounds were implemented in the model. Some of the key linear structures in the 2D domain were set up as weirs to more accurately simulate the flow pattern near those structures. These structures include the flood control berm, Highway 2, the railway, and several large local roads. A total of approximately 24 km of Swan River was modelled in this study, with the floodplain extending over 5 km in some directions. Figure 4-4 provides a detailed view of a section of the model.

4.3.2.3 Boundary Conditions and Other Inflows

The 2D HEC-RAS models require the specification of boundary conditions at all open and internal boundaries. The open boundaries of the hydraulic model are listed below.

- Discharges at the upstream model boundary of the Swan River
- Normal flow condition (with an estimated energy slope of 0.05%) at the downstream model boundary of the Swan River
- Normal flow condition (with an estimated energy slope of 0.05%) at five model boundaries of the floodplain

The hydraulic model boundary conditions are shown on Figure 4-3.



LEGEND

- STUDY AREA
- FLOW DIRECTION
- HYDRAULIC MODEL BOUNDARY CONDITION LINE
- SWAN RIVER
- SECONDARY HIGHWAY
- LOCAL ROAD

0 1 2
KILOMETRES
SCALE: 1:50,000

REFERENCES

ORTHOPHOTO IMAGERY ACQUIRED BY OGL ENGINEERING FOR ALBERTA ENVIRONMENT AND PROTECTED AREAS: OGL ENGINEERING (2023). ESRI IMAGERY SOURCED BY MAXAR (2023).

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

Alberta
Canada

HYDRAULIC MODEL BOUNDARY CONDITIONS
KINUSO FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS
FIGURE 4-3

BARR

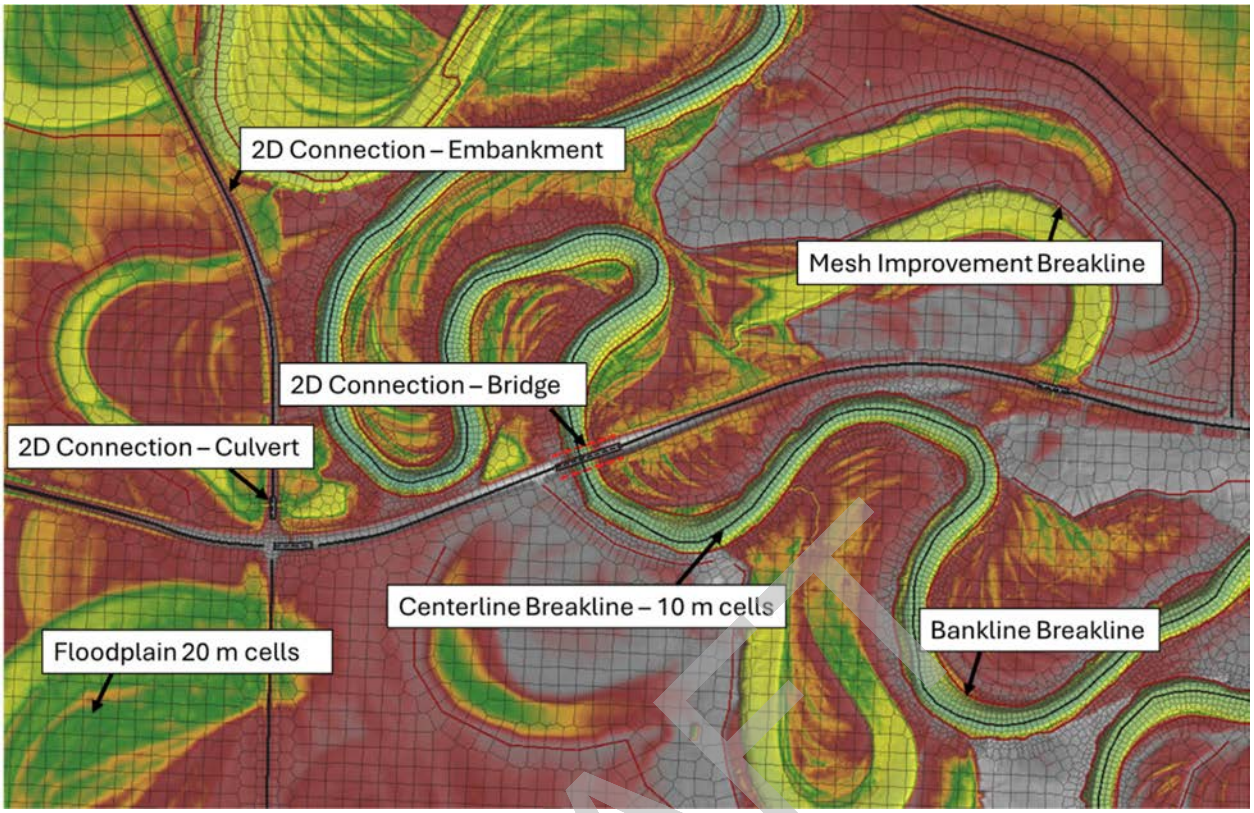


Figure 4-4 An Example of a 2D Model

4.3.2.4 Modelling Methodology

As described earlier, the development of hydrographs was required for the hydraulic modelling of the Kinuso Flood Study due to the unique nature of the Swan River channel and its wider floodplain. Appendix E explains the methodologies used to derive the hydrographs for the flood frequency peak discharges in detail. When the hydrographs were developed, several sensitivity analyses were performed in the HEC-RAS model, and results were extensively discussed with EPA to select a modelling methodology that best suits this unique study. The main question was whether a quasi-steady-state simulation or an unsteady-state simulation should be used for flood mapping which reflects ground conditions. Barr selected 100-year and 1,000-year flood events and simulated multiple scenarios (a total of 10 scenarios), as listed below:

- Quasi-steady-state simulations using the peak flows estimated from flood frequency analysis
- Unsteady-state simulations using hydrographs developed as part of hydrology assessment with a:
    - 6-hour sustained peak flow
    - 3-hour sustained peak flow
    - 1-hour sustained peak flow
    - no sustained peak flow

As expected, the quasi-steady-state simulation resulted in the greatest inundation extent. The 6-hour sustained peak was, however, only slightly smaller. With the remaining sustained peak further decreasing from the 6-hour sustained peak. Reviewing the inundation results from the above-mentioned 10 scenarios and discussions with EPA, it was decided to use an unsteady-state modelling methodology with a 6-hour sustained peak flow. This was to achieve more realistic flood routing and attenuation on the Swan River floodplain and a reasonable flood mapping.

4.3.2.5 Numerical Details

Based on the modelling approach selected (as explained above), the HEC-RAS model required an unsteady-state numerical solver. A robust solver available in HEC-RAS was selected for computation: SWE-LIA. Shallow Water Equations with a local inertia approximation approach uses a simplified momentum equation. The LIA equation solution method is a reasonable balance between efficient run times and numerical accuracy. In general, this solver captures changes in water surfaces and velocities at and around hydraulic structures, piers/abutments, and tight contractions and expansions, better than the diffusion wave solver in HEC-RAS.

A refined mesh system was used to balance between accuracy and computational cost. A total of approximately 128,740 cells were used in the model. Modelling started with a uniform coarse mesh of 30 m × 30 m for the floodplain. It was reduced to 10 m × 10 m for the river channel to ensure mesh independency in water level results and the accuracy of the model. Mesh independency testing was completed and determined that a finer mesh of 7 m x 7 m would not significantly change the model results (i.e., change of smaller than 2% in water levels and velocities). Given the computational cost of a finer mesh, the 10 m x 10 m refinement was selected.

Breaklines and weirs were used in the 2D model where needed. Table 4-2 summarizes the numerical details of the HEC-RAS model.

Table 4-2 Model Numerical Details

Parameter	Value
Fully 2D Reach Length (km)	23.7
Computational Solver	SWE-LIA
Timestep (s)	4/2 [1]
Approx. Simulation Time (hr.)	4
Number of Cells in 2D Domain	128,740
Smallest Cell Size (m)	3
Largest Cell Size (m)	30
Number of Breaklines	143
Number of 2D Connections (2D hydraulic structures and weirs on major roads)	77

1 An advanced time step control was used to reduce the timestep from 4 seconds to 2 seconds during the peak of the hydrograph.

4.3.3 Geometric Data Base

The geometric data base provides all of the components of the HEC-RAS model geometry, including cross sections, 2D model domain and mesh, roughness, and hydraulic structures. Each component is described below.

4.3.3.1 2D Model Terrain

A composite surface of surveyed cross sections (for the main channel) and high resolution DTM (for the floodplain) were used as terrain in the model. A Barr-developed GIS tool, which utilizes the surveyed cross sections to create interpolated intermediate cross sections, was used to create the composite surface. The tool defines the distance between the interpolated cross sections, which allows it to accurately capture the geometry of the channel. The cross sections were then used to create a Triangulated Irregular Network (TIN) surface within the bank toes, which was then converted to a channel bathymetric DTM. This raster was finally mosaicked into the floodplain DTM to create a final model surface. Special attention was paid to inspecting the composite surface for accuracy and anomalies, as it was the basis for modelling and mapping. Figure 4-5 shows an example of a composite surface created to be used in the HEC-RAS model.

It is noted that bank toes were delineated and mostly used for bounding the TIN surface and bathymetric surface creation instead of banklines that are usually used for this purpose. This was to eliminate any artifacts introduced due to the steep banks of the Swan River in the creation of TIN surfaces. Moreover, the high-resolution DTM was used to exclude numerous point bars and cutbanks from the extent of the TIN surface creation as it sometimes produced artificial point bars in between cross sections. Finally, it is noted that the Swan River is a highly mobile river system, both laterally and in bed sediment transport. Figure 4-6 shows signs of changes of approximately 3-km of the Swan River reach from RS 18,500 m to 15,500 m within one year. Swan River experiences frequent summer flooding, the last one being on July 27, 2024. The estimated flood peak discharge was 477 m^3/s. This corresponds to approximately a 10-year return period. It is, therefore, important to consider uncertainties in using the terrain data of the Swan River and its immediate overbank areas.

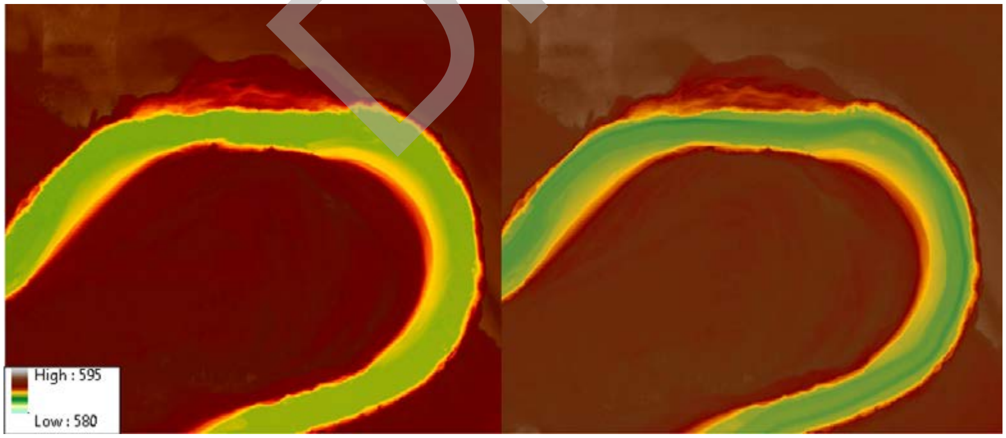
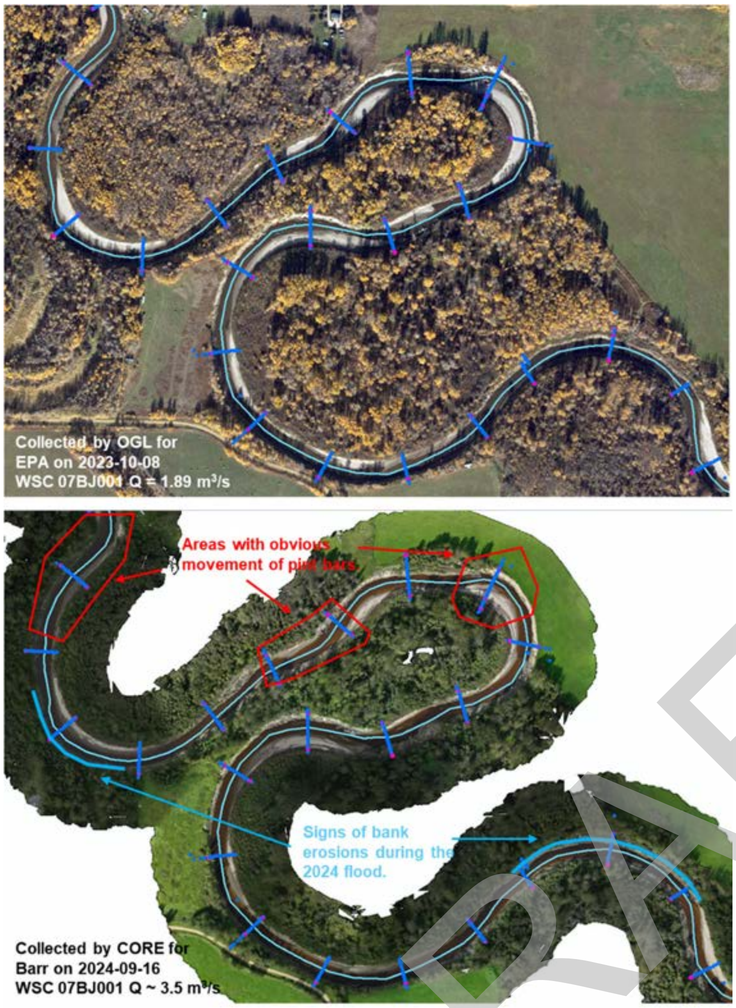


Figure 4-5 Comparison of the LiDAR DTM (left); Same Area with the Channel Bathymetry Tied into the DTM (right)



Top: 2023 Image, Bottom: 2024 Image

Figure 4-6 Changes of Swan River Due to 2024 Flood

4.3.3.2 Roughness Coefficients

Manning's n values were specified using the distributed roughness approach, which allows for multiple, varying roughness values within the study area. The initial roughness distribution was specified based on the following data.

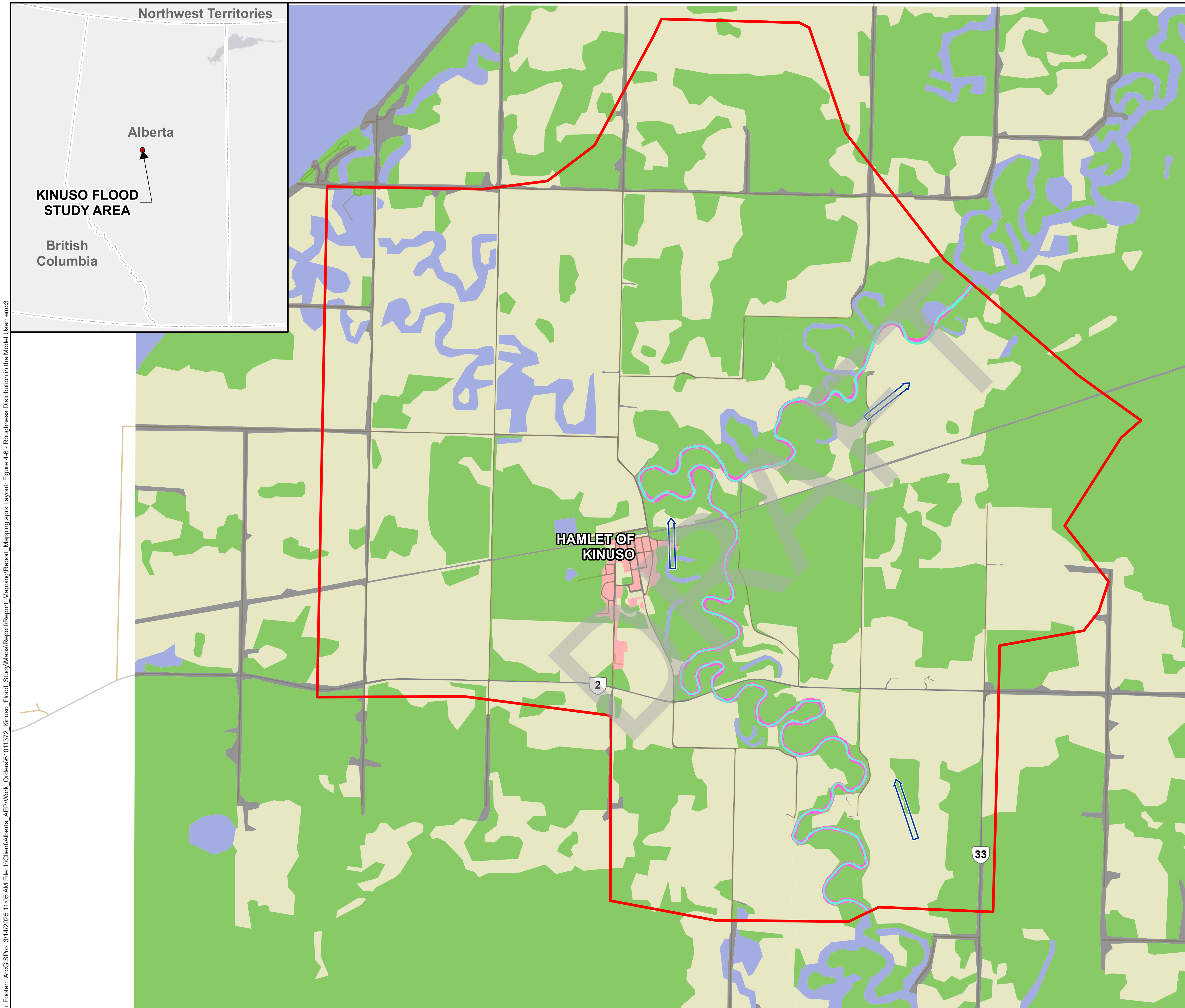
- Bed and banklines established from the LiDAR data, aerial imagery, and surveys to identify the main channels
- Land use information from the Government of Alberta

Model construction began with a single roughness value for the channel ranging from 0.03 and 0.05. In the process of calibration, it was decided that a composite two-layer channel roughness layer would represent the river system more accurately. The Swan River has tall banks that are often heavily vegetated, which contrasts sharply with the smoother sediments making up the channel bottom. Therefore, assigning two different roughness values for these areas increased the accuracy of the model.

Seven roughness classes were used for the model setup. The initial Manning’s n values assigned to the classes are listed in Table 4-3. These initial values were selected based on channel bed materials and vegetation types (Chow 1959; USACE 2024). The distribution of the roughness classes is shown in Figure 4-7.

Table 4-3 Roughness Classes and Initial Manning's n Values

Roughness Class	Initial Manning’s n Values
Swan River Bed	0.035
Swan River Bank	0.045
Grassland and Farmland	0.05
Developed – Residential	0.08
Roads	0.025
Brush and Forest	0.12
Lakes and Ponds	0.03



LEGEND

- STUDY AREA
- FLOW DIRECTION
- SECONDARY HIGHWAY
- LOCAL ROAD
- BRUSH AND FOREST
- DEVELOPED - RESIDENTIAL
- GRASSLAND AND FARMLAND
- PONDS AND LAKES
- ROADS
- SWAN RIVER BANK
- SWAN RIVER BED

N

0 1 2
KILOMETRES
SCALE: 1:50,000

REFERENCES
BASE DATA FROM ALBERTA ENVIRONMENT AND PROTECTED AREAS.

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LANDCOVER DATA FROM ALBERTA BIODIVERSITY MONITORING INSTITUTE.

DATUM: NAD 83 CSRS PROJECTION: 3TM 114

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LAND USE DISTRIBUTION IN THE MODEL
KINUSO FLOOD STUDY
ALBERTA ENVIRONMENT AND PROTECTED AREAS
FIGURE 4-7

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4.3.3.3 Hydraulic Structures

4.3.3.3.1 Bridges

The bridge geometries used in the HEC-RAS model were defined based on the river and bridge surveys conducted in 2024 (see Section 2). The bridge deck, pier, and abutment information were included in the model. Losses through bridges were calculated in the model using the energy equation (i.e., standard step method). Flows over the bridge and approach embankment were calculated using the standard weir equation. Since a 2D approach was used in the model, there was no need to identify the ineffective areas for bridge constrictions. The initial values of the contraction and expansion coefficients at the bridge were selected to be 0.3 and 0.5, respectively. These are typical values listed in the HEC-RAS User Manual. A total of five bridges were implemented in the model as 2D connections under the bridge classification. Two bridges are located on the Swan River channel and three are located in the wider floodplain.

4.3.3.3.2 Culverts

Based on the survey data, the culverts were represented in the HEC-RAS model. The pertinent culvert information, including size, length, and upstream and downstream invert elevations, was specified in the model. Culvert entrance loss coefficients of 0.5, 0.7, and 0.9 were used depending on the culvert inlet configuration. An exit loss coefficient of 1 was used for all culvert structures. A total of 14 culverts were implemented in the model. All culverts are located in the floodplain of the Swan River.

4.3.3.3.3 Weirs and Dams

There are no weirs or dams in the study area.

4.3.3.3.4 Flood Control Structures

One flood control berm is located east of Kinuso in the study area. This structure was modelled as a 2D connection which incorporated the surveyed profile into the model. A weir coefficient of 1.45 was selected to represent the broad-crested weir overflow condition. A summary of the flood control structure is provided in Appendix C.

4.3.4 Model Calibration

4.3.4.1 Methodology

Generally, in flood models, the Manning's n and contraction/expansion coefficients are the two primary model calibration parameters. Selection of initial Manning's n values included consideration of river bed/bank materials, vegetation cover, site information collected during the field inspection, and experience from previous hydraulic modelling studies. Manning's n values may reduce with increased stage.

There is a rich history of HWM available for Swan River within the study area, and therefore, a high flow calibration was completed. In addition to the HWMs, the surveyed water levels and measured discharges during the river survey were used for the low flow calibration.

The model calibration process involved multiple iterations to adjust the model parameter values, conduct simulations, and compare the simulated water levels to the surveyed water levels or HWMs. The objective of the model calibration was to achieve good matches between the simulated water levels and measured water levels or HWMs.

4.3.4.2 Low Flow Calibration

Initial channel roughness used for Swan River during the model construction was based on our team's understanding of the main channel condition from the site visit, past project experiences, and previous EPA investigations. The channel roughness values were then calibrated based on the water level and discharge data from September 14 and 16, 2024. Two discharges were measured on Swan River at river stations 14,400 m and 7,300 m, with values of 3.67 m^3/s and 3.22 m^3/s, respectively.

Figure 4-8 and Figure 4-9 compare the simulated water surface profiles to the surveyed water levels for the surveyed low flow conditions. The average difference between simulated and surveyed water levels (simulated minus surveyed) was 0.03 m for both measurement days (September 14 and 16). The average difference between simulated and surveyed water levels (simulated minus surveyed) for all water levels (surveyed over multiple days) was 0.04 m and 0.00 m for September 14 and 16, respectively. The calibrated channel Manning's value was a composite of 0.04 for bed and 0.045 for the banks during both September 2024 low flow events.

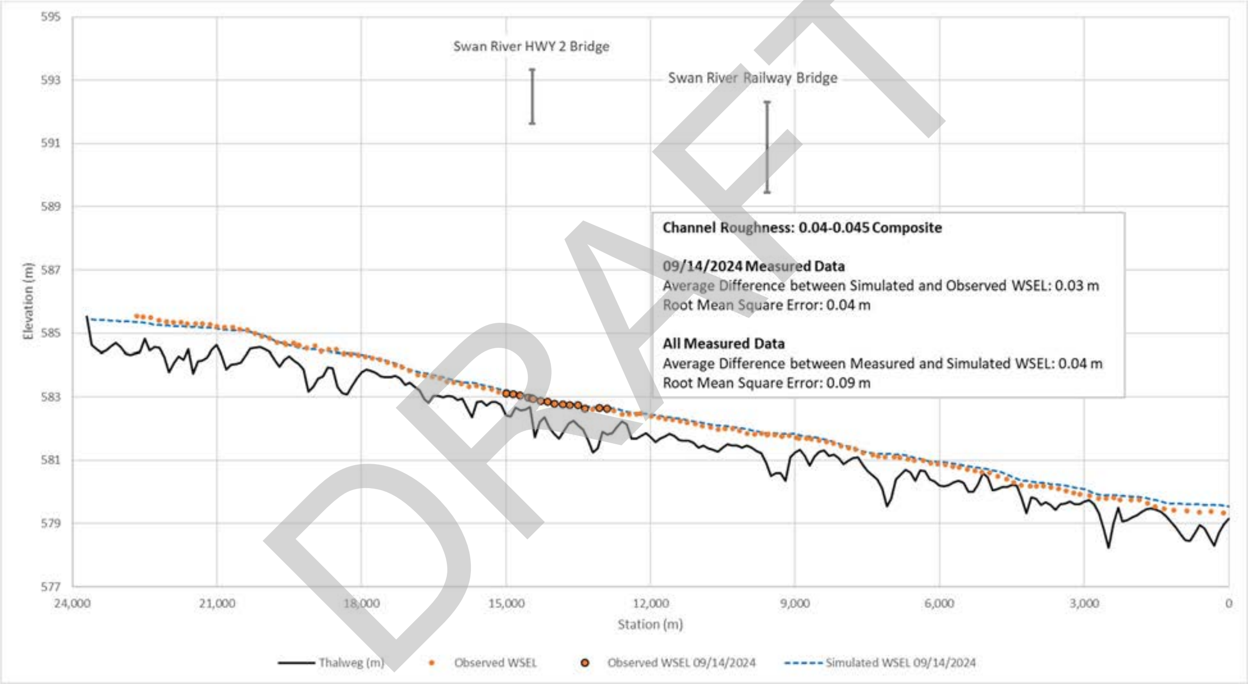

Figure 4-8 Low Flow Calibration Results for 09/14/2024

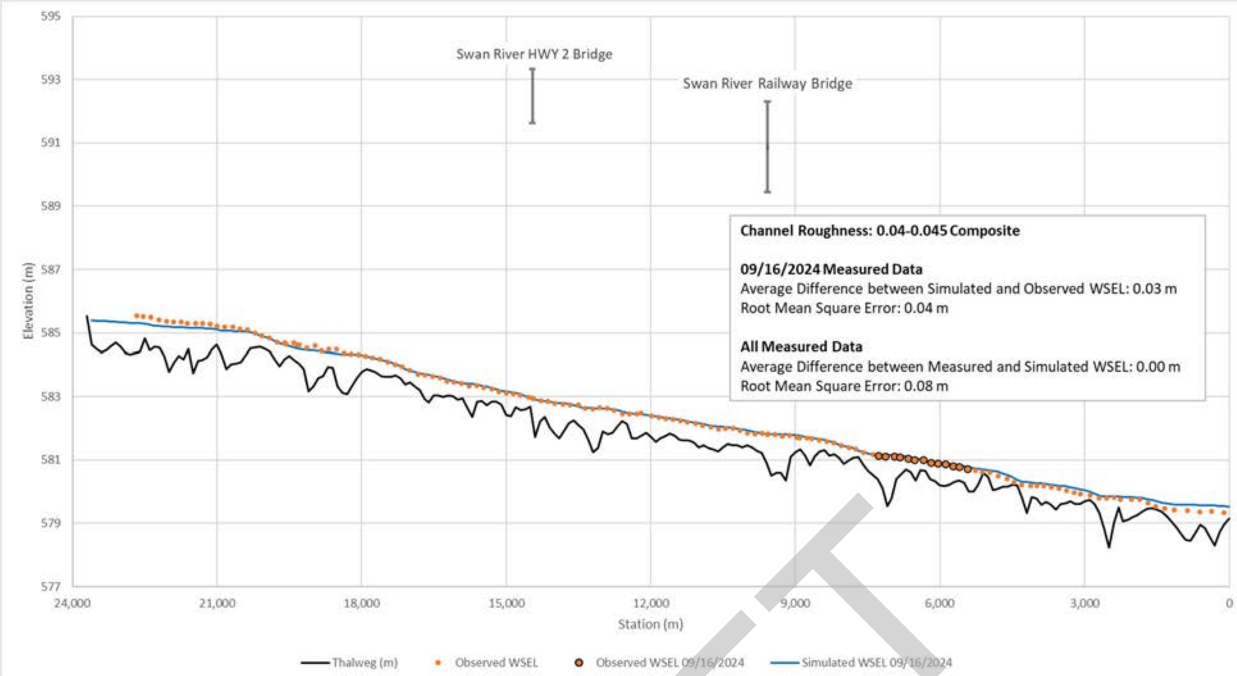

Figure 4-9 Low Flow Calibration Results for 09/16/2024

4.3.4.3 High Flow Calibration

The HEC-RAS model was calibrated based on eight flood events (1979-2024), as listed in Table 4-1, with an emphasis on more recent events. The calibration to each year is described in the sections below. The profiles of simulated water level and observed HWMs are shown in Figure 4-10 to Figure 4-17.

1979 Flood

The estimated flood peak discharge for 1979 was 362 m^3/s. This corresponds to approximately a 5-year return period. Table 4-4 shows the comparison of simulated water surface elevation (WSEL) and surveyed HWMs from the 1979 event. The average difference between simulated and observed data was - 1.52 m with a RMSE of 1.54 m. This represents a relatively consistent underestimate of water surface elevation compared to the measured HWMs. This discrepancy could be attributed to the 46 years of channel movement, straightening, and degradation.

Table 4-4 Comparison of Simulated and 1979 Surveyed HWM along the Swan River Study Reach

HWM ID	Approximate Station (m)	HWM Description	Observed WSEL (m)	Simulated WSEL (m)	Diff. (Sim. – Obs.) (m)
79_1	14,490	Channel bank, 36 m US of HWY 2 B	590.08	588.80	-1.28
79_2	14,476	Channel bank, 25 m US of HWY 2 B	590.08	588.80	-1.28
79_3	14,415	Channel bank, 30 m DS of HWY 2 B	590.13	588.72	-1.40
79_4	14,190	Channel bank, 250 m DS of HWY 2 B	590.12	588.66	-1.46
79_5	7,300	Channel bank, ~ 2km NW of Railway B	588.13	586.18	-1.95
79_6	17,875	Channel bank	591.26	589.92	-1.34
79_7	9,600	Bank/almost floodplain, 14 US of Railway B	588.68	586.96	-1.72
79_8	9,530	Channel bank, 37 m DS of Railway B	588.68	586.95	-1.73

1982 Flood

The estimated flood peak discharge for 1982 was 200 m^3/s. This corresponds to less than a 2-year return period. Table 4-5 shows the comparison of simulated water levels and surveyed HWM from the 1982 event. Only one HWM in 1982 shows an underestimate of water level by 1.47 m. Like 1979, the 1982 event is quite old and relatively small, making the changes in channel geometry over the years more prominent.

Table 4-5 Comparison of Simulated and 1982 Surveyed HWM along the Swan River Study Reach

HWM ID	Approximate Station (m)	Description	Observed WSEL (m)	Simulated WSEL (m)	Diff. (Sim. – Obs.) (m)
82_1	14,425	Channel bank, 11 m DS of HWY 2 B	588.63	587.16	-1.47

1983 Flood

The estimated flood peak discharge for 1983 was 571 m^3/s. This corresponds to approximately a 20-year return period. Table 4-6 shows the comparison of simulated water levels and surveyed HWMs from the 1983 event. The average difference between simulated and observed data was -0.10 m with a RMSE of 0.48 m. The 1983 event is larger in magnitude than 1979 and 1982 and therefore, is less likely to be influenced by channel evolution over time. An average difference of -0.10 m is a good fit to the observed HWMs considering the age of this event.

Table 4-6 Comparison of Simulated and 1983 Surveyed HWM along the Swan River Study Reach

HWM ID	Approximate Station (m)	Description	Observed WSEL (m)	Simulated WSEL (m)	Diff. (Sim. – Obs.) (m)
83_4	2,100	Floodplain on road.	584.15	584.51	0.36
83_5	2,135	Channel bank	584.75	585.01	0.26
83_6	2,250	Bank/almost floodplain	584.51	585.05	0.54
83_7	1,450	Channel bank	584.22	584.62	0.40
83_8	1,700	Channel bank	584.25	584.80	0.55
83_9	14,415	Channel bank, 30 m DS of HWY 2 B	590.51	589.89	-0.62
83_10	14,445	Channel bank, 3 m DS of HWY 2 B	590.49	589.93	-0.56
83_11	14,470	Channel bank, 11 m US of HWY 2 B	590.77	590.04	-0.73
83_12	14,470	Channel bank, 12 m US of HWY 2 B	590.58	590.04	-0.54
83_13	17,740	Floodplain, by a road.	593.12	591.10	NA[1]
83_14	9,575	Channel bank, 3 m DS of Railway B	588.5	587.98	-0.52
83_15	9,585	Channel bank, 13 m US of Railway B	588.56	588.04	-0.52
83_16	9,550	Floodplain on road.	587.49	587.62	0.13

1 HWM not included in statistics as data quality is in question and considered an outlier. AWSEL of 593.12 m would suggest upwards of 2 m of water on the floodplain.

1986 Flood

The estimated flood peak discharge for 1986 was 332 m^3/s. This corresponds to between a 2- and 5-year return period. Table 4-7 shows the comparison of simulated water levels and surveyed HWMs from the 1986 event. The average difference between simulated and observed data was -0.20 m with a RMSE of 0.86 m. The 1986 event was a smaller event and is expected to be heavily influenced by channel evolution. However, an average difference of -0.2 m is still a reasonable agreement between simulated and observed water surface elevations.

Table 4-7 Comparison of Simulated and 1986 Surveyed HWM along the Swan River Study Reach

HWM ID	Approximate Station (m)	Description	Observed WSEL (m)	Simulated WSEL (m)	Diff. (Sim. – Obs.) (m)
86_5	2,315	Bank	583.69	584.18	0.49
86_6	2,140	Bank	582.72	584.15	1.43
86_7	1,035	Bank/almost floodplain	583.5	583.68	0.18
86_8	1,665	Bank	583.69	583.95	0.26
86_9	1,050	Bank	582.72	583.68	0.96
86_10	14,495	Bank, 40 m US of HWY 2 B	589.56	588.59	-0.97
86_11	14,460	Bank, 8 m US of HWY 2 B	589.43	588.57	-0.86
86_12	14,440	Bank, 2 m DS of HWY 2 B	589.5	588.53	-0.97
86_13	14,400	Bank, 37 m DS of HWY 2 B	589.61	588.51	-1.10
86_14	4,750	Bank	585.5	585.11	-0.39
86_15	20,485	Bank	592.58	590.50	NA
86_16	9,580	Bank, 10 m US of Railway B	587.52	586.79	-0.73
86_17	9,570	Bank, 2 m DS of Railway B	587.49	586.78	-0.71

[1] HWM not included in statistics as data quality is in question. The observed WSEL does not match with the location and surrounding HWMs.

1988 Flood

The estimated flood peak discharge for 1988 was 654 m^3/s. This corresponds to between a 35- and 50-year return period. Table 4-8 shows the comparison of simulated water levels and surveyed HWMs from the 1988 event. The average difference between simulated and observed data was -0.59 m with a RMSE of 0.60 m. An average difference of -0.59 m is considered to be a reasonable fit to the observed HWMs considering the age of this event.

Table 4-8 Comparison of Simulated and 1988 Surveyed HWM along the Swan River Study Reach

HWM ID	Approximate Station (m)	Description	Observed WSEL (m)	Simulated WSEL (m)	Diff. (Sim. – Obs.) (m)
88_2	14,490	Bank, 37 m US of HWY 2 B	591.03	590.39	-0.64
88_3	14,455	Bank, 2 m US of HWY 2 B	591.05	590.36	-0.69
88_4	14,440	Bank, 2 m DS of HWY 2 B	590.87	590.24	-0.63
88_5	14,250	190 m DS of HWY 2 B	590.61	590.15	-0.46
88_6	11,300	Floodplain by road	589.61	589.03	-0.58
88_7	9,580	Bank, 2 m US of Railway B	588.86	588.32	-0.54

2011 Flood

The estimated flood peak discharge for 2011 was 582 m^3/s. This corresponds to between a 20- and 35-year return period. Table 4-9 shows the comparison of simulated water levels and surveyed HWMs from the 2011 event. The average difference between simulated and observed data was -0.24 m with a RMSE of 0.24 m. An average difference of -0.24 m is considered to be a reasonable fit to the observed HWMs.

Table 4-9 Comparison of Simulated and 2011 Surveyed HWM along the Swan River Study Reach

HWM ID	Approximate Station (m)	Description	Observed WSEL (m)	Simulated WSEL (m)	Diff. (Sim. – Obs.) (m)
11_1	14,440	Bank, 5 m US of HWY 2 B	590.36	590.15	-0.21
11_2	14,470	Bank, 17 m DS of HWY 2 B	590.30	590.03	-0.27

2018 Flood

The estimated flood peak discharge for 2018 was 637 m^3/s. This corresponds to approximately a 35-year return period. Table 4-10 shows the comparison of simulated water levels and surveyed HWM from the 2018 event. The average difference between simulated and observed data was 0.00 m with a RMSE of 0.07 m. The 2018 flood is the second largest magnitude event observed (after the 1988 flood) and is, therefore, an important calibration event to meet. An average difference of 0.00 is an excellent fit for the observed data.

Table 4-10 Comparison of Simulated and 2018 Surveyed HWM along the Swan River Study Reach

HWM ID	Approximate Station (m)	Description	Observed WSEL [1] (m)	Simulated WSEL (m)	Diff. Sim – Obs. (m)
18_1	14,425	Bank, 11 m DS of HWY 2 B	590.27	590.22	-0.05
18_2	14,445	Bank, 1 m DS of HWY 2 B	590.35	590.29	-0.06
18_3	14,445	Bank, 1 m DS of HWY 2 B	590.19	590.29	0.10

1 The observed WSEL includes a +1.6 m correction based on an investigation of HWM data by EPA that was communicated with Barr in an email correspondence on 01/30/2025.

2024 Flood

The estimated flood peak discharge for 2024 was 477 m^3/s. This corresponds to approximately a 10-year return period. Table 4-11 shows the comparison of simulated water levels and surveyed HWMs from the 2024 event. The average difference between simulated and observed data was 0.05 m with a RMSE of 0.21 m. The 2024 event is the most recent event and occurred during the same year as the bathymetric survey. Therefore, this event should be a great representation of the modelled condition at a high flow. An average difference of 0.05 is a great fit for the observed data.

Table 4-11 Comparison of Simulated and 2024 Surveyed HWM along the Swan River Study Reach

HWM ID	Station (m)	Description	Observed WSEL (m)	Simulated WSEL (m)	Diff. Sim – Obs. (m)
24_1	17,950	Bank/almost floodplain	591.17	590.76	-0.41
24_2	14,475	Bank, 20 m US of HWY 2 B	591.12	589.59	NA[1]
24_3	14,472	Bank, 15 m US of HWY 2 B	589.44	589.59	0.15
24_4	14,455	Bank, 1 m US of HWY 2 B	589.62	589.57	-0.04
24_5	9,575	Bank, 1 m US of Railway B	587.43	587.67	0.24
24_6	9,570	Bank, 5 m US of Railway B	587.51	587.67	0.15
24_7	9,575	Bank, 1 m US of Railway B	587.54	587.67	0.13
24_8	9,575	Bank, 1 m US of Railway B	587.56	587.67	0.10

1 HWM not included in statistics as data quality is in question. The observed WSEL does not match with the location and to surrounding HWMs.

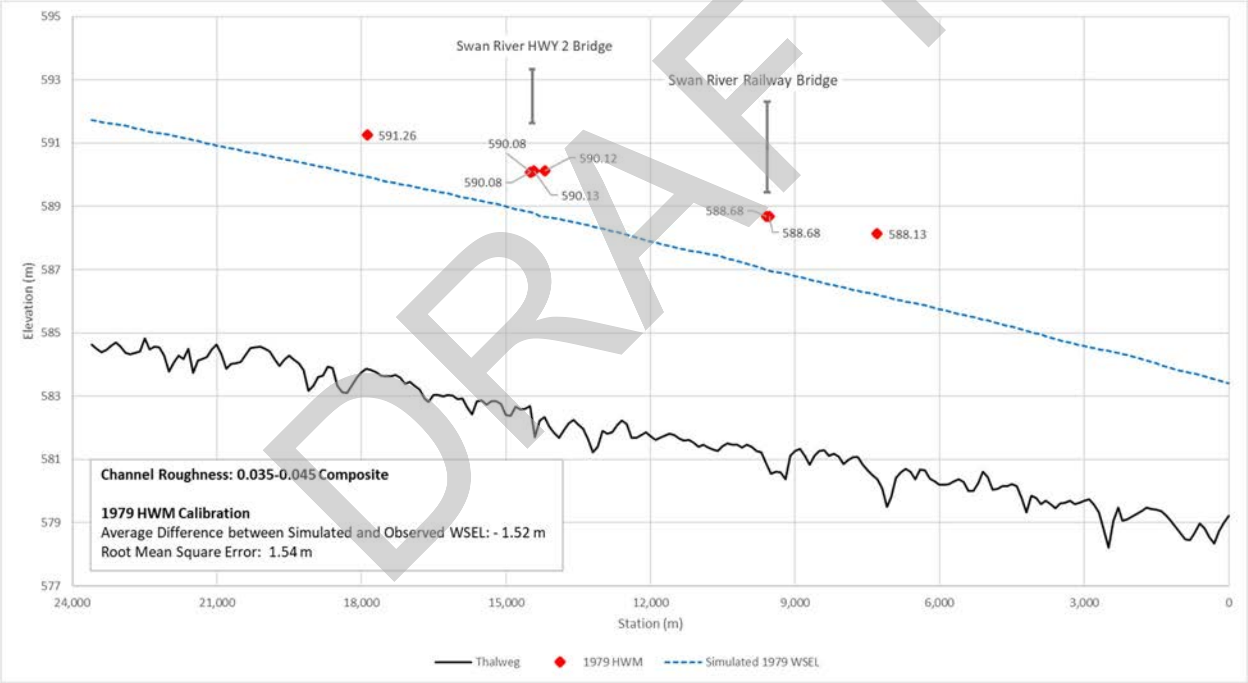

Figure 4-10 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 1979 Event

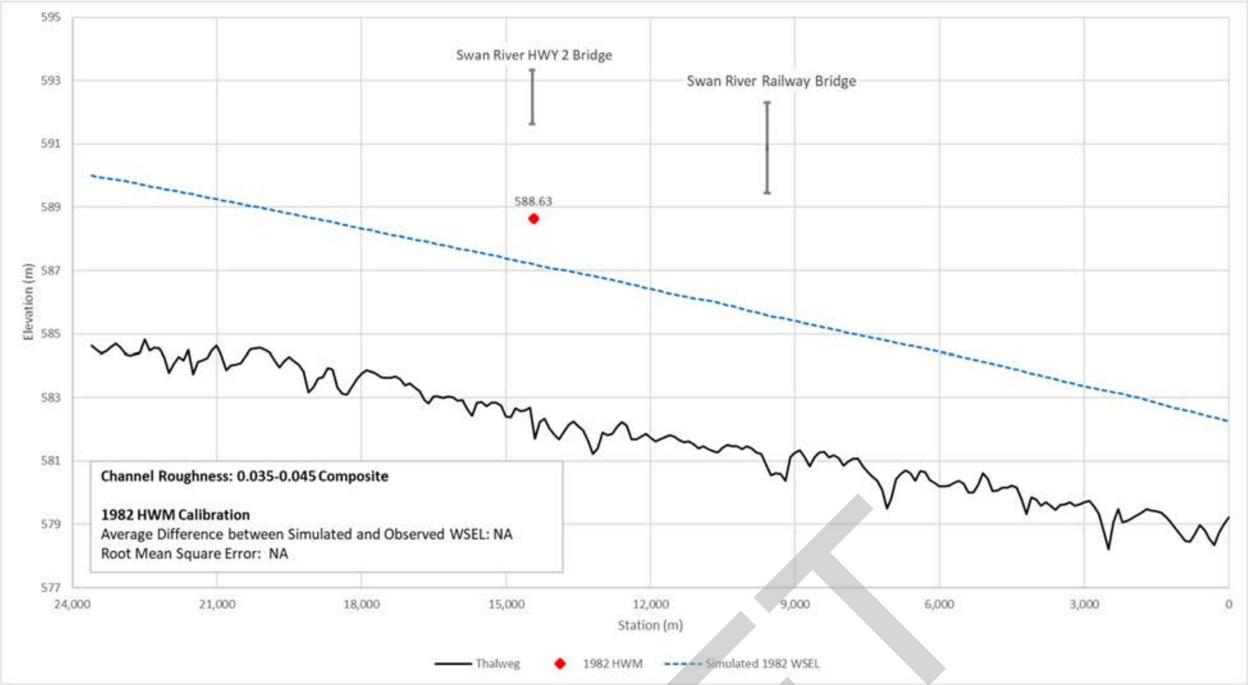

Figure 4-11 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 1982 Event

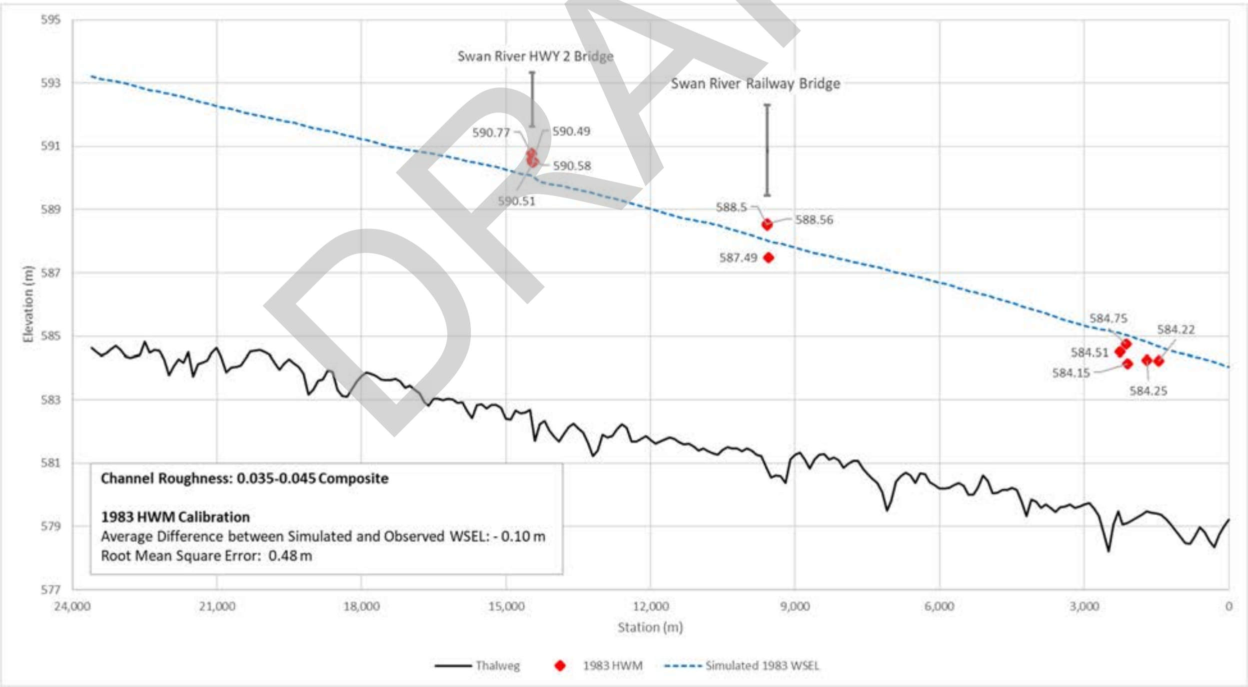

Figure 4-12 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 1983 Event

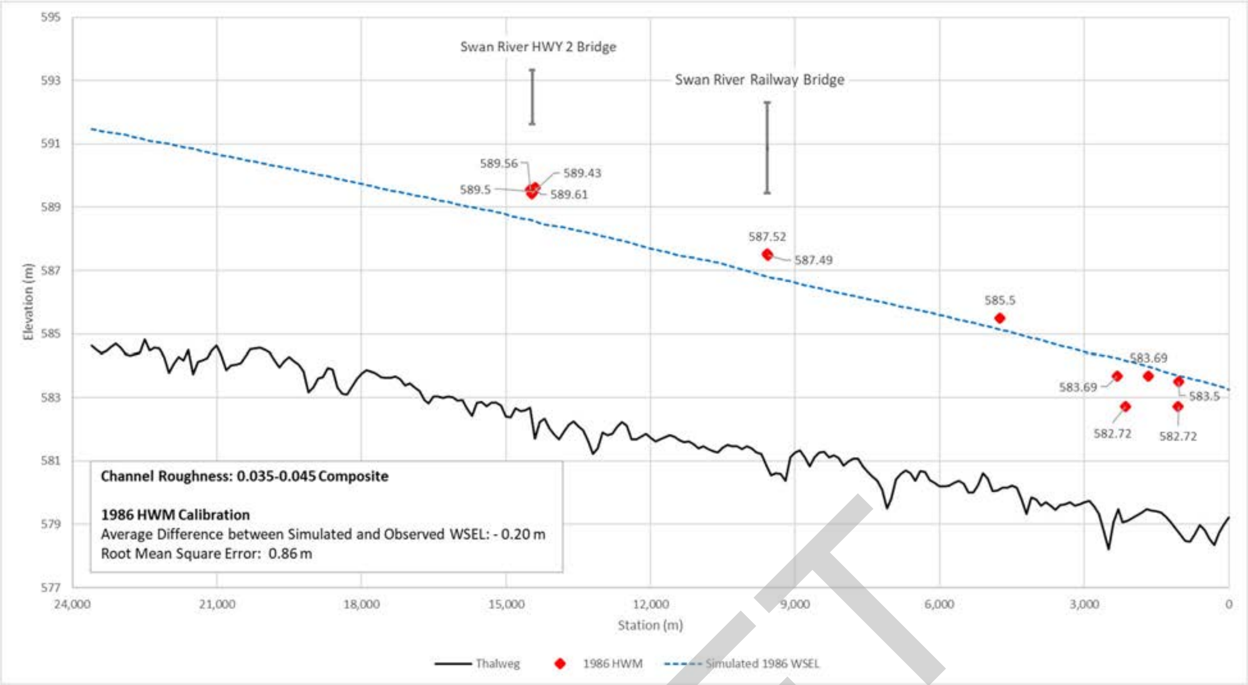

Figure 4-13 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 1986 Event

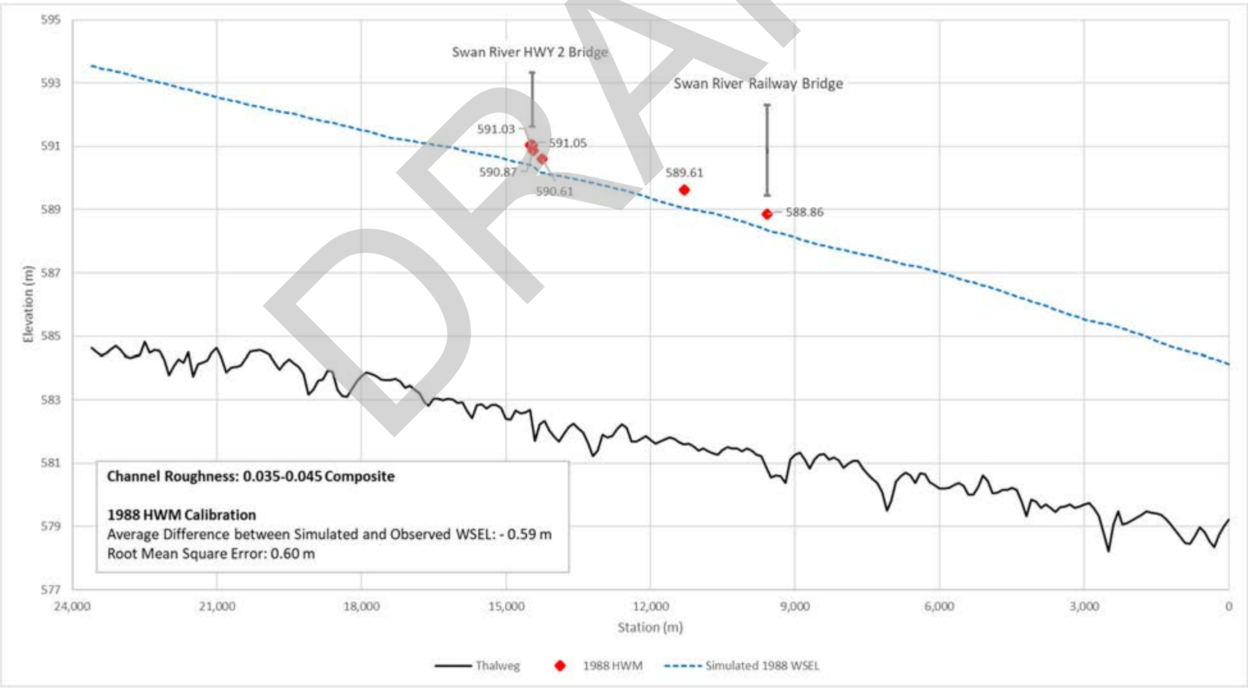

Figure 4-14 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 1988 Event

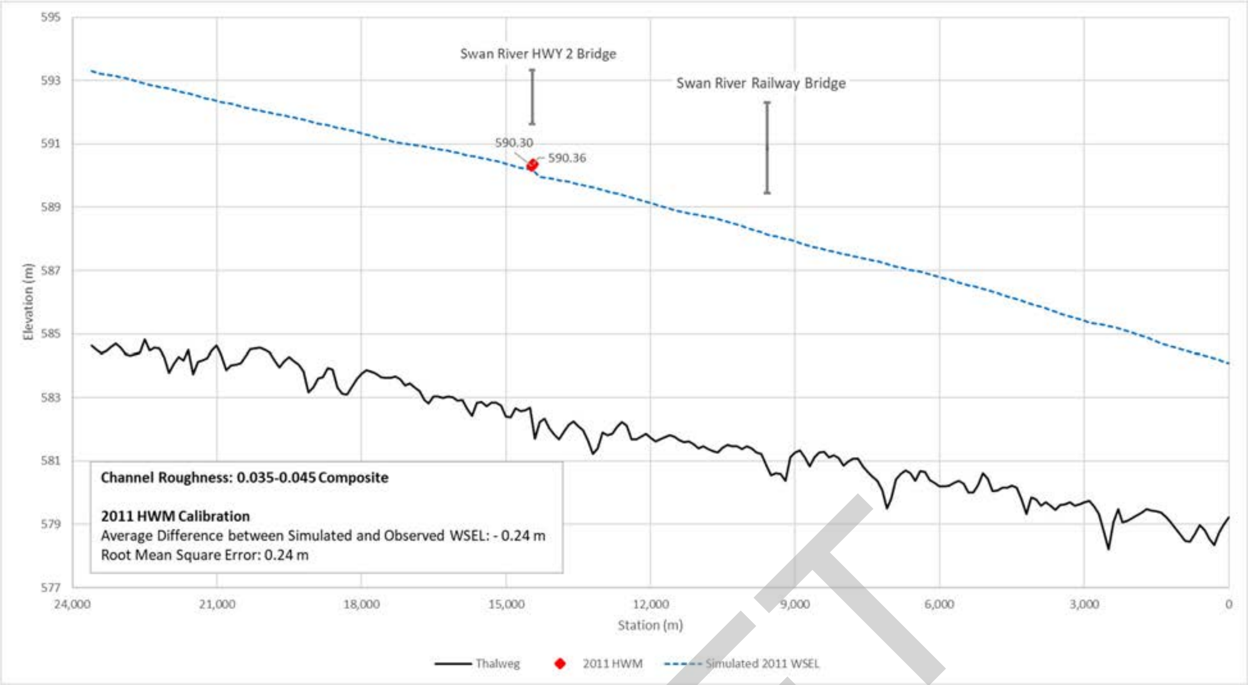

Figure 4-15 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 2011 Event

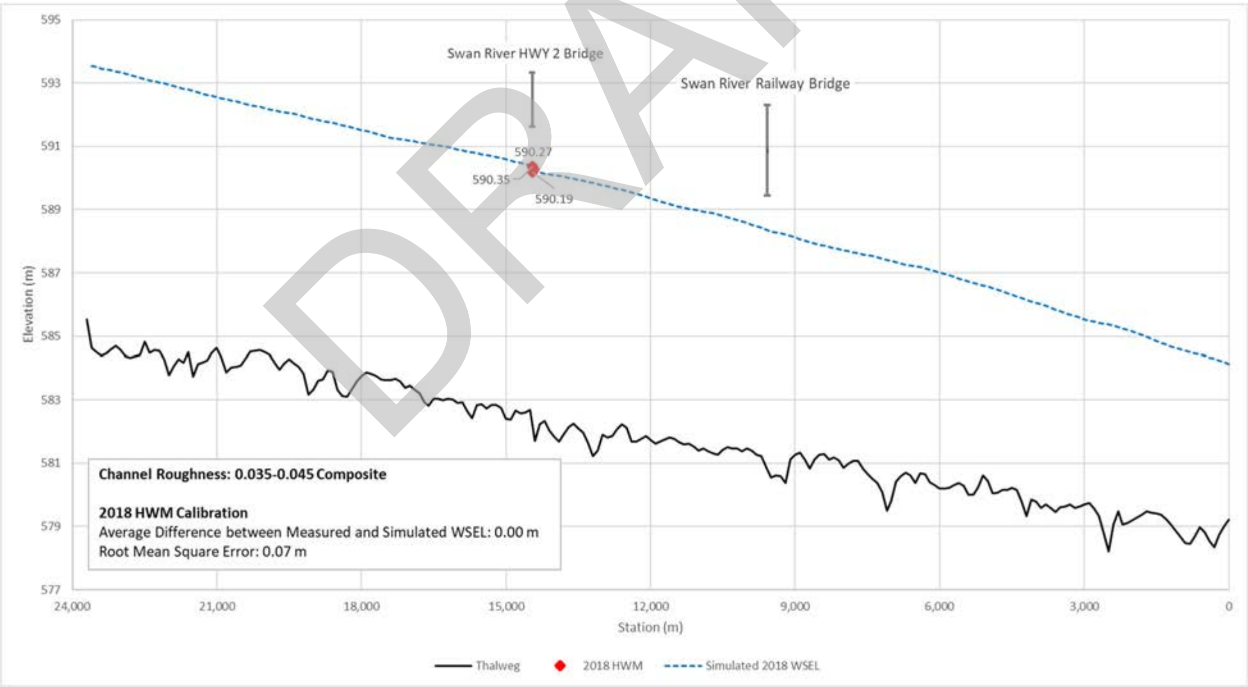

Figure 4-16 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 2018 Event

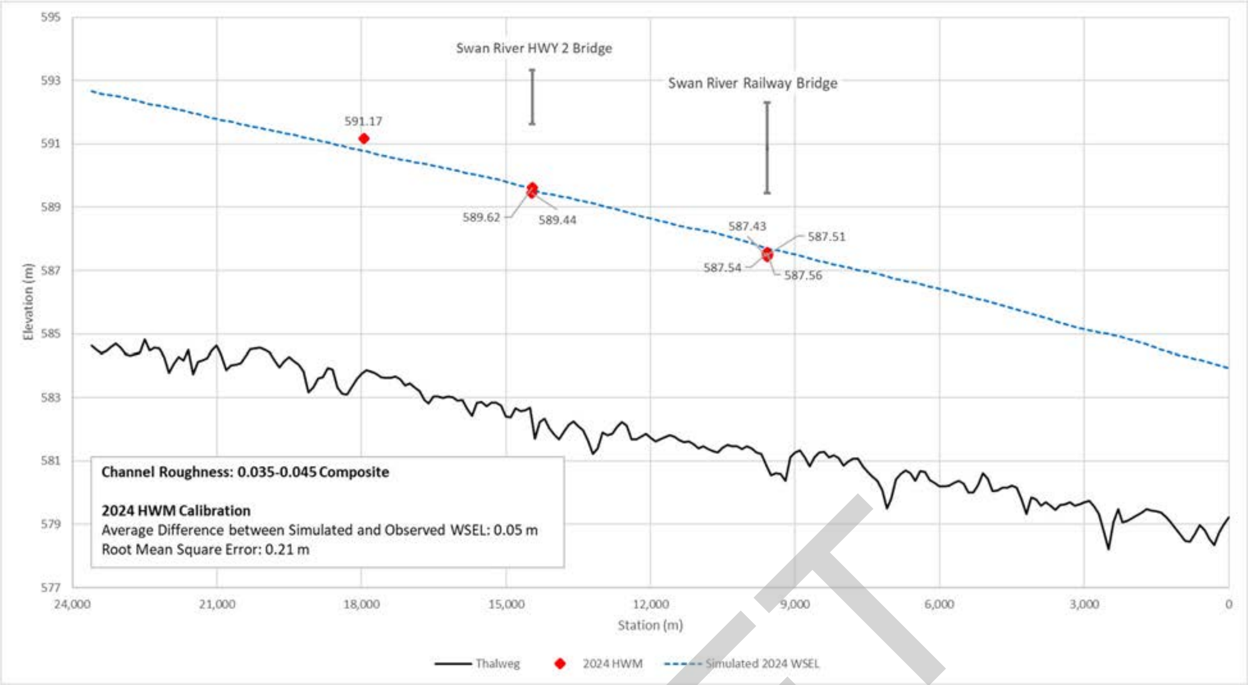

Figure 4-17 Comparison of Simulated Water Level and Surveyed HWMs Along Swan River for the 2024 Event

4.3.4.4 Water Survey Canada Rating Curve

In addition to the above high flow calibration, the model was validated against the WSC rating curve and measured data just downstream of the Highway 2 bridge. Figure 4-18 shows the comparison between the simulated water levels at various flows (8 HWM, 2 low flow events, and 6 flood frequency events) and both the derived rating curve and measured data by WSC. The simulated water levels show a reasonable fit of the overall shape of the rating curve. It is noted that the simulated water levels are lower than the measured data and the rating curve is beyond 300 m^3/s.

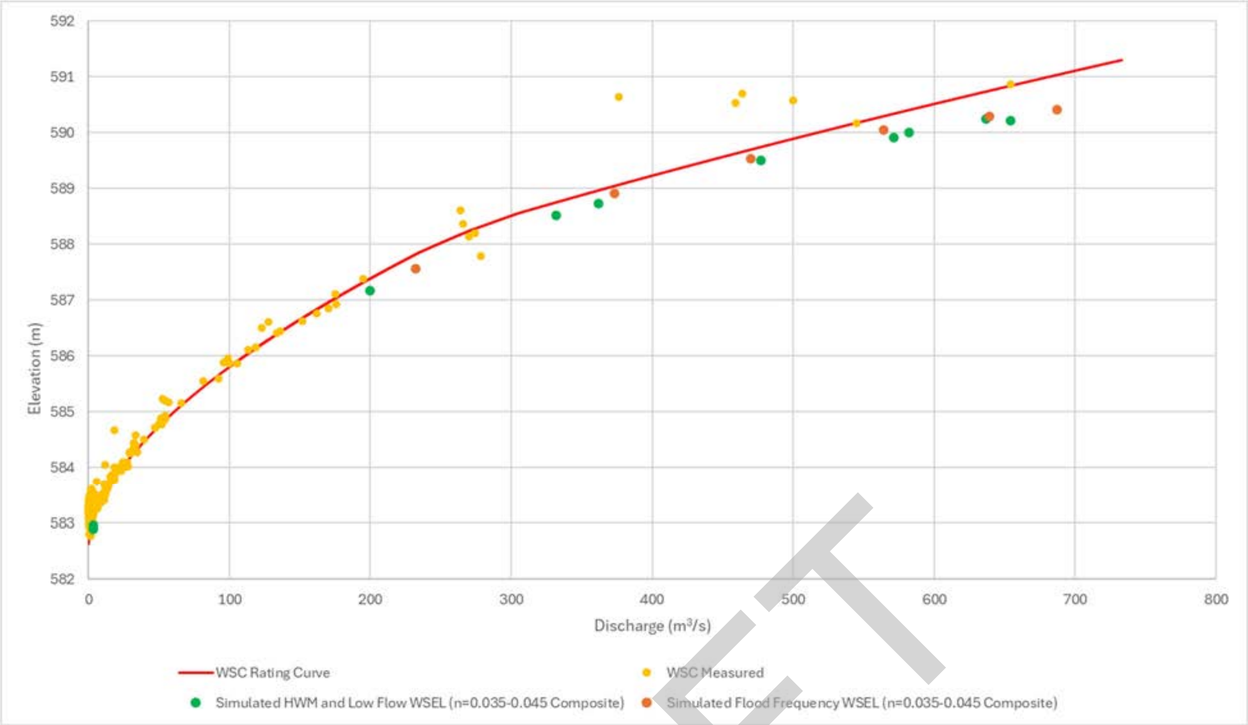

Figure 4-18 Comparison of Simulated Water Levels and WSC Measured Data and Rating Curve at Swan River near Kinuso (07BJ001)

4.3.5 Model Parameters and Options

The following sections describe the key model parameters and options adopted in the HEC-RAS model. These include Manning's roughness coefficients for the channel and overbank areas, contraction and expansion loss coefficients, roadway weir coefficient, and ineffective areas.

4.3.5.1 Manning's Roughness Values

Manning's roughness is used to account for an array of energy losses that may vary with respect to discharge.

4.3.5.1.1 Channel Roughness

A composite Manning's n roughness was used for Swan River to characterize the smoothing bed and rough vegetated banks. A Manning's n roughness of 0.04 was used for the bed in low flow conditions and a Manning's roughness of 0.035 was used in flood conditions. A Manning's roughness of 0.045 was used for the bank in both scenarios. A composite Manning's n of 0.035 and 0.045 was selected for flood frequency simulations. The selected Manning's n values were found to be in a reasonable range in comparison to typical values of comparable streams (Chow, 1959).

4.3.5.1.2 Overbank Roughness

No change was made for the overbank roughness values and the same values as Table 4-3 were adopted in the model.

4.3.5.2 Expansion and Contraction Coefficient

HEC-RAS multiplies the absolute difference in velocity head by a coefficient to account for the effect of flow contraction or expansion on the energy balance between successive cross sections. The coefficients range from 0.10 for gradual transitions to 0.80 for abrupt transitions (Brunner, 2010). These coefficients are applied in a steady state simulation at all cross sections. In an unsteady model, the momentum equation accounts for these characteristics; therefore, coefficients are not necessary. The default coefficients of 0.3 and 0.5 were used in 2D domain bridges (i.e., defaults values). Finally, culverts in 2D domain do not require any contraction and expansion coefficients.

4.3.5.3 Weir Coefficient

As mentioned previously, weirs were implemented in the 2D domain on large roads, highways, railways, etc. HEC-RAS uses a broad-crested weir formulation to represent flow overtopping road, rail, or similar embankments crossing the flow path. Typical discharge coefficients range between 1.4 to 1.7, with larger values generating less backwater. For this study, a weir coefficient of 1.45 was assigned for all hydraulic structure embankments.

4.3.6 Flood Frequency Profiles

The calibrated hydraulic model was used to generate flood frequency profiles for the thirteen open water floods of varying magnitude ranging from 50% to 0.1% AEPs. The simulated open water flood profiles and tables along the reaches within the study are plotted in Appendix F. Note that to plot, the water levels were extracted every 100 m along the channel centerline of the modelled reach.

4.3.7 Model Sensitivity

A model sensitivity analysis was conducted to evaluate the effects of changing model roughness values and downstream boundary conditions on the simulated water levels. The 100-year flood event was used for the model sensitivity analysis. The sensitivity analysis results were used to quantify the level of uncertainty associated with the simulated flood levels along the study reach.

The analysis of model sensitivity to Manning's n involves the following two sets of Manning's n values for the main channels and floodplains and one set of downstream boundary conditions:

- ±10% changes of the base channel Manning's n values only
- ±10% changes of the base floodplain Manning's n values only
- ±20% changes of the specified energy slope for the downstream boundary

The differences between the simulated water levels for the 100-year flood along the study reach of Swan River are graphically presented in Appendix G. The results of the sensitivity analysis indicate the following:

- The uncertainty in the simulated flood levels, on average, is within a range of -0.05 to +0.04 m for Swan River based on the differences in the simulated flood levels for a ±10% change to the base channel Manning's n value only.

- The uncertainty in the simulated flood levels, on average, is within a range of ±0.01 m for Swan River, based on the differences in the simulated flood levels for a ±10% change to the base floodplain Manning's n values only.

- A ±20% change to the energy slope at the downstream boundary influences the simulated flood levels by ±0.007 m for approximately 3 km upstream of the downstream boundary.

5 Open Water Flood Inundation Maps

Flood inundation mapping shows areas of ground that could be covered by water under one or more flood scenarios for existing conditions. For this study, one flood inundation map series was created for each of the 13 flood frequency return periods from the 2-year through 1,000-year scenarios. The study area is covered by a total of fifteen sheets in tabloid format (11 x 17 in). The mapping scale is 1:10,000. The maps were prepared using the local 3-Degree Transverse Mercator (3TM) zone and the Canadian Spatial Reference System North American Datum of 1983 (NAD83 CSRS) coordinate system and datum. The maps include the 2023 aerial imagery and other base data (roads and railways) provided by EPA. The flood inundation maps were prepared in a geographical information system (Esri ArcGIS Pro 3.3). The maps, including all layers, were provided to EPA as digital files in the Esri ArcGIS Pro project package file format.

The open water flood inundation maps are provided in Appendix H.

5.1 Methodology

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

- Simulated water levels for the 13 flood frequency return periods from the 2-year through 1,000-year scenarios
- DTM from the 2023 LiDAR survey
- Aerial imagery of the study area obtained in October 2023

Direct flood inundation areas are identified as being part of the actively flowing river channels or flooded overbank areas directly connected to the actively flowing areas. The following general procedure was used in ArcGIS to develop the inundation extent of the 13 open water flood events:

- Flood inundation boundaries, water level grids and depth grids are exported from the HEC-RAS model. The maximum profile function in HEC-RAS was used to ensure that the model captured the peak of the unsteady hydrograph.
- Areas that are not directly connected to the main channels are manually removed. Areas where there is no direct overland connection, but a hydraulic connection exists through culverts or other features such as railroad berms, may be included in the inundation extent.

5.2 Manual Flood Extent Modifications

Flood inundation mapping at some locations required manual edits to produce reasonable inundation extents. Necessary modifications were made to the water surface elevation TIN for areas that required manual edits.

These manual edits are summarized in Table 5-1.

Table 5-1 Summary of Manual Edits for Flood Inundation Polygons

Floodplain	Location	Description	Flood Events
Left	Range Rd 101 A, south of Kinuso	Due to the steep road embankment, the inundation polygon downstream of the culvert was disconnected. Manual edits were required to connect the polygon.	10 to 1,000-year
Right	Range Rd 95 A, south of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	35 to 50-year
Left	Range Rd 103, north of Railway, northwest of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	35 to 50-year
Right	Range Rd 100, south of Railway, southeast of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	75 to 100-year
Right	HWY 2 and Range Rd 100	The road is overtopped at this location and needed manual edits to connect the polygon.	100 to 1,000-year
Left	Range Rd 101 south of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	100 to 1,000-year
Right	Range Rd 100, south of Railway, east of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	100 to 1,000-year
Left	Range Rd 102 north of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	100 to 1,000-year
Right	Range Rd 100A	The road is overtopped at this location and needed manual edits to connect the polygon.	100-Year
Right	Range Rd 100, north of Railway, east of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	100-Year
Left	Unnamed Rd in the northeast corner of the study area, south of TWP Rd 740	The road is overtopped at this location and needed manual edits to connect the polygon.	100 to 1,000-year
Left	Range Rd 104, north of the Railway, west of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	100 to 1,000-year
Left	Range Rd 102 N of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	200 to 1,000-year
Left	North of Range Rd 103 and HWY 2	The road is overtopped at this location and needed manual edits to connect the polygon.	200 to 350-year
Left	Southeast of Range Rd 102 and TWP Rd 731A	Due to the steep terrain, the inundation polygon was disconnected.	200 to 1000-year
Left	TWP Rd 734A north of Kinuso	The road is overtopped at this location and needed manual edits to connect the polygon.	200 to 1,000-year
Left	TWP Rd 740 east of Range Rd 102	The road is overtopped at this location and needed manual edits to connect the polygon.	350 to 1,000-Year
Left	Northwest of TWP Rd 740 Range Rd 103	Due to the steep terrain, the inundation polygon was disconnected.	1,000-Year
Left	Railway, west of Kinuso	Inundation was extended beyond permeable railways according to AEP standards.	50 to 1,000-Year

5.2.1 Flood Control Structure

In addition to delineating direct flood inundation areas for each flood frequency scenario, delineation of areas at residual flood risk due to potential flood berm failure is also required. This area is delineated assuming that the dedicated flood berm fails, using water levels calculated along the structure under non-failure conditions, and is typically established using the same flood profile as the main channel without adjustment. There is a flood berm protecting Kinuso located to the east of the hamlet. This berm posed a unique challenge in showing the risk of inundation due to potential failure. Due to the perched nature of the Swan River, flood water levels in the adjacent river could not be used, as it would result in unrealistic larger area protected by the berm. Therefore, Barr instead utilized the hydraulic model to more realistically estimate the protected areas. The flood berm was removed by the RAS-Mapper terrain modification tool to what was identified as the toe of the berm based on the survey (see Appendix C for surveyed flood control structure (FCS) cross sections). The model was then simulated with the same parameters identified in Section 4. The DTM before and after removal of the flood control structure is shown in Figure 5-1.

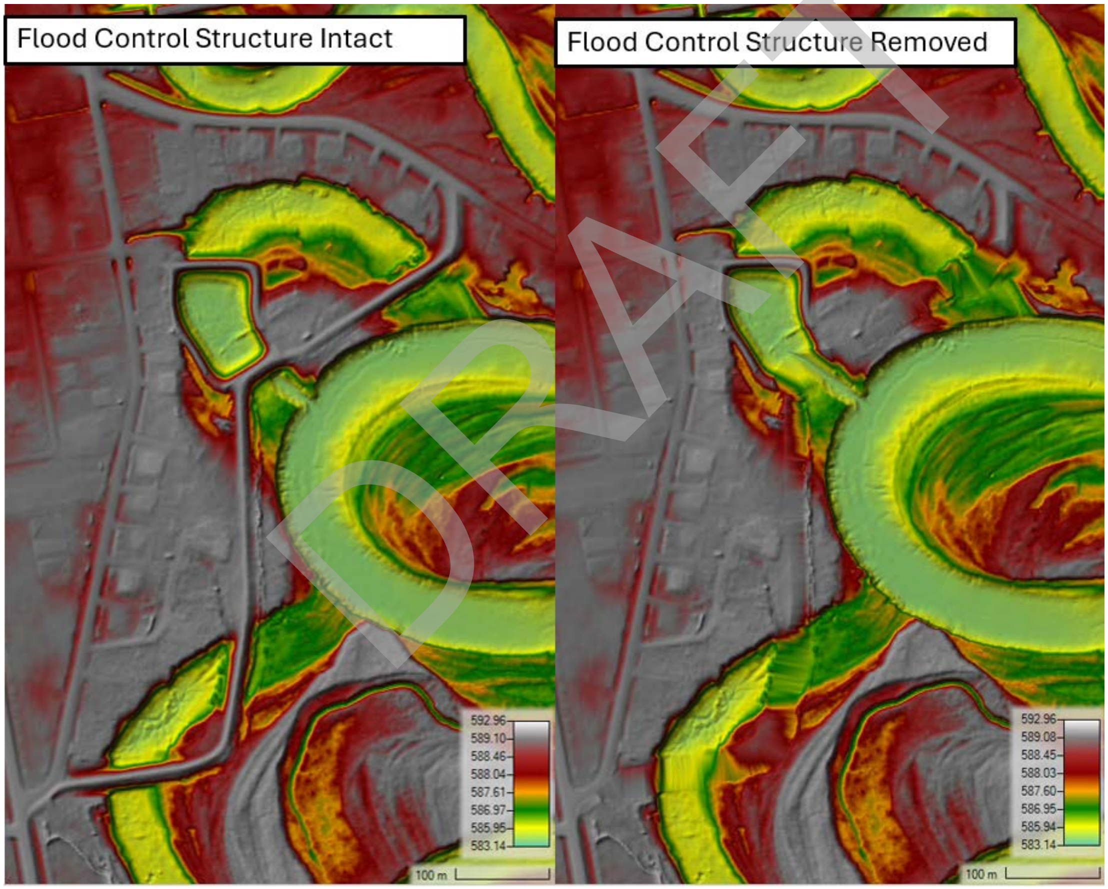

Figure 5-1 Hydraulic Model Terrain Modifications Used for flood berm Removal

The resultant water surface raster was exported from HEC-RAS, and only the additional flooding caused by the berm removal was utilized in mapping to identify the areas protected by the berm.

5.3 Flood Inundation Areas

The residential and commercial areas affected by direct inundation are described below. Detailed inundation maps are provided in Appendix H.

5.3.1 Residential Areas

5.3.1.1 Hamlet of Kinuso

- There are no impacted residential areas within the Kinuso boundary.

5.3.1.2 Big Lakes County and Swan River First Nation

- Flooding would occur during the 35-year event and above at a residence northeast of the intersection between Range Road (Rd) 101A and Highway (HWY) 2.
- Flooding would occur during the 50-year event and above at a possible residence southeast of the intersection between Range Rd 103 and HWY 2.
- Flooding would occur during the 35-year event and above at a residence east of Kinuso off Range Rd 101.
- Flooding would occur during the 500-year event and above at multiple residences southeast of the intersection between Range Rd 100 and HWY 2.
- Flooding would occur during the 200-year event and above at a residence west of Range Rd 102.
- Flooding would occur during the 35-year event and above at a residence west of Range Rd 100 north of the railroad.

5.3.2 Commercial and Industrial Areas

5.3.2.1 Hamlet of Kinuso

- There are no impacted commercial or industrial areas within the Kinuso boundary.

5.3.2.2 Big Lakes County and Swan River First Nation

- Flooding would occur during the 50-year event and above at a large establishment southwest of HWY 2 and HWY 33. This establishment does not appear in the October 2023 imagery provided by EPA, but it does in more recent public datasets.

5.3.3 Hydraulic and Flood Berms

The Kinuso study area is dominated by two large bridges and numerous floodplain culverts. In many cases, these structures have capacity for the 1,000-year event, while others are exceeded in the 10-year event. Table 5-2 summarizes any hydraulic structure that would overtop and the smallest event that causes the overtopping.

Table 5-2 Hydraulic Structure Overtopping Summary

Description	Structure Type	Lowest Event Overtopped
TWP Rd. 731A Culvert	Culvert	10-Year
HWY 2 E2 Culvert		500-Year
Range Rd. 102 S Culvert		750-Year
HWY 2 Mid Culvert		35-Year

The Kinuso flood berm offers protection up to the 1,000-year event (largest event simulated). In the event of a failure of this berm, residences will be impacted as early as the 20-year flood event, as shown in inundation maps in Appendix H.

5.3.4 Water Surface Elevation and Water Depth Grids

The following GIS data were provided to EPA for each of the 13 open water flood events:

- Inundation polygons
- Water surface elevation rasters
- Flood depth rasters

All GIS data were created in ArcGIS Pro 3.3 compatible format in the native study coordinate system (Canadian Spatial Reference System, North American Datum of 1983 (CSRS NAD83), Epoch 2002, and 3-Degree Transverse Mercator projection with the Central Meridian of 111° (3TM 114). All raster files have a spatial resolution of 0.5 m. The inundation polygons and raster files were stored in ArcGIS file geodatabases.

6 Floodway Determination

Flood hazard identification involves the delineation of floodway and flood fringe zones for the design flood using the FHIP Guidelines (Alberta Environment and Parks, June 2022).

6.1 Design Flood Selection

The minimum design flood standard in Alberta is the 1:100 flood, which is defined as a flood whose flow has a 1% chance of being equaled or exceeded in any year. The design flood can also reflect 1:100 ice jam flood levels if they are more severe than 1:100 open water flood levels or be based on a historical flood. In this study, the 100-year open water flood was selected as the design flood for Swan River.

6.2 Floodway and Flood Fringe Terminology

The flood hazard area is the area of land that will be flooded during the design flood event. The flood hazard area is typically divided into two zones: floodway and flood fringe and may include additional flood fringe sub-zones. Flood hazard maps also show incremental areas at risk for more severe floods such as the 200-year and 500-year floods. Flood hazard mapping is typically used by communities for planning or to help make local land use and development decisions.

6.2.1 Floodway Definition

Floodway typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 100-year design flood. The floodway generally includes areas where the water is 1 m deep or greater and the local velocities are 1 m/s or faster. The floodway typically 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. New development is discouraged in the floodway and may not be permitted in some communities.

6.2.2 Flood Fringe Definition

The flood fringe is the portion of the flood hazard area outside of the floodway. The flood fringe typically represents areas with shallower (less than 1 m deep), slower (less than 1 m/s velocity), 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. New development in the flood fringe may be permitted in some communities.

6.3 Open Water Flood Hazard Identification

6.3.1 Floodway Determination Criteria

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 (2022), are used to delineate the floodway in such cases:

- Areas in which the water depth 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
- For reaches of supercritical flow, the floodway boundary should correspond to the edge of inundation or the main channel, whichever is larger

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.

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.

The open water design flood water surface elevations and flow velocities were generated from the HEC-RAS model. The HEC-RAS maximum profile tool was used to extract the flood water surface elevations and flow velocities directly from the RAS-Mapper tool of the HEC-RAS model.

The floodway boundary was delineated in a way that is considered hydraulically smooth. The majority of the time, the floodway followed the bankline or the 1 m depth contour, although in some locations the 1 m/s velocity contour dictated.

6.3.2 Design Flood Levels and Profile

The design flood profile levels were those calculated for the 100-year open water flood condition. The resulting design flood level values and profiles are shown in Appendix F.

6.3.3 Floodway Criteria Maps

Floodway criteria maps show the basis for determining the floodway, high hazard flood fringe zone, protected flood fringe areas, and flood fringe zone for the design flood, and documenting the results of water levels, depths, and flow velocities. The floodway criteria maps include the following information:

- inundation extents of the 100-year design flood
- areas meeting or exceeding the 1 m depth floodway criterion for the design flood
- areas meeting or exceeding the 1 m/s velocity floodway criterion for the design flood
- proposed floodway boundary for the design flood
- background aerial imagery collected in 2023
- roads, bridges, culverts, and flood control structures, as applicable

The floodway criteria maps were produced using the same template as the inundation maps. The maps are provided in Appendix I.

6.3.4 Design Flood Hazard Maps

The flood hazard maps divide the design flood extents into floodway and flood fringe zones, including boundaries of high hazard flood fringe. The information used to create the flood hazard maps was based on the open water floodway criteria mapping information.

The limits of the floodway were delineated by the floodway boundary developed for the open water floodway criteria map. Areas of high ground or areas of depth less than 1 m inside the floodway boundaries were included as part of the floodway. The resulting floodway was represented as a single contiguous polygon.

The design flood extent developed for the floodway criteria maps was adjusted to create the flood fringe. The limits of the flood fringe followed the extent of direct inundation of the design flood. Areas of high ground within the extent of direct inundation (and outside of the floodway) were preserved and were not indicated as flood fringe in the flood hazard map.

The flood hazard maps were produced using the same template as the inundation maps. The maps are provided in Appendix I.

6.3.4.1 Areas in Floodway

There are no notable residential or commercial infrastructure located in the floodway.

6.3.4.2 Areas in High Hazard Flood Fringe

There are no notable residential or commercial infrastructure located in the high hazard flood fringe.

6.3.4.3 Areas in Flood Fringe

The flood fringe includes all inundated areas outside the limits of the floodway and high hazard flood fringe. Notable inundated areas within the flood fringe include:

- A residence northeast of the intersection between Range Road (Rd) 101A and Highway (HWY) 2.
- A possible residence southeast of the intersection between Range Rd 103 and HWY 2.
- A residence east of Kinuso off Range Rd 101.
- A residence west of Range Rd 100 north of the railroad.

7 Potential Climate Change Impacts

To address the potential impacts of climate change on flood levels, more severe open water flood scenarios were compared to the current design flood estimates in order to obtain a measure of "*freeboard*" that may generally be appropriate for long-term planning purposes. It is noted that the analysis relies on simplified assumptions rather than a comprehensive regional climate change impact assessment. To obtain information appropriate for other applications, the simplified approach taken herein could be supplemented in the future by a more rigorous regional climate analysis and site-specific impact assessment.

For the open water flood hazard, the current 100-year design flood water levels were compared to those associated with discharges that are 10% and 20% greater than the current 100-year flood estimates. This approach is consistent with guidelines prepared by Engineers and Geoscientists British Columbia (EGBC, 2018). EGBC recommends that for basins where no historical trend is detectable in local or regional streamflow magnitude frequency relations, a 10% upward adjustment in design discharge be applied to account for likely future changes in water input from precipitation. On the other hand, if a statistically significant trend is detected, a 20% adjustment may be appropriate, particularly for smaller basins.

No hydraulic modelling parameters were varied other than discharges under the open water conditions. Water level profiles were produced along the study reach for the two additional flow scenarios. The water level differences compared to the baseline 100-year open water discharge were an average of 0.05 m and 0.08 m for a 10% and 20% increase in flow, respectively.

The difference between the simulated water levels for a 100-year climate-impacted flood along Swan River is presented in Appendix J. The simulated climate-impacted open water flood levels are compared to the baseline 100-year open water discharge and summarized in Appendix J.

8 Conclusions

8.1 Survey and Base Data Collection

Topographic, bathymetric, and supporting base data required for this study were collected in accordance with the requirements by EPA. The following conclusions are made:

- Cross Section Surveys: Cross section survey data collected in the 2024 field season meet the current study requirements with regard to cross section spacing and alignment, extents of cross sections on the floodplains, labeling of survey points, and data accuracy.
- Hydraulic and Flood Control Structure Surveys: Hydraulic structure survey data collected in May 2024 meet the study requirements and include the necessary details for the hydraulic modelling.
- Digital Terrain Model: The differences in elevation between the selected survey points and the DTM data are considered to be within an acceptable range. Therefore, the DTM is considered suitable for overbank cross section data extraction and flood mapping.

8.2 Open Water Hydrology Assessment

The results of the open water hydrology assessment completed in this study support the following conclusions:

- The flood frequency estimates obtained in this study are the most up to date for Swan River at Kinuso. These estimates provide the updated flood hydrology information as inputs to the other components of the study (e.g., hydraulic modelling). Estimates of flood peak discharges were obtained for various return periods ranging from 2 to 1,000 years.
- The WSC station on the Swan River near Kinuso was used to conduct a Bulletin 17C analysis of the gage record.
- Given the unique nature of the Swan River floodplain, an inflow hydrograph was developed for use in hydraulic modelling. This hydrograph was developed using a pattern hydrograph and critical duration for the flood hydrographs observed on the Swan River.

8.3 Open Water Hydraulic Modelling

8.3.1 Selection of Manning's n Values

The HEC-RAS hydraulic model built for this study was calibrated to two surveyed low flow events, eight HWM events, and the WSC rating curve.

A composite channel Manning's was used to represent the vegetated banks of the Swan River and sediment-dominated riverbed. Through calibration, a channel bottom roughness of 0.035 and a bank roughness of 0.045 were selected for the flood frequency scenarios. The selected Manning's n values were found to be reasonable in comparison to typical values of comparable streams (Chow, 1959).

The Manning's n values for the floodplain areas were estimated based on the land use types.

8.3.2 Model Sensitivity

The model sensitivity analysis was conducted for the 100-year flood event to evaluate the effects of changing model roughness values and downstream boundary conditions on the simulated water levels. The results of the sensitivity analysis for Swan River indicate the following:

- The uncertainty in the simulated flood levels, on average, is within a range of -0.05 to +0.04 m based on the differences in the simulated flood levels for a ±10% change to the base channel Manning’s n value only.
- The uncertainty in the simulated flood levels, on average, is within a range of ±0.01 m based on the differences in the simulated flood levels for a ±10% change to the base floodplain Manning’s n values only.
- A ±20% change to the energy slope at the downstream boundary influences the simulated flood levels by ±0.007 m for approximately 3.0 km upstream of the downstream boundary.

8.3.3 Flood Profiles

The HEC-RAS model is a reliable tool for simulating the flood profiles of the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year flood events in the study area.

8.4 Open Water Flood Inundation Mapping

The HEC-RAS model results and the LiDAR DTM were used to prepare inundation maps for the 13 open water flood events (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods), including direct flood inundation areas and other indirect flood inundation areas.

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

- Flooding would occur during the 35-year event and above at a residence northeast of the intersection between Range Road (Rd) 101A and Highway (HWY) 2.
- Flooding would occur during the 50-year event and above at a possible residence southeast of the intersection between Range Rd 103 and HWY 2.
- Flooding would occur during the 35-year event and above at a residence east of Kinuso off Range Rd 101.
- Flooding would occur during the 500-year event and above at multiple residences southeast of the intersection between Range Rd 100 and HWY 2.
- Flooding would occur during the 200-year event and above at a residence west of Range Rd 102.
- Flooding would occur during the 35-year event and above at a residence west of Range Rd 100 north of the railroad.

8.5 Design Flood Hazard Mapping

The 100-year open water flood is selected as the design flood on Swan River in accordance with the Flood Hazard Identification Program (FHIP) Guidelines (2022). The floodway was determined as part of the floodway criteria mapping. No residential or commercial buildings are located within the *floodway* or *high hazard flood fringe* along Swan River. Multiple rural residences with Big Lakes County and Swan River First Nation are located within the flood fringe,

8.6 Potential Climate Change Impacts

Potential effects of climate change on open water floods were assessed through a sensitivity analysis of flood water level differences due to 10- and 20-percent increases in the 100-year flood peak discharge. These water level differences were identified as potential *freeboards* that could be applied to the design water levels to account for flow changes that could result from climate change. The results of the climate change effect assessment show an average increase of 0.05 m to 0.08 m in water levels on Swan River.

The analysis in this study was not based on a regional climate change impact assessment but on a simplified assumption that climate changes would result in increased flood peak discharges.

References

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LSWC, 2009. State of the Lesser Slave Watershed.

USACE. 2024. HEC-RAS River Analysis System - User’s Manual, Version 6.6, September 2024.

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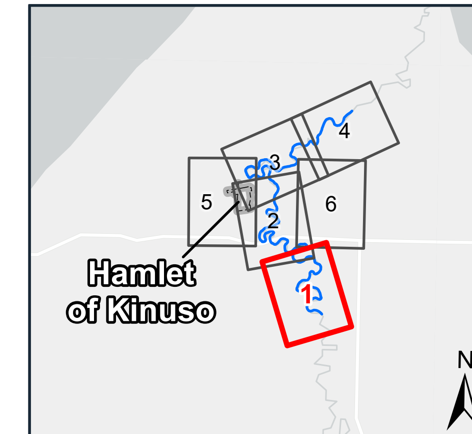
Appendices

Appendix A

Location of Surveyed Cross Sections



- FLOW DIRECTION
- BRIDGE
- CULVERT
- SURVEYED CROSS SECTION
- APPENDIX D - SWAN RIVER TYPICAL CROSS SECTION
- SURVEY POINT
- STREAM CENTERLINE
- HAMLET OF KINUSO BOUNDARY
- RAILWAY
- SECONDARY HIGHWAY
- LOCAL ROAD

Alberta

Canada

0 100 200 300
Metres

Scale: 1:10,000

Locations of Cross Sections and Hydraulic Structures

Kinuso Flood Study

SHEET A-1

BARR

Classification: Public

FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
APPENDIX D - SWAN RIVER TYPICAL CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
HAMLET OF KINUSO BOUNDARY
RAILWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta
Canada

0 100 200 300
Metres
Scale: 1:10,000

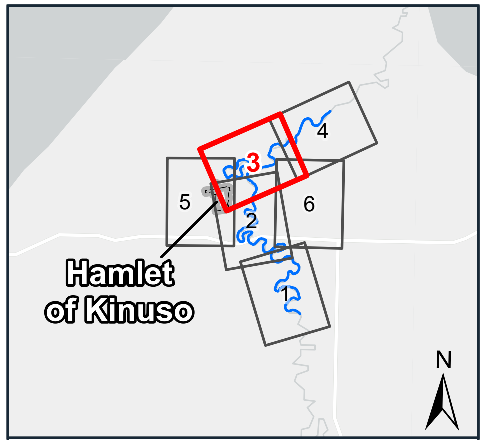
Locations of Cross Sections and Hydraulic Structures

Kinuso Flood Study

SHEET A-2

BARR

Classification: Public



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
APPENDIX D - SWAN RIVER TYPICAL CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
HAMLET OF KINUSO BOUNDARY
RAILWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta
Canada

0 100 200 300
Metres
Scale: 1:10,000
N

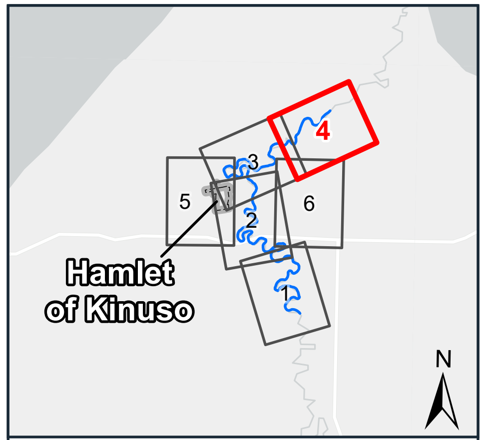
Locations of Cross Sections and Hydraulic Structures

Kinuso Flood Study

SHEET A-3

BARR

Classification: Public



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
APPENDIX D - SWAN RIVER TYPICAL CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
HAMLET OF KINUSO BOUNDARY
RAILWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta

Canada

0 100 200 300
Metres
N
Scale: 1:10,000

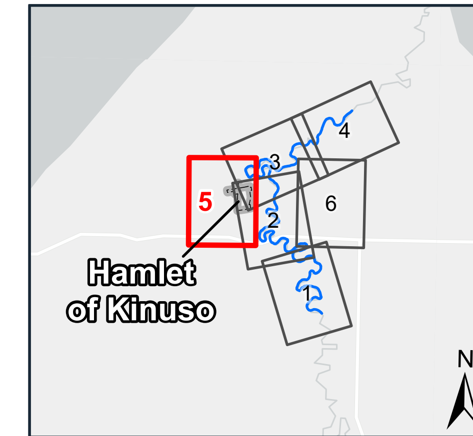
Locations of Cross Sections and Hydraulic Structures

Kinuso Flood Study

SHEET A-4

BARR

Classification: Public



FLOW DIRECTION
BRIDGE
CULVERT
SURVEYED CROSS SECTION
APPENDIX D - SWAN RIVER TYPICAL CROSS SECTION
SURVEY POINT
STREAM CENTERLINE
HAMLET OF KINUSO BOUNDARY
RAILWAY
SECONDARY HIGHWAY
LOCAL ROAD

Alberta
Canada

0 100 200 300
Metres
N
Scale: 1:10,000

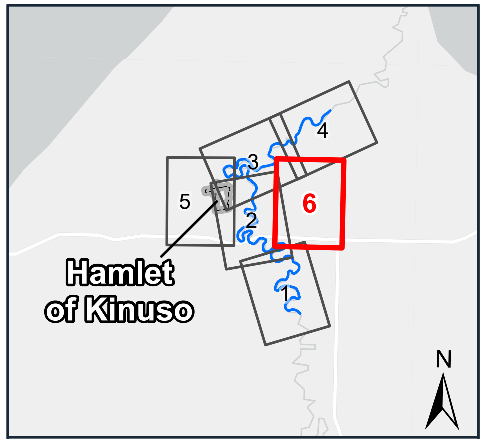
Locations of Cross Sections and Hydraulic Structures

Kinuso Flood Study

SHEET A-5

BARR

Classification: Public



- FLOW DIRECTION
- BRIDGE
- CULVERT
- SURVEYED CROSS SECTION
- APPENDIX D - SWAN RIVER TYPICAL CROSS SECTION
- SURVEY POINT
- STREAM CENTERLINE
- HAMLET OF KINUSO BOUNDARY
- RAILWAY
- SECONDARY HIGHWAY
- LOCAL ROAD

Alberta

Canada

0 100 200 300
Metres
N
Scale: 1:10,000

Locations of Cross Sections and Hydraulic Structures

Kinuso Flood Study

SHEET A-6

BARR

Classification: Public

Appendix B

Hydraulic Structure Datasheets

Structure ID:	B1				
Structure Name:	HWY 2 E1 Culvert				
Water Course:	Floodplain		**Location:**	HWY 2, SE of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Double barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	591.76	m			
Barrel One					
Length:	26	m	**Diameter**	0.57	m
Upstream Invert	589.36	m	**Downstream Invert**	589.29	m
Upstream Crown	589.99	m	**Downstream Crown**	589.80	m
Barrel Two					
Length:	26.20	m	**Diameter**	0.50	m
Upstream Invert	589.36	m	**Downstream Invert**	589.21	m
Upstream Crown	589.87	m	**Downstream Crown**	589.69	m

Photo(s):

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Structure ID:	B2				
Structure Name:	TWP Rd. 731A Culvert				
Water Course:	Floodplain		Location:	TWP Rd. 731A, S of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	589.16	m			
Length:	14.4	m	Diameter	0.55	m
Upstream Invert	588.23	m	Downstream Invert	588.11	m
Upstream Crown	588.78	m	Downstream Crown	588.66	m

Photo(s):

Structure ID:	B3				
Structure Name:	HWY 2 W Culvert				
Water Course:	Floodplain		Location:	HWY 2, S of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	590.97	m			
Length:	32.1	m	Diameter	0.79	m
Upstream Invert	589.37	m	Downstream Invert	588.93	m
Upstream Crown	590.16	m	Downstream Crown	589.72	m

Photo(s):

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Structure ID:	B4				
Structure Name:	HWY 2 E2 Culvert				
Water Course:	Floodplain		Location:	HWY 2, SE of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Double barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	591.22	m			
Barrel One					
Length:	27	m	Diameter	0.60	m
Upstream Invert	589.03	m	Downstream Invert	588.55	m
Upstream Crown	589.63	m	Downstream Crown	589.15	m
Barrel Two					
Length:	27	m	Diameter	0.46	m
Upstream Invert	588.92	m	Downstream Invert	588.71	m
Upstream Crown	589.38	m	Downstream Crown	589.17	m

Photo(s):

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Structure ID:	B5				
Structure Name:	Range Rd. 102 S Culvert				
Water Course:	Floodplain		Location:	Range Rd. 102S, SW of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	588.29	m			
Length:	30.7	m	Diameter	0.50	m
Upstream Invert	585.64	m	Downstream Invert	585.15	m
Upstream Crown	586.14	m	Downstream Crown	585.65	m

Photo(s):

Structure ID:	B6				
Structure Name:	Range Rd. 102 N Culvert				
Water Course:	Floodplain		**Location:**	Range Rd. 102N, NW of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	588.10	m			
Length:	13	m	**Diameter**	0.63	m
Upstream Invert	586.95	m	**Downstream Invert**	586.88	m
Upstream Crown	587.58	m	**Downstream Crown**	587.51	m

Photo(s):

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Structure ID:	B7		
Structure Name:	5 St. Culvert		
Water Course:	Floodplain	Location:	5th St., NW Kinuso

Description and Type:	
Type:	Culvert
Description:	Single barrel, corrugated metal culvert

Information:					
Minimum Road Elevation	587.67	m			
Length:	12.80	m	Diameter	0.40	m
Upstream Invert	587.06	m	Downstream Invert	586.90	m
Upstream Crown	587.46	m	Downstream Crown	587.3	m

Photo(s):
Source: Google Earth

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Structure ID:	B8				
Structure Name:	Railway Ave Culvert				
Water Course:	Floodplain		Location:	Railway Ave, NW Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Double barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	587.44	m			
Barrel One					
Length:	19	m	Diameter	0.44	m
Upstream Invert	587.23	m	Downstream Invert	586.91	m
Upstream Crown	587.67	m	Downstream Crown	587.35	m
Barrel Two					
Length:	12.70	m	Diameter	0.49	m
Upstream Invert	586.65	m	Downstream Invert	586.54	m
Upstream Crown	587.14	m	Downstream Crown	587.03	m

Photo(s):
Source: Google Earth

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Structure ID:	B9				
Structure Name:	Range Rd. 101A N Culvert				
Water Course:	Floodplain		Location:	Range Rd. 101A, S of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	589.61	m			
Length:	20.70	m	Diameter	0.32	m
Upstream Invert	587.91	m	Downstream Invert	587.70	m
Upstream Crown	588.23	m	Downstream Crown	588.02	m

Photo(s):

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Structure ID:	B10				
Structure Name:	Railway Range Rd. 100 Culvert				
Water Course:	Floodplain		Location:	Range Rd. 100 and Railway, NE of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert, some blockage observed				
Information:					
Minimum Road Elevation	585.63	m			
Length:	12.4	m	Diameter	0.63	m
Upstream Invert	584.22	m	Downstream Invert	584.14	m
Upstream Crown	584.85	m	Downstream Crown	584.77	m

Photo(s):

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403.592.8300

Structure ID:	B11				
Structure Name:	Range Rd. 100 Culvert				
Water Course:	Floodplain		Location:	Range Rd. 100, NE of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	585.65	m			
Length:	15	m	Diameter	0.82	m
Upstream Invert	583.93	m	Downstream Invert	583.89	m
Upstream Crown	584.75	m	Downstream Crown	584.71	m

Photo(s):

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Structure ID:	B12				
Structure Name:	Unnamed Rd. Kinuso NW Culvert				
Water Course:	Floodplain/ Strawberry Creek		Location:	Unnamed Rd., NW of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	586.50	m			
Length:	20.7	m	Diameter	1.21	m
Upstream Invert	583.31	m	Downstream Invert	583.21	m
Upstream Crown	584.52	m	Downstream Crown	584.42	m

Photo(s):
Source: Google Earth

1000 7th Avenue SW, Suite 450
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Structure ID:	B13				
Structure Name:	HWY 2 Mid Culvert				
Water Course:	Floodplain		Location:	HWY 2, SE of Kinuso	
Description and Type:					
Type:	Culvert				
Description:	Single barrel, corrugated metal culvert				
Information:					
Minimum Road Elevation	590.30	m			
Length:	21.70	m	Diameter	0.91	m
Upstream Invert	588.10	m	Downstream Invert	587.72	m
Upstream Crown	589.01	m	Downstream Crown	588.63	m

Photo(s):

1000 7th Avenue SW, Suite 450
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403.592.8300

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Structure ID:	B14		
Structure Name:	Range Rd. 101 A S Culvert		
Water Course:	Floodplain	**Location:**	Range Rd. 101A, S of Kinuso

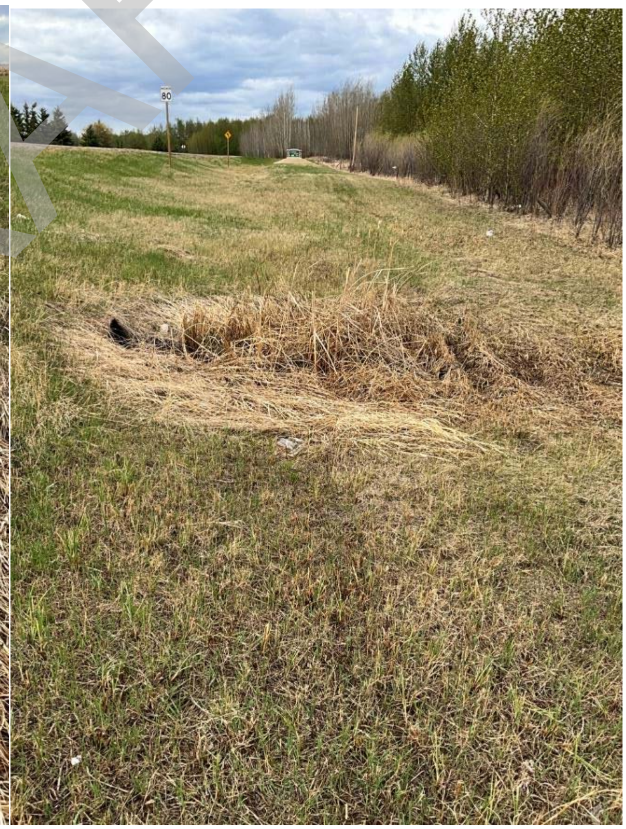
Description and Type:

Type:	Culvert
Description:	Single barrel, corrugated metal culvert

Information:

Minimum Road Elevation	590.40	m			
Length:	28.20	m	**Diameter**	0.74	m
Upstream Invert	587.54	m	**Downstream Invert**	587.30	m
Upstream Crown	588.28	m	**Downstream Crown**	588.04	m

Photo(s):



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Study ID:	B15				
Structure Name:	Railway E Bridge		Bridge File:	N/A	
Water Course:	Floodplain; Eula Creek		Location:	Railway, NE of Kinuso	
Description and Type:					
Type:	Bridge				
Description:	Multiple spans, railway bridge				
Information:					
Span:	35.80	m	No. Pier	7	
Width:	4.50	M	Pier Width:	0.5	m
High Chord:	585.20	m			
Low Chord:	584.03	m			

Photo(s):
Source: Google Earth

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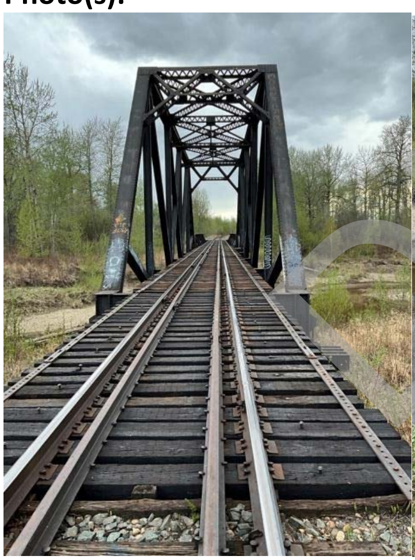
Study ID:	B16				
Structure Name:	Swan River Railway Bridge		Bridge File:	N/A	
Water Course:	Floodplain		Location:	Railway, Swan River E of Kinuso	
Description and Type:					
Type:	Bridge				
Description:	Multiple spans, railway bridge				
Information:					
Span:	97.60	m	No. Pier	3	
Length:	6	M	Pier Width:	2.4, 3.5, 2.4	m
High Chord:	591.72	m			
Low Chord:	590.02	m			

Photo(s):



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403.592.8300

Study ID:	B17		
Structure Name:	Railway NE Kinuso Bridge	Bridge File:	N/A
Water Course:	Floodplain	Location:	Railway, E of Kinuso

Description and Type:

Type:	Bridge
Description:	Multiple spans, railway bridge

Information:

Span:	13.4	m	No. Pier	2	
Width:	3.70	M	Pier Width:	0.50	m
High Chord:	589.28	m			
Low Chord:	588.31	m			

Photo(s):

BARR

Study ID:	B18				
Structure Name:	Railway NW Bridge		Bridge File:	N/A	
Water Course:	Floodplain/ Strawberry Creek		Location:	Railway, NW of Kinuso	
Description and Type:					
Type:	Bridge				
Description:	Multiple spans, railway bridge				
Information:					
Span:	18.2	m	No. Pier	3	
Width:	5.4	M	Pier Width:	0.50	m
High Chord:	587.8	m			
Low Chord:	586.91	m			

Photo(s):


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Study ID:	B19				
Structure Name:	Swan River HWY 2 Bridge		Bridge File:	N/A	
Water Course:	Swan River		Location:	HWY 2, SE of Kinuso	
Description and Type:					
Type:	Bridge				
Description:	Multiple spans, railway bridge				
Information:					
Span:	75.90	m	No. Pier	2	
Width:	9.8	M	Pier Width:	1	m
High Chord:	593.90	m			
Low Chord:	591.05	m			

Photo(s):

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403.592.8300

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Appendix C

Memorandum on Flood Control Structure

Technical Memorandum

To: Muhammad Durrani, M.Eng., P.Eng.
From: Hossein Kheirkhah Gildeh, Ph.D., P.Eng.
Subject: Flood Berm for Kinuso Flood Study
Date: July 8, 2024
Project: Kinuso Flood Study
c: Thomas MacDonald, M.Sc., P.Eng.

1 INTRODUCTION

In 2024, Alberta Environment and Protected Areas (EPA) retained Barr Engineering and Environmental Science Canada Limited (Barr) to conduct the Kinuso Flood Study. This study is for approximately 21 km of the Swan River extending from the south edge of NE 1-73-10-W5M downstream to approximately the middle of SE 31-73-9-W5M. The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. This project includes working with the Swan River First Nation. Project stakeholders include the Government of Alberta, Big Lakes County and the public.

The Kinuso Flood Study includes multiple components and deliverables. This technical memorandum documents existing flood berms in the study area.

2 SURVEY PROGRAM

2.1 General

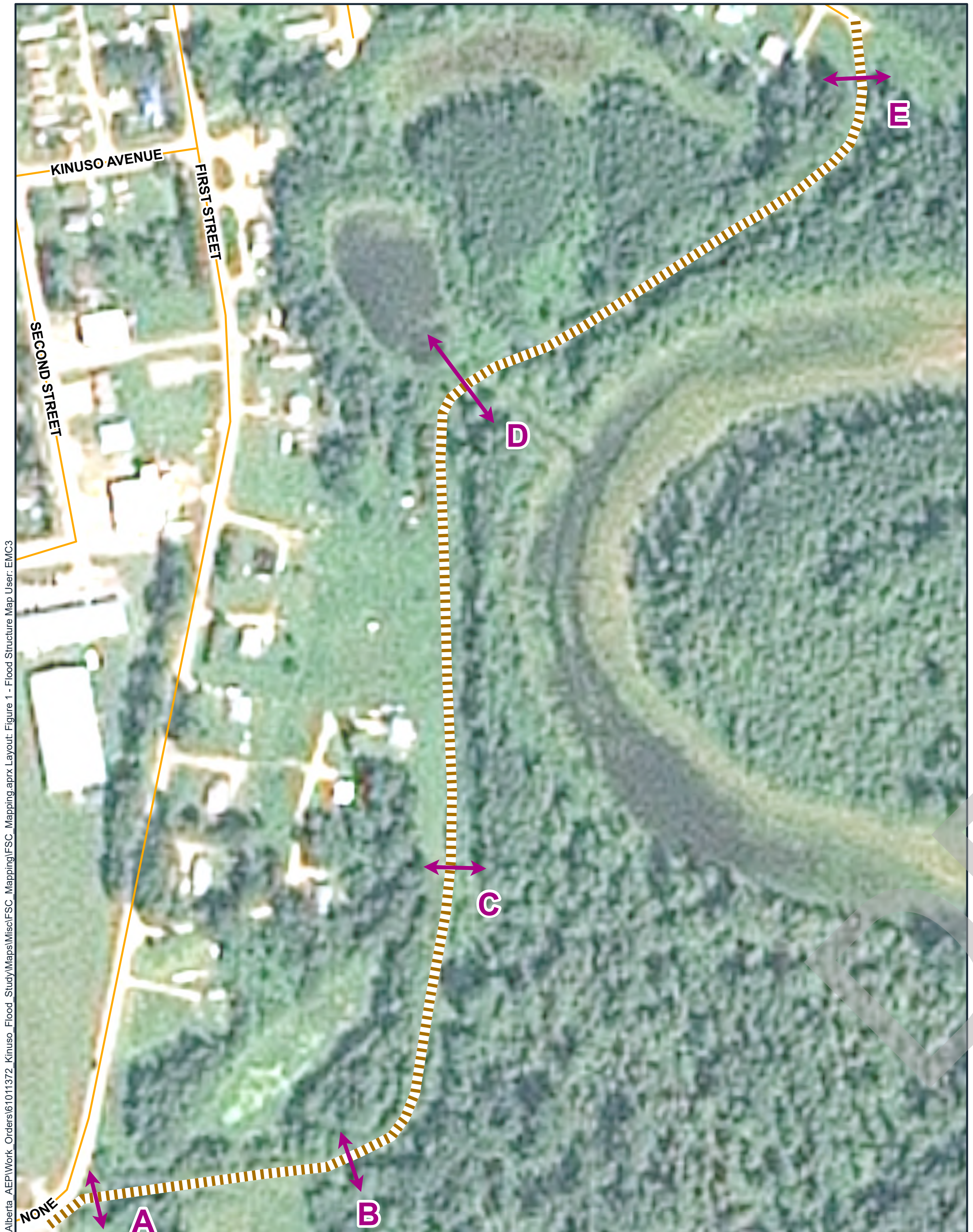
A site visit of the study area was completed by Barr, EPA and Trout Hydrography (Trout) on May 14 and 15, 2024. The first part of the survey was conducted between May 21 and 23 which was terminated due to rain and unstable river banks which made the survey unsafe. All structures on the Swan River and key structures on the floodplain were surveyed during May 2024, including the only flood berm within the study area. The details of the stream survey are described in the hydraulic model creation and calibration report.

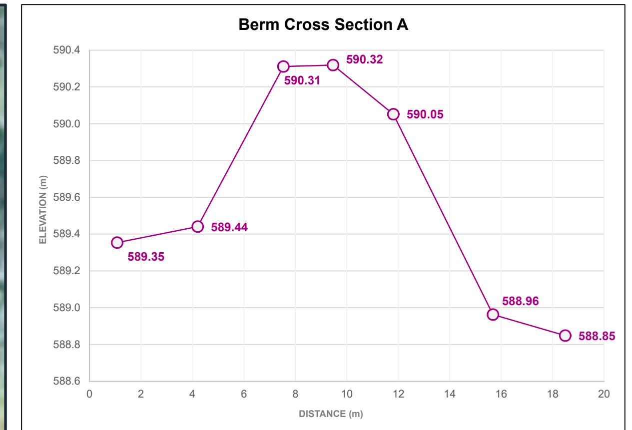
2.2 Flood Berms

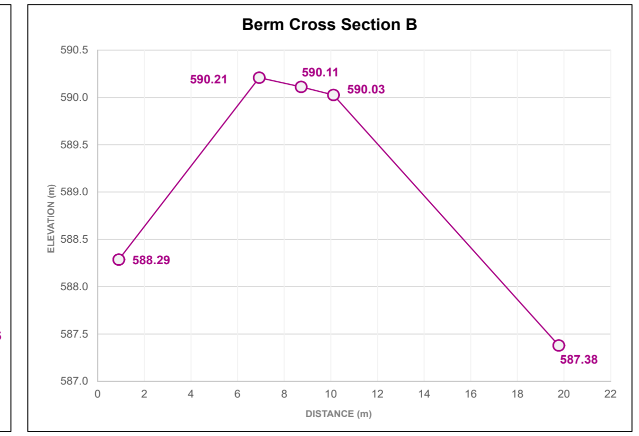
There is one flood berm on the Swan River near Kinuso. The location of this flood berm is shown on Figure 1 and is described in Table 1. This flood berm is an earthen berm located on the east side of Kinuso and left floodplain of the Swan River. Remnant oxbow lakes from the Swan River exist between the berm and the current river alignment, as shown in Figure 2 and Figure 3. This berm, which is approximately 919 m long, was constructed in 1983 to prevent the Swan River from flooding into Kinuso. A longitudinal profile and five cross sections were collected during the May 2024 survey and are shown on Figure 1.

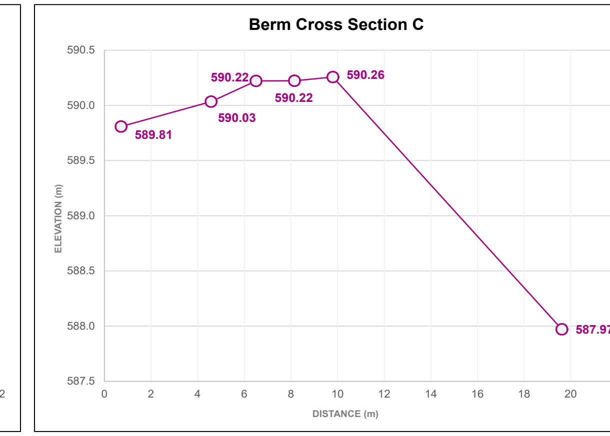
Table 1 Details of the flood berm

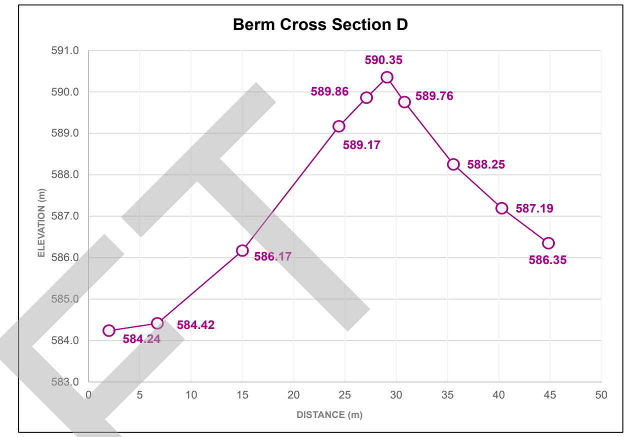
Location	Approximate Length of Structure (m)	Type of Structure	Note
Kinuso	919	Berm	On the east side of Kinuso and west floodplain of the Swan River

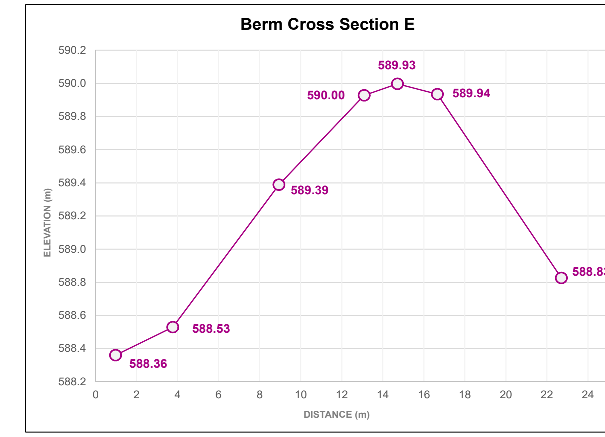


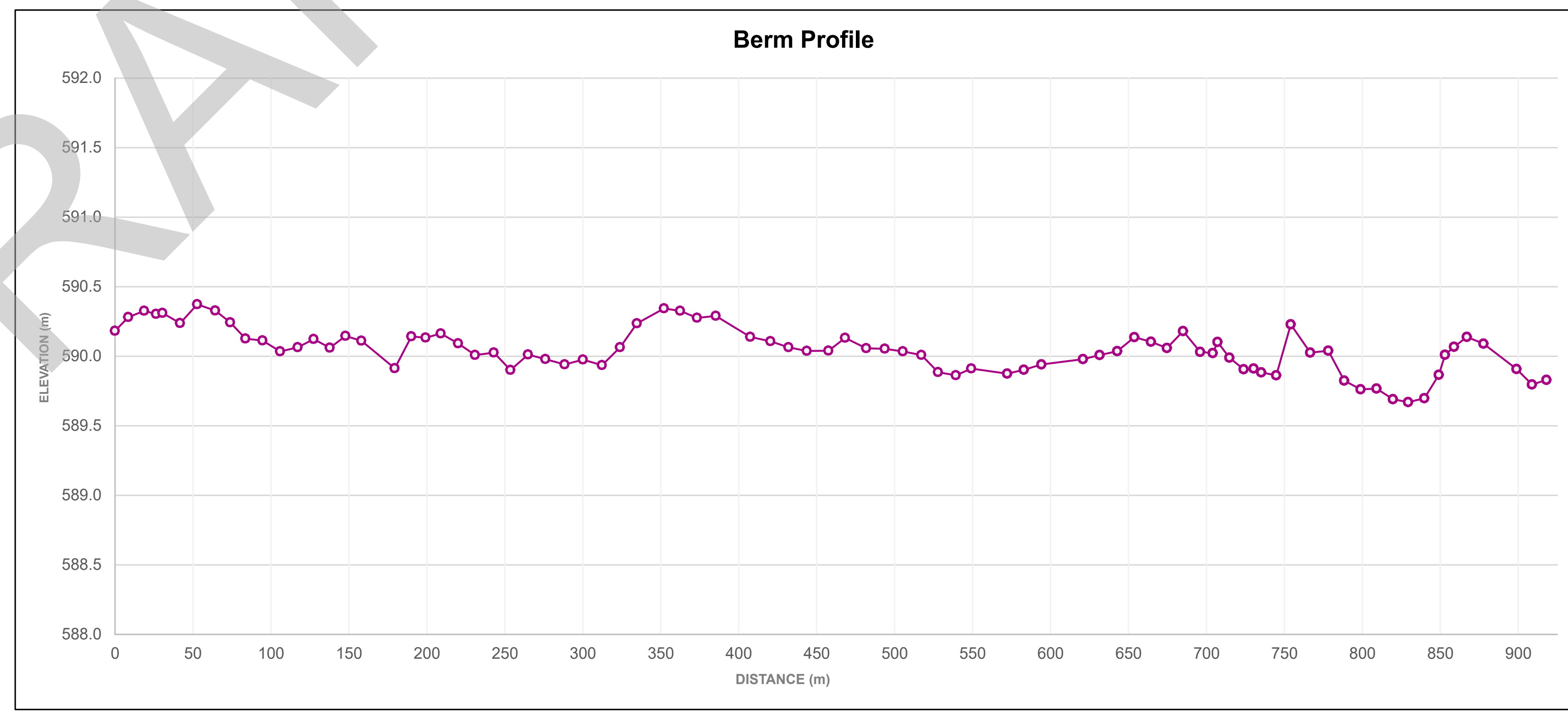












LEGEND

- Flood Control Structure
- Berm Cross Section
- Road

Location	Kinuso
Approx. Length of Structure (m)	919
Type of Structure	Berm

0 100 200
Meters
Scale: 1:3,000

Notes:
Flood control structure completed to support hydraulic modelling and flood mapping.
Profile stationing is from south to north and cross section stationing is from west to east.

References:
Flood control structure survey by Trout on May 22, 2024.
Imagery: Alberta Environment and Protected Areas (2022).
Roads: Natural Resources Canada, all rights reserved.
Coordinate System: NAD 1983 CSRS 3TM 114.

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Canada

Berm, West Side of the Swan River to Protect Kinuso
Kinuso Flood Study
Alberta Environment and Protected Areas

FIGURE 1

BARR

Figure 2 Berm at Kinuso. a) Standing on the Berm Crest and Viewing SW, b) Location of Picture in (a)

Figure 3 Berm at Kinuso. a) Standing on the Berm Toe and Viewing NW, b) Location of Picture in (a)

Certification

Prepared by:

Hossein Kheirkhah Gildeh, Ph.D., P.Eng.
Senior Water Resources Engineer

Reviewed by:

Thomas MacDonald, M.Sc., P.Eng.
Principal, Senior Water Resources Engineer

Disclaimer

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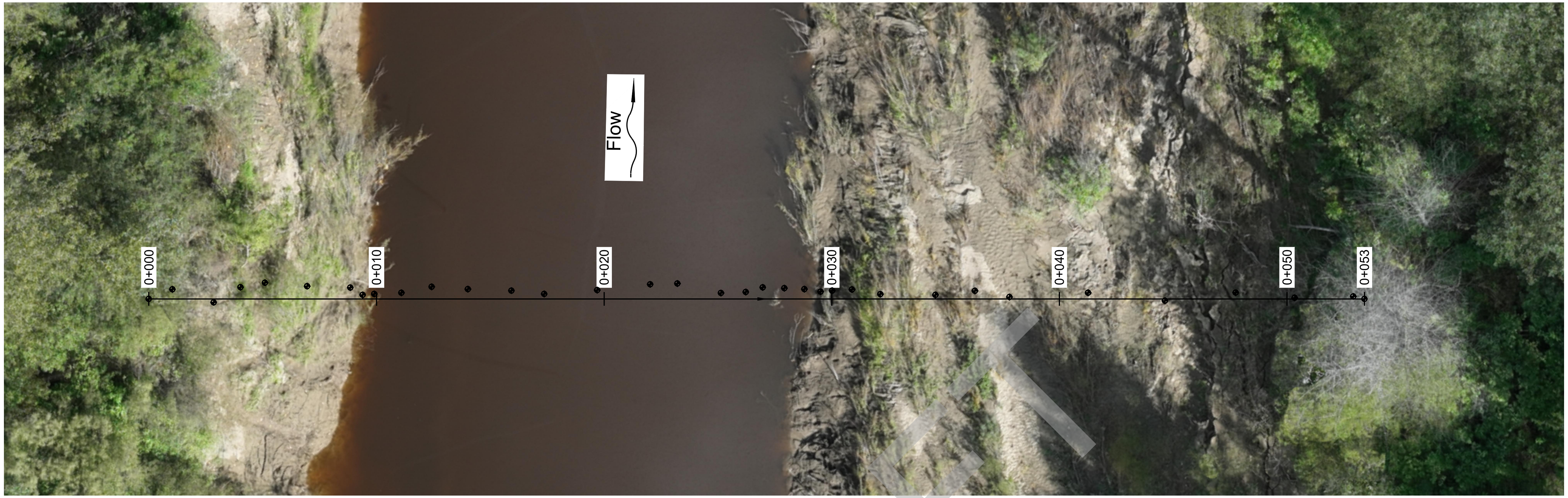
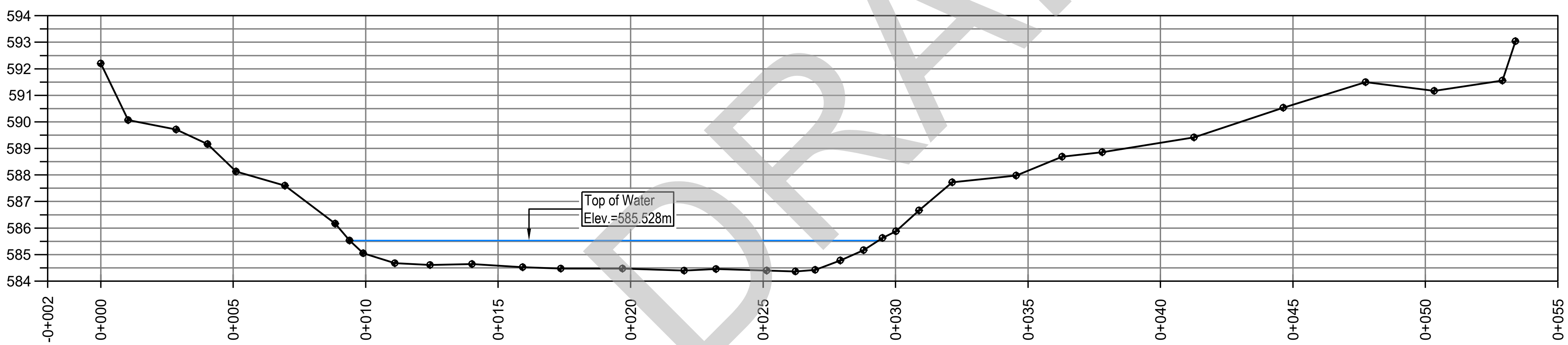
Appendix D

Reach Representative Photos



PLAN VIEW
Scale - 1:200



PROFILE VIEW
Scales: H = 1 : 200 / V = 1 : 200

Legend/Notes

Ground Shot	⊕	Distances and elevations shown are in metres.
Water Level Line	———	Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground	———	Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

Kinuso Flood Study
Swan River Survey
Cross Section X-005 and Profile Plan
LSD 8, Section 1, Township 73, Range 10, Meridian 5
Big Lakes County
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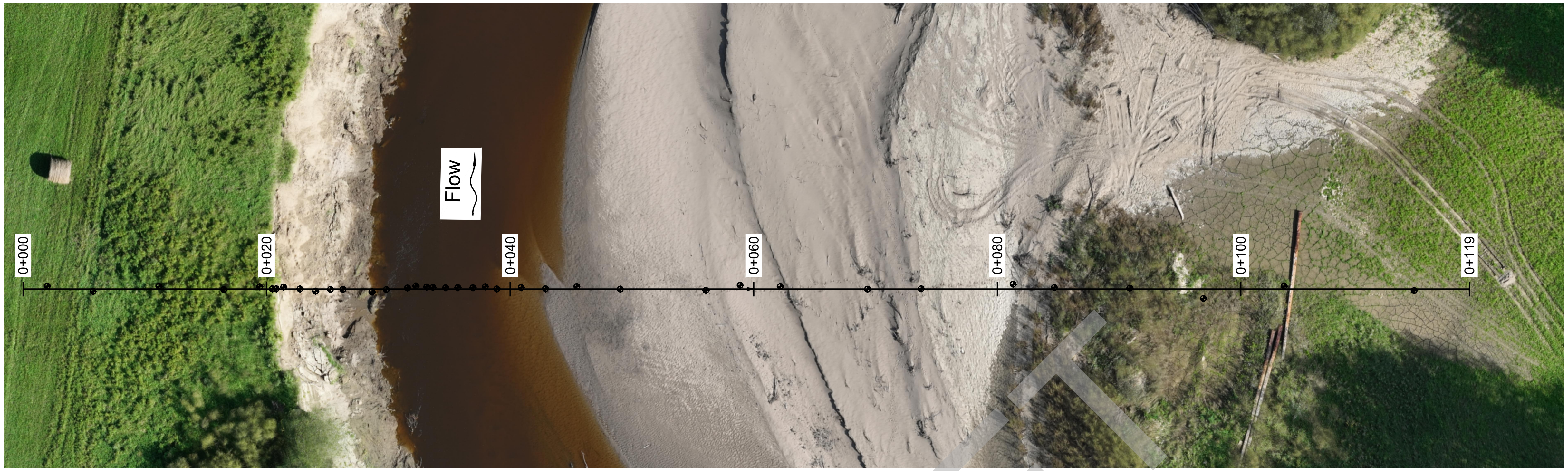
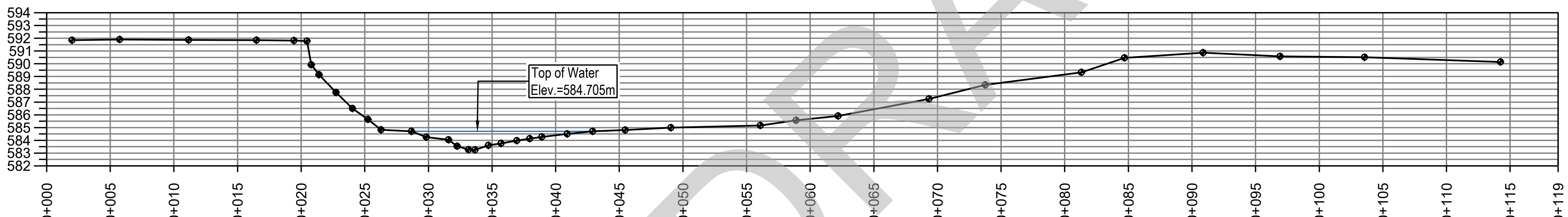


PLAN VIEW

Scale - 1:400



PROFILE VIEW

Scales: H = 1 : 400 / V = 1 : 400

Legend/Notes

Ground Shot	⊕	Distances and elevations shown are in metres.
Water Level Line	(blue line)	Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground	(black line)	Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

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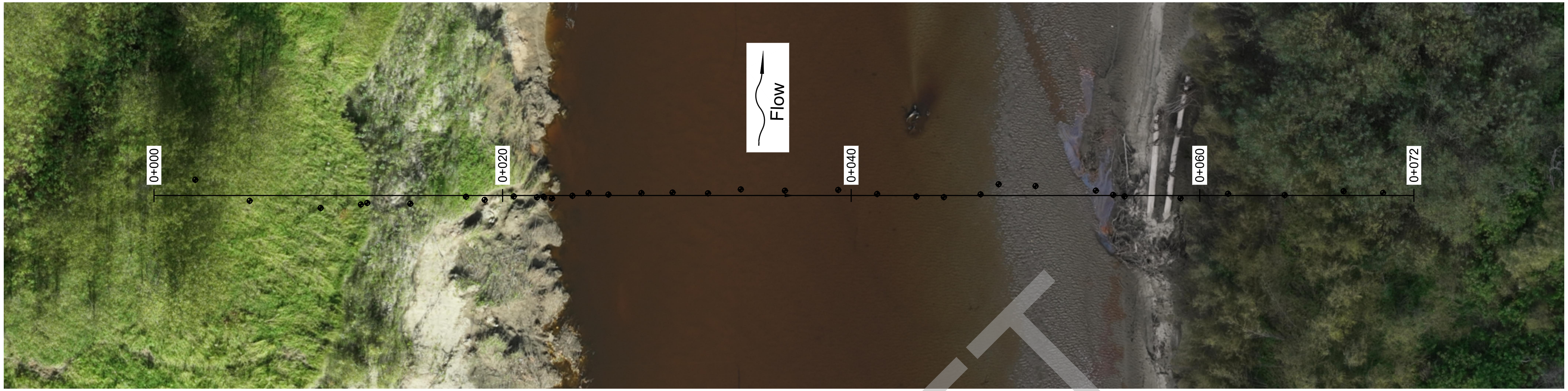
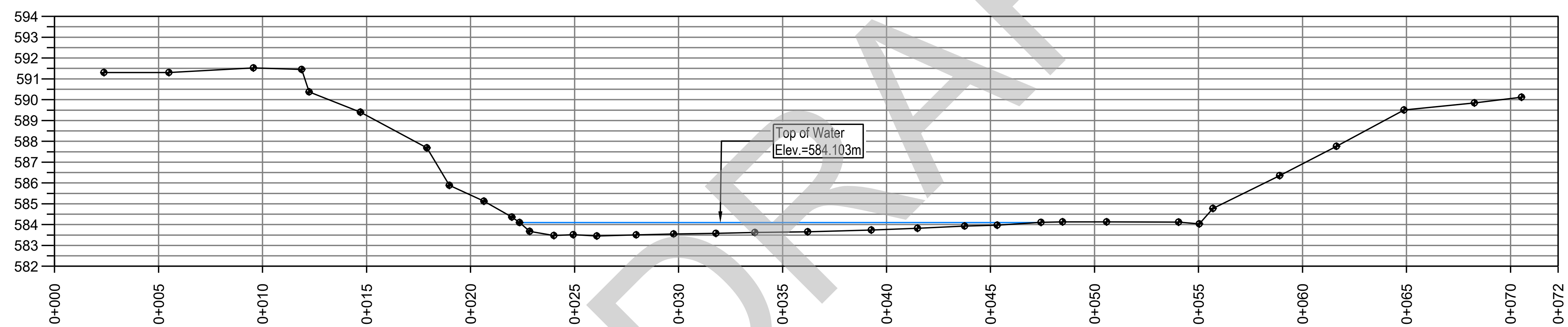


PLAN VIEW
Scale - 1:250



PROFILE VIEW
Scales: H = 1 : 250 / V = 1 : 250

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Legend/Notes

Ground Shot		Distances and elevations shown are in metres.
Water Level Line		Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground		Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

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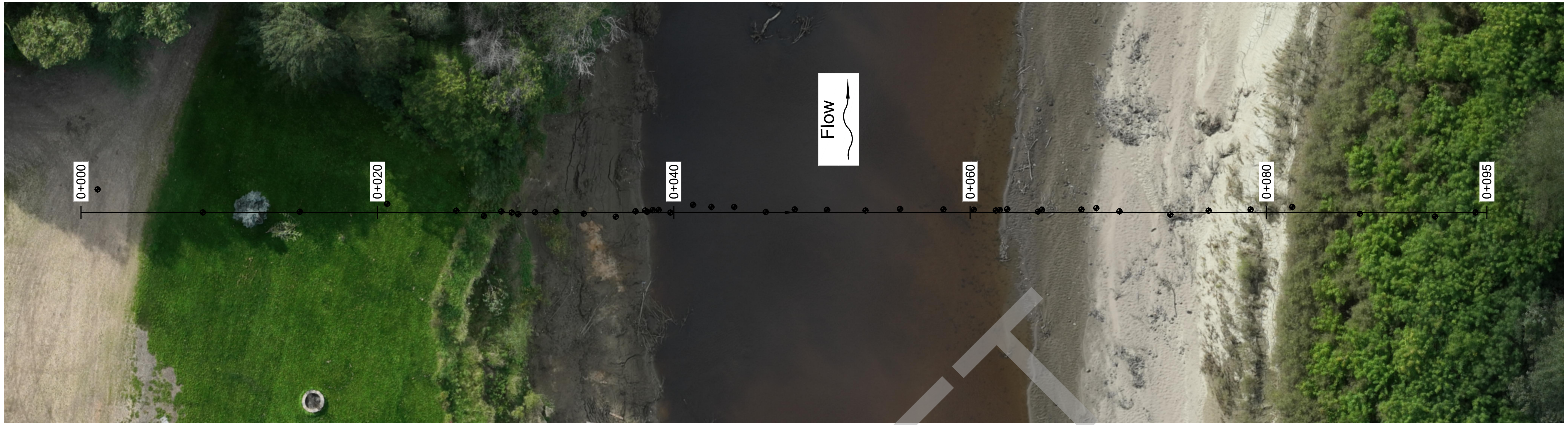
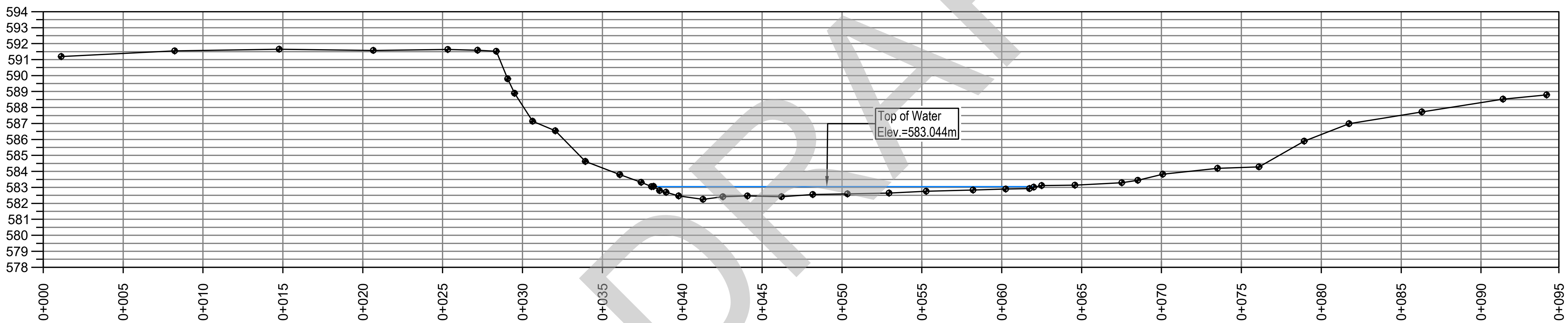


PLAN VIEW
Scale - 1:300



PROFILE VIEW
Scales: H = 1 : 300 / V = 1 : 300

Legend/Notes

Ground Shot	●	Distances and elevations shown are in metres.
Water Level Line	(blue line)	Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground	(black line)	Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

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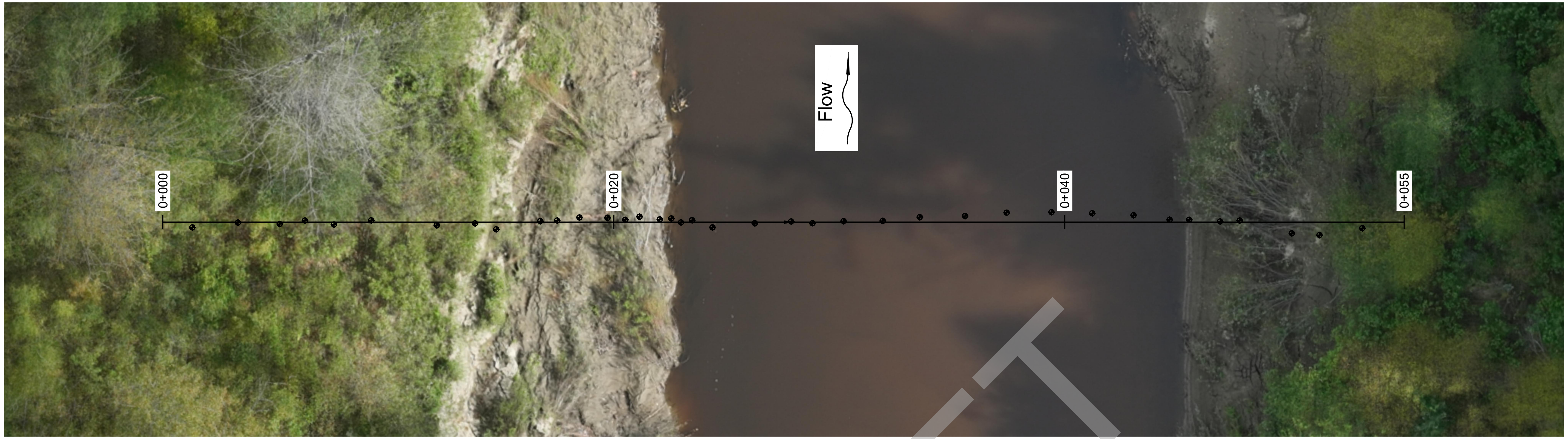

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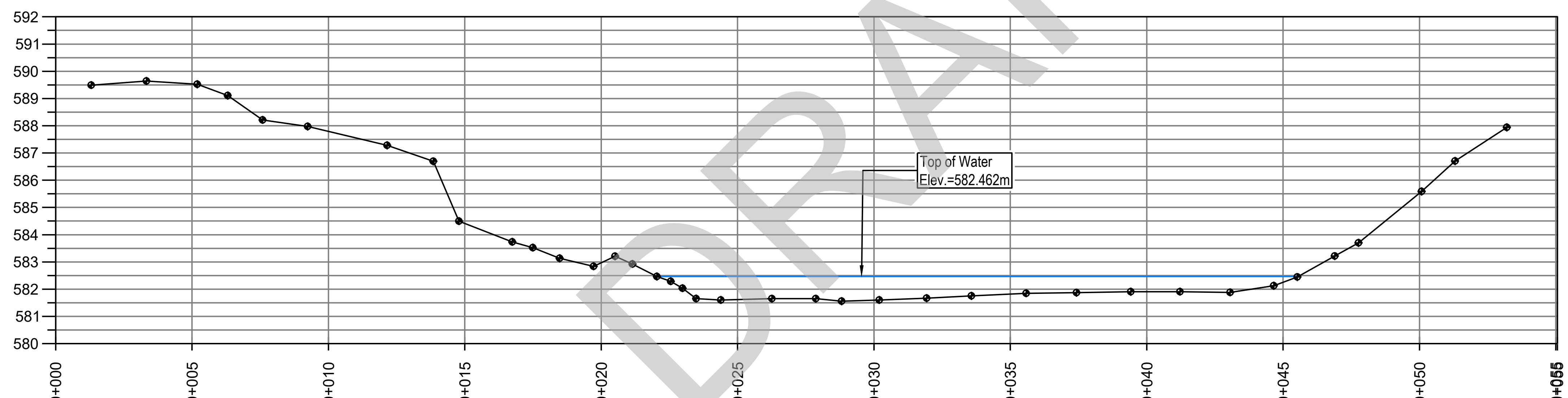

PROFILE VIEW
Scales: H = 1 : 200 / V = 1 : 200

Legend/Notes

Ground Shot	●	Distances and elevations shown are in metres.
Water Level Line	(blue line)	Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground	(black line)	Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

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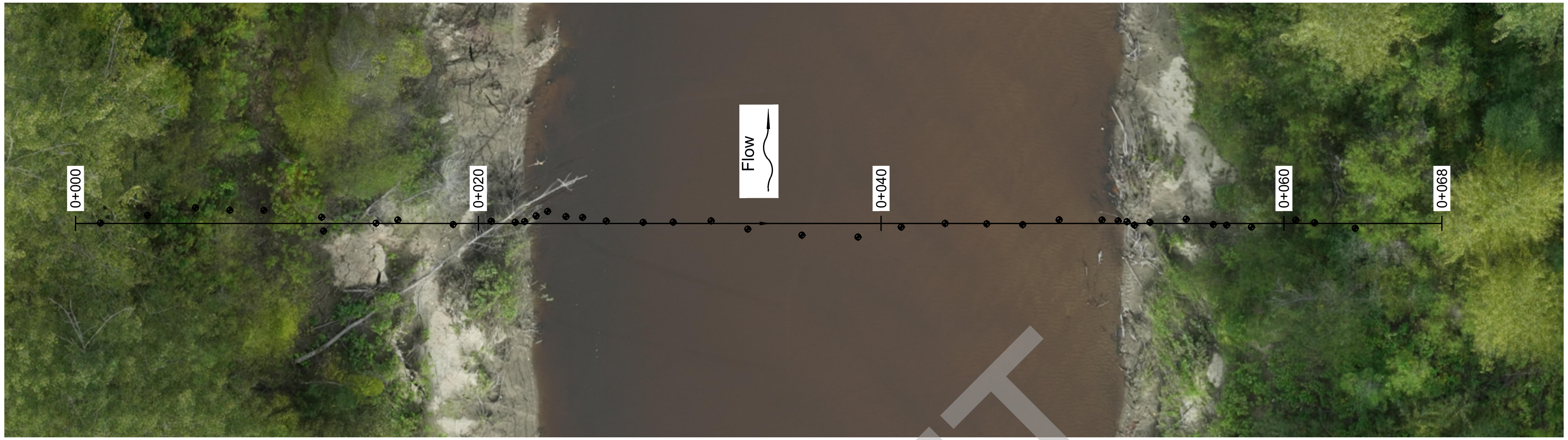

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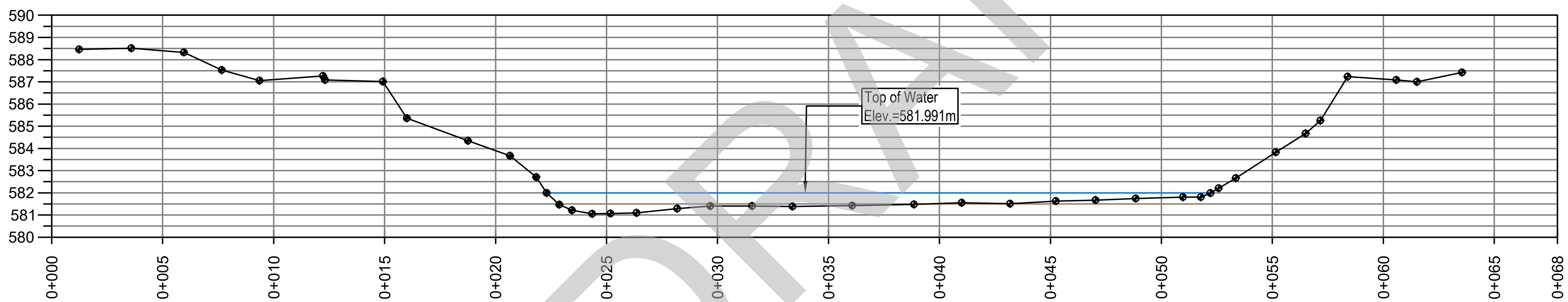

PROFILE VIEW
Scales: H = 1 : 250 / V = 1 : 250

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Legend/Notes

Ground Shot		Distances and elevations shown are in metres.
Water Level Line		Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground		Coordinates are 3TM Grid Referenced to CM 114°W.
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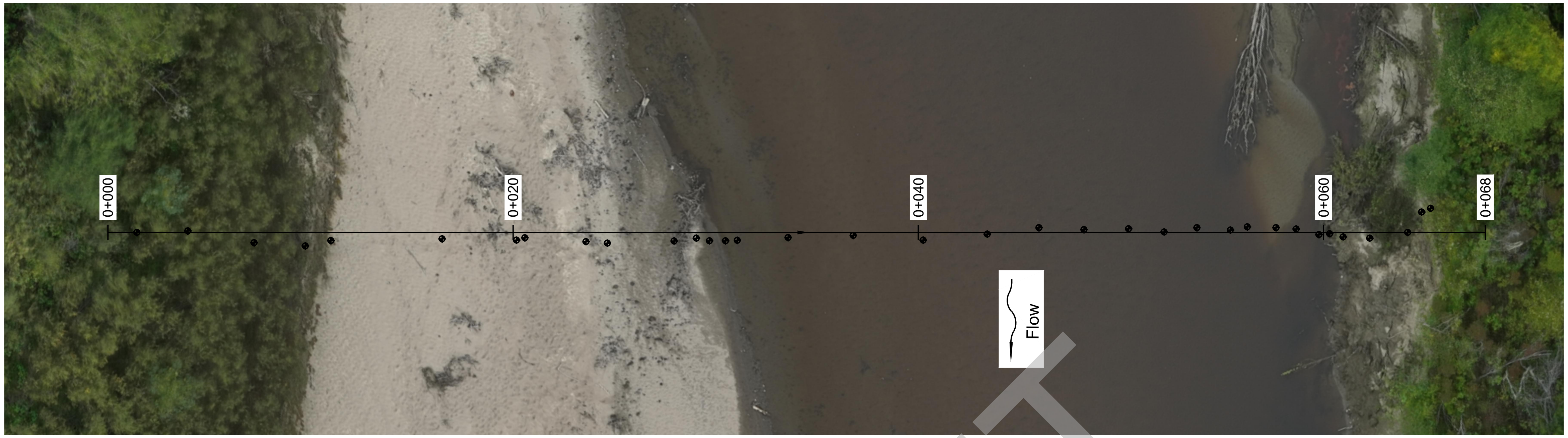

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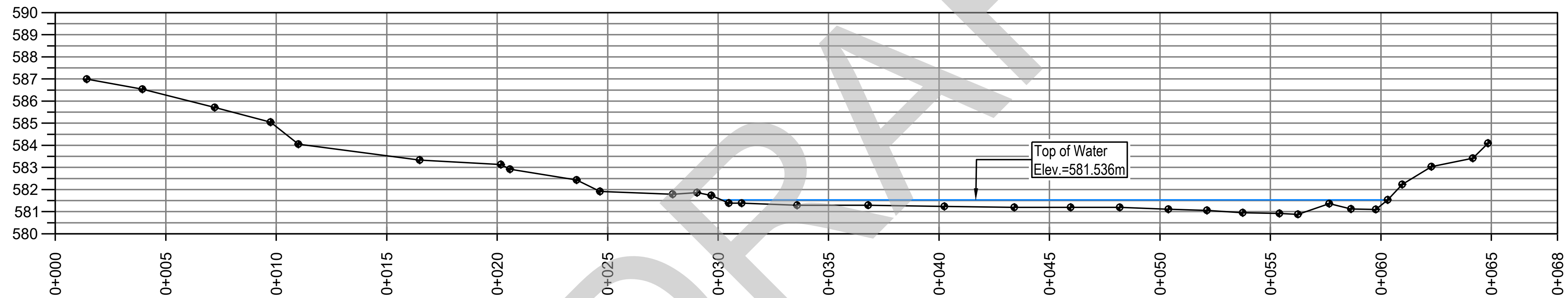

PROFILE VIEW
Scales: H = 1 : 250 / V = 1 : 250

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Legend/Notes

Ground Shot		Distances and elevations shown are in metres.
Water Level Line		Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground		Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

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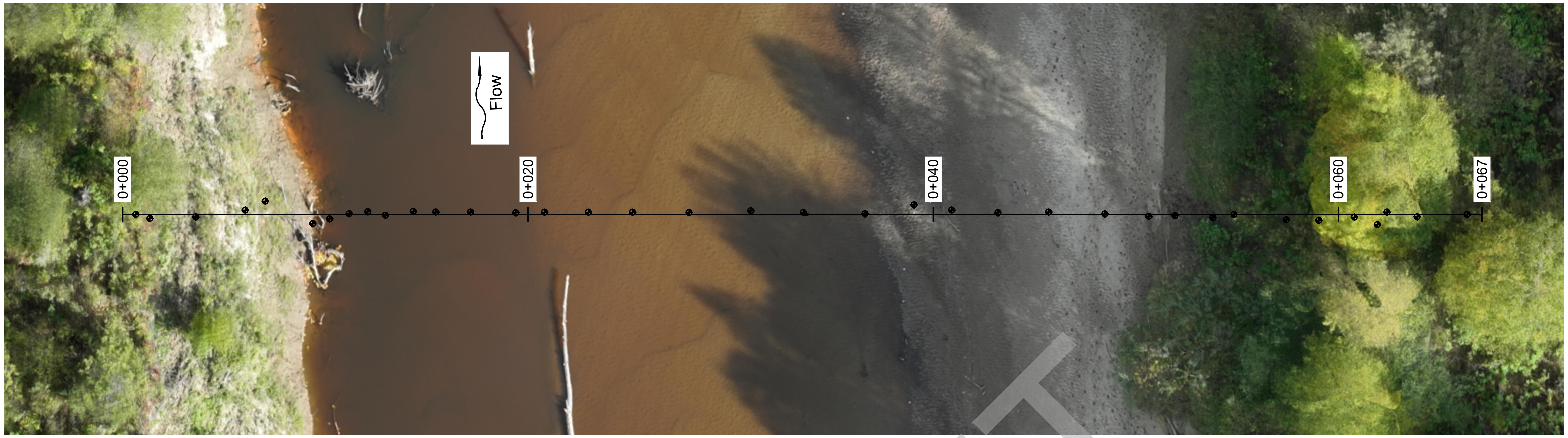

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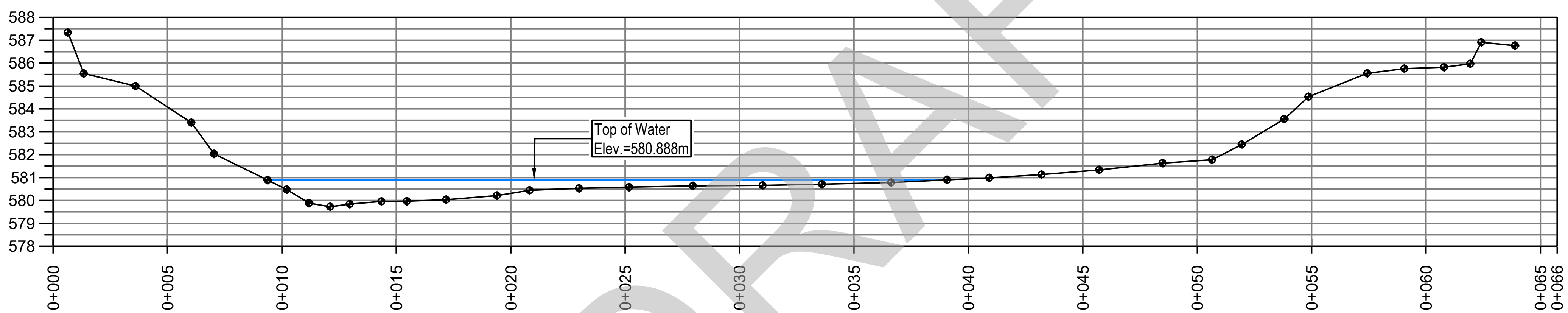

PROFILE VIEW
Scales: H = 1 : 250 / V = 1 : 250

DRAFT

Legend/Notes		
Ground Shot	⊕	Distances and elevations shown are in metres.
Water Level Line		Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground		Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

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Swan River Survey
Cross Section X-116 and Profile Plan
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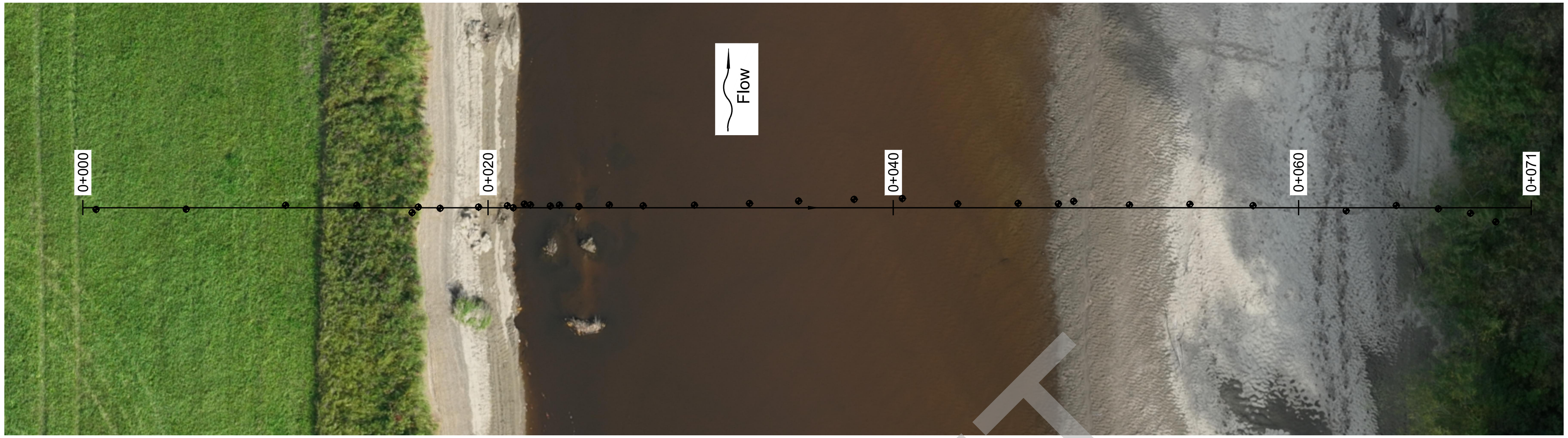
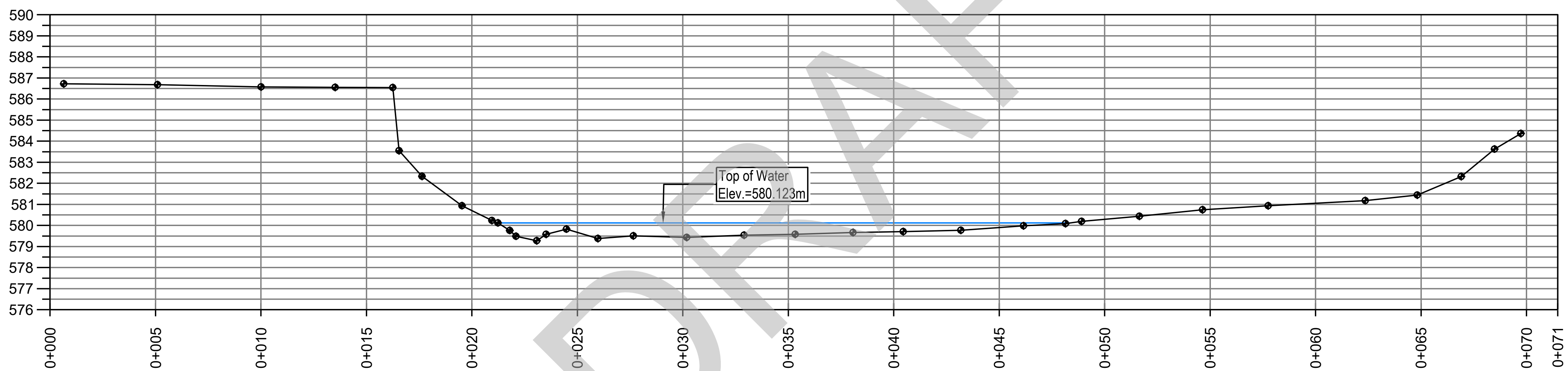


PLAN VIEW

Scale - 1:250



PROFILE VIEW

Scales: H = 1 : 250 / V = 1 : 250

DRAFT

Legend/Notes

Ground Shot	⊕	Distances and elevations shown are in metres.
Water Level Line	(blue line)	Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground	(black line)	Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

Kinuso Flood Study
Swan River Survey
Cross Section X-132 and Profile Plan
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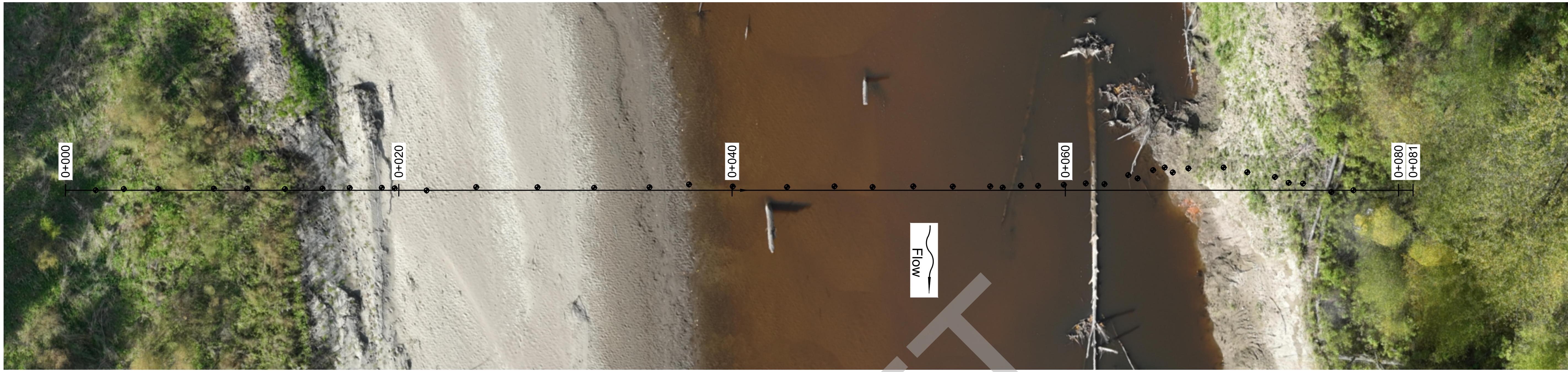
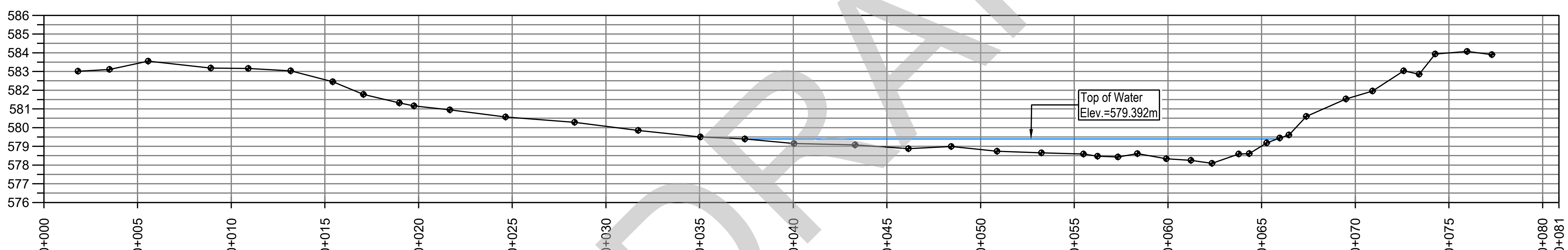


PLAN VIEW
Scale - 1:250



PROFILE VIEW
Scales: H = 1 : 250 / V = 1 : 250

DRAFT

Legend/Notes

Ground Shot	⊕	Distances and elevations shown are in metres.
Water Level Line	blue line	Elevations are derived from the CSRS-PPP Service (Datum: HT2.0).
Profile - Existing Ground	black line	Coordinates are 3TM Grid Referenced to CM 114°W.
		Date(s) of Survey: Sept. 10th, 2024.

Revision 0

No.	Revision	Date
0	Original Issue	Sep 26/24

PC: MM | DR: ZT | CH: MM

File: 24-0786-00 | Dwg: 24-0786-00 X146 Cross Section

coregeomatics
p | 403-648-2772
f | 403-648-2767
www.coregeomatics.com

Kinuso Flood Study
Swan River Survey
Cross Section X-146 and Profile Plan
LSD 8, Section 1, Township 73, Range 10, Meridian 5
Big Lakes County
Alberta

Canada Alberta BARR

Classification: Public

Cross Section # 5

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 24

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 39

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 57

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 73

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 87

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 102

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 116

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 132

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Cross Section # 146

Looking Upstream

Looking Downstream

Looking Right Bank

Looking Left Bank

Appendix E

Technical Memorandum on Open Water Hydrology Assessment

Technical Memorandum

To: Mr. Muhammad Durrani, M.Eng., P.Eng.
From: Moges Wagena, Ph.D., Omid Mohseni, Ph.D.
Subject: Kinuso Open Water Hydrology Assessment
Date: January 27, 2025
Project: Kinuso Flood Study - 61011372
c: Hossein Kheirkhah Gildeh, Ph.D., P.Eng. (Barr), Tom MacDonald, P.Eng. (Barr)

1 Introduction

In 2024, Alberta Environment and Protected Areas (EPA) retained Barr Engineering and Environmental Science Canada Limited (Barr) to assess and identify flood hazards along approximately 21 km of the Swan River through Big Lakes County, including the Hamlet of Kinuso, and the Swan River First Nation (SRFN). The study area for the Swan River extends from the south edge of NE 1-73-10-W5M downstream to approximately the middle of SE 31-73-9-W5M. The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. Project stakeholders include the Government of Alberta, Big Lakes County, and SRFN.

The Kinuso flood mapping study includes multiple components and deliverables. This technical memorandum summarizes the open water hydrology assessment of the Swan River within the study area, including the flood frequency estimates and flood hydrographs.

1.1 Study Area

The Swan River drains an area of approximately 3,000 km^2 (LSWC, 2009), originating from the Swan Hills and flowing north to its terminus at Swan Point on Lesser Slave Lake (LSL), about 12 km northeast of the Town of Kinuso. Figure 1-1 shows the project location, study extent and the overall watershed area of the Swan River at the Water Survey of Canada (WSC) hydrometric station 07BJ001, where flood frequency estimates are required for the open water hydrology assessment.

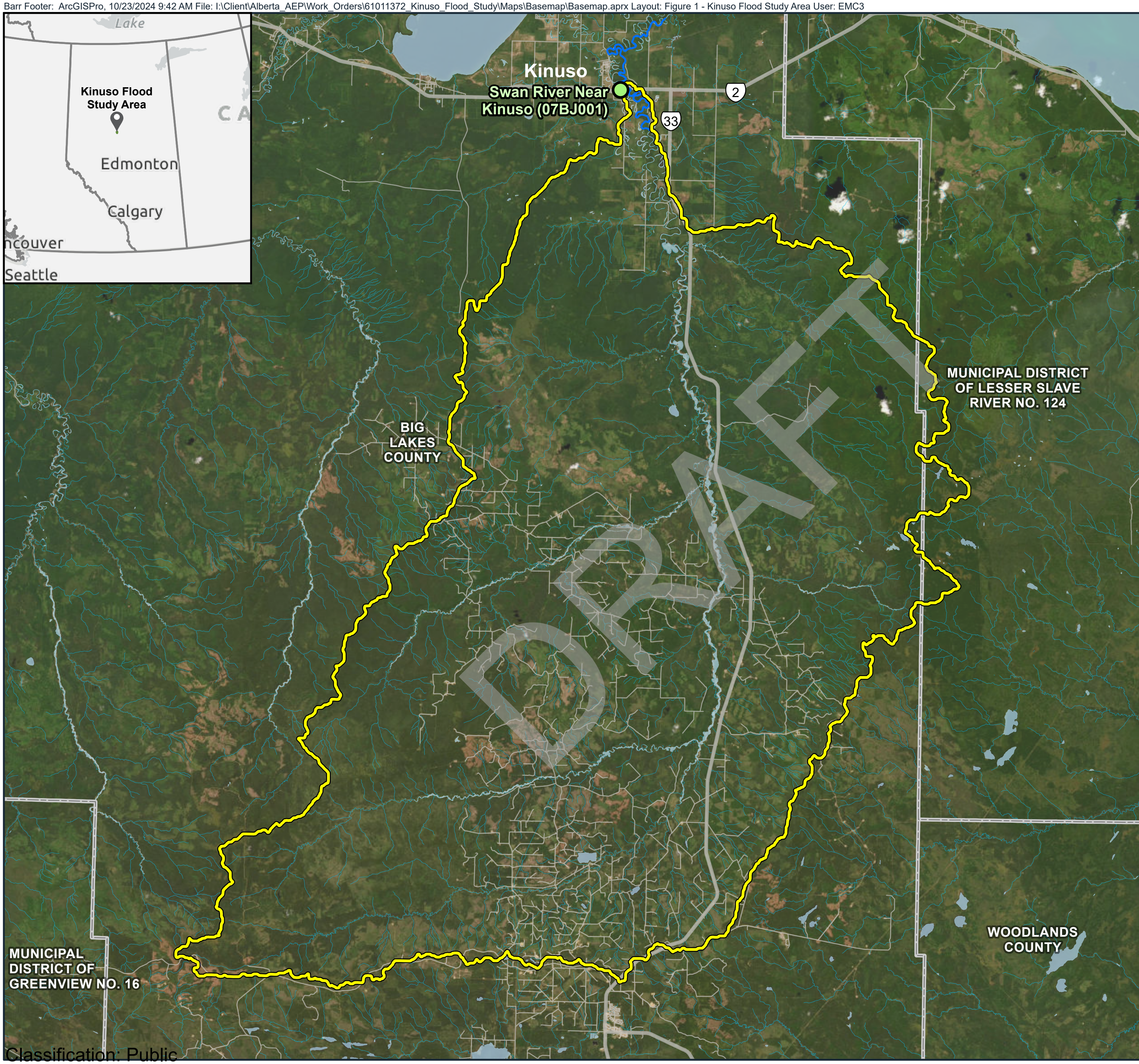
1.2 Study Objectives

The main objective of the flood frequency analysis was to estimate the flood flows with annual exceedance probabilities (AEPs) of 1:2, 1:5, 1:10, 1:20, 1:35, 1:50, 1:75, 1:100, 1:200, 1:350, 1:500, 1:750, and 1:1,000 for the Swan River within the study area and the flood hydrographs for the same AEPs.

1.3 Watershed Setting and Flood History

The Swan River flows northward through the boreal forest of Alberta, and it eventually empties into LSL, which is part of the Athabasca River basin. The river has a tortuously meandering channel pattern and is incised within a delta deposit and floodplain. The channel is perched, and ground elevation generally drops away from the river, particularly in the east and northeast of Kinuso. Significant channelization of the Swan River is evident downstream of Kinuso, with five previous meanders eliminated by cutoffs constructed in 1983 and 1984. The Swan River slope within the study area is quite gentle (~0.005 m/m). The Swan River watershed upstream of the WSC gauge 07BJ001 was delineated using the available digital elevation model (DEM) from the Alberta Flow Estimation Tool for Ungauged Watersheds (AFETUW). Figure 1-1 shows the Swan River watershed area upstream of the WSC gauge 07BJ001 and the Swan River tributaries.

The Swan River exhibits frequent flooding from late spring to late summer. Based on the available flow data, there are years where flooding occurred several times, but the significant recent flooding was in June 2018 and July 2024.



LEGEND

- Watershed Boundary
- WSC Hydrometric Gauge
- Kinuso River Centreline
- NHN Flow Line
- Waterbody
- Other Road
- Primary Road
- Municipal Boundary

Notes:
Watershed boundary for WSC gauge 07BJ001 (Swan River near Kinuso) was obtained from Alberta Flow Estimation Tool for Ungauged Watershed (afetuw.alberta.ca) and is based on a coarse digital elevation model.

References
Roads and Waterbodies: Altalis, all rights reserved.
Coordinate System: NAD 1983 CSRS 3TM 114.
National Hydro Network (NHN): Government of Canada.
Imagery: ESRI (2023).

0 5 10
Kilometers

Scale: 1:380,000

Study Area
Kinuso Flood Study
Alberta Environment and Protected Areas

FIGURE 1-1

Classification: Public

2 Flow Data

There is a WSC hydrometric station on the Swan River near Kinuso at the Highway 2 Bridge (07BJ001). The drainage area of the WSC gauge is 1,902 km^2 based on the delineated watershed area for this study. The gauging station has monitoring data over two periods. The gauge was first established in 1915 and operated only until 1917 (i.e., 3 years), for which no instantaneous annual peak flow is available. The gauge was then reestablished in 1961 and has remained in operation to the present time. Annual maximum instantaneous discharges are available for 59 years (until 2022). Due to the presence of a significant gap between two monitoring periods and to ensure consistency in the peak flow data, the recorded data from 1961 to 2022 was used for flood frequency analysis and generating flood hydrographs. After completing the analysis of the data from 1961 to 2022, EPA instructed Barr to include the 2024 flood event, a major flood event in the past few years, to determine if the results of the flood frequency analysis would change. After incorporating the data from 2023 and 2024, the results of flood frequency analysis changed very slightly with a 2.7% increase in the magnitude of the 1:2 AEP flood event, and a 1% decrease in the 1:1,000 AEP flood event. Because of the decrease in the 1:1,000 AEP event, and the 2024 data provisional status, the results used in this study only include the data from 1961 to 2022.

2.1 Previous Studies

In 2021, Management and Solution in Environmental Science (MSES) completed a flood risk mapping study supported by First Nation Adapt Program, Crown Indigenous Relations and Northern Affair Canada (CIRNAC) for the community of SRFN to assess the potential of climate change on risk of flooding in the main reserve and the associated communities (MSES, 2021). The study used the data at the WSC gauge 07BJ001 to perform flood frequency analysis. MSES used the flow record from 1961 to 2018 and estimated the 1:5, 1:10, 1:20, 1:100 and 1:200 AEP flood using the 2-parameter log-Normal distribution. The magnitudes of flood flows with AEPs of 1:5, 1:10, 1:20, 1:200 were not explicitly reported in their report, but the magnitude of the 1:100 AEP flood was reported to be 827 m^3/s.

3 Flood Frequency Analysi

3.1 Streamflow Gauges

Since there is a WSC hydrometric station on the Swan River near Kinuso (07BJ001) within the study area, the annual instantaneous peak flows and daily flow time series of the WSC hydrometric station was downloaded from the Environment and Climate Change Canada (ECCC) website for performing flood frequency analysis and for flood hydrograph generation (ECCC, 2024). The gross watershed area of the WSC gauge is 1902 km^2, with no upstream dam, i.e., the flow is not regulated.

The annual instantaneous peak flows and daily flows were downloaded for the period of record as discussed in Section 2. The WSC hydrometric station operates from March through October (i.e., open water period), with the peak flow often occurring in late spring or summer. For instance, the 1996 daily flows recorded at the WSC gauge near Kinuso are plotted in **Figure 3-1** which shows that flood flow started in April, peaked in late June and ended by late August. In the flow data provided by ECCC, no streamflow record was labeled as ice affected.

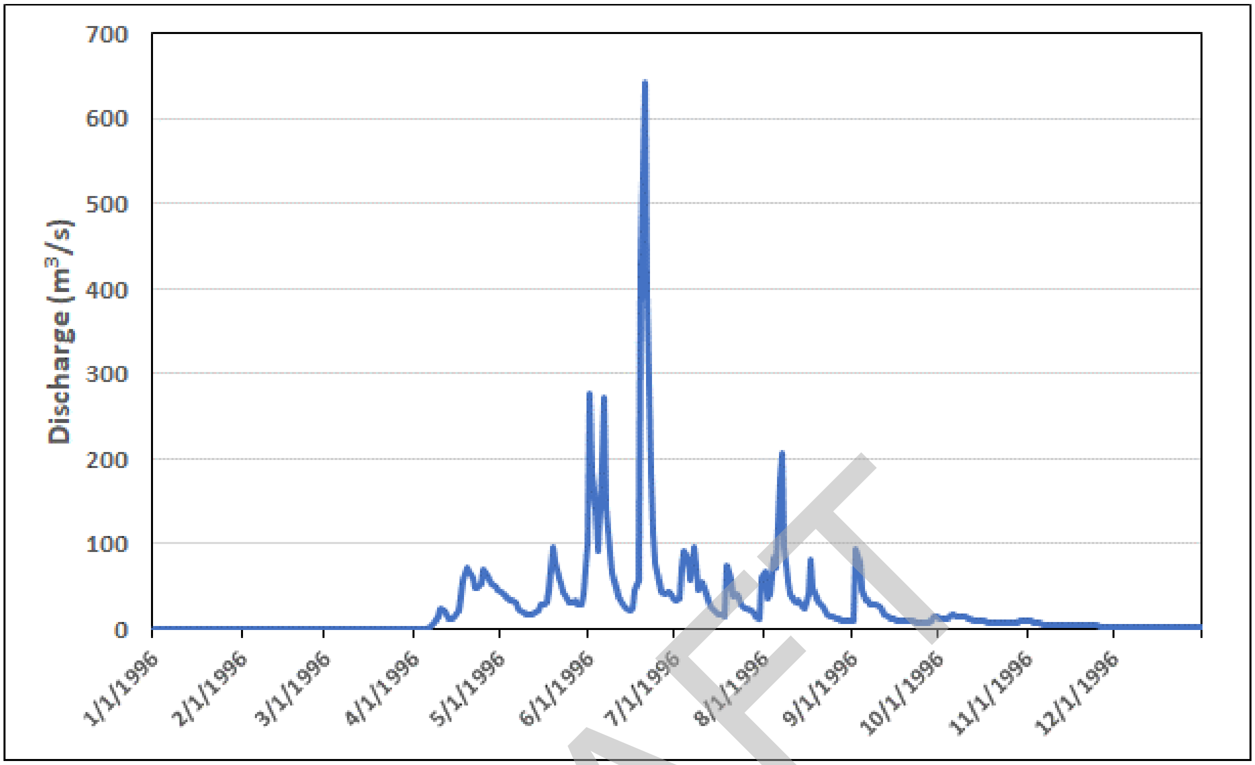


Figure 3-1 1996 Daily Discharge for the Swan River Near Kinuso (07BJ001)

Some of the instantaneous peak flows were missing from the records, specifically the record in 1963, 1965 and 1993. As a result, the available annual instantaneous peak flows were plotted versus the associated annual maximum daily flows (see **Figure 3-2**). **Figure 3-2** shows that a linear relationship could adequately explain the relationship between annual instantaneous peak flows and annual maximum daily flows. Maximum daily flows of 1963, 1965 and 1993 were used to approximate the instantaneous peak flows by applying a factor of 1.132 to the daily flow data.

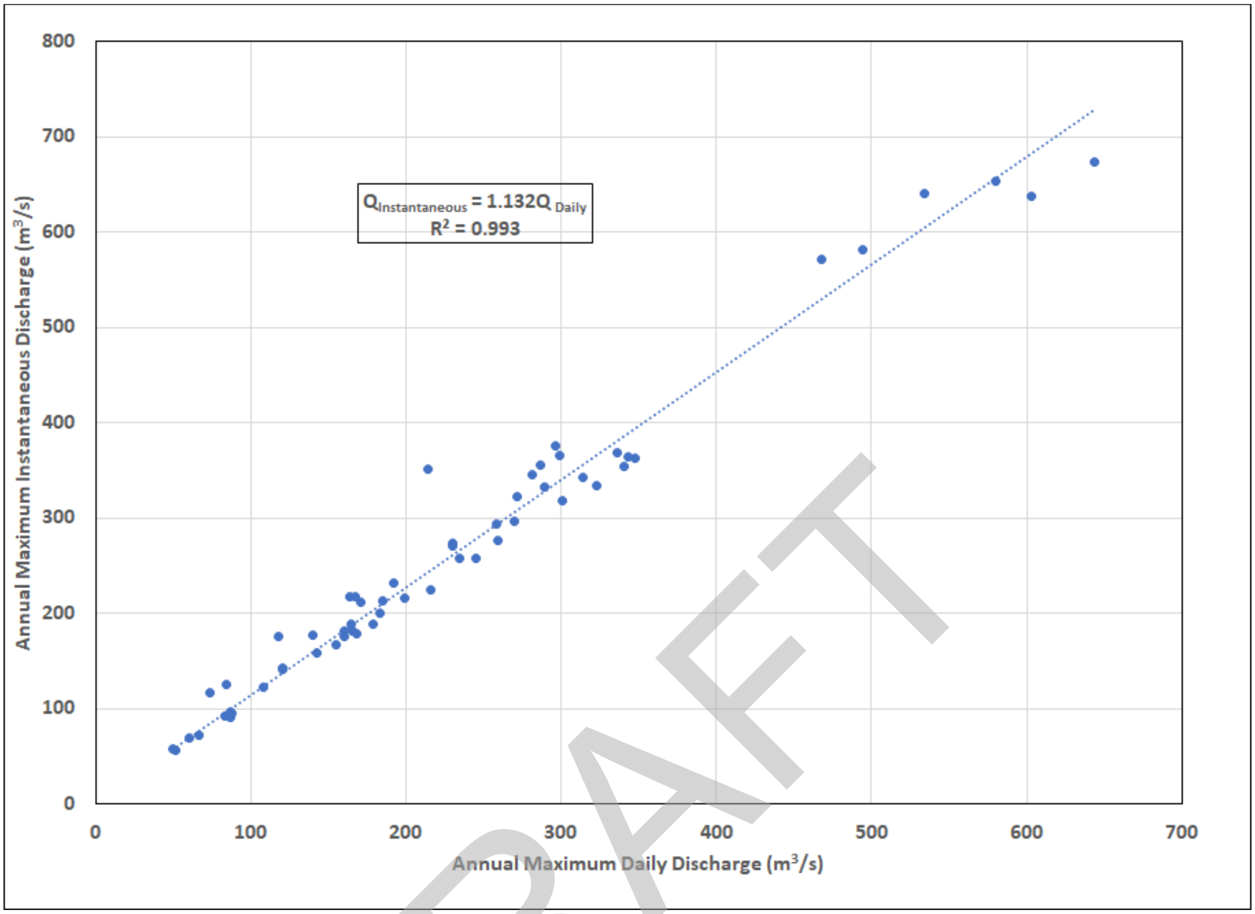


Figure 3-2 Swan River Near Kinuso (07BJ001) Instantaneous Annual Peak Flows versus Annual Maximum Daily Flows

3.2 Methodology

Flood frequency analysis was performed for the Swan River near Kinuso using annual instantaneous peak flows (i.e., annual maximum series [AMS]). Table A-1 in Attachment A lists the AMS used in this study. The HEC-SSP version 2.3 software program was used for flood frequency analysis. The frequency analysis started with Bulletin 17C EMA (Expected Moments Algorithm), which uses Log-Pearson Type III probability distribution; however, other probability distributions were also investigated. To fill the missing annual maximum flow in Bulletin 17C, a perception threshold of 673 m³/s, i.e., the maximum observed data in the record, was used for 1964 with very limited data.

Bulletin 17C EMA distribution parameters are estimated from the moments of sample data such as mean, standard deviation, and skew. The method also includes adjustments for missing years, estimated flow, low outliers, and historical events by using conditional probability and historical (weighted moments) adjustment, and characterizes the peak flows as systematic (observed record), historical event, and censured where the peak flow values are missing. The annual peak flow values are presented by flow range with a specified perception threshold for each year. For this project, the maximum peak flow value of the station was used as the perception threshold for the 1964 flow data that included a significant number of missing flow values. Bulletin 17C EMA also provides a computed probability distribution with the upper and lower bounds of the selected confidence interval.

The result of the flood frequency analysis using Bulletin 17C EMA is presented in **Figure 3-3**. The results show the fitted flood frequency curve and the observed peak flow data with the upper and lower bounds of the 90% confidence interval. The fitted flood frequency curve captured higher peak values and lower peak values as shown in **Figure 3-3**, i.e., no low outlier was identified.

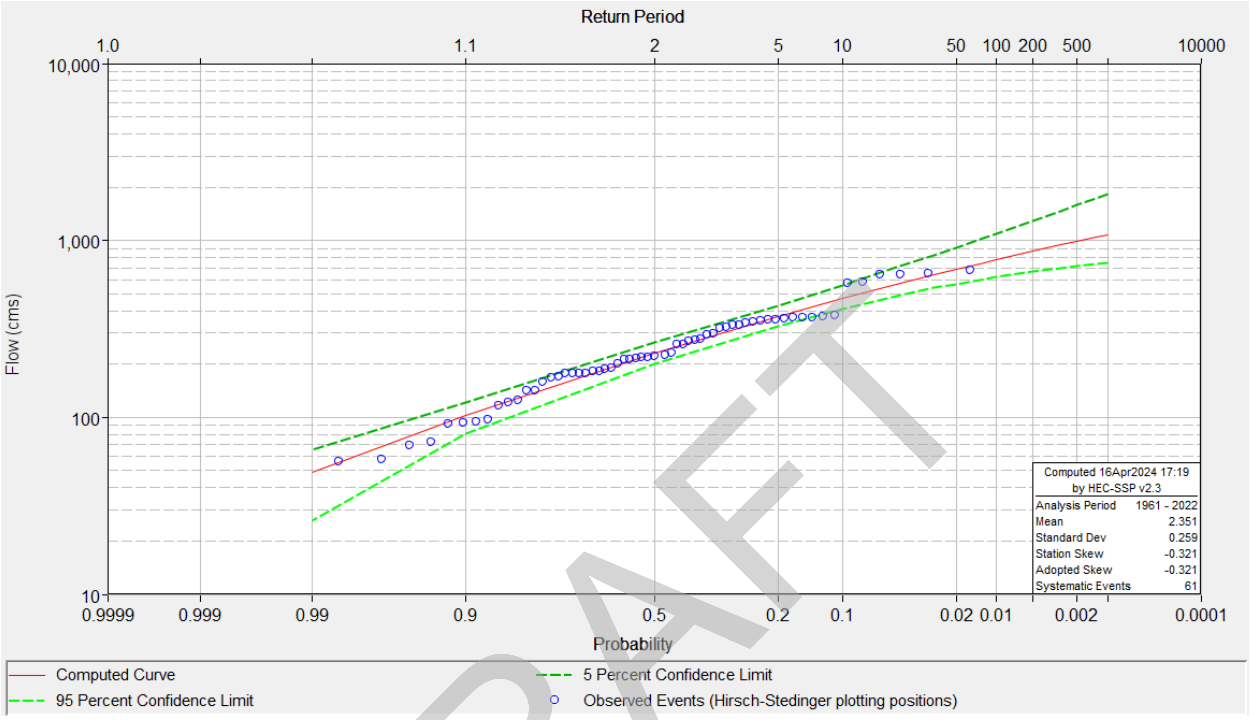


Figure 3-3 Bulletin 17C Flood Frequency Analysis Result for Swan River Near Kinuso (07BJ001)

The general frequency analysis tool in HEC-SSP was also used to compare different distributions with the Bulletin 17C EMA. This tool analyzes flood flow frequency using various probability distribution functions. The tested distributions were Generalized Extreme Value, Generalized Pareto, Gamma, Normal, Log-Normal, Pearson Type III, Log-Pearson Type III, Generalized Logistic, and Empirical. **Table 3-1** lists the calculated Kolmogorov-Smirnov (K-S) and Chi-Square test results for the best-fitted probability distributions. The listed distributions pass the Chi-Square and K-S test at 5% and 1% significant levels, respectively.

Table 3-1 Statistical Test Results for Generalized Frequency Analysis Method for the Swan River Near Kinuso (WSC Gauge 07BJ001)

Fitted Distribution	K-S	Chi-Square
Gamma	0.103	15.5
Generalized Extreme Value	0.098	20.2
Generalized Pareto	0.111	19.5
Gumbel	0.098	20.2
Log-Logistic	0.087	28.9
Normal	0.133	29.7
Log-Normal	0.095	21.8
Pearson Type III	0.103	15.5
Log-Pearson Type III	0.098	17.5

Figure A-1 through **Figure A-9** in Attachment A show the results of the generalized frequency analyses for flood flows at the Swan River near Kinuso with the best-fitted distributions as listed in **Table 3-1**. The fitted frequency curves to the WSC gauge data mainly overestimated or underestimated the high peak values. While all fitted probability distribution functions passed the tests, it appears that the Bulletin 17C EMA and the Log-Person Type III provided the most reasonable fitted distributions for the Swan River near Kinuso. It is important to note that the Bulletin 17C EMA also uses the Log-Pearson Type III distribution.

The results of flood frequency using Bulletin 17C EMA and generalized frequency analysis methods are listed in Table 3-2. Floods with large AEPs, i.e., up to the 1:20 AEP flood events, are similar among all fitted probability distribution functions, however, Log-Normal and Log-Logistic start deviating from the rest of the distributions for floods with 1:35 AEP and larger. The 1:100 AEP flood estimated using the log-Normal probability distribution function is larger than those estimated in 2021 (MSES, 2021). The main difference is most likely due to the difference in the record length of these studies. The estimated 1:100 AEP flood using Bulletin 17C EMA is 778 m^3/s, which is about 5% smaller than the 2021 study. This difference is due to the record length, the fitted probability distribution function, and to some extent due to the weight of the missing data (the 1964 data) in flood frequency analysis. In addition, an instantaneous peak flow of 640 m^3/s that occurred in 2019, which was not used in the previous study, has most likely decreased the magnitude of floods with small AEPs.

Given the robustness of the Bulletin 17C method in flood frequency analysis, Barr recommends the Bulletin 17C results in generating flood hydrographs for the two-dimensional (2D) hydraulic model of the Swan River in the Kinuso Flood Study.

Table 3-2 The Swan River Flood Frequency Estimates near Kinuso Using Different Probability Distribution Functions

AEP	Computed Peak flow (m3/s)									
	Bulletin 17 C	Log-Normal	Normal	Log Pearson Type III	Pearson Type III	Gamma	Generalized Extreme Value	Generalized Pareto	Gumbel	Log-Logistic
1:2	**232**	224	264	229	233	236	234	230	239	224
1:5	**373**	371	392	369	375	377	368	389	374	354
1:10	**470**	482	459	466	467	468	462	483	463	462
1:20	**564**	598	514	560	552	554	555	559	548	591
1:35	**639**	697	554	636	618	620	632	609	616	715
1:50	**687**	763	577	684	658	661	682	636	659	806
1:75	**740**	841	601	739	704	707	740	664	707	923
1:100	**778**	898	618	778	735	739	782	682	741	1016
1:200	**870**	1042	656	872	810	815	886	719	824	1278
1:350	**943**	1165	685	947	870	875	972	743	890	1537
1:500	**990**	1248	702	997	907	913	1029	757	933	1729
1:750	**1044**	1345	721	1052	950	956	1095	771	981	1977
1:1,000	**1082**	1416	734	1092	979	986	1142	779	1015	2172

4 Hydrograph Generation for all Flood Scenarios

The unique nature of the floodplain topography around Kinuso and the anticipated challenges with modelling and mapping realistic flood extents, EPA may consider deviating from its standard steady state or quasi-steady state modelling approach, if warranted to avoid any overly conservative prediction of the inundated areas. An unsteady state hydraulic model requires an inflow hydrograph as an upstream boundary condition to the hydraulic model. As a result, additional hydrologic analysis was completed to develop appropriate hydrographs for all modelled flood scenarios. Two methods of analysis were used for developing the inflow hydrographs, which are discussed in detail in the following sub-sections.

4.1 Scaling Pattern Hydrograph (Method 1)

In the first method (herein Method 1), a pattern hydrograph was selected from the largest flood events in the record with a classical shape of a flood hydrograph, i.e., a relatively smooth rising limb, one peak, and a relatively smooth falling limb. In Method 1, the selected pattern hydrograph was used to generate hydrographs for the selected AEPs.

Care was given to select the large flood events during the snowmelt season, however, there were no relatively high peak flows during the snowmelt seasons. The top three floods of record were identified as potential candidates for the pattern hydrograph. The potential candidates for the pattern hydrograph are shown in **Figure 4-1** through **Figure 4-3**. Among the hydrographs, the hydrograph of 1996 storm was selected as the pattern hydrograph because it has the highest peak flow and has the classical shape of a hydrograph.

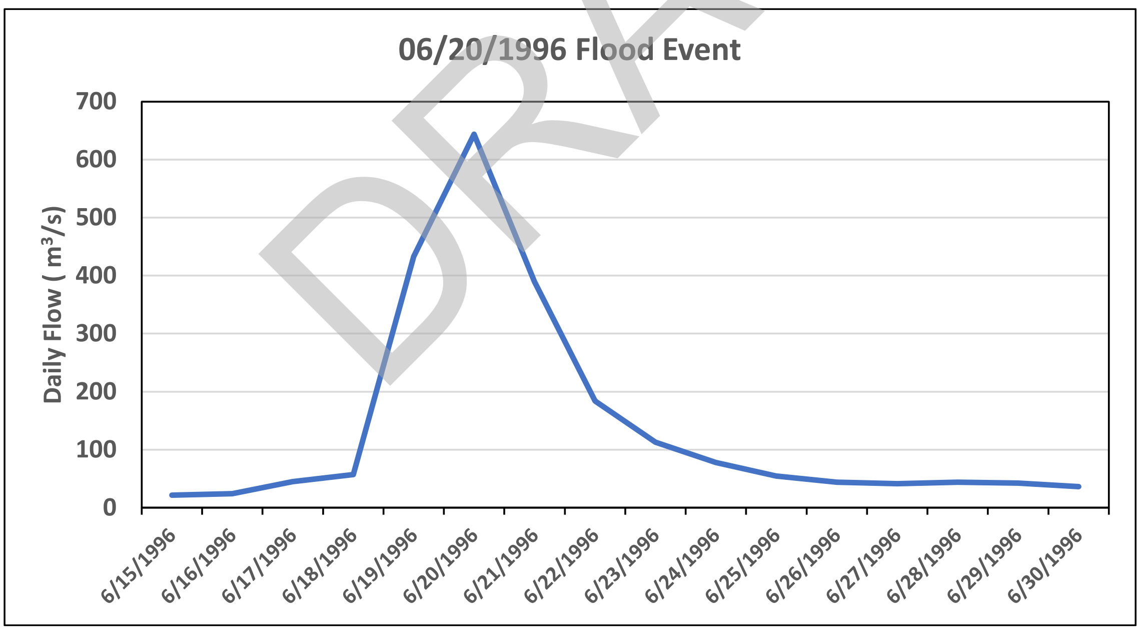


Figure 4-1 Daily flow hydrograph for 1996 storm at the WSC gauge Swan River near Kinuso (07BJ001)

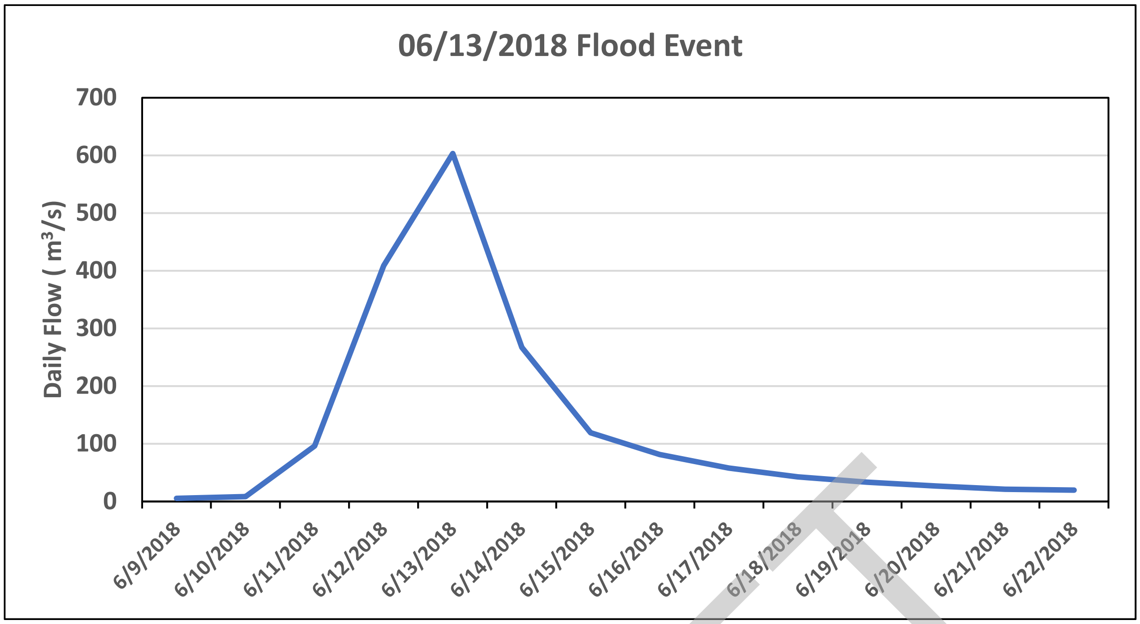


Figure 4-2 **Daily flow hydrograph for 2018 storm at the WSC gauge Swan River near Kinuso (07BJ001)**

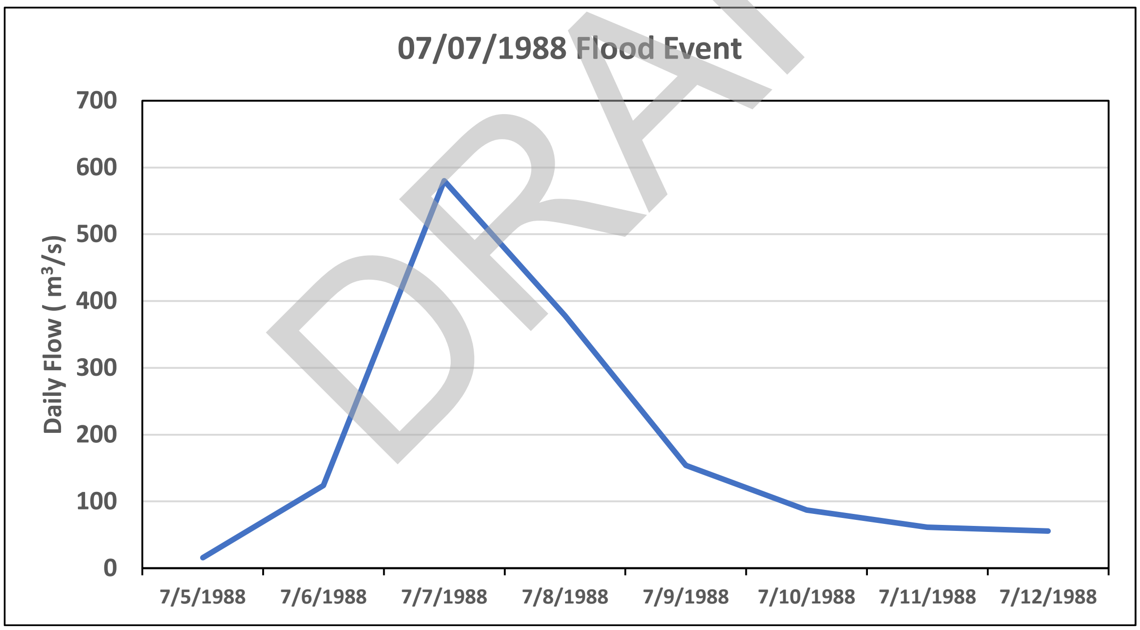


Figure 4-3 **Daily flow hydrograph for 1988 storm at the WSC gauge Swan River near Kinuso (07BJ001)**

The next step was to use the results of the flood frequency analysis and the pattern hydrograph to develop the flood hydrographs with different AEPs. The goal of developing the flood hydrographs was to incorporate the volume of flood events in the flood mapping study. However, simply scaling the pattern hydrograph to the estimated peak flood flows estimated from flood frequency analysis could be subjective and may result in overestimation or underestimation of the volume associated with flood hydrographs. To account for a more realistic representation of the volume of the flood hydrograph, a critical duration was estimated for the pattern hydrograph, which is from the beginning of the rising limb to the inflection point on the falling limb, i.e., where base flow becomes the main component of the runoff hydrograph (in **Figure 4-1**, the critical duration will be from 6/18/1996 to 6/22/1996). The critical duration was estimated to be 5 days.

The 5-day moving average time series was developed from the WSC gauge 07BJ001 daily flow data. Only the daily flow data from 1970 to 2022 was used for volume frequency analysis. The data prior to 1970 was eliminated because the number of missing data would not allow developing a complete 5-day moving average for that period.

Subsequently, the annual maximum series of flood volumes (5-day moving average) was determined as shown in **Figure 4-4**. Flood frequency analysis was performed on the maximum annual series of the 5-day moving average flows using Bulletin 17C as shown in the second column of **Table 4-1**. To determine the scaling factor for each AEP flood event, the maximum 5-day flow of the 1996 flood event (pattern hydrograph) was developed which was estimated to be 351.8 m^3/s. The maximum 5-day moving average of the 1996 flood event was developed from the hourly data of that event. The scaling factor of each AEP flood event was calculated by dividing the peak flow of each AEP (the value of the second column of Table 4-1) by the maximum 5-day moving average flow of the pattern hydrograph. The scaling factors are listed in the last column of Table 4-1.

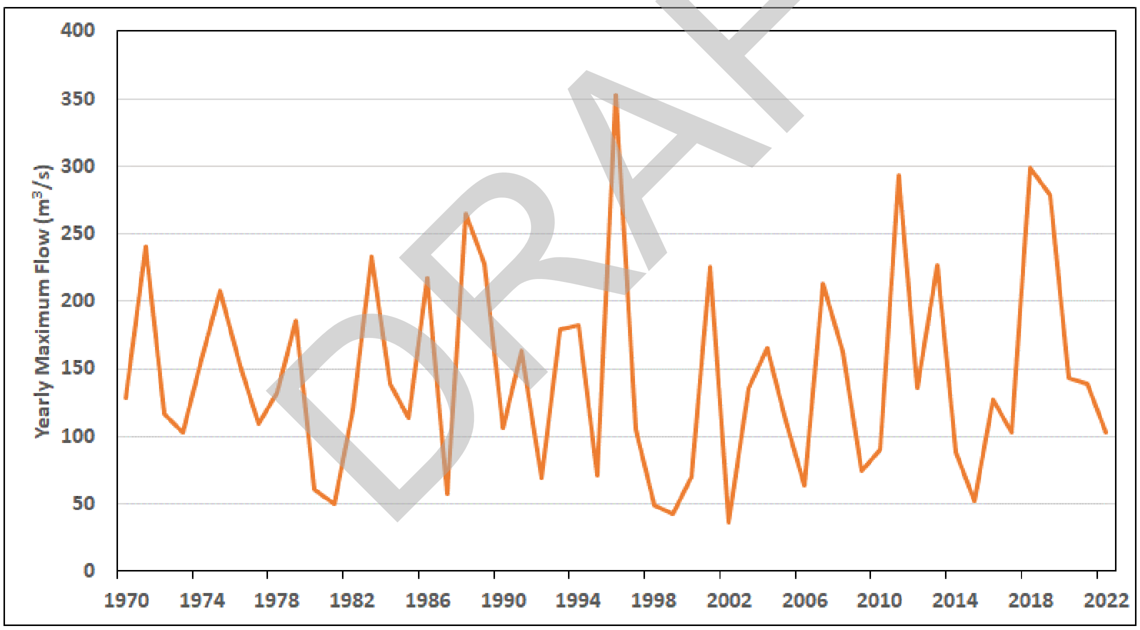


Figure 4-4 Yearly Maximum Flow of the 5-day Moving Average for the Swan River near Kinuso (07BJ001)

Table 4-1 Estimated Peak flow for the 5-Day Moving Average Using Bulletin 17 C

AEP	Peak flow (m^3/s)	Scaling Factor[1]
1:2	130	0.37
1:5	202	0.57
1:10	250	0.71
1:20	296	0.84
1:35	333	0.95
1:50	356	1.01
1:75	382	1.08
1:100	400	1.14
1:200	444	1.26
1:350	479	1.36
1:500	501	1.42
1:750	526	1.50
1:1,000	544	1.55

1 Scaling factor was calculated by dividing each peak flows in the table by the maximum of 5-day moving average of the pattern hydrograph (351.8 m^3/s).

The scaling factors of each AEP (**Table 4-1**) were multiplied by hourly flows of the pattern hydrograph from 06/15/1996 through 6/30/1996 to obtain the flood hydrographs for the flood mapping study as shown in **Figure 4-5**. The figure shows the flood hydrographs for 1:100 to 1:1,000 AEP events. The simulated flood hydrographs followed the pattern hydrograph; however, the peak flows did not match the results of the flood frequency analysis performed on the instantaneous peak flows recorded at the WSC gauge.

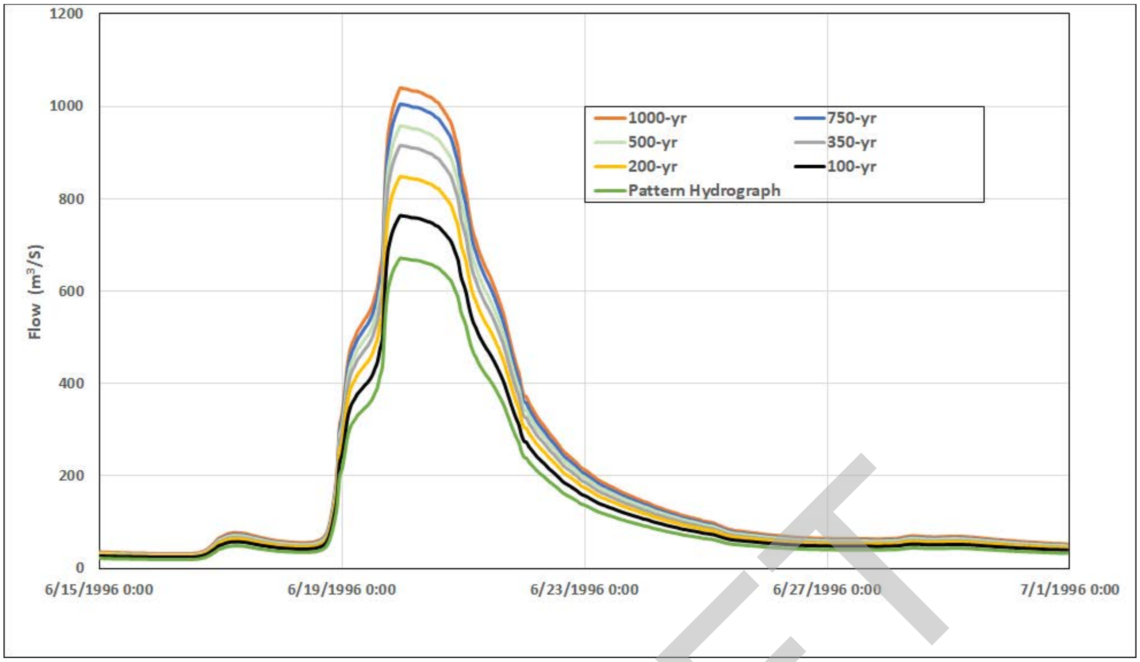


Figure 4-5 Balanced hydrograph using Scale factor for Swan River near Kinuso (07BJ001)

Because the simulated hydrographs were based on the flood frequency analysis of the volumes, i.e., the 5-day moving average, the peak flow would not match the flood frequency analysis performed on the annual maximum series of the instantaneous flows. To adjust the peak flows of the simulated hydrographs shown in **Figure 4-5**, the estimated peak flows developed in Section 3.0 were replaced as shown in **Figure 4-6**. The figure shows the flood hydrographs for 1:100 to 1:1,000 AEP events. The results show the peak flows as short spikes in the hydrographs, i.e., a relatively unrealistic representation of the flood hydrographs.

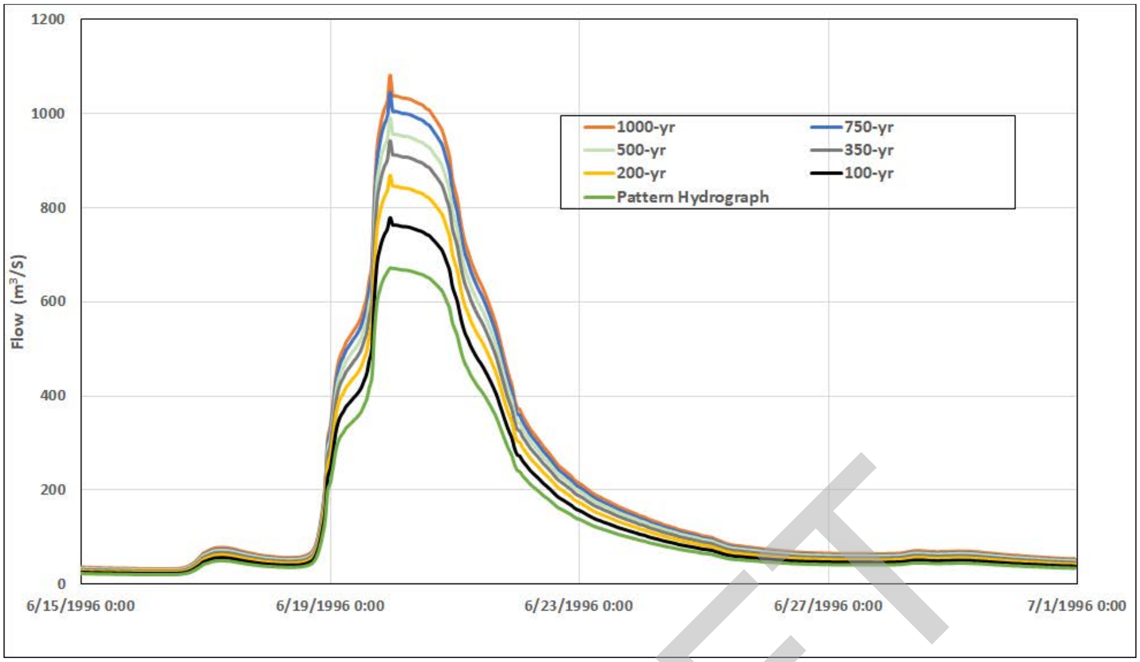


Figure 4-6 Simulated flood Hydrographs with the Added Peak Flows Using Bulletin 17 C Flood Frequency Analysis Result for the Swan River Gauge near Kinuso (07BJ001)

To eliminate the spikiness of the flood hydrographs, the flood hydrographs near the peak were smoothed using linear interpolation for the flows around the peaks. The results of the smoothed hydrographs are shown in **Figure 4-7**. Again, the figure shows the flood hydrographs for 1:100 to 1:1,000 AEP events.

The resulting hydrographs are better representation of the Swan River flood hydrographs for the flood mapping study. However, the Swan River, with a drainage area of approximately 1,902 km^2, is more likely to have a relatively flat hydrograph near the peak, i.e., the peak would not decrease as shown in **Figure 4-7**. In addition, the conventional method in flood mapping study is to run the hydraulic model with a constant flow (i.e., steady-state condition). To partially meet the requirements of the conventional method and to develop the flood hydrographs to better represent the characteristics of a large watershed like the Swan River watershed on its flood hydrographs, additional adjustments were made to the simulated flood hydrographs. The final adjustment was to maintain the instantaneous peak flows for a period of six hours and linearly interpolate the flows to a lower flow on the falling limb. The final hydrographs for all AEP flood events are shown in Figure 4-8.

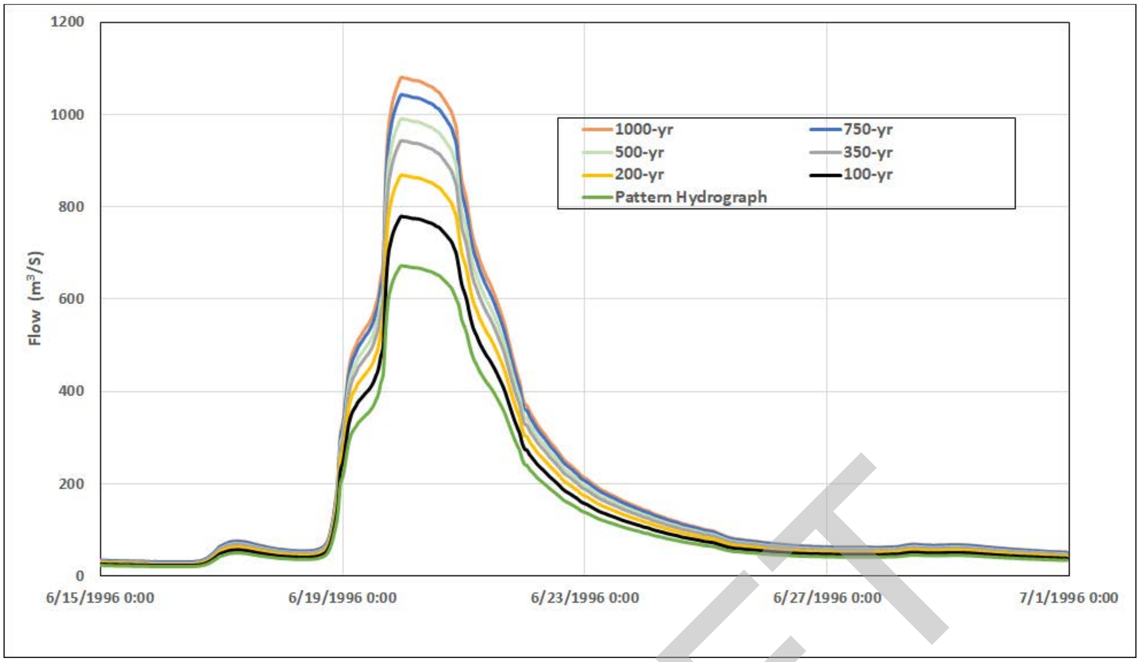


Figure 4-7 **Simulated hydrographs with smoothed peak flows for the Swan River Near Kinuso (07BJ001)**

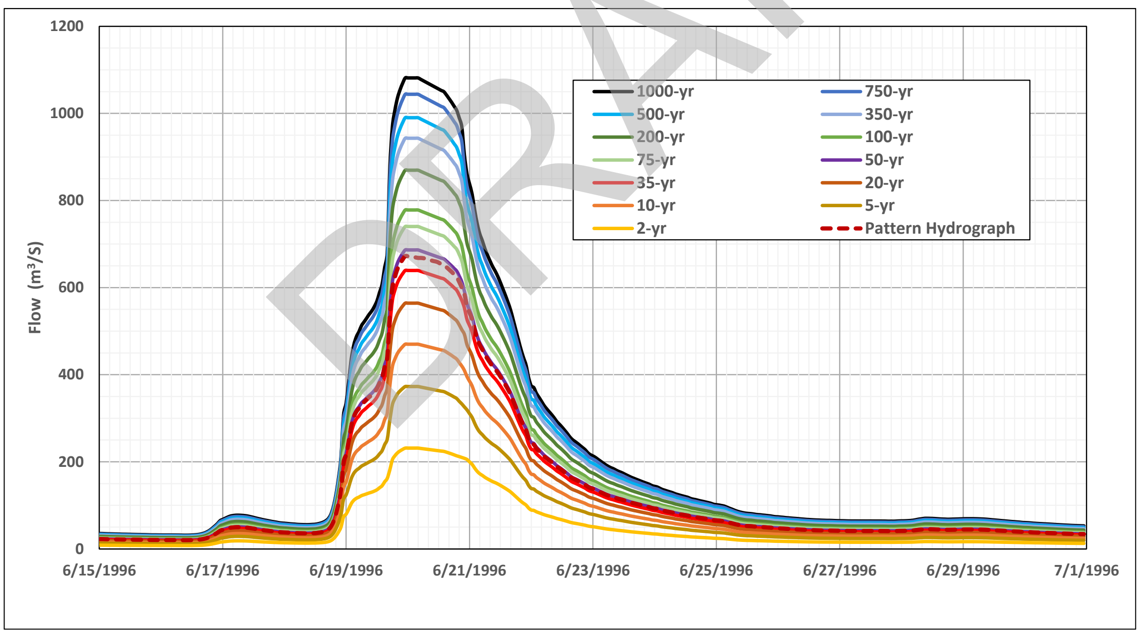


Figure 4-8 **Simulated flood Hydrographs with the Adjusted Peak Flows for the Swan River Gauge near Kinuso (07BJ001)**

4.2 The USACE Balanced Hydrographs (Method 2)

The HEC-SSP 2.3 software program was used to develop balanced hydrographs that the US Army Corps of Engineers (USACE) uses in their projects. A balanced hydrograph is a hydrograph that has an equal exceedance probability for all possible critical durations. For this method, a pattern hydrograph like the one in Method 1 was utilized. In addition, the daily flow data were rearranged using 1-day, 3-day and 7-day moving average to develop the annual maximum series of 1-, 3- and 7-day volumes. Subsequently, frequency analyses were performed on the annual maximum series of 1-, 3-, and 7-day moving average flows. The resulting volume frequency analyses were combined to develop balanced hydrographs by using the pattern hydrograph as a template. The results are shown in **Figure 4-9**. In the last stage of the balance hydrograph development, the flood frequency peak flows of different AEPs were added to the hydrographs. The resulting balanced hydrographs were in general agreement with those developed using Method 1 and shown in **Figure 4-6**.

To eliminate the spikiness of the peaks, the flows around the peaks were adjusted using linear interpolation. The results are shown in **Figure 4-10**. The resulting balanced hydrographs are relatively similar to those obtained in Method 1. The main differences are primarily around the beginning of the rising limbs and towards the end of the falling limbs. It also appears that the volume of the hydrographs around the peak are slightly larger in Method 1 when compared to those in Method 2. Given the relatively smooth characteristics of the flood hydrographs developed in Method 2, no further adjustments were made to the developed balanced hydrographs and the flood hydrographs shown are the ones recommended to be used in the hydraulic model for the flood mapping study of the Swan River near Kinuso.

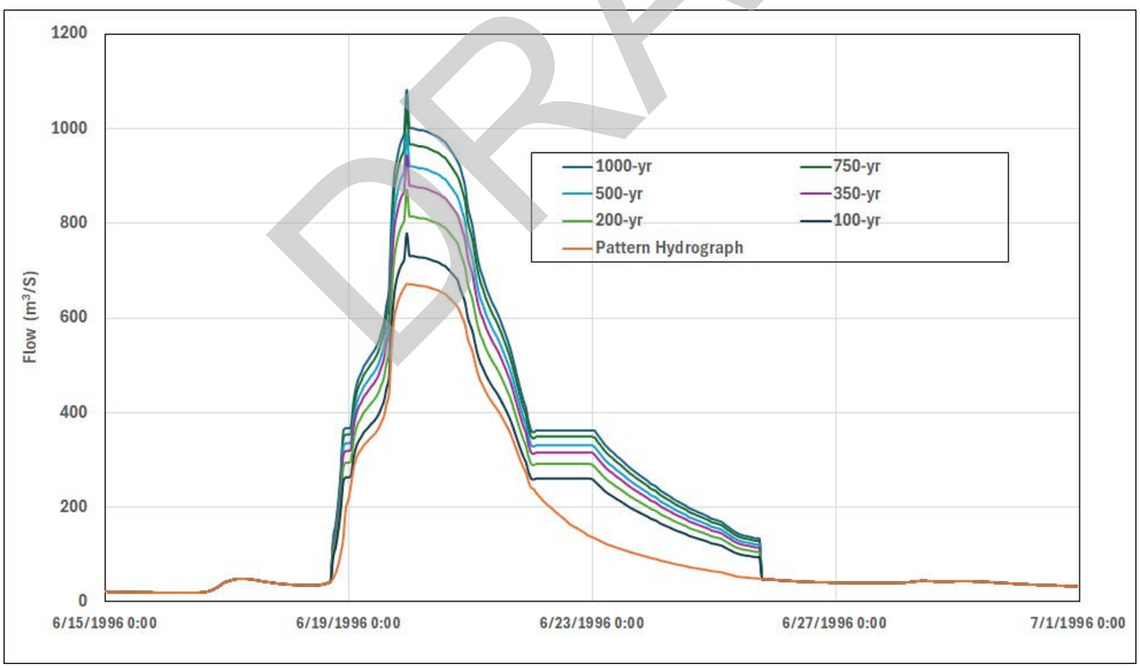


Figure 4-9 Balanced Hydrographs for the Swan River near Kinuso (07BJ001)

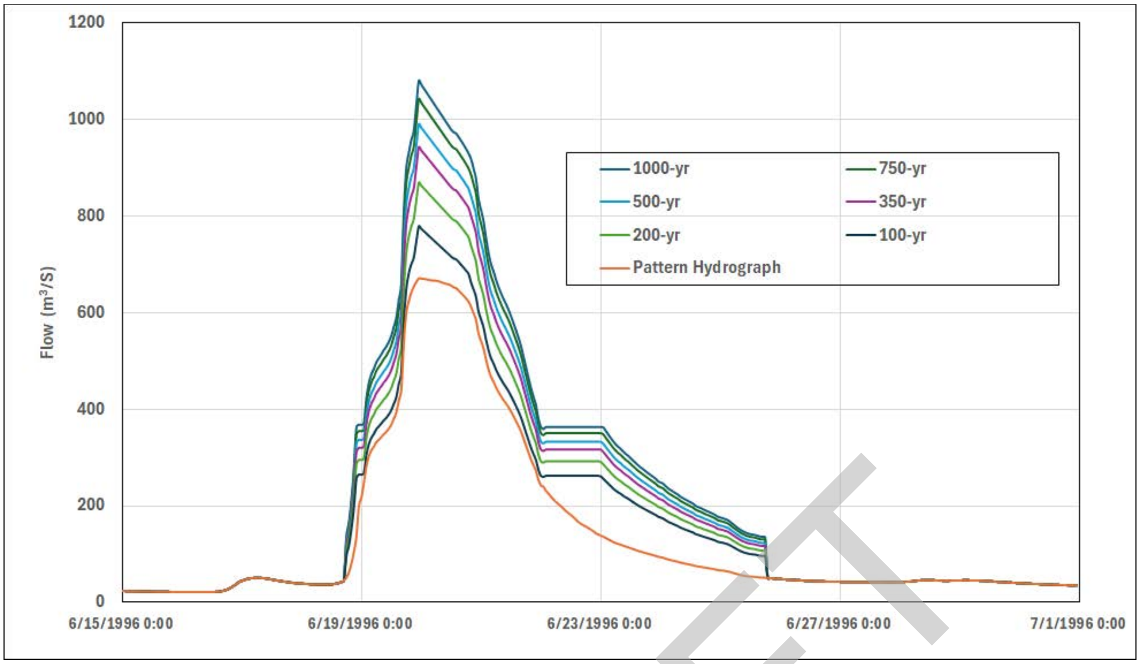


Figure 4-10 Final Balanced Hydrograph using HEC-SSP2.3 with the Smoothed Peak Flows for the Swan River near Kinuso (07BJ001)

5 Potential Effects of Climate Change on Flood Peak Discharges and Flood Frequency Estimates

It is anticipated that to the end of the 21st century, the emission of greenhouse gases would affect the climate of Earth and increase warming across our planet. The projected climate change due to greenhouse gas emissions under the different scenarios studied by climate scientists and presented in the Intergovernmental Panel on Climate Change (IPCC) assessment reports appears to increase the annual precipitation globally. It is also anticipated that the increase in warming and, therefore, evaporation from the oceans and transpiration from the canopy over land surfaces would impact the weather patterns and increase the likelihood of extreme precipitation events.

The results of general circulation models (GCMs), e.g., the GCMs used in CMIP6 were reviewed in the past year, and the downscaling methods applied to the GCM's output show about 5 to 30 percent increase in the magnitude of daily storm events with an AEP of 1:100 in the northern US and southern parts of Canada by the end of 21st century. However, the increases in precipitations also depend on different Shared Socioeconomic Pathways (SSPs) (there are five SSPs with the "business as usual" world in the absence of a future climate policy, with global warming in 2100 ranging from a low of 3.1 ^{o}C to a high of 5.1 ^{o}C above the preindustrial levels).

In 2022, the National Oceanic and Atmospheric Administration (NOAA) completed a study on storm frequencies in the northeastern portion of the United States (NOAA 2022). Depending on the downscaling method, it showed a potential increase of 7 to 15 percent under representative concentration pathway (RCP) of 4.5 and 10 to 25 percent under RCP 8.5. Given the location of the Swan River in Alberta, it is anticipated that climate change could increase the magnitude of the 1:100 AEP storms with a duration of 24 hours by 10 to 20 percent, based on our review of the BCCAQv2 downscaling method applied to the output of eight GCMs.

In 2021, MSES completed a study of the Swan River for the SRFN and calculated the 100-year flood at the WSC gauge 07BJ001. MSES used the output of three GCMs (HRM3, CRCM, and RCM3). They projected between 43 percent increase to 4 percent decrease in the 1:100 AEP flood in the Swan River.

Based on the 2021 study and the projected precipitation increases, it is anticipated that the Swan River flood flows of different AEPs would exhibit an increase by approximately 20 to 30 percent to the end of the 21st century.

6 Summary and Conclusion

Flood frequency analysis was completed for the Swan River near Kinuso using annual instantaneous peak flows (i.e., annual maximum series) to estimate the flood flows with AEPs of 1:2, 1:5, 1:10, 1:20, 1:35, 1:50, 1:75, 1:100, 1:200, 1:350, 1:500, 1:750, and 1:1000. The flood frequency analyses were completed using a number of probability distribution functions. The results of the Bulletin 17C EMA method was recommended to be used for the flood mapping study of the Swan River near Kinuso. The recommended results were also compared to the previous flood study for the Swan River completed in 2021. The current study recommended value for the 1:100 AEP flood event is approximately 5% smaller than that estimated in the 2021 study.

In addition, two methods were used to develop flood hydrographs with different AEPs for the unsteady state hydraulic model of the Swan River. The first method was based on the use of a pattern hydrograph and a critical duration for the flood hydrographs observed in the Swan River near Kinuso. The second method was the USACE balanced hydrographs. Both methods incorporated some variation of flood volume frequency analysis of the daily flow data recorded at the WSC gauge near Kinuso. Both methods also used the 1996 flood hydrograph recorded at the WSC gauge as the pattern hydrograph for developing flood hydrographs with different AEPs. The peaks of the resulting flood hydrographs were further adjusted to match the results of the flood frequency analysis on the instantaneous peak flows. After further evaluation, it was determined that the flood hydrographs developed using Method 1 appear to be more suitable for the flood mapping study and therefore it is recommended to use the hydrographs developed using Method 1 for the 2D model of Kinuso Flood Study.

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Attachment A

Table A-1: Annual Maximum Series Used in Flood Frequency Analyses

Year	Flow (m^3/s)	Year	Flow (m^3/s)
1961	351	1993	371[1]
1962	188	1994	318
1963	170[1]	1995	177
1964	673[2]	1996	673
1965	221[1]	1997	158
1966	116	1998	70
1967	92	1999	56
1968	182	2000	176
1969	167	2001	364
1970	213	2002	58
1971	334	2003	297
1972	232	2004	346
1973	189	2005	273
1974	257	2006	122
1975	343	2007	368
1976	294	2008	276
1977	216	2009	95
1978	225	2010	178
1979	362	2011	582
1980	93	2012	323
1981	97	2013	356
1982	200	2014	142
1983	571	2015	72
1984	257	2016	217
1985	182	2017	212
1986	332	2018	637
1987	125	2019	640
1988	654	2020	270
1989	354	2021	376
1990	176	2022	218
1991	366	2023	407[3]
1992	141	2024	477[3]

[1] The maximum instantaneous flow was estimated from the maximum daily flow
[2] The perception threshold was used
[3] The data was used later to determine if the flood flows with different AEP values would change. They were not used in the final flood frequency analysis as explained in Section 3

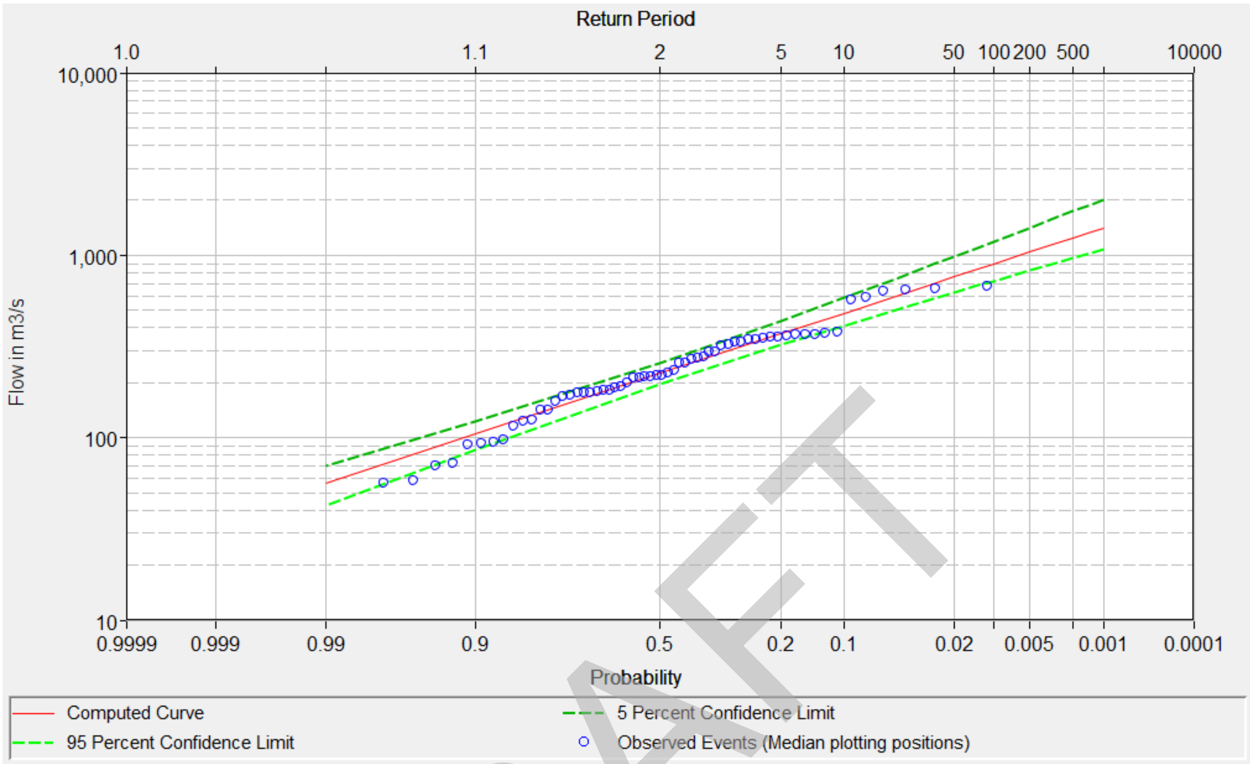


Figure A-1 Log Normal Plot for Swan River Near Kinuso (07BJ001)

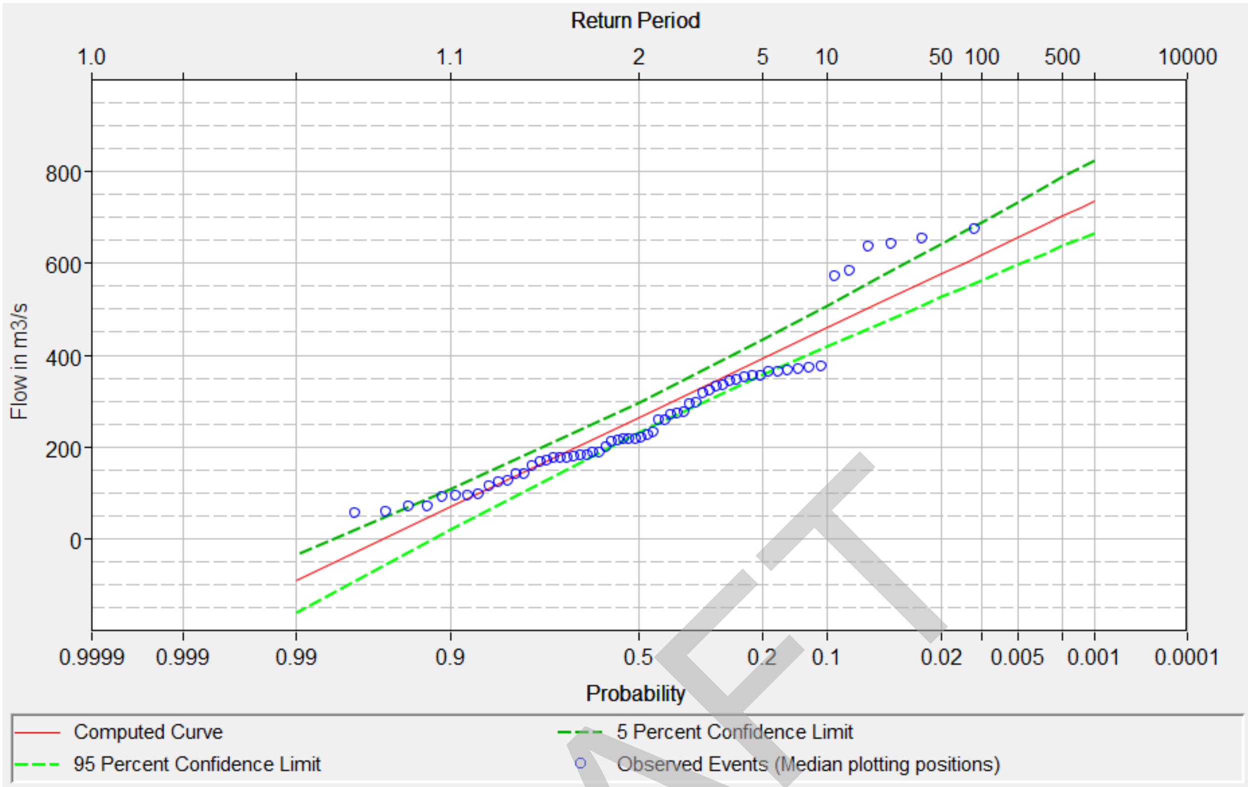


Figure A-2 Normal Plot for Swan River Near Kinuso (07BJ001)

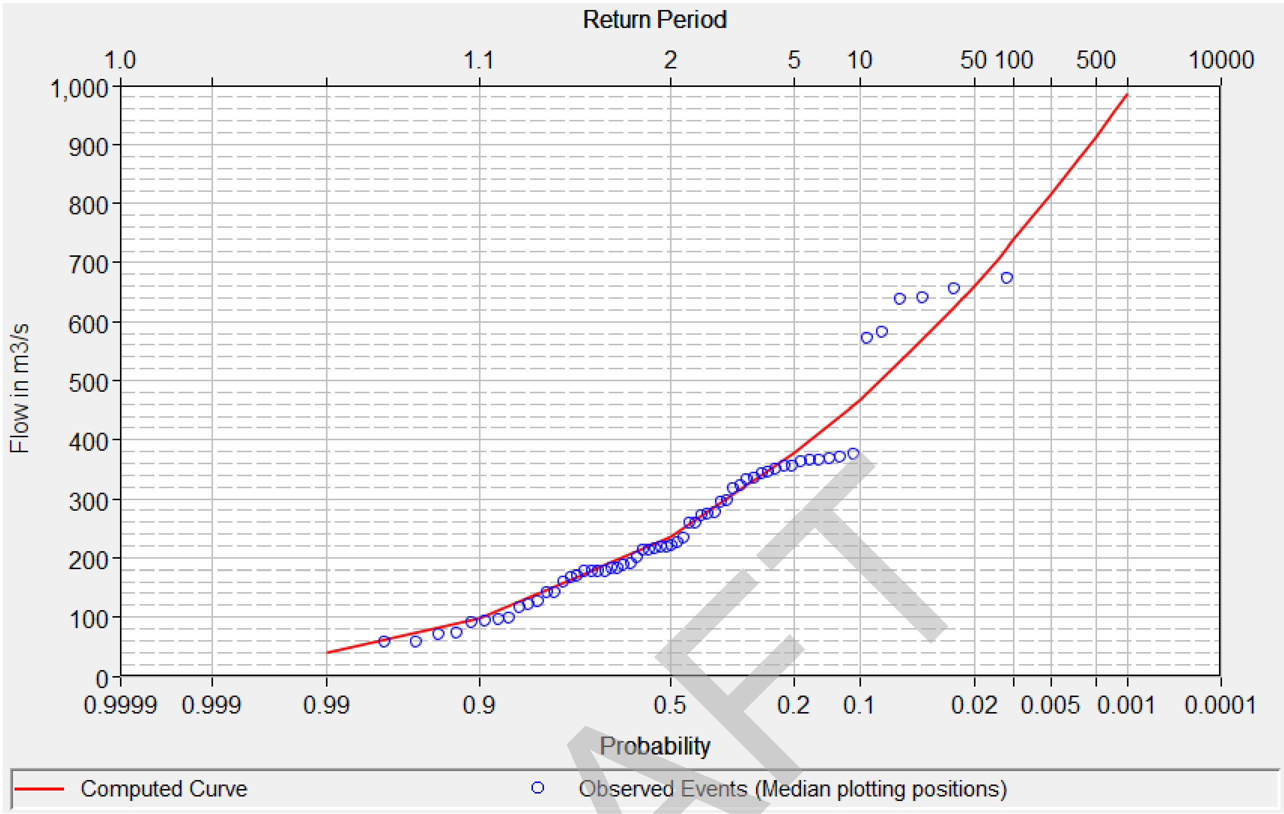


Figure A-3 **Gamma Plot for Swan River Near Kinuso (07BJ001)**

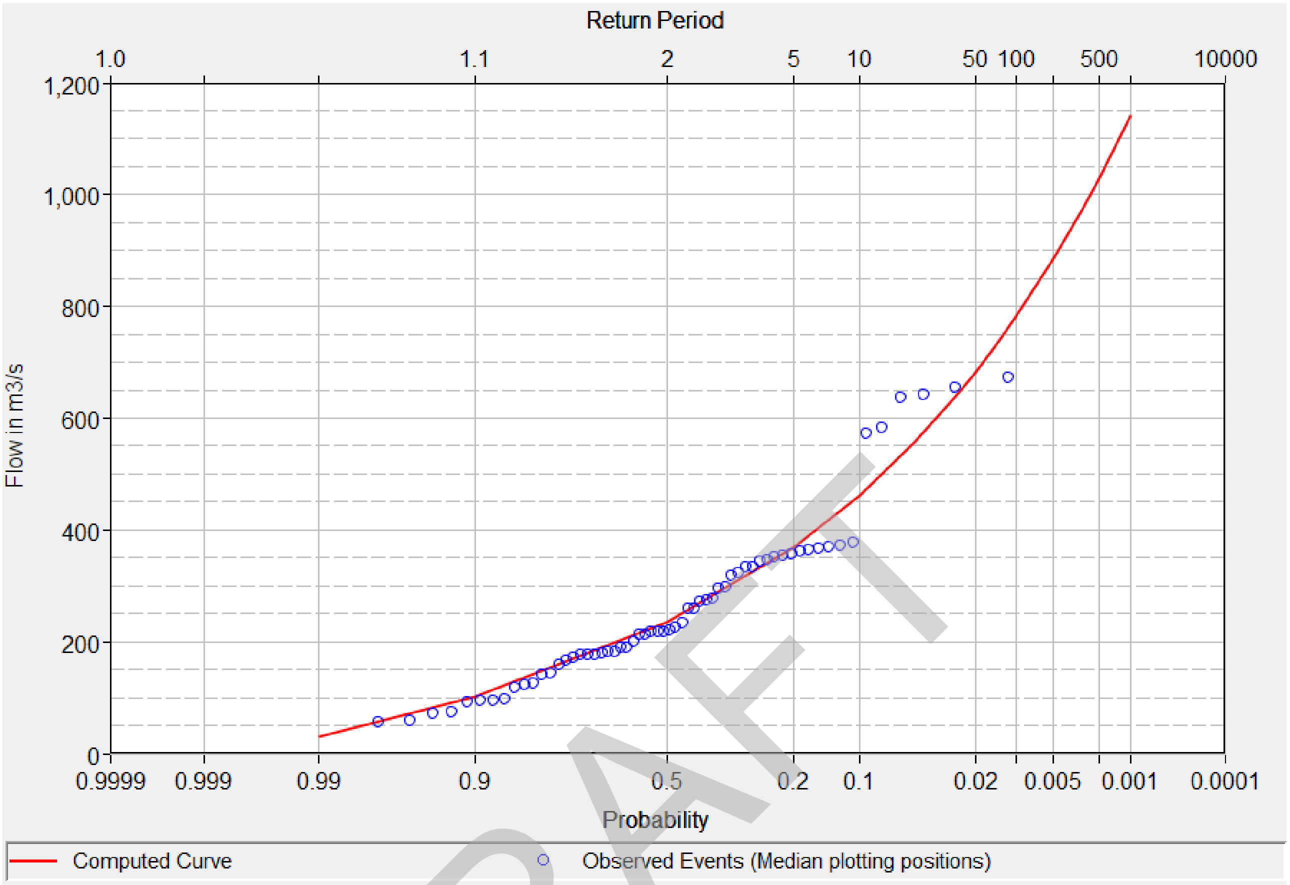


Figure A- 4 Generalized Extreme Value Plot for Swan River Near Kinuso (07BJ001)

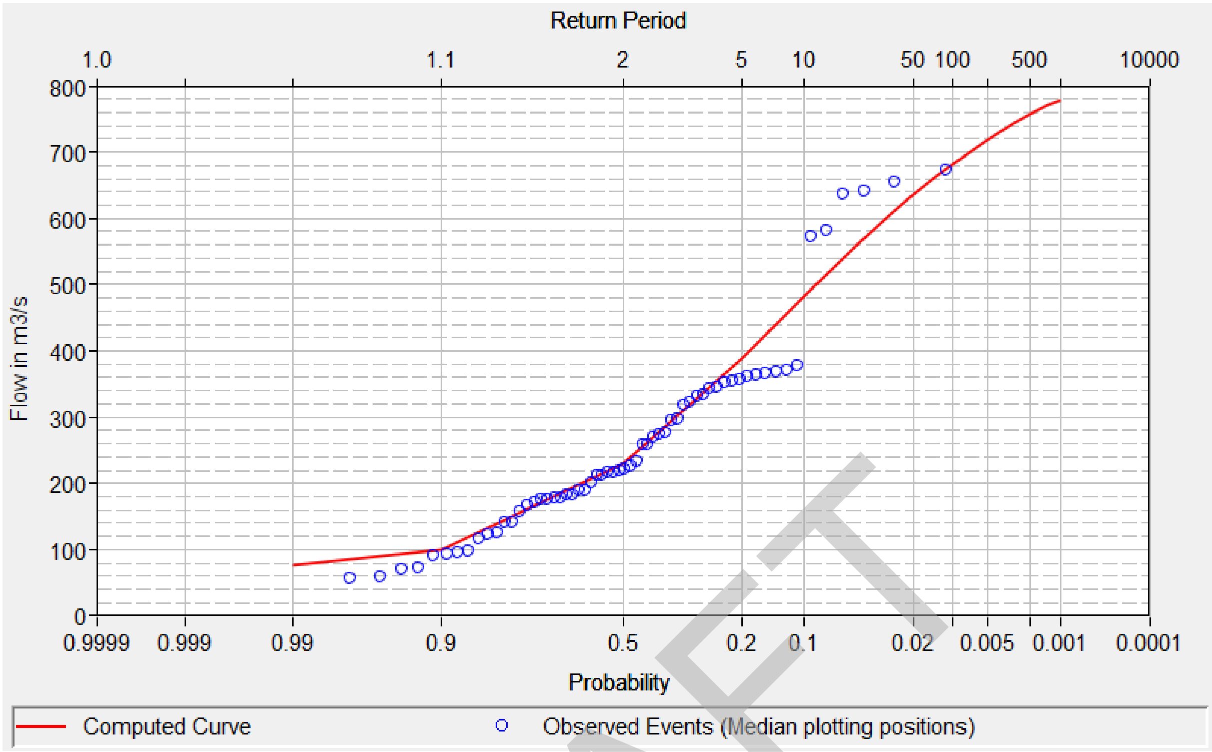


Figure A-5 Generalized Pareto Plot for Swan River Near Kinuso (07BJ001)

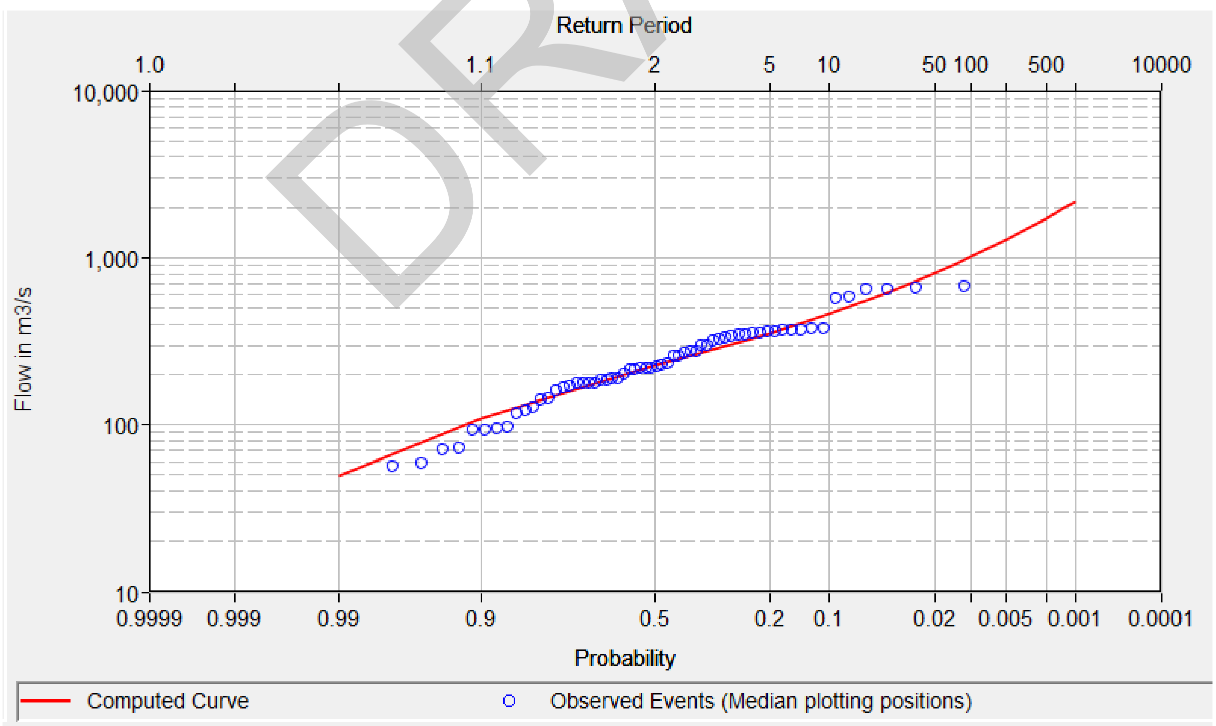


Figure A-6 Log Logistic Plot for Swan River Near Kinuso (07BJ001)

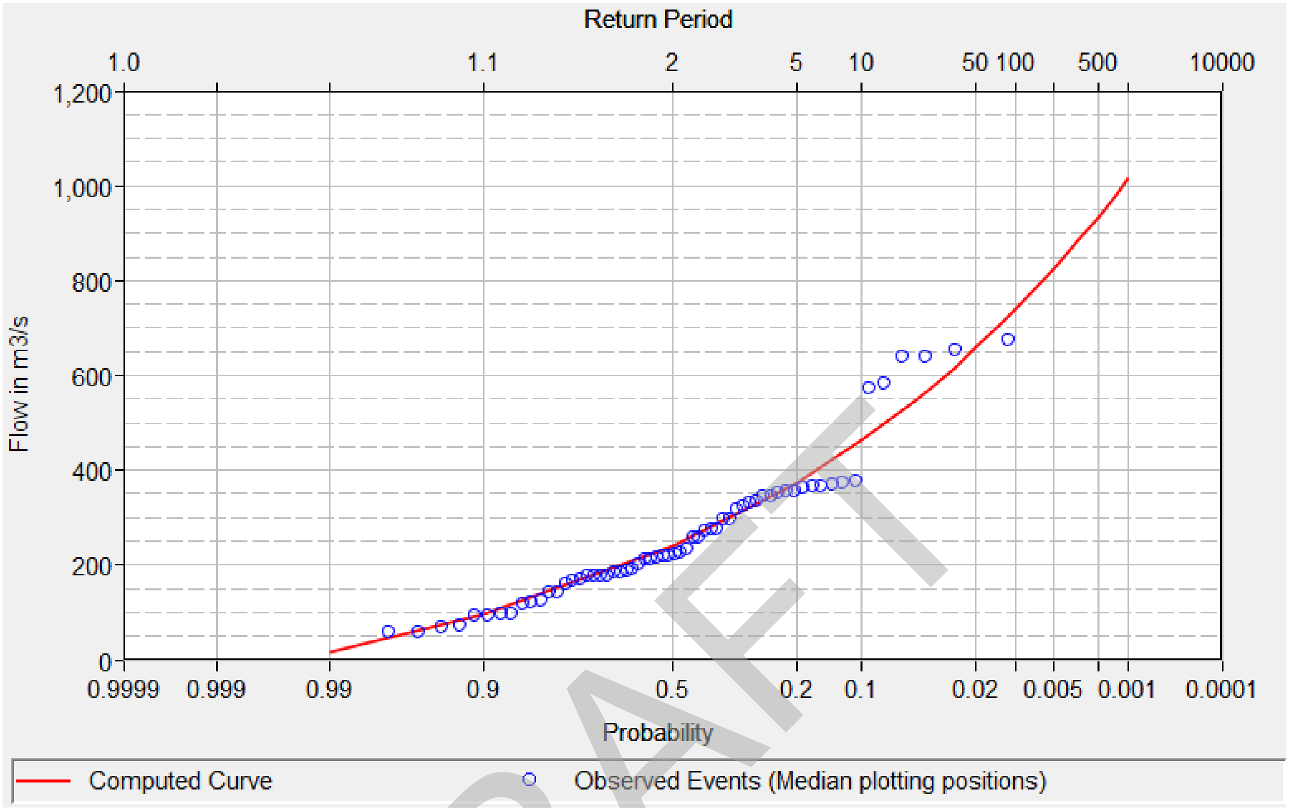


Figure A-7 Gumbel Plot for Swan River Near Kinuso (07BJ001)

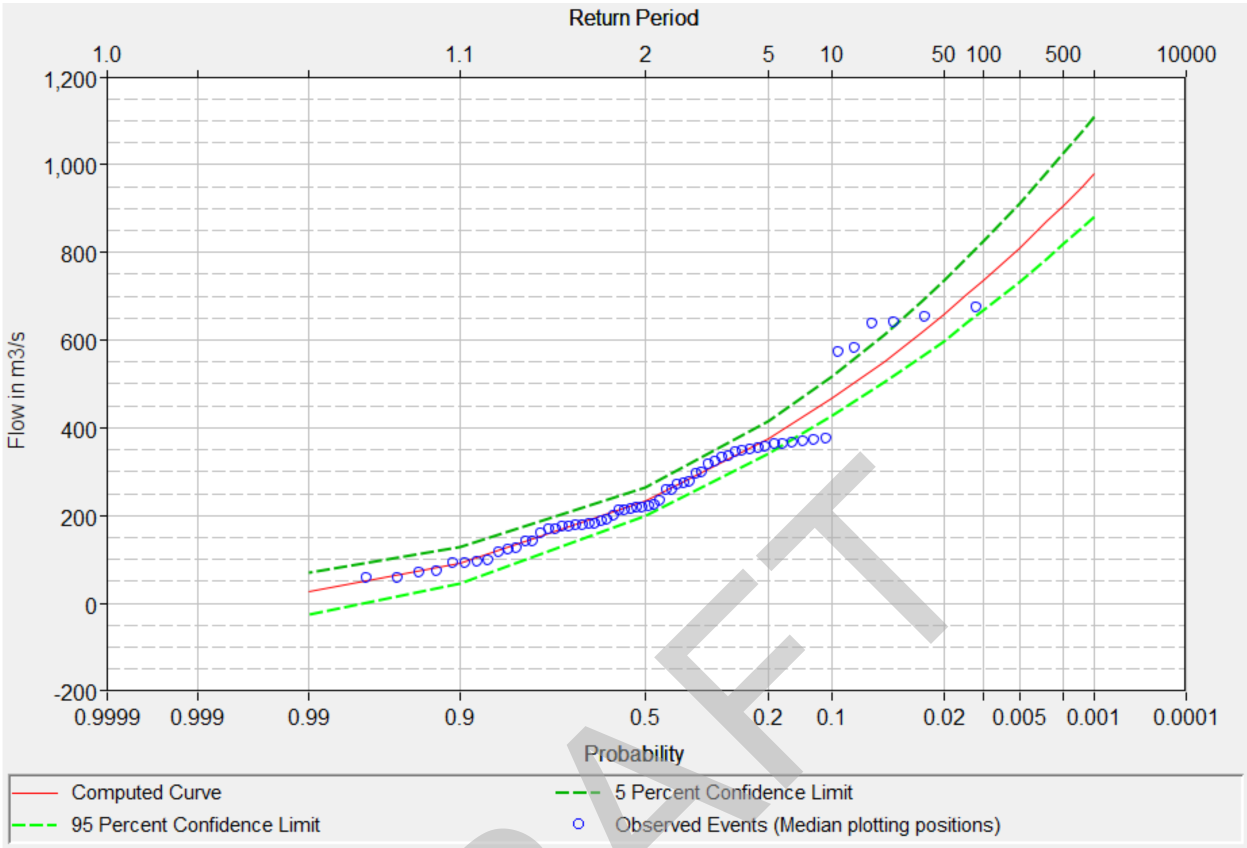


Figure A-8 Pearson Type III Plot for Swan River Near Kinuso (07BJ001)

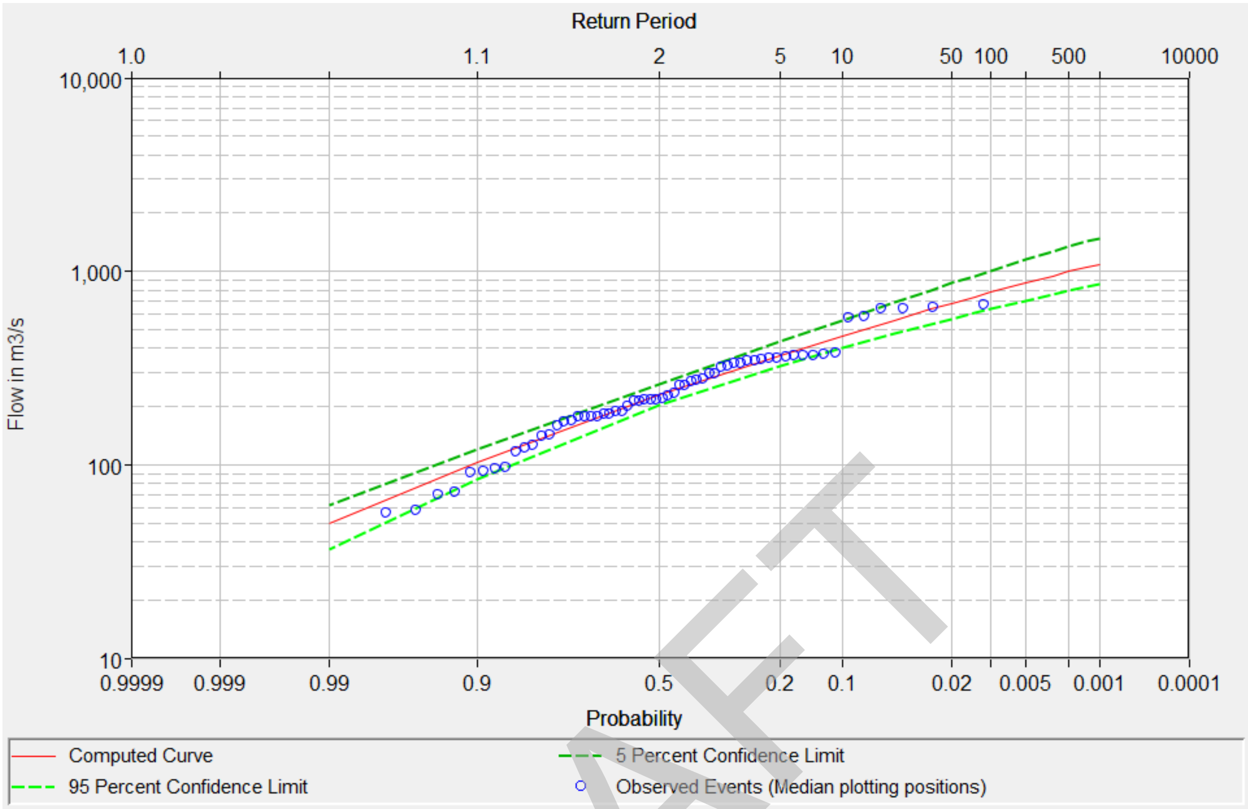


Figure A-9 Log Pearson Type III Plot for Swan River Near Kinuso (07BJ001)

Appendix F

Open Water Flood Profiles

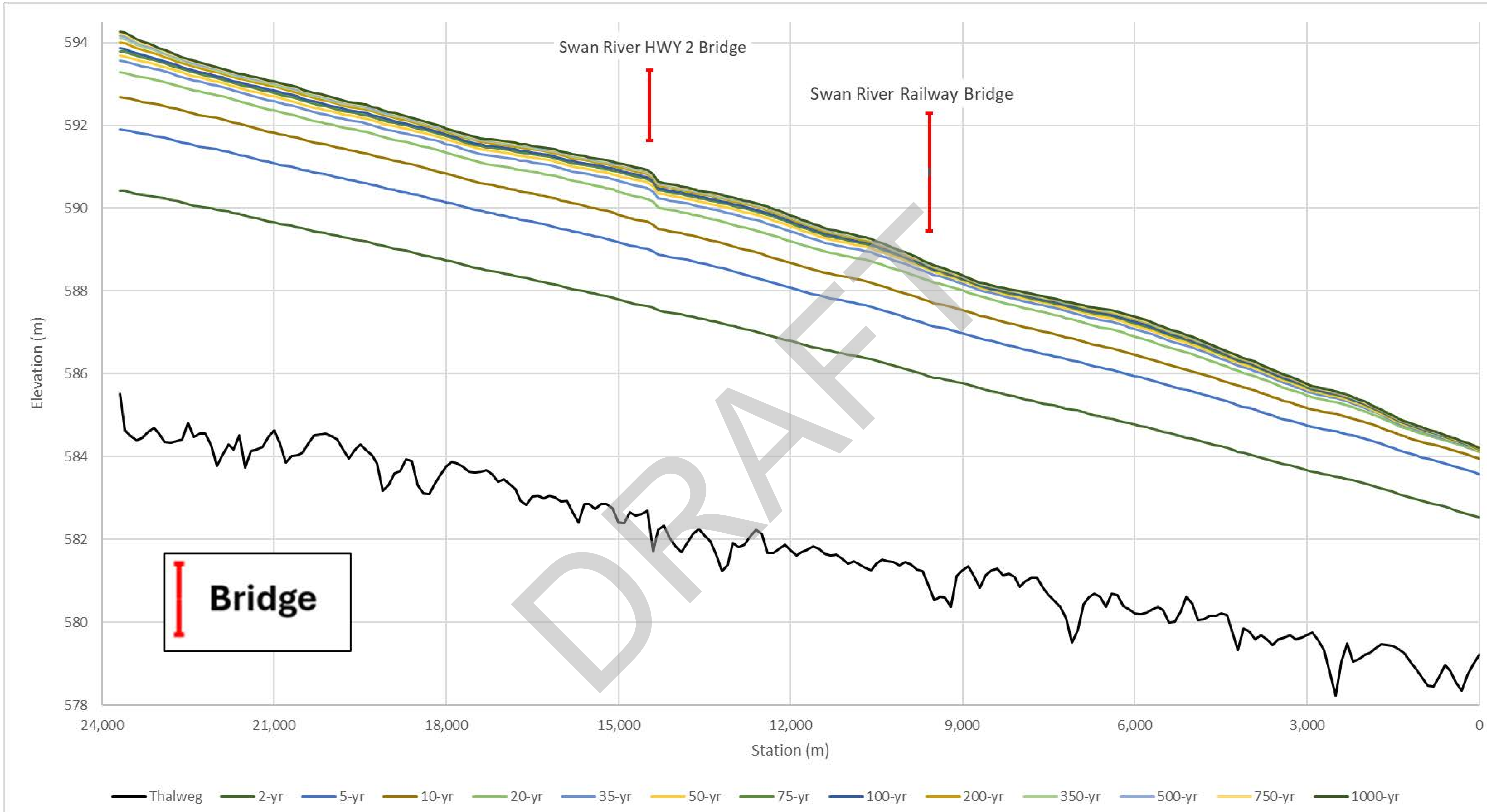


Figure F-1 Simulated Water Surface Profiles Along Swan River

Table F-1 Swan River Profiles

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
23,680	585.51	590.42	591.90	592.68	593.27	593.55	593.68	593.79	593.86	594.00	594.10	594.16	594.22	594.26
23,600	584.63	590.41	591.89	592.67	593.26	593.54	593.66	593.77	593.84	593.98	594.08	594.13	594.19	594.23
23,500	584.50	590.38	591.85	592.63	593.22	593.50	593.62	593.72	593.79	593.92	594.01	594.06	594.12	594.16
23,400	584.40	590.35	591.82	592.60	593.19	593.45	593.57	593.67	593.74	593.86	593.95	593.99	594.04	594.08
23,300	584.45	590.33	591.79	592.57	593.16	593.42	593.54	593.64	593.70	593.82	593.90	593.94	593.99	594.02
23,200	584.59	590.31	591.78	592.55	593.14	593.40	593.51	593.61	593.67	593.79	593.86	593.91	593.95	593.98
23,100	584.69	590.29	591.75	592.52	593.11	593.37	593.48	593.57	593.63	593.74	593.81	593.85	593.90	593.93
23,000	584.56	590.26	591.72	592.50	593.08	593.33	593.44	593.53	593.59	593.70	593.77	593.80	593.84	593.87
22,900	584.36	590.24	591.70	592.47	593.05	593.30	593.41	593.49	593.55	593.65	593.72	593.75	593.79	593.81
22,800	584.33	590.20	591.66	592.43	593.01	593.25	593.36	593.45	593.50	593.60	593.66	593.69	593.73	593.75
22,700	584.37	590.17	591.63	592.39	592.97	593.21	593.32	593.40	593.45	593.55	593.61	593.64	593.68	593.70
22,600	584.41	590.14	591.59	592.35	592.92	593.17	593.27	593.36	593.41	593.50	593.56	593.59	593.63	593.65
22,500	584.82	590.10	591.55	592.32	592.88	593.13	593.23	593.32	593.37	593.46	593.52	593.55	593.58	593.60
22,400	584.47	590.07	591.52	592.28	592.85	593.08	593.19	593.27	593.32	593.42	593.47	593.50	593.53	593.56
22,300	584.56	590.04	591.49	592.25	592.81	593.05	593.16	593.24	593.29	593.38	593.43	593.46	593.50	593.52
22,200	584.55	590.01	591.46	592.22	592.79	593.02	593.12	593.21	593.26	593.35	593.40	593.43	593.46	593.48
22,100	584.28	589.99	591.44	592.20	592.76	592.99	593.09	593.17	593.22	593.31	593.36	593.39	593.42	593.44
22,000	583.77	589.97	591.41	592.17	592.73	592.96	593.06	593.14	593.19	593.28	593.33	593.36	593.39	593.41
21,900	584.06	589.94	591.39	592.14	592.69	592.92	593.02	593.10	593.15	593.24	593.29	593.32	593.35	593.37
21,800	584.29	589.91	591.35	592.10	592.66	592.88	592.98	593.06	593.11	593.20	593.25	593.28	593.30	593.32
21,700	584.17	589.88	591.32	592.07	592.62	592.84	592.94	593.02	593.07	593.16	593.21	593.24	593.26	593.28
21,600	584.51	589.85	591.29	592.04	592.58	592.80	592.90	592.99	593.04	593.13	593.18	593.20	593.23	593.25
21,500	583.73	589.82	591.25	592.00	592.54	592.76	592.87	592.95	593.00	593.09	593.14	593.17	593.20	593.22
21,400	584.14	589.79	591.22	591.96	592.50	592.72	592.83	592.92	592.97	593.06	593.11	593.14	593.17	593.19
21,300	584.17	589.75	591.18	591.93	592.46	592.68	592.79	592.88	592.94	593.03	593.08	593.11	593.14	593.16
21,200	584.23	589.72	591.15	591.89	592.42	592.65	592.76	592.85	592.90	593.00	593.05	593.08	593.10	593.12
21,100	584.47	589.69	591.11	591.85	592.38	592.61	592.72	592.81	592.87	592.96	593.01	593.04	593.07	593.09
21,000	584.64	589.66	591.08	591.82	592.35	592.58	592.69	592.78	592.84	592.93	592.99	593.01	593.04	593.06
20,900	584.32	589.62	591.05	591.78	592.31	592.54	592.65	592.75	592.80	592.90	592.95	592.98	593.01	593.02
20,800	583.86	589.60	591.02	591.75	592.28	592.50	592.62	592.71	592.76	592.86	592.91	592.94	592.97	592.99
20,700	584.02	589.57	590.99	591.73	592.25	592.47	592.59	592.68	592.73	592.83	592.88	592.91	592.93	592.95
20,600	584.03	589.54	590.96	591.69	592.22	592.43	592.55	592.64	592.69	592.79	592.84	592.86	592.89	592.91
20,500	584.09	589.51	590.93	591.65	592.18	592.39	592.51	592.60	592.65	592.74	592.79	592.82	592.85	592.87
20,400	584.31	589.48	590.89	591.62	592.14	592.35	592.47	592.55	592.61	592.70	592.75	592.78	592.80	592.82
20,300	584.52	589.45	590.86	591.59	592.11	592.32	592.43	592.52	592.57	592.66	592.71	592.74	592.77	592.78
20,200	584.54	589.42	590.84	591.56	592.08	592.29	592.40	592.49	592.54	592.63	592.68	592.71	592.74	592.75

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
20,100	584.56	589.40	590.81	591.53	592.05	592.26	592.37	592.46	592.51	592.60	592.64	592.67	592.70	592.72
20,000	584.50	589.37	590.78	591.50	592.02	592.22	592.33	592.42	592.47	592.55	592.60	592.63	592.66	592.67
19,900	584.41	589.34	590.75	591.47	591.98	592.19	592.30	592.38	592.43	592.52	592.56	592.59	592.62	592.63
19,800	584.18	589.30	590.71	591.43	591.95	592.15	592.26	592.35	592.40	592.48	592.53	592.55	592.58	592.59
19,700	583.95	589.27	590.69	591.40	591.92	592.13	592.24	592.32	592.37	592.45	592.50	592.52	592.55	592.56
19,600	584.16	589.24	590.66	591.38	591.89	592.10	592.21	592.29	592.34	592.43	592.47	592.50	592.52	592.54
19,500	584.29	589.21	590.63	591.35	591.86	592.07	592.19	592.27	592.32	592.40	592.45	592.47	592.50	592.52
19,400	584.15	589.19	590.61	591.32	591.84	592.05	592.16	592.24	592.29	592.38	592.42	592.45	592.48	592.49
19,300	584.04	589.15	590.57	591.28	591.79	592.00	592.12	592.20	592.25	592.33	592.38	592.41	592.43	592.45
19,200	583.83	589.12	590.54	591.25	591.76	591.97	592.08	592.16	592.21	592.30	592.34	592.37	592.39	592.41
19,100	583.17	589.09	590.50	591.21	591.72	591.93	592.04	592.12	592.17	592.26	592.30	592.33	592.35	592.37
19,000	583.31	589.06	590.47	591.18	591.68	591.89	592.00	592.09	592.14	592.22	592.26	592.29	592.31	592.33
18,900	583.60	589.03	590.44	591.14	591.65	591.86	591.97	592.05	592.10	592.18	592.23	592.25	592.28	592.29
18,800	583.65	589.00	590.41	591.11	591.62	591.83	591.94	592.02	592.07	592.15	592.19	592.22	592.24	592.26
18,700	583.93	588.97	590.38	591.09	591.59	591.80	591.92	592.00	592.04	592.12	592.16	592.19	592.21	592.23
18,600	583.90	588.94	590.35	591.05	591.56	591.77	591.88	591.96	592.01	592.09	592.13	592.15	592.17	592.19
18,500	583.32	588.90	590.31	591.01	591.52	591.73	591.85	591.93	591.97	592.04	592.08	592.11	592.13	592.14
18,400	583.12	588.87	590.28	590.98	591.49	591.70	591.81	591.89	591.94	592.01	592.05	592.07	592.09	592.10
18,300	583.09	588.83	590.24	590.94	591.45	591.67	591.78	591.85	591.90	591.97	592.01	592.03	592.05	592.06
18,200	583.35	588.80	590.21	590.91	591.42	591.63	591.74	591.82	591.86	591.93	591.97	591.99	592.01	592.03
18,100	583.58	588.77	590.17	590.87	591.38	591.59	591.70	591.78	591.82	591.89	591.92	591.94	591.96	591.98
18,000	583.76	588.74	590.14	590.83	591.34	591.55	591.66	591.73	591.77	591.84	591.88	591.90	591.92	591.93
17,900	583.87	588.71	590.11	590.80	591.31	591.51	591.62	591.69	591.73	591.80	591.84	591.85	591.87	591.89
17,800	583.83	588.68	590.08	590.77	591.27	591.47	591.58	591.65	591.69	591.76	591.79	591.81	591.83	591.84
17,700	583.75	588.63	590.04	590.72	591.22	591.43	591.53	591.60	591.64	591.71	591.74	591.76	591.78	591.79
17,600	583.64	588.60	590.00	590.68	591.18	591.39	591.49	591.57	591.61	591.67	591.71	591.72	591.74	591.76
17,500	583.62	588.57	589.96	590.65	591.14	591.35	591.46	591.53	591.57	591.64	591.67	591.69	591.71	591.72
17,400	583.63	588.53	589.93	590.61	591.10	591.31	591.42	591.49	591.54	591.60	591.64	591.66	591.68	591.69
17,300	583.67	588.51	589.90	590.58	591.07	591.28	591.39	591.47	591.51	591.58	591.61	591.63	591.65	591.67
17,200	583.58	588.48	589.88	590.56	591.05	591.26	591.38	591.45	591.49	591.56	591.60	591.62	591.64	591.65
17,100	583.40	588.45	589.85	590.52	591.02	591.24	591.36	591.43	591.48	591.54	591.58	591.60	591.62	591.63
17,000	583.46	588.43	589.82	590.50	591.00	591.22	591.34	591.42	591.46	591.53	591.57	591.59	591.61	591.62
16,900	583.33	588.39	589.78	590.46	590.97	591.19	591.31	591.39	591.43	591.50	591.54	591.56	591.58	591.60
16,800	583.21	588.36	589.76	590.44	590.95	591.17	591.29	591.37	591.41	591.48	591.52	591.54	591.56	591.57
16,700	582.93	588.33	589.73	590.41	590.92	591.15	591.27	591.34	591.39	591.46	591.50	591.52	591.54	591.55
16,600	582.83	588.31	589.70	590.39	590.91	591.13	591.25	591.33	591.37	591.44	591.48	591.50	591.52	591.53
16,500	583.04	588.27	589.67	590.35	590.88	591.11	591.22	591.30	591.35	591.42	591.45	591.47	591.50	591.51

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
16,400	583.05	588.24	589.64	590.32	590.85	591.08	591.20	591.28	591.32	591.39	591.43	591.45	591.47	591.49
16,300	582.99	588.21	589.61	590.29	590.83	591.06	591.18	591.26	591.30	591.37	591.41	591.43	591.45	591.46
16,200	583.05	588.19	589.58	590.27	590.81	591.04	591.16	591.23	591.28	591.35	591.39	591.41	591.43	591.44
16,100	583.02	588.15	589.55	590.23	590.77	591.00	591.12	591.20	591.25	591.32	591.35	591.38	591.40	591.41
16,000	582.91	588.11	589.51	590.19	590.73	590.96	591.08	591.16	591.20	591.27	591.31	591.33	591.36	591.37
15,900	582.94	588.08	589.47	590.15	590.69	590.92	591.04	591.12	591.16	591.23	591.27	591.29	591.32	591.33
15,800	582.65	588.05	589.44	590.12	590.66	590.89	591.01	591.09	591.13	591.20	591.24	591.26	591.28	591.30
15,700	582.42	588.02	589.42	590.09	590.64	590.87	590.98	591.06	591.11	591.18	591.22	591.24	591.26	591.28
15,600	582.85	587.99	589.39	590.06	590.61	590.84	590.96	591.04	591.09	591.16	591.20	591.22	591.24	591.26
15,500	582.86	587.96	589.35	590.03	590.57	590.81	590.93	591.01	591.06	591.13	591.17	591.19	591.21	591.23
15,400	582.74	587.93	589.32	589.99	590.55	590.79	590.91	590.99	591.04	591.11	591.15	591.17	591.19	591.21
15,300	582.85	587.90	589.29	589.97	590.52	590.76	590.89	590.97	591.01	591.09	591.13	591.15	591.17	591.18
15,200	582.85	587.87	589.26	589.93	590.49	590.73	590.86	590.94	590.99	591.06	591.10	591.12	591.14	591.16
15,100	582.76	587.84	589.23	589.89	590.45	590.70	590.83	590.91	590.95	591.03	591.07	591.09	591.11	591.13
15,000	582.41	587.80	589.18	589.85	590.41	590.66	590.79	590.87	590.92	590.99	591.03	591.05	591.08	591.09
14,900	582.39	587.75	589.14	589.80	590.36	590.61	590.75	590.83	590.88	590.95	590.99	591.01	591.04	591.05
14,800	582.66	587.72	589.10	589.76	590.32	590.58	590.72	590.80	590.85	590.92	590.96	590.98	591.01	591.02
14,700	582.57	587.69	589.07	589.73	590.29	590.55	590.68	590.77	590.81	590.89	590.93	590.95	590.97	590.99
14,600	582.61	587.66	589.05	589.70	590.26	590.52	590.65	590.74	590.79	590.86	590.90	590.92	590.94	590.96
14,500	582.69	587.63	589.01	589.67	590.23	590.49	590.62	590.70	590.75	590.82	590.86	590.88	590.91	590.92
14,400	581.71	587.59	588.96	589.61	590.15	590.40	590.53	590.61	590.66	590.73	590.77	590.79	590.81	590.82
14,300	582.23	587.53	588.88	589.50	590.01	590.25	590.36	590.44	590.49	590.55	590.59	590.60	590.62	590.64
14,200	582.34	587.51	588.85	589.47	589.99	590.22	590.34	590.41	590.46	590.52	590.56	590.58	590.60	590.61
14,100	582.04	587.48	588.83	589.44	589.96	590.19	590.31	590.39	590.43	590.49	590.53	590.55	590.57	590.58
14,000	581.83	587.46	588.80	589.42	589.93	590.16	590.28	590.36	590.40	590.46	590.50	590.52	590.54	590.55
13,900	581.69	587.43	588.78	589.39	589.91	590.14	590.25	590.33	590.37	590.43	590.47	590.49	590.51	590.52
13,800	581.92	587.41	588.75	589.37	589.88	590.11	590.23	590.31	590.35	590.41	590.44	590.46	590.48	590.49
13,700	582.14	587.38	588.72	589.33	589.85	590.08	590.20	590.27	590.32	590.38	590.41	590.43	590.45	590.46
13,600	582.25	587.34	588.68	589.30	589.81	590.05	590.17	590.24	590.28	590.35	590.38	590.40	590.42	590.43
13,500	582.09	587.31	588.65	589.26	589.78	590.02	590.14	590.22	590.26	590.32	590.35	590.37	590.39	590.40
13,400	581.96	587.28	588.61	589.23	589.75	589.99	590.11	590.19	590.23	590.29	590.33	590.34	590.36	590.38
13,300	581.63	587.25	588.58	589.20	589.72	589.96	590.08	590.16	590.20	590.26	590.30	590.32	590.34	590.35
13,200	581.24	587.22	588.55	589.16	589.68	589.92	590.05	590.13	590.17	590.23	590.27	590.29	590.31	590.32
13,100	581.40	587.19	588.51	589.12	589.64	589.88	590.01	590.09	590.14	590.20	590.24	590.25	590.27	590.29
13,000	581.91	587.15	588.47	589.08	589.61	589.85	589.98	590.06	590.10	590.17	590.21	590.23	590.25	590.26
12,900	581.81	587.12	588.44	589.04	589.57	589.81	589.94	590.03	590.07	590.14	590.17	590.19	590.21	590.22
12,800	581.87	587.08	588.40	589.00	589.53	589.78	589.91	589.99	590.03	590.10	590.14	590.16	590.18	590.19

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
12,700	582.08	587.05	588.36	588.97	589.50	589.75	589.88	589.96	590.00	590.07	590.11	590.13	590.15	590.16
12,600	582.24	587.02	588.33	588.93	589.46	589.71	589.84	589.92	589.97	590.03	590.07	590.09	590.11	590.12
12,500	582.13	586.98	588.28	588.89	589.42	589.67	589.80	589.88	589.93	589.99	590.03	590.05	590.07	590.08
12,400	581.68	586.94	588.24	588.85	589.38	589.63	589.76	589.84	589.88	589.95	589.98	590.00	590.02	590.03
12,300	581.68	586.90	588.19	588.80	589.33	589.58	589.71	589.79	589.83	589.90	589.93	589.95	589.97	589.98
12,200	581.77	586.86	588.15	588.76	589.29	589.54	589.66	589.74	589.78	589.85	589.88	589.90	589.92	589.93
12,100	581.87	586.82	588.11	588.72	589.25	589.49	589.61	589.69	589.73	589.79	589.83	589.85	589.87	589.88
12,000	581.73	586.79	588.08	588.68	589.20	589.44	589.56	589.64	589.68	589.74	589.77	589.79	589.81	589.83
11,900	581.61	586.76	588.04	588.64	589.16	589.40	589.51	589.59	589.63	589.69	589.72	589.74	589.76	589.78
11,800	581.69	586.72	588.00	588.60	589.12	589.35	589.47	589.54	589.58	589.64	589.67	589.69	589.71	589.73
11,700	581.75	586.69	587.97	588.57	589.08	589.31	589.42	589.50	589.53	589.59	589.63	589.65	589.67	589.68
11,600	581.83	586.65	587.93	588.53	589.04	589.26	589.37	589.44	589.48	589.54	589.57	589.59	589.61	589.63
11,500	581.78	586.61	587.89	588.49	588.99	589.21	589.32	589.39	589.43	589.49	589.52	589.54	589.56	589.57
11,400	581.65	586.58	587.85	588.45	588.95	589.17	589.28	589.35	589.39	589.44	589.47	589.49	589.51	589.53
11,300	581.60	586.55	587.82	588.42	588.92	589.13	589.24	589.31	589.35	589.40	589.44	589.46	589.48	589.49
11,200	581.62	586.52	587.79	588.39	588.89	589.10	589.21	589.28	589.32	589.37	589.40	589.42	589.44	589.45
11,100	581.54	586.49	587.77	588.36	588.87	589.08	589.18	589.25	589.29	589.34	589.37	589.39	589.41	589.42
11,000	581.41	586.46	587.74	588.33	588.84	589.05	589.15	589.22	589.26	589.31	589.34	589.36	589.38	589.39
10,900	581.47	586.44	587.71	588.30	588.81	589.02	589.12	589.19	589.23	589.28	589.31	589.33	589.35	589.36
10,800	581.39	586.41	587.68	588.27	588.78	588.99	589.10	589.16	589.20	589.25	589.28	589.30	589.32	589.33
10,700	581.32	586.39	587.66	588.25	588.76	588.97	589.07	589.14	589.17	589.22	589.25	589.27	589.29	589.30
10,600	581.26	586.35	587.62	588.21	588.72	588.93	589.03	589.10	589.13	589.18	589.21	589.23	589.25	589.26
10,500	581.41	586.31	587.58	588.16	588.68	588.89	588.99	589.05	589.09	589.13	589.16	589.18	589.20	589.21
10,400	581.52	586.27	587.53	588.11	588.63	588.84	588.94	589.00	589.03	589.08	589.11	589.13	589.14	589.16
10,300	581.47	586.23	587.49	588.07	588.59	588.79	588.89	588.95	588.98	589.03	589.06	589.08	589.09	589.10
10,200	581.46	586.19	587.45	588.03	588.54	588.75	588.84	588.90	588.93	588.97	589.00	589.02	589.03	589.04
10,100	581.38	586.16	587.41	587.99	588.50	588.70	588.79	588.85	588.88	588.92	588.95	588.96	588.98	588.99
10,000	581.46	586.12	587.37	587.94	588.45	588.65	588.74	588.80	588.82	588.87	588.89	588.91	588.92	588.93
9,900	581.40	586.07	587.32	587.89	588.40	588.60	588.69	588.74	588.77	588.81	588.83	588.85	588.86	588.87
9,800	581.28	586.03	587.28	587.85	588.35	588.55	588.63	588.68	588.71	588.75	588.77	588.79	588.80	588.81
9,700	581.23	585.99	587.23	587.80	588.30	588.49	588.57	588.62	588.65	588.69	588.71	588.73	588.74	588.75
9,600	580.89	585.95	587.18	587.75	588.25	588.43	588.51	588.56	588.59	588.62	588.65	588.66	588.67	588.68
9,500	580.54	585.91	587.14	587.70	588.20	588.38	588.45	588.50	588.52	588.56	588.58	588.59	588.60	588.61
9,400	580.61	585.89	587.12	587.68	588.17	588.35	588.42	588.47	588.49	588.53	588.55	588.56	588.57	588.58
9,300	580.59	585.86	587.09	587.65	588.14	588.31	588.38	588.43	588.45	588.48	588.50	588.51	588.52	588.53
9,200	580.38	585.83	587.06	587.61	588.10	588.27	588.34	588.38	588.40	588.44	588.46	588.47	588.48	588.48
9,100	581.11	585.80	587.02	587.58	588.05	588.22	588.29	588.33	588.35	588.39	588.41	588.41	588.42	588.43

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	**5-Year Flood Event**	**10-Year Flood Event**	**20-Year Flood Event**	**35-Year Flood Event**	**50-Year Flood Event**	**75-Year Flood Event**	**100-Year Flood Event**	**200-Year Flood Event**	**350-Year Flood Event**	**500-Year Flood Event**	**750-Year Flood Event**	**1000-Year Flood Event**
9,000	581.26	585.77	586.98	587.54	588.01	588.18	588.24	588.28	588.30	588.34	588.35	588.36	588.37	588.38
8,900	581.34	585.73	586.94	587.50	587.97	588.13	588.19	588.23	588.25	588.28	588.30	588.31	588.32	588.32
8,800	581.12	585.69	586.90	587.45	587.91	588.07	588.14	588.17	588.19	588.22	588.24	588.25	588.26	588.26
8,700	580.84	585.65	586.86	587.41	587.87	588.02	588.08	588.12	588.14	588.17	588.19	588.19	588.20	588.21
8,600	581.12	585.62	586.83	587.37	587.83	587.98	588.04	588.08	588.10	588.13	588.15	588.16	588.16	588.17
8,500	581.26	585.59	586.79	587.34	587.80	587.95	588.01	588.05	588.06	588.10	588.11	588.12	588.13	588.13
8,400	581.30	585.55	586.76	587.31	587.77	587.92	587.98	588.02	588.04	588.07	588.09	588.09	588.10	588.11
8,300	581.13	585.52	586.72	587.27	587.73	587.88	587.94	587.98	588.00	588.04	588.05	588.06	588.07	588.08
8,200	581.17	585.48	586.68	587.23	587.69	587.84	587.91	587.95	587.97	588.01	588.02	588.03	588.04	588.05
8,100	581.08	585.45	586.65	587.20	587.66	587.82	587.88	587.92	587.94	587.98	588.00	588.01	588.01	588.02
8,000	580.86	585.41	586.62	587.16	587.62	587.78	587.85	587.89	587.91	587.95	587.97	587.98	587.99	587.99
7,900	580.99	585.38	586.58	587.12	587.59	587.75	587.81	587.86	587.88	587.92	587.94	587.95	587.95	587.96
7,800	581.07	585.35	586.55	587.09	587.55	587.72	587.78	587.83	587.85	587.89	587.91	587.92	587.92	587.93
7,700	581.07	585.32	586.52	587.06	587.52	587.68	587.75	587.79	587.82	587.86	587.87	587.88	587.89	587.90
7,600	580.84	585.29	586.49	587.02	587.49	587.65	587.72	587.76	587.79	587.83	587.85	587.86	587.87	587.87
7,500	580.65	585.26	586.46	586.99	587.46	587.62	587.69	587.74	587.76	587.80	587.82	587.83	587.84	587.84
7,400	580.51	585.23	586.43	586.96	587.43	587.59	587.66	587.71	587.73	587.77	587.79	587.80	587.81	587.82
7,300	580.38	585.20	586.39	586.93	587.39	587.56	587.62	587.67	587.70	587.74	587.76	587.77	587.78	587.78
7,200	580.08	585.16	586.35	586.88	587.34	587.51	587.58	587.63	587.66	587.70	587.72	587.73	587.74	587.74
7,100	579.51	585.14	586.32	586.85	587.31	587.48	587.55	587.60	587.63	587.67	587.69	587.70	587.71	587.72
7,000	579.82	585.11	586.29	586.81	587.27	587.44	587.52	587.56	587.59	587.64	587.66	587.67	587.68	587.69
6,900	580.43	585.07	586.25	586.77	587.23	587.40	587.47	587.52	587.55	587.60	587.62	587.63	587.64	587.65
6,800	580.59	585.04	586.21	586.73	587.19	587.36	587.44	587.49	587.52	587.57	587.59	587.60	587.61	587.62
6,700	580.70	585.00	586.18	586.70	587.15	587.33	587.41	587.46	587.49	587.54	587.56	587.58	587.59	587.59
6,600	580.61	584.97	586.15	586.67	587.13	587.31	587.38	587.44	587.47	587.52	587.54	587.55	587.57	587.57
6,500	580.37	584.95	586.12	586.64	587.10	587.28	587.36	587.42	587.45	587.50	587.52	587.54	587.55	587.56
6,400	580.69	584.91	586.09	586.61	587.07	587.25	587.33	587.39	587.42	587.47	587.50	587.51	587.52	587.53
6,300	580.66	584.88	586.05	586.57	587.03	587.21	587.29	587.35	587.39	587.44	587.46	587.47	587.49	587.49
6,200	580.39	584.84	586.02	586.53	586.99	587.17	587.25	587.31	587.34	587.40	587.42	587.43	587.45	587.45
6,100	580.31	584.81	585.98	586.49	586.94	587.12	587.21	587.27	587.30	587.35	587.38	587.39	587.40	587.41
6,000	580.20	584.77	585.94	586.45	586.90	587.08	587.16	587.22	587.26	587.31	587.33	587.35	587.36	587.37
5,900	580.19	584.74	585.91	586.42	586.86	587.04	587.13	587.19	587.22	587.27	587.30	587.31	587.32	587.33
5,800	580.23	584.71	585.87	586.38	586.82	587.00	587.08	587.15	587.18	587.23	587.25	587.27	587.28	587.29
5,700	580.31	584.68	585.83	586.34	586.77	586.95	587.03	587.09	587.13	587.18	587.20	587.22	587.23	587.24
5,600	580.37	584.64	585.79	586.29	586.72	586.90	586.98	587.04	587.07	587.12	587.15	587.16	587.17	587.18
5,500	580.29	584.60	585.75	586.25	586.68	586.85	586.93	586.99	587.03	587.08	587.10	587.11	587.13	587.13
5,400	580.00	584.57	585.71	586.21	586.63	586.80	586.88	586.94	586.97	587.02	587.04	587.06	587.07	587.08

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
5,300	580.01	584.54	585.68	586.18	586.60	586.76	586.84	586.90	586.93	586.98	587.01	587.02	587.03	587.04
5,200	580.25	584.50	585.64	586.14	586.55	586.72	586.79	586.86	586.89	586.93	586.96	586.97	586.98	586.99
5,100	580.61	584.46	585.61	586.10	586.51	586.67	586.75	586.81	586.84	586.89	586.91	586.92	586.93	586.94
5,000	580.45	584.43	585.58	586.06	586.47	586.63	586.71	586.77	586.80	586.84	586.86	586.88	586.89	586.89
4,900	580.05	584.39	585.53	586.02	586.42	586.58	586.65	586.71	586.74	586.79	586.81	586.82	586.83	586.84
4,800	580.08	584.36	585.50	585.98	586.38	586.53	586.60	586.66	586.69	586.73	586.75	586.77	586.78	586.78
4,700	580.15	584.32	585.46	585.94	586.33	586.48	586.54	586.60	586.63	586.67	586.69	586.70	586.71	586.72
4,600	580.16	584.28	585.42	585.89	586.27	586.42	586.49	586.54	586.57	586.61	586.63	586.64	586.65	586.66
4,500	580.21	584.25	585.37	585.85	586.22	586.37	586.43	586.49	586.51	586.55	586.57	586.58	586.59	586.60
4,400	580.16	584.21	585.34	585.80	586.18	586.32	586.38	586.43	586.46	586.50	586.52	586.53	586.54	586.55
4,300	579.78	584.17	585.29	585.76	586.12	586.26	586.33	586.38	586.40	586.44	586.46	586.47	586.48	586.49
4,200	579.33	584.12	585.24	585.71	586.07	586.21	586.27	586.32	586.35	586.39	586.40	586.42	586.43	586.43
4,100	579.85	584.09	585.21	585.67	586.03	586.16	586.22	586.27	586.30	586.34	586.36	586.37	586.38	586.38
4,000	579.78	584.06	585.17	585.63	585.98	586.12	586.18	586.23	586.26	586.29	586.31	586.32	586.33	586.34
3,900	579.59	584.02	585.13	585.59	585.94	586.07	586.13	586.18	586.20	586.24	586.26	586.27	586.28	586.29
3,800	579.69	583.98	585.08	585.54	585.88	586.01	586.07	586.12	586.14	586.18	586.20	586.21	586.22	586.22
3,700	579.59	583.94	585.04	585.49	585.83	585.95	586.01	586.06	586.08	586.12	586.14	586.15	586.16	586.16
3,600	579.45	583.90	584.99	585.44	585.77	585.89	585.95	586.00	586.02	586.06	586.08	586.09	586.09	586.10
3,500	579.60	583.85	584.95	585.39	585.71	585.83	585.89	585.93	585.96	585.99	586.01	586.02	586.03	586.03
3,400	579.63	583.81	584.90	585.34	585.66	585.77	585.83	585.87	585.90	585.93	585.95	585.96	585.97	585.97
3,300	579.69	583.79	584.87	585.31	585.62	585.74	585.79	585.83	585.86	585.89	585.91	585.92	585.93	585.93
3,200	579.59	583.75	584.83	585.26	585.57	585.68	585.74	585.78	585.80	585.84	585.85	585.86	585.87	585.88
3,100	579.62	583.71	584.79	585.22	585.53	585.63	585.68	585.73	585.75	585.78	585.80	585.81	585.81	585.82
3,000	579.70	583.67	584.75	585.18	585.48	585.58	585.63	585.67	585.69	585.72	585.74	585.75	585.76	585.76
2,900	579.74	583.63	584.71	585.14	585.43	585.53	585.58	585.62	585.64	585.67	585.68	585.69	585.70	585.70
2,800	579.57	583.61	584.69	585.11	585.40	585.50	585.55	585.59	585.61	585.64	585.65	585.66	585.67	585.67
2,700	579.33	583.57	584.66	585.08	585.37	585.47	585.52	585.56	585.58	585.61	585.62	585.63	585.64	585.64
2,600	578.79	583.55	584.63	585.06	585.34	585.44	585.48	585.52	585.54	585.57	585.59	585.60	585.60	585.61
2,500	578.22	583.52	584.61	585.03	585.31	585.41	585.45	585.49	585.51	585.54	585.56	585.56	585.57	585.58
2,400	579.06	583.49	584.58	584.99	585.27	585.37	585.41	585.45	585.47	585.50	585.51	585.52	585.53	585.53
2,300	579.48	583.46	584.54	584.96	585.24	585.33	585.37	585.41	585.43	585.46	585.47	585.48	585.49	585.49
2,200	579.06	583.43	584.51	584.92	585.19	585.28	585.33	585.36	585.38	585.41	585.42	585.43	585.44	585.44
2,100	579.11	583.39	584.47	584.88	585.15	585.23	585.27	585.31	585.32	585.35	585.36	585.37	585.38	585.38
2,000	579.20	583.36	584.43	584.84	585.10	585.18	585.22	585.25	585.27	585.30	585.31	585.32	585.32	585.33
1,900	579.28	583.32	584.39	584.79	585.04	585.12	585.16	585.19	585.21	585.23	585.24	585.25	585.26	585.26
1,800	579.38	583.28	584.35	584.75	584.99	585.07	585.11	585.14	585.15	585.18	585.19	585.19	585.20	585.20
1,700	579.47	583.24	584.31	584.70	584.94	585.01	585.04	585.07	585.09	585.11	585.12	585.13	585.13	585.14

River Station (m)	Channel Thalweg (m)	Simulated Water Level (m)												
		2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
1,600	579.44	583.20	584.26	584.64	584.87	584.94	584.97	585.00	585.02	585.04	585.05	585.05	585.06	585.06
1,500	579.42	583.15	584.21	584.59	584.81	584.87	584.90	584.93	584.94	584.96	584.97	584.98	584.99	584.99
1,400	579.36	583.10	584.15	584.53	584.74	584.81	584.84	584.86	584.87	584.89	584.90	584.91	584.91	584.92
1,300	579.24	583.06	584.11	584.49	584.69	584.75	584.78	584.81	584.82	584.84	584.85	584.85	584.86	584.86
1,200	579.05	583.02	584.07	584.45	584.65	584.71	584.74	584.76	584.77	584.79	584.80	584.80	584.81	584.81
1,100	578.88	582.97	584.03	584.40	584.60	584.66	584.69	584.71	584.72	584.74	584.75	584.75	584.76	584.76
1,000	578.66	582.93	583.98	584.36	584.56	584.61	584.64	584.66	584.67	584.69	584.70	584.70	584.71	584.71
900	578.47	582.90	583.95	584.32	584.52	584.57	584.59	584.61	584.62	584.64	584.65	584.65	584.66	584.66
800	578.45	582.86	583.91	584.29	584.48	584.53	584.55	584.57	584.58	584.60	584.60	584.61	584.61	584.61
700	578.70	582.83	583.88	584.25	584.44	584.48	584.51	584.53	584.54	584.55	584.56	584.56	584.57	584.57
600	578.97	582.79	583.84	584.22	584.40	584.44	584.46	584.48	584.49	584.51	584.51	584.52	584.52	584.52
500	578.83	582.75	583.80	584.18	584.36	584.40	584.42	584.44	584.45	584.46	584.47	584.47	584.48	584.48
400	578.54	582.70	583.76	584.13	584.31	584.35	584.37	584.39	584.40	584.41	584.42	584.42	584.42	584.43
300	578.35	582.66	583.72	584.10	584.27	584.31	584.33	584.34	584.35	584.37	584.37	584.38	584.38	584.38
200	578.73	582.62	583.67	584.05	584.22	584.26	584.27	584.29	584.30	584.31	584.32	584.32	584.33	584.33
100	578.99	582.58	583.63	584.00	584.17	584.20	584.22	584.24	584.25	584.26	584.27	584.27	584.27	584.28
0	579.21	582.53	583.58	583.95	584.11	584.15	584.16	584.18	584.19	584.20	584.21	584.21	584.22	584.22

Appendix G

Open Water Sensitivity Analysis

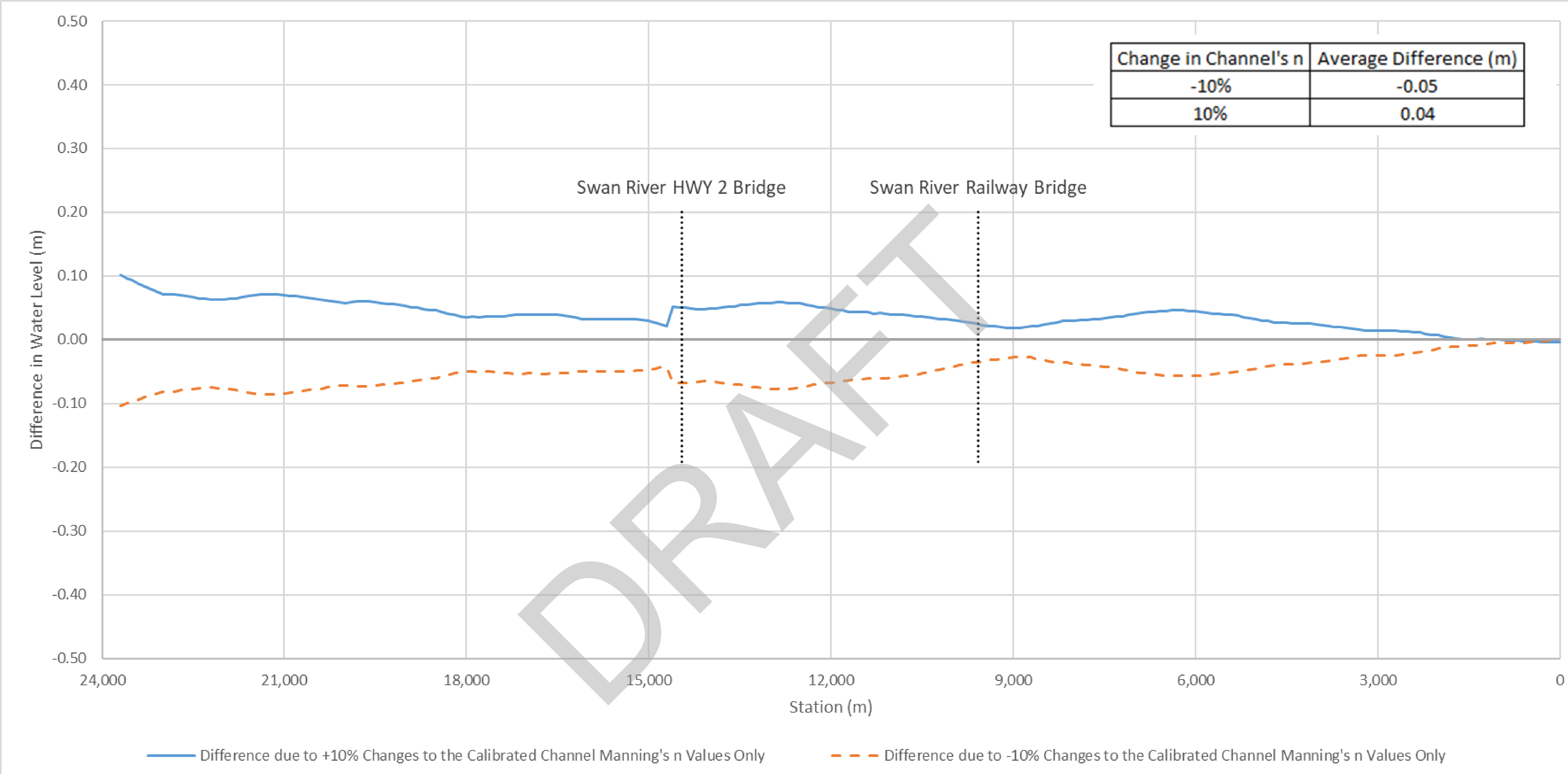


Figure G-1 Sensitivity of Simulated Water Level Along Swan River (Channel Manning's n Only)

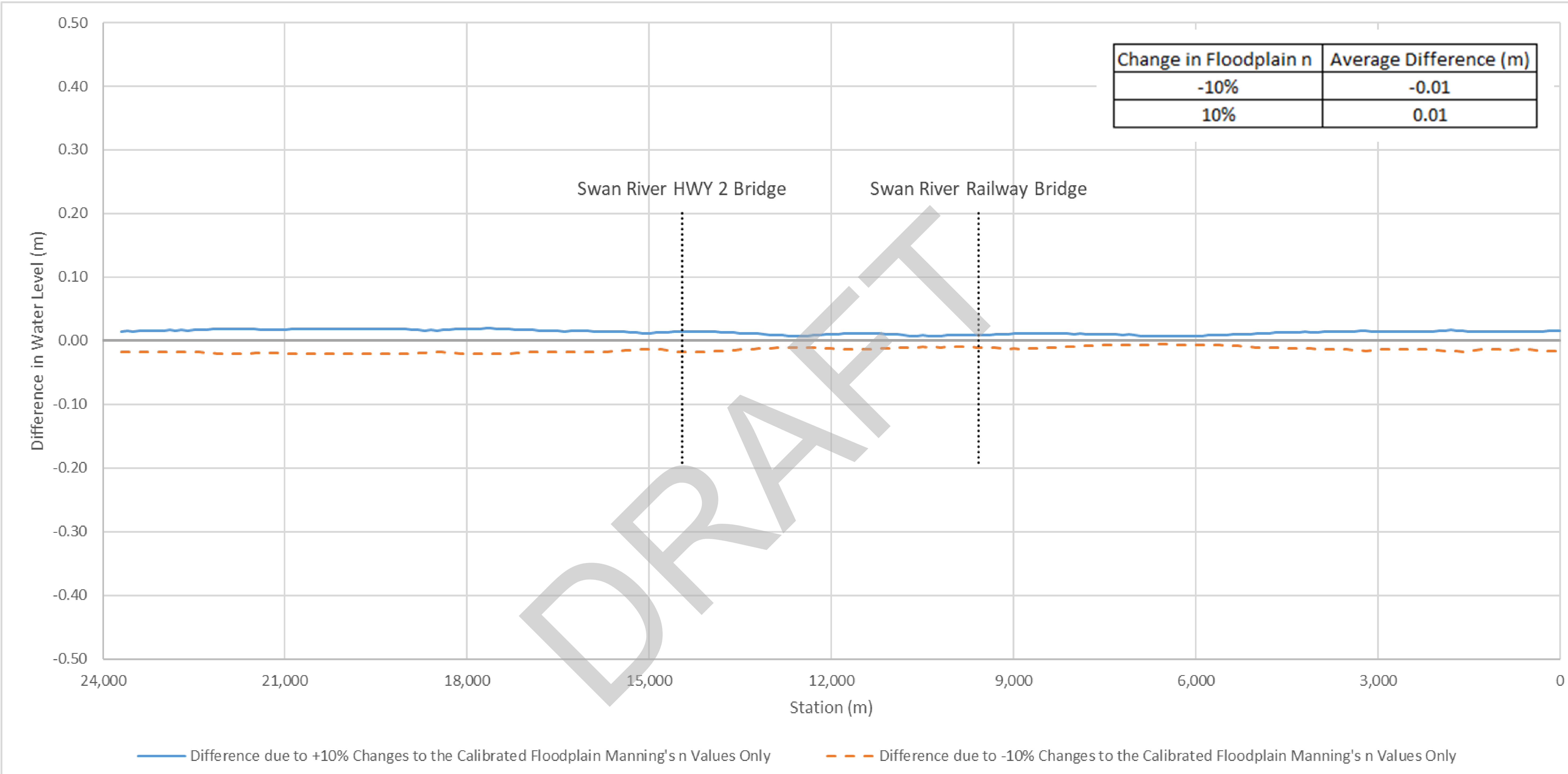


Figure G-2 Sensitivity of Simulated Water Level Along Swan River (Floodplain Manning's n Only)

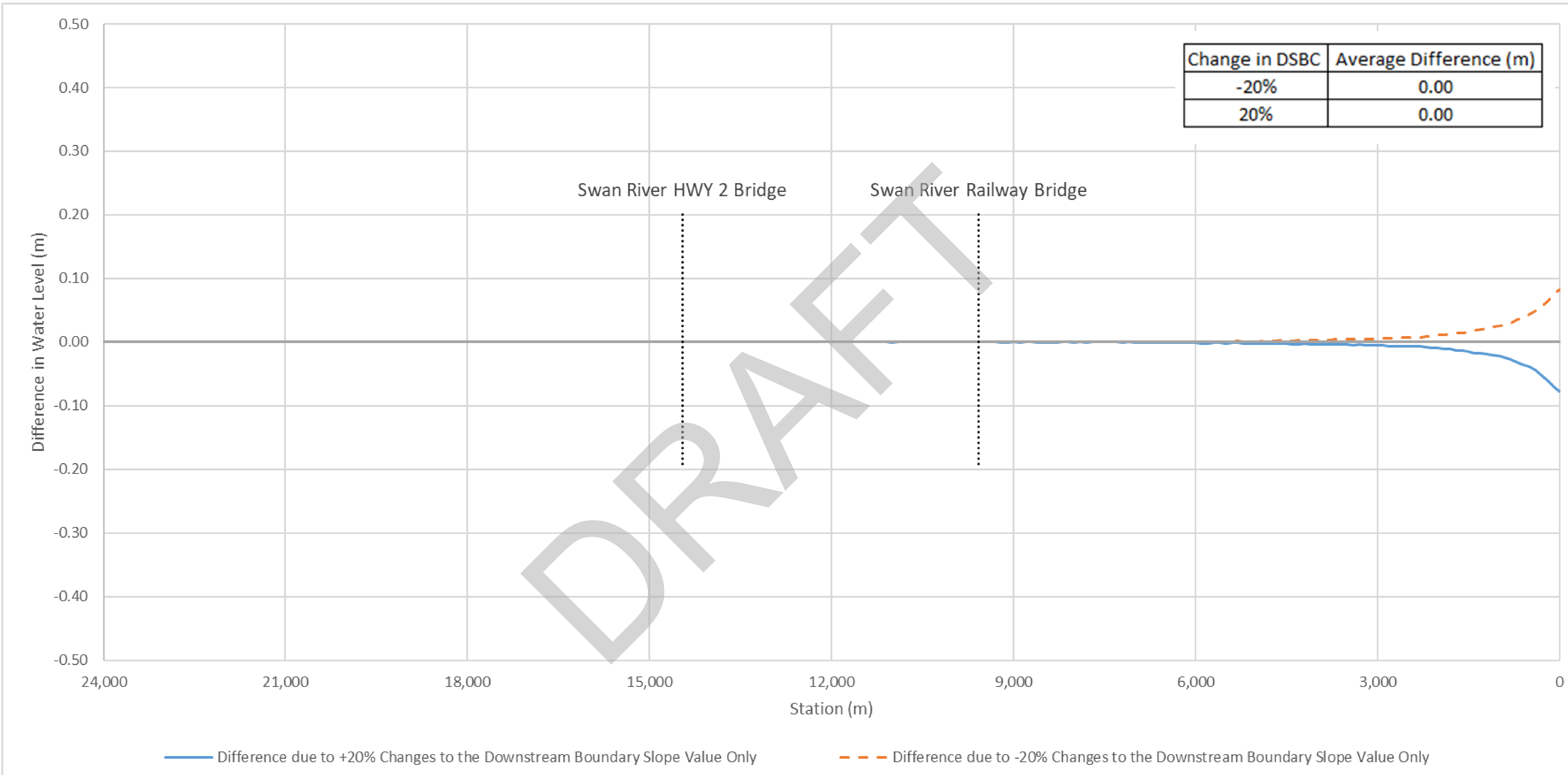


Figure G-3 Sensitivity of Simulated Water Level Along Swan River (Downstream Boundary Only)

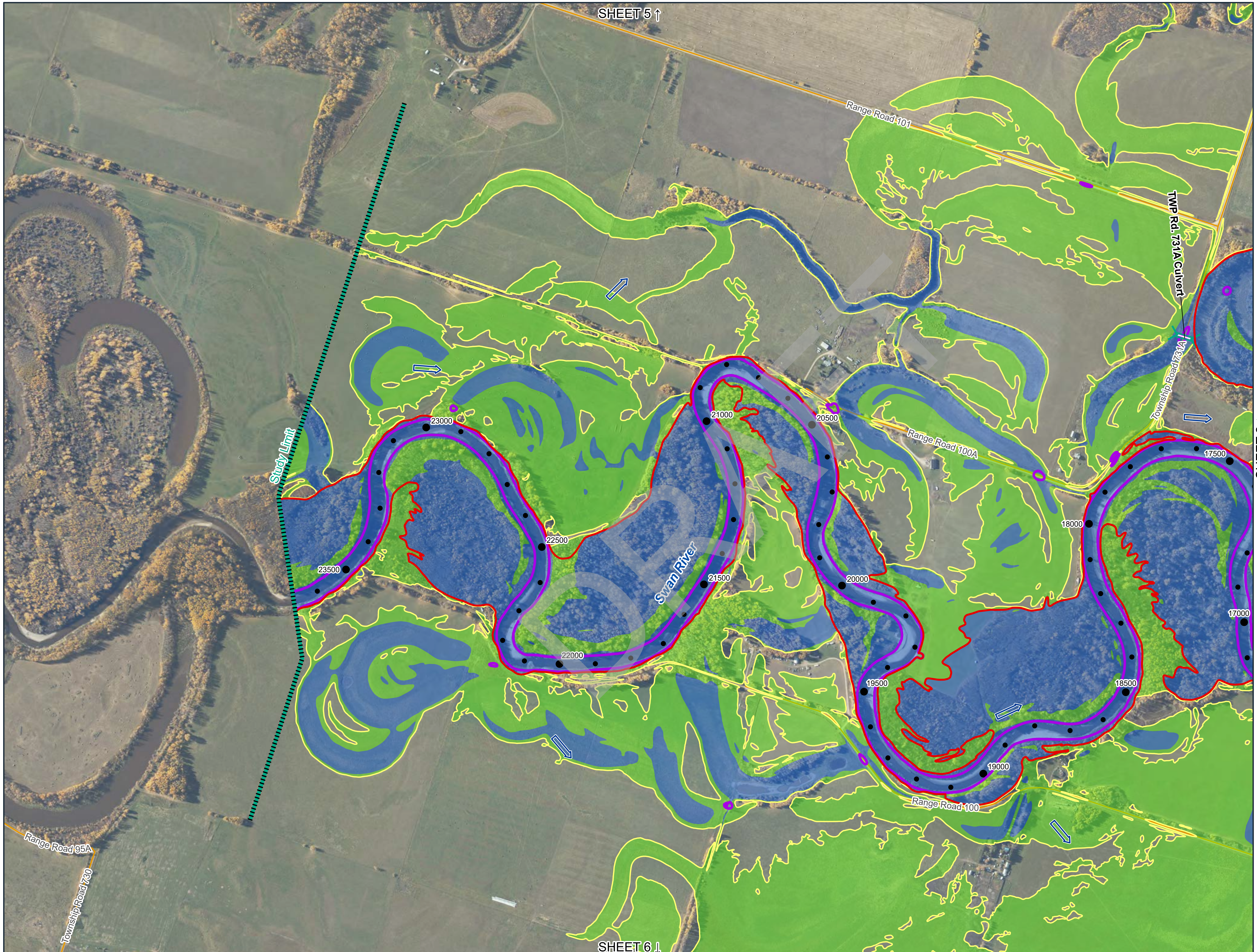
Appendix H

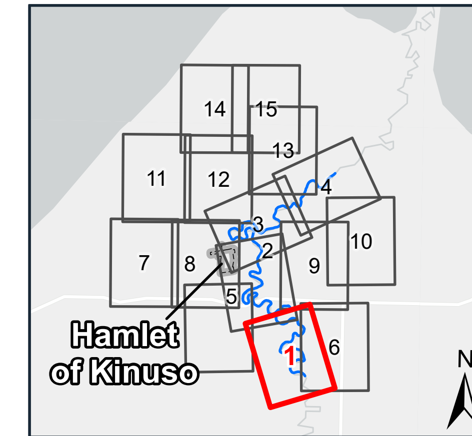
Open Water Inundation Maps

Provided Separately in the Map Library

Appendix I

Floodway Criteria Maps and Flood Hazard Maps





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- 2D MODEL PROFILE STATION
- HAMLET OF KINUSO BOUNDARY
- PROPOSED FLOODWAY BOUNDARY
- PROTECTED FLOOD AREA
- 100-YEAR OPEN WATER DESIGN FLOOD EXTENT
- DEPTH ≥ 1M
- VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres

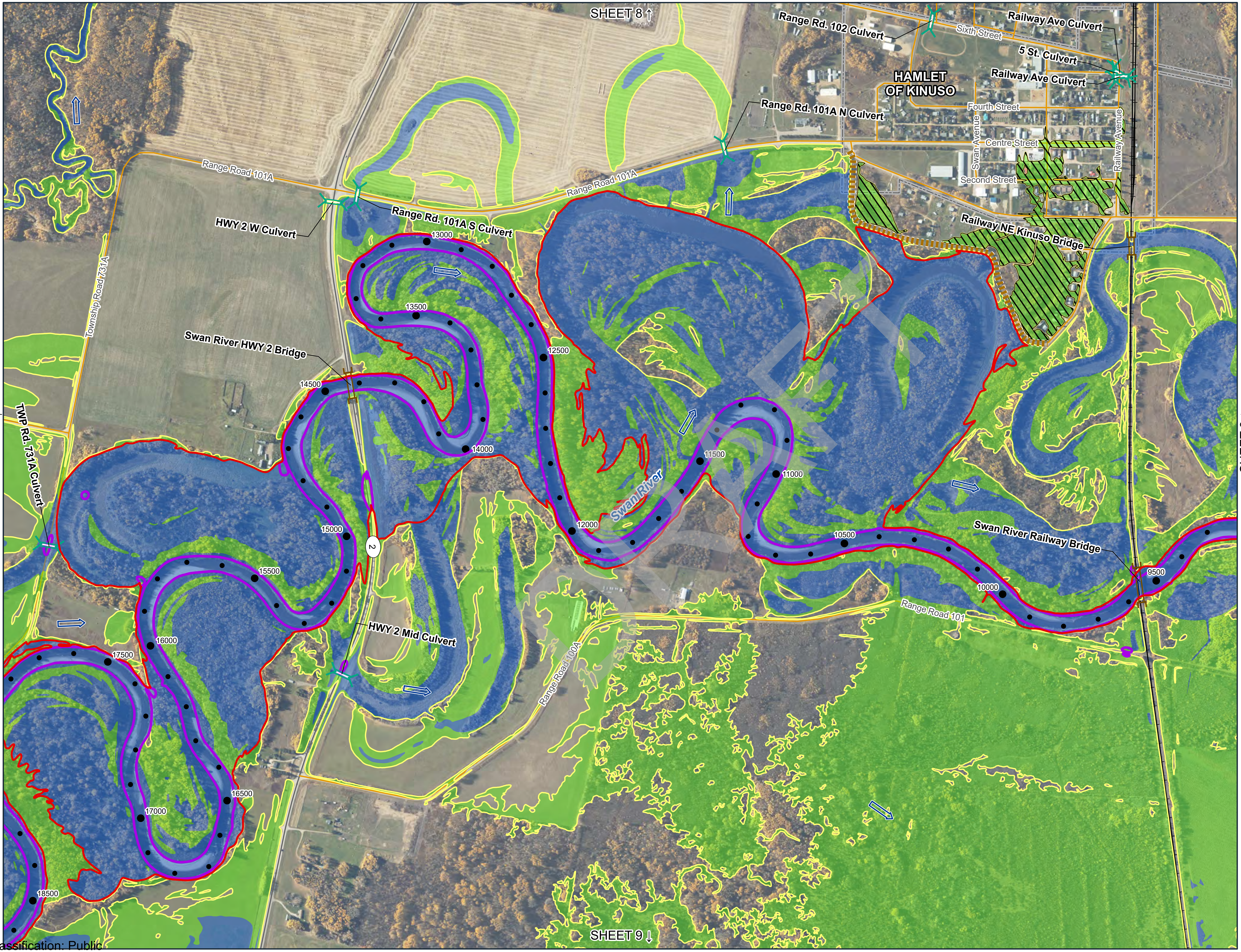
Scale: 1:10,000

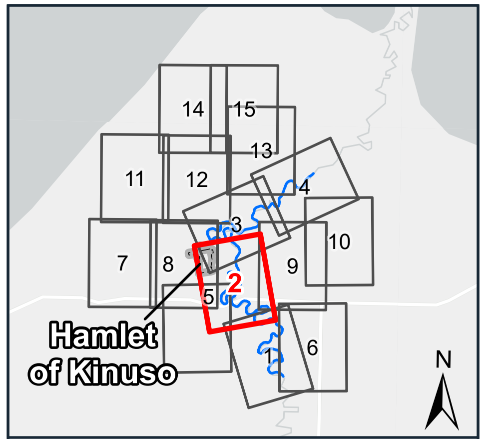
Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 1 OF 15

BARR





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- 2D MODEL PROFILE STATION
- HAMLET OF KINUSO BOUNDARY
- PROPOSED FLOODWAY BOUNDARY
- PROTECTED FLOOD AREA
- 100-YEAR OPEN WATER DESIGN FLOOD EXTENT
- DEPTH ≥ 1M
- VELOCITY ≥ 1M/S

Alberta

Canada

DISCHARGE

Swan River = 778 m^3/s

0 100 200 300

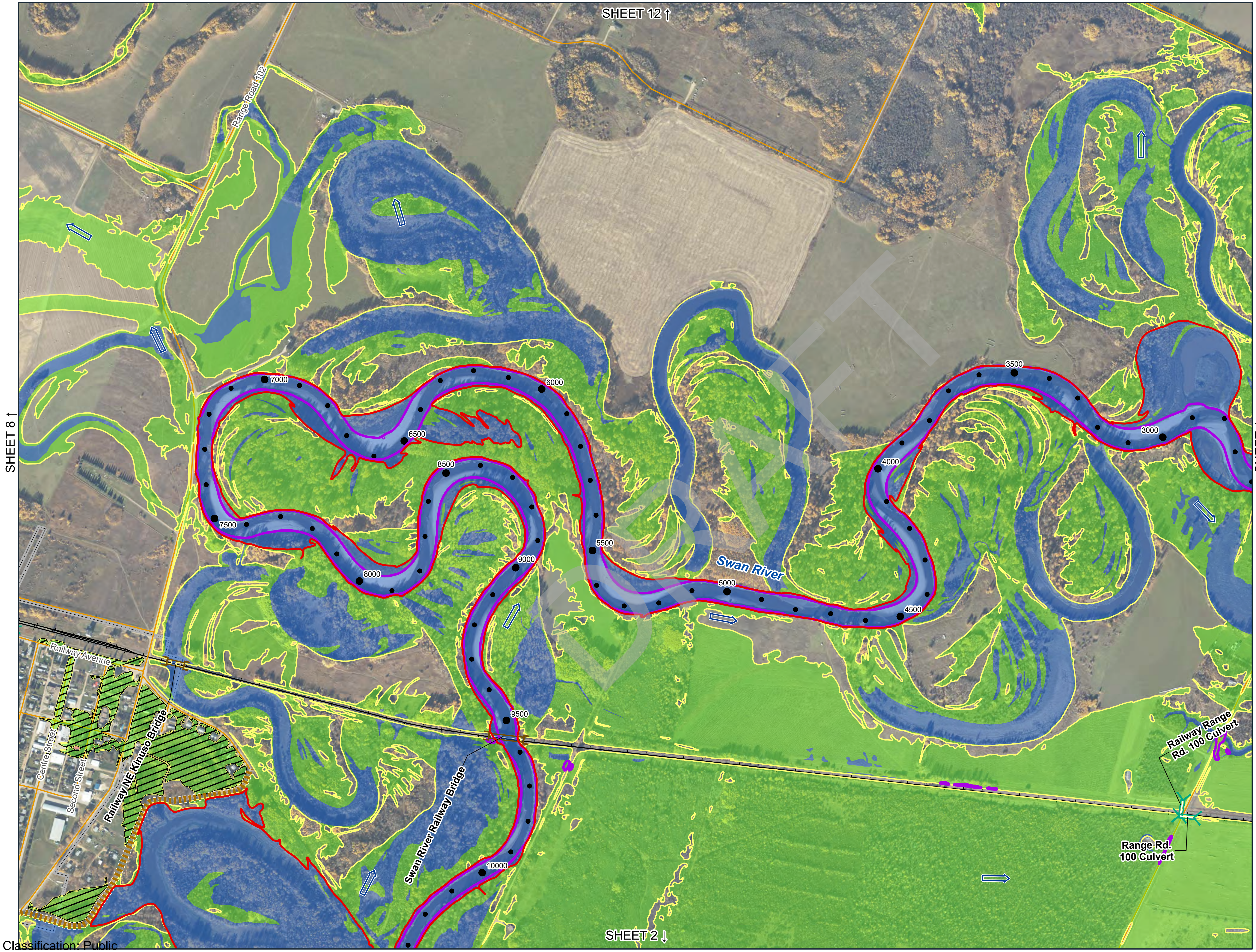
Metres

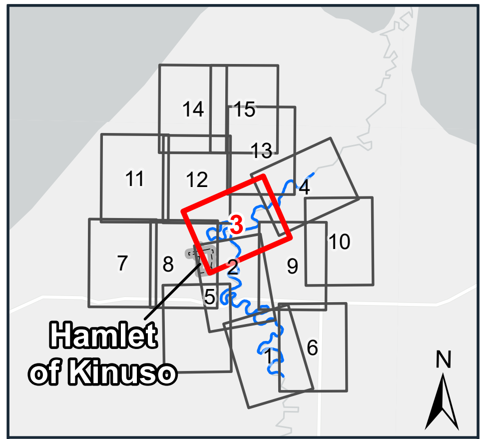
Scale: 1:10,000

Open Water Floodway Criteria Map

Kinuso Flood Study

BARR





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
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- DEPTH ≥ 1M
- VELOCITY ≥ 1M/S

Alberta

Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
N

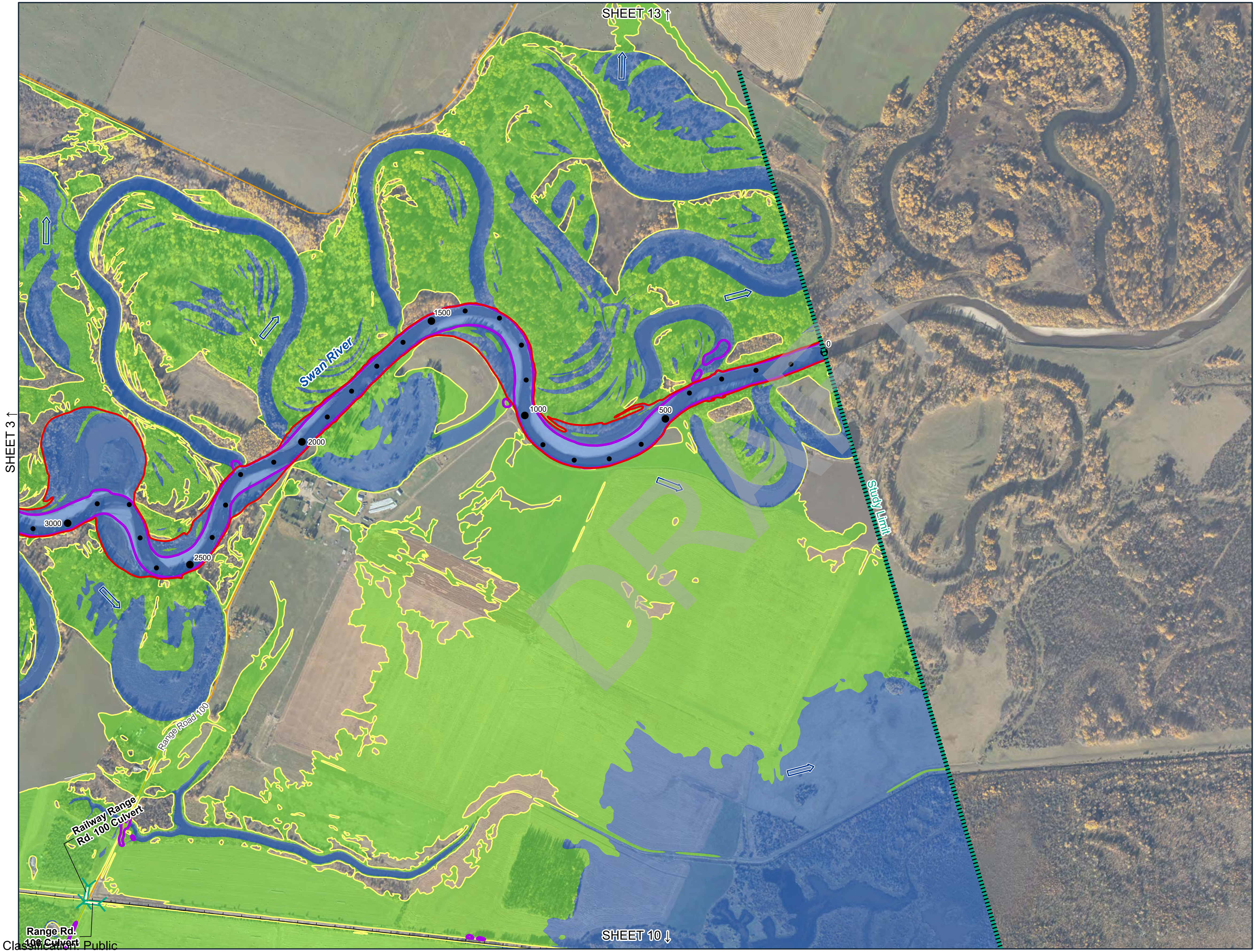
Scale: 1:10,000

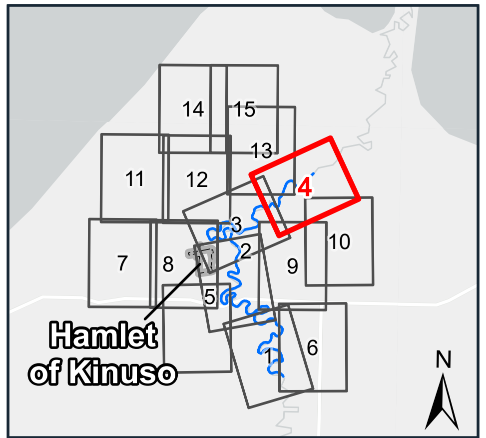
Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 3 OF 15

BARR





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
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- PROTECTED FLOOD AREA
- 100-YEAR OPEN WATER DESIGN FLOOD EXTENT
- DEPTH ≥ 1M
- VELOCITY ≥ 1M/S

Alberta

Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres

Scale: 1:10,000

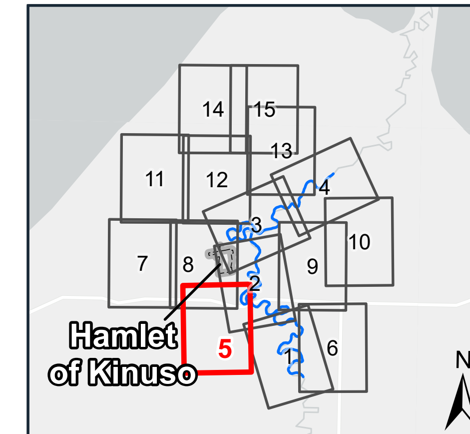
Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 4 OF 15

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
HAMLET OF KINUSO BOUNDARY
PROPOSED FLOODWAY BOUNDARY
PROTECTED FLOOD AREA
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
N
Scale: 1:10,000

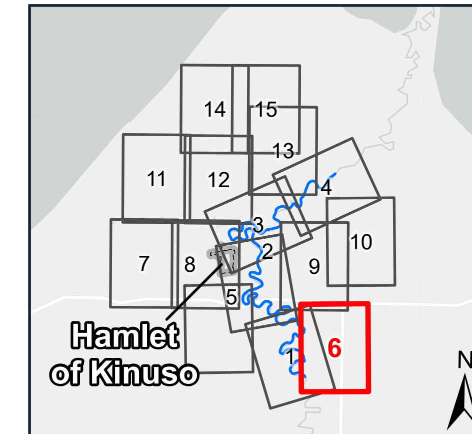
Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 5 OF 15

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
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DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres

N

Scale: 1:10,000

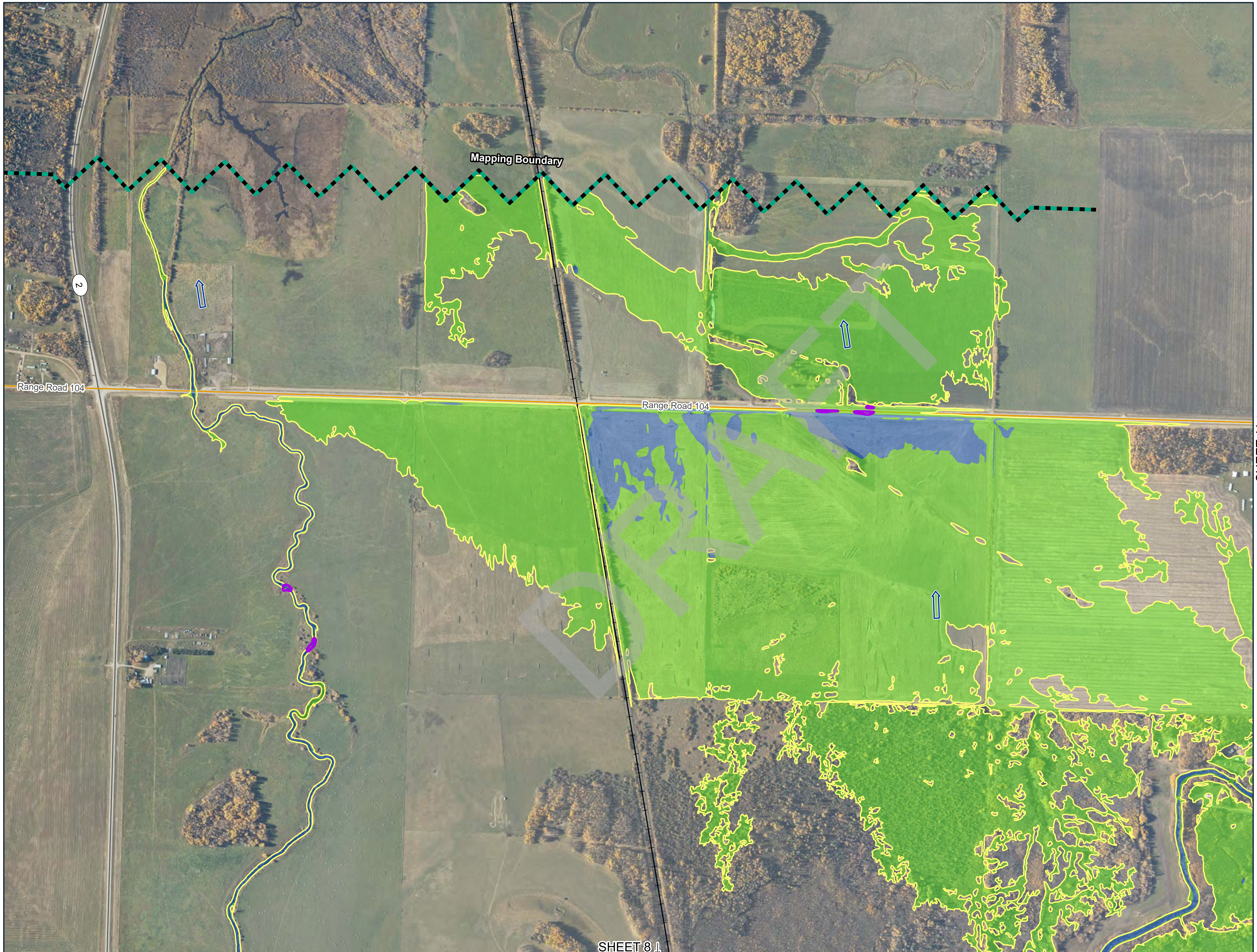
Open Water Floodway Criteria Map

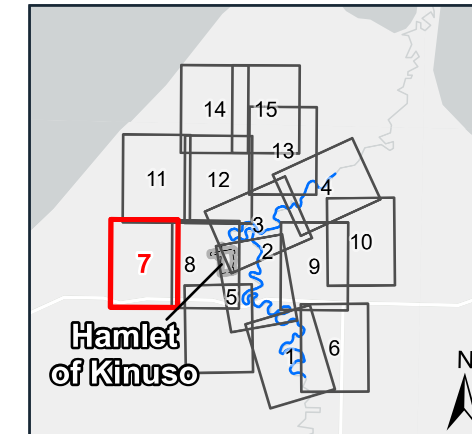
Kinuso Flood Study

SHEET 6 OF 15

BARR

Classification: Public





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
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- DEPTH ≥ 1M
- VELOCITY ≥ 1M/S

Alberta
Canada

0 100 200 300
Metres
N
Scale: 1:10,000

Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 7 OF 15

BARR

Classification: Public

STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
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DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta

Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
N
Scale: 1:10,000

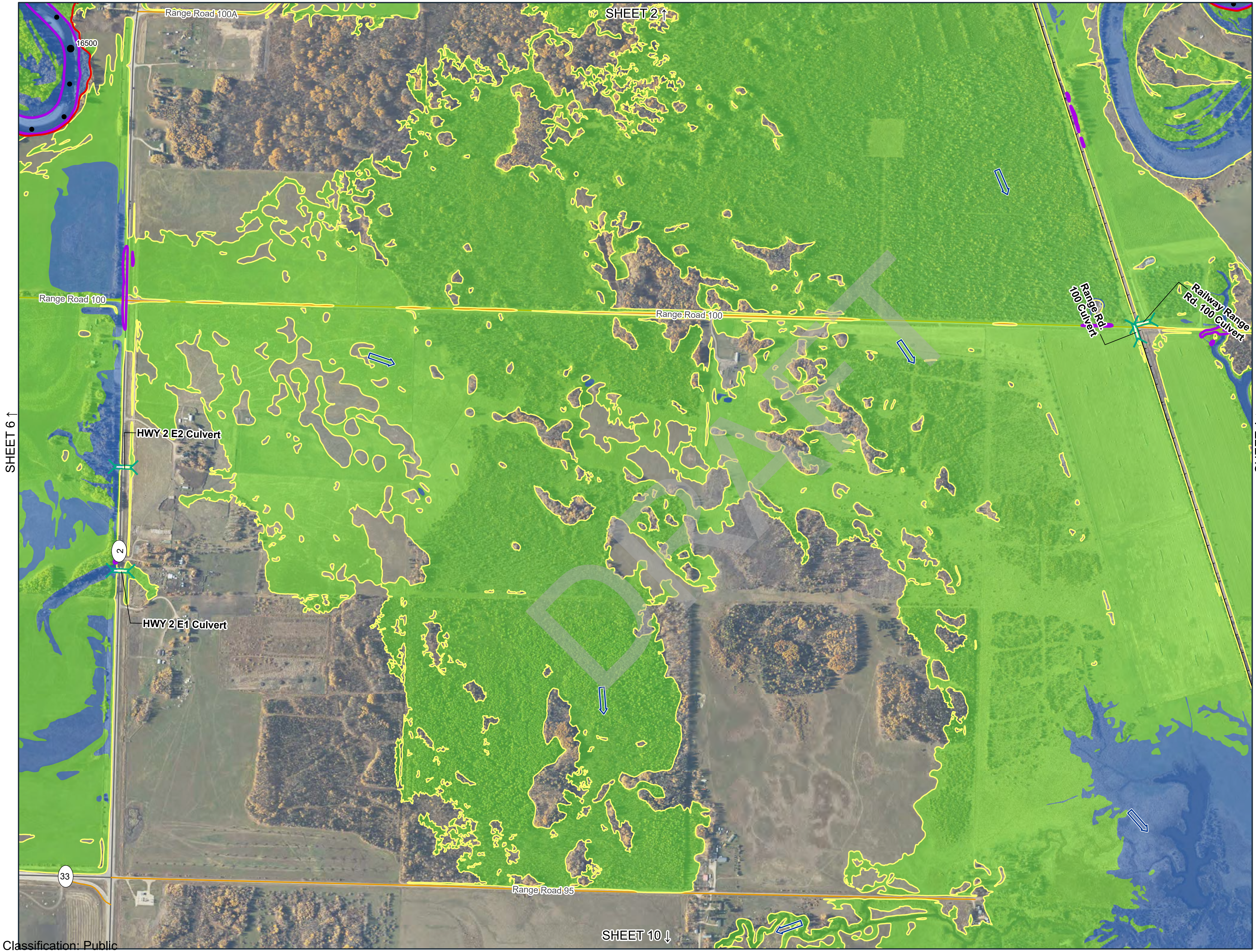
Open Water Floodway Criteria Map

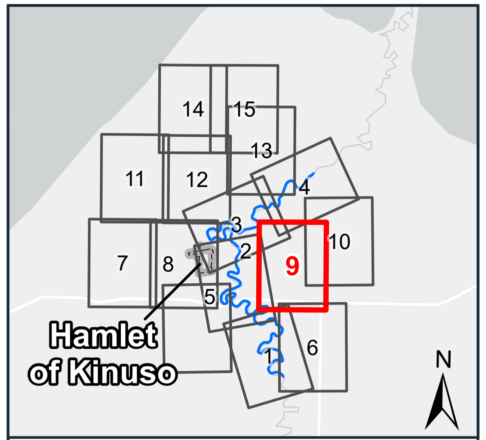
Kinuso Flood Study

SHEET 8 OF 15

BARR

Classification: Public





STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
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VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
Scale: 1:10,000

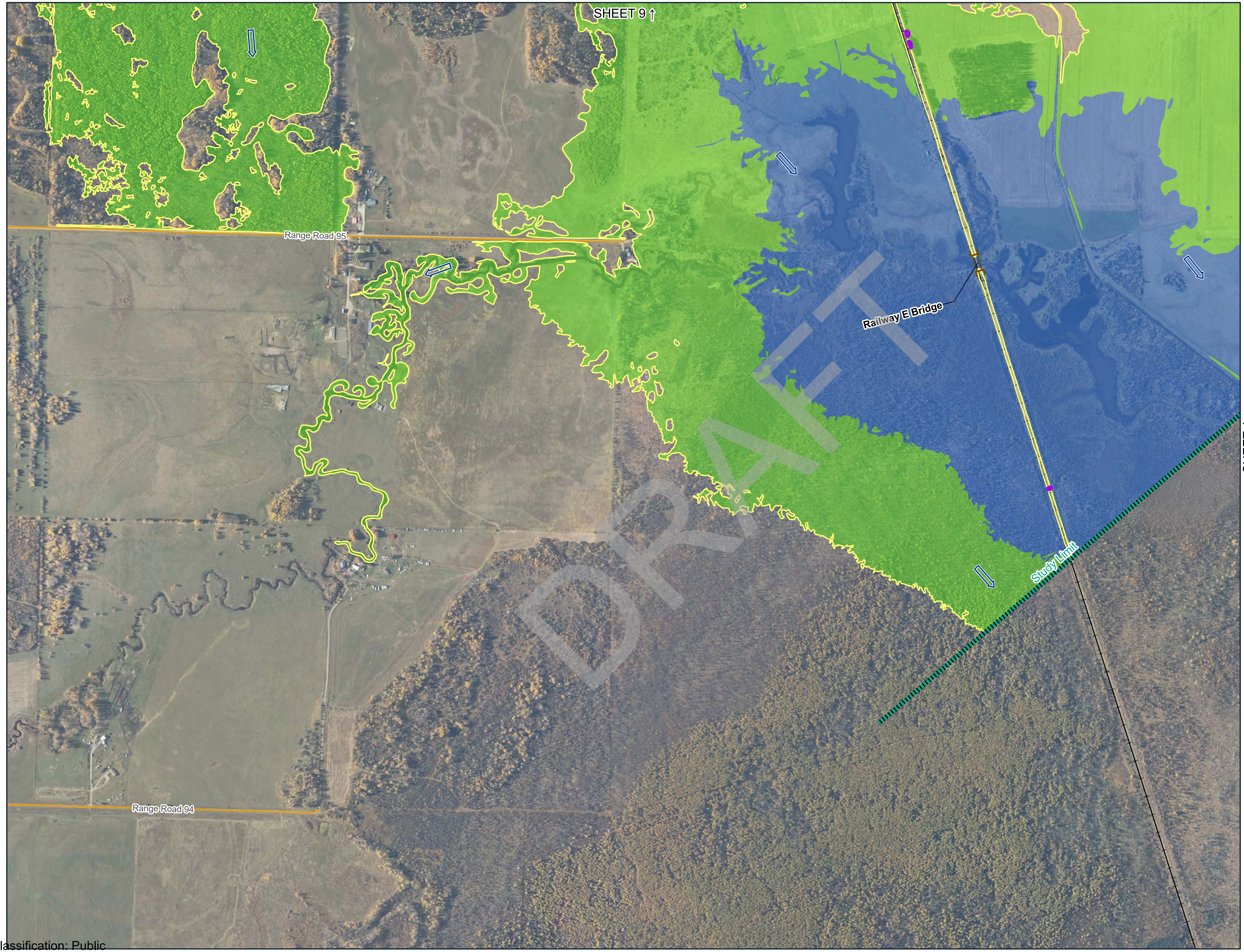
Open Water Floodway Criteria Map

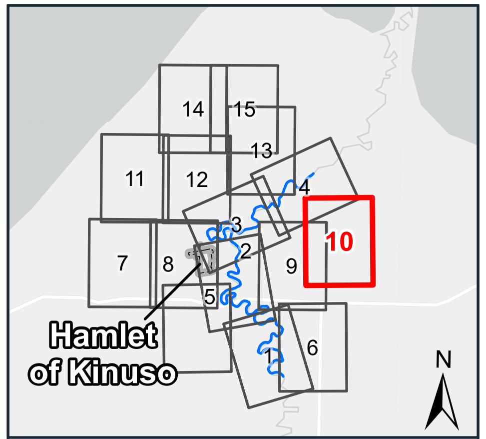
Kinuso Flood Study

SHEET 9 OF 15

BARR

Classification: Public





STUDY LIMIT
FLOW DIRECTION
BRIDGE
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DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

0 100 200 300
Metres
N
Scale: 1:10,000

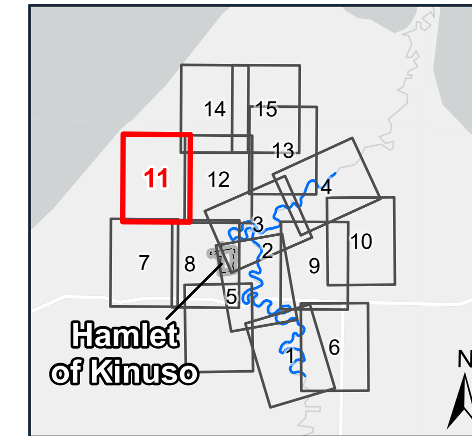
Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 10 OF 15

BARR

Classification: Public



STUDY LIMIT
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BRIDGE
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FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
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HAMLET OF KINUSO BOUNDARY
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100-YEAR OPEN WATER DESIGN FLOOD EXTENT
DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

0 100 200 300
Metres
N

Scale: 1:10,000

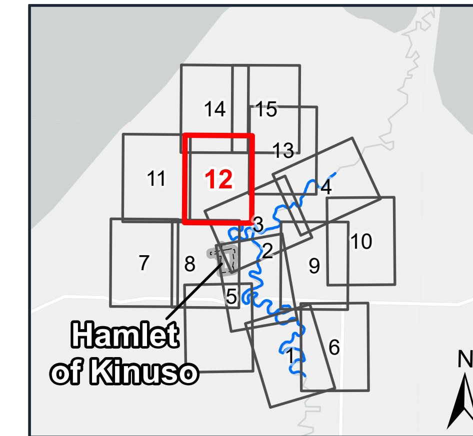
Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 11 OF 15

BARR

Classification: Public



STUDY LIMIT
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FLOOD CONTROL STRUCTURE
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DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
Scale: 1:10,000

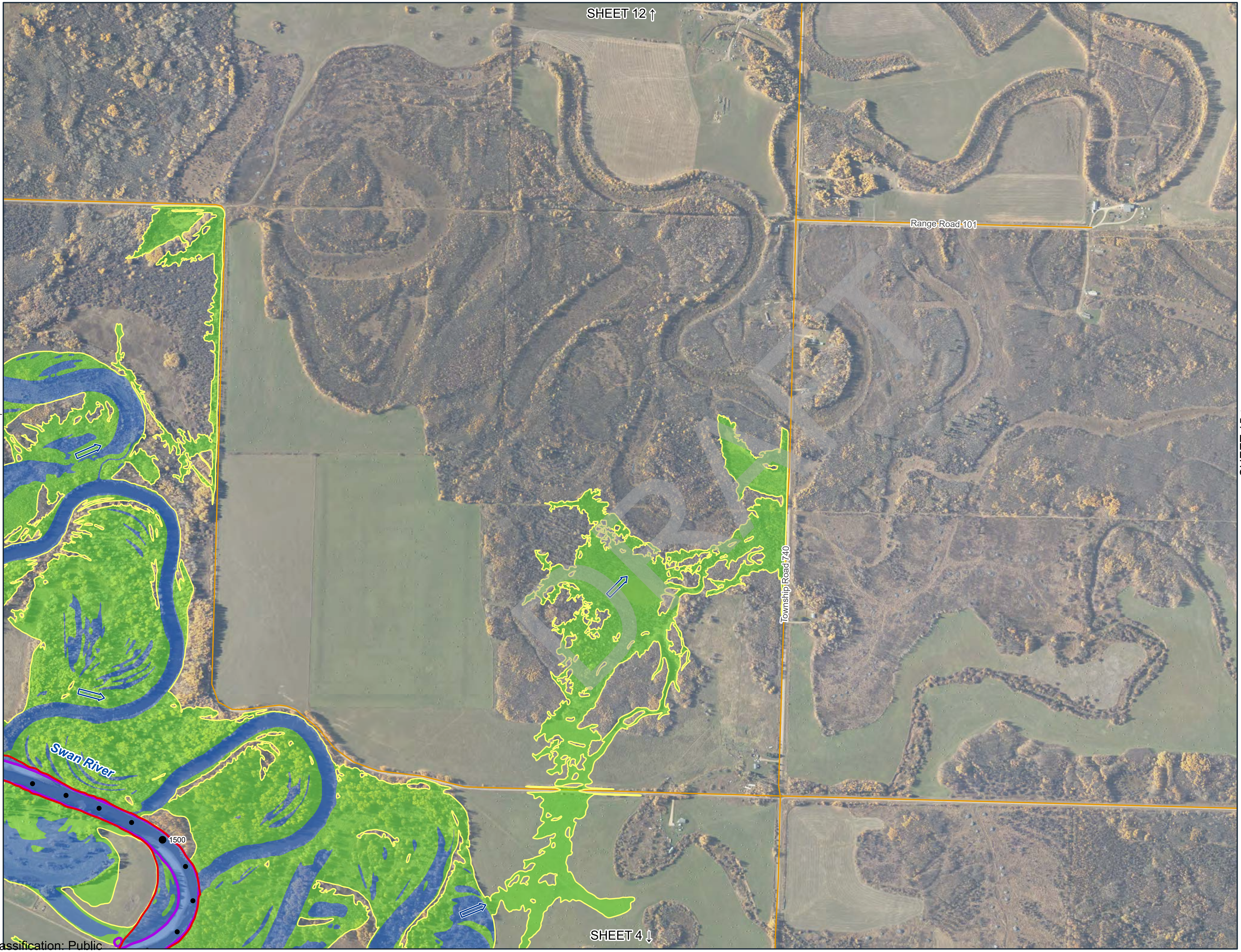
Open Water Floodway Criteria Map

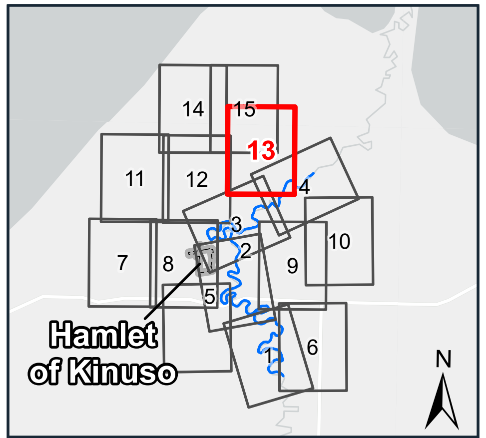
Kinuso Flood Study

SHEET 12 OF 15

BARR

Classification: Public





STUDY LIMIT
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DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres

Scale: 1:10,000

Open Water Floodway Criteria Map

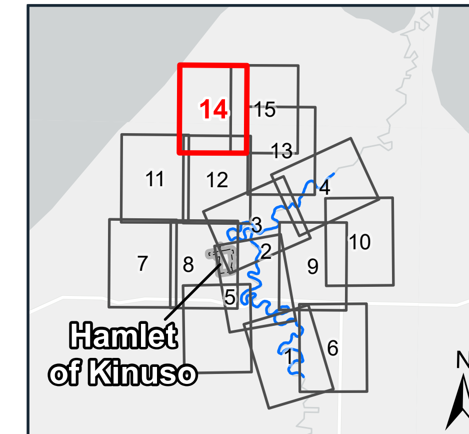
Kinuso Flood Study

SHEET 13 OF 15

BARR

Classification: Public

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
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SECONDARY HIGHWAY
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PROPOSED FLOODWAY BOUNDARY
PROTECTED FLOOD AREA
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
DEPTH ≥ 1M
VELOCITY ≥ 1M/S

Alberta
Canada

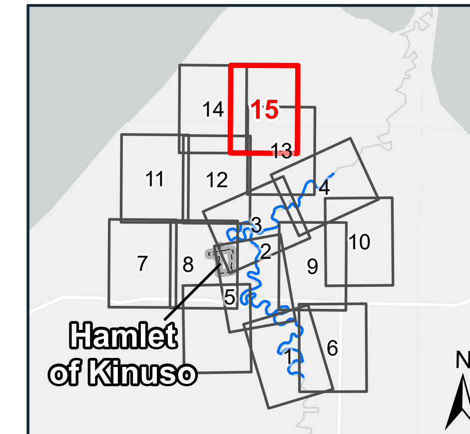
0 100 200 300
Metres
N
Scale: 1:10,000

Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 14 OF 15

BARR



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
HAMLET OF KINUSO BOUNDARY
PROPOSED FLOODWAY BOUNDARY
PROTECTED FLOOD AREA
100-YEAR OPEN WATER DESIGN FLOOD EXTENT
DEPTH ≥ 1M
VELOCITY ≥ 1M/S

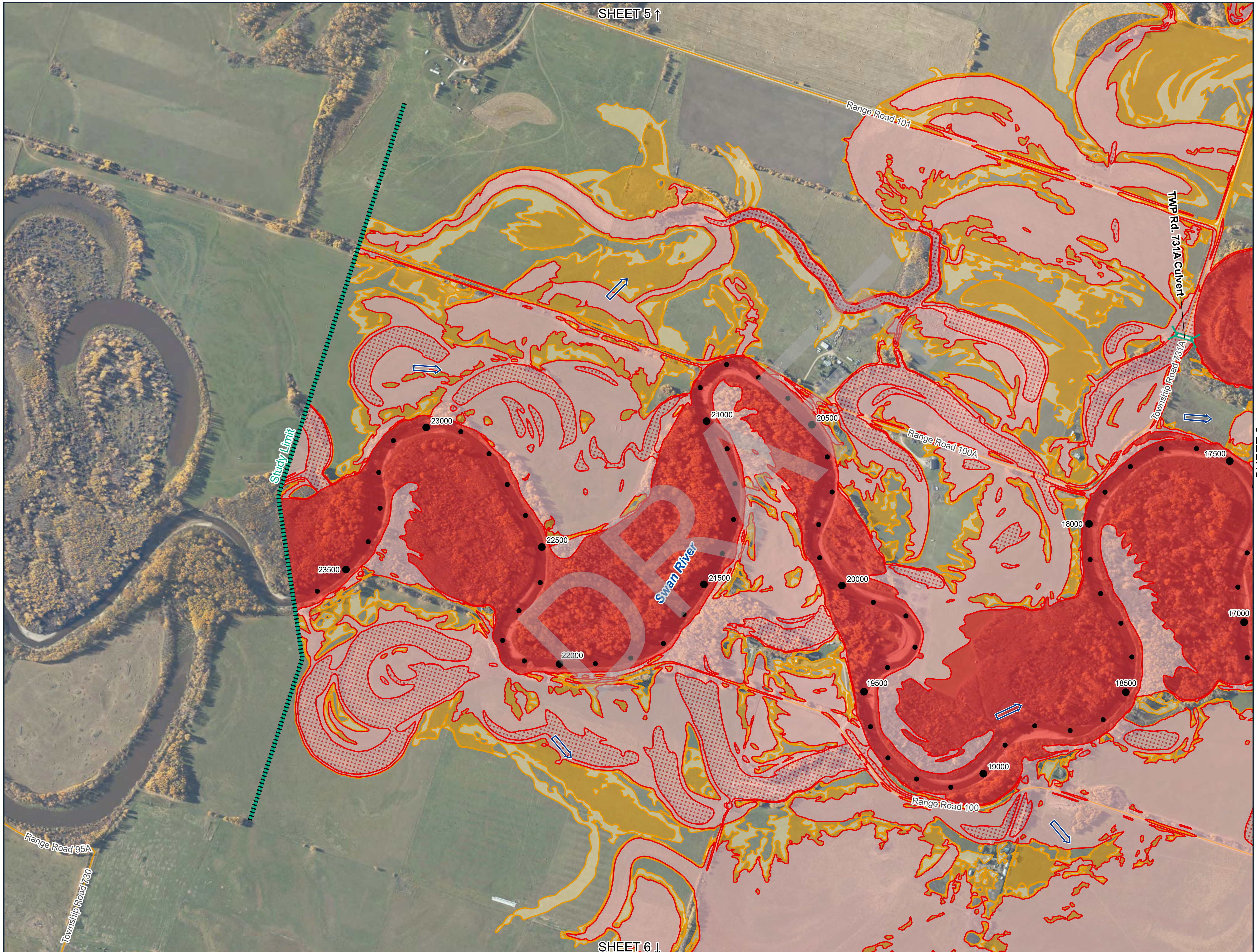
0 100 200 300
Metres
N
Scale: 1:10,000

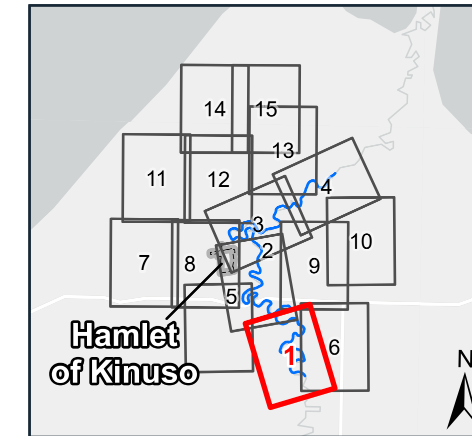
Open Water Floodway Criteria Map

Kinuso Flood Study

SHEET 15 OF 15

BARR





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- 2D MODEL PROFILE STATION
- HAMLET OF KINUSO BOUNDARY
- FLOODWAY
- PROTECTED FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE
Swan River = 778 m³/s

0 100 200 300
Metres

Scale: 1:10,000

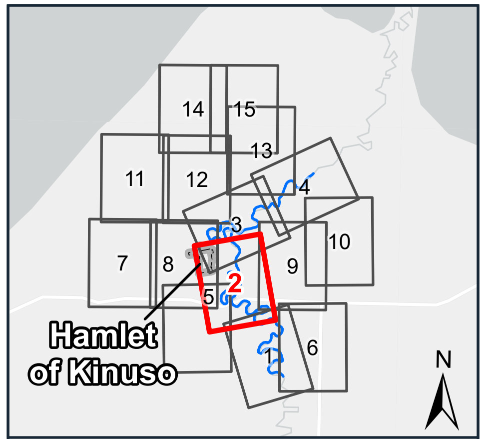
Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 1 OF 15

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
HAMLET OF KINUSO BOUNDARY
FLOODWAY
PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta

Canada

DISCHARGE
Swan River = 778 m³/s

0 100 200 300
Metres
N
Scale: 1:10,000

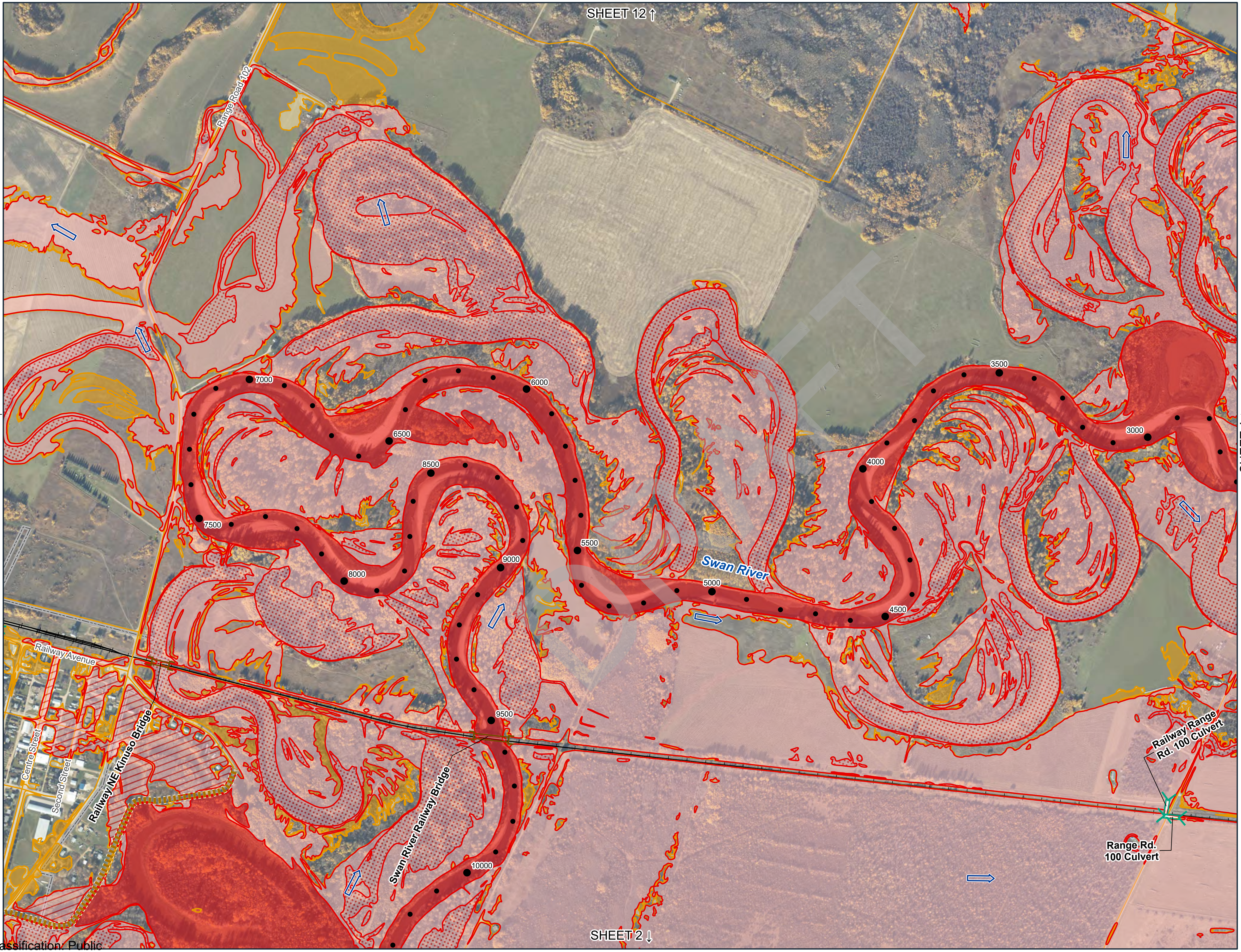
Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 2 OF 15

BARR

Classification: Public



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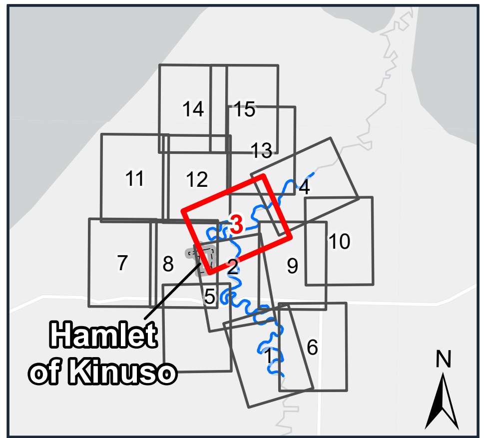

- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
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- PROTECTED FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
N
Scale: 1:10,000

Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 3 OF 15

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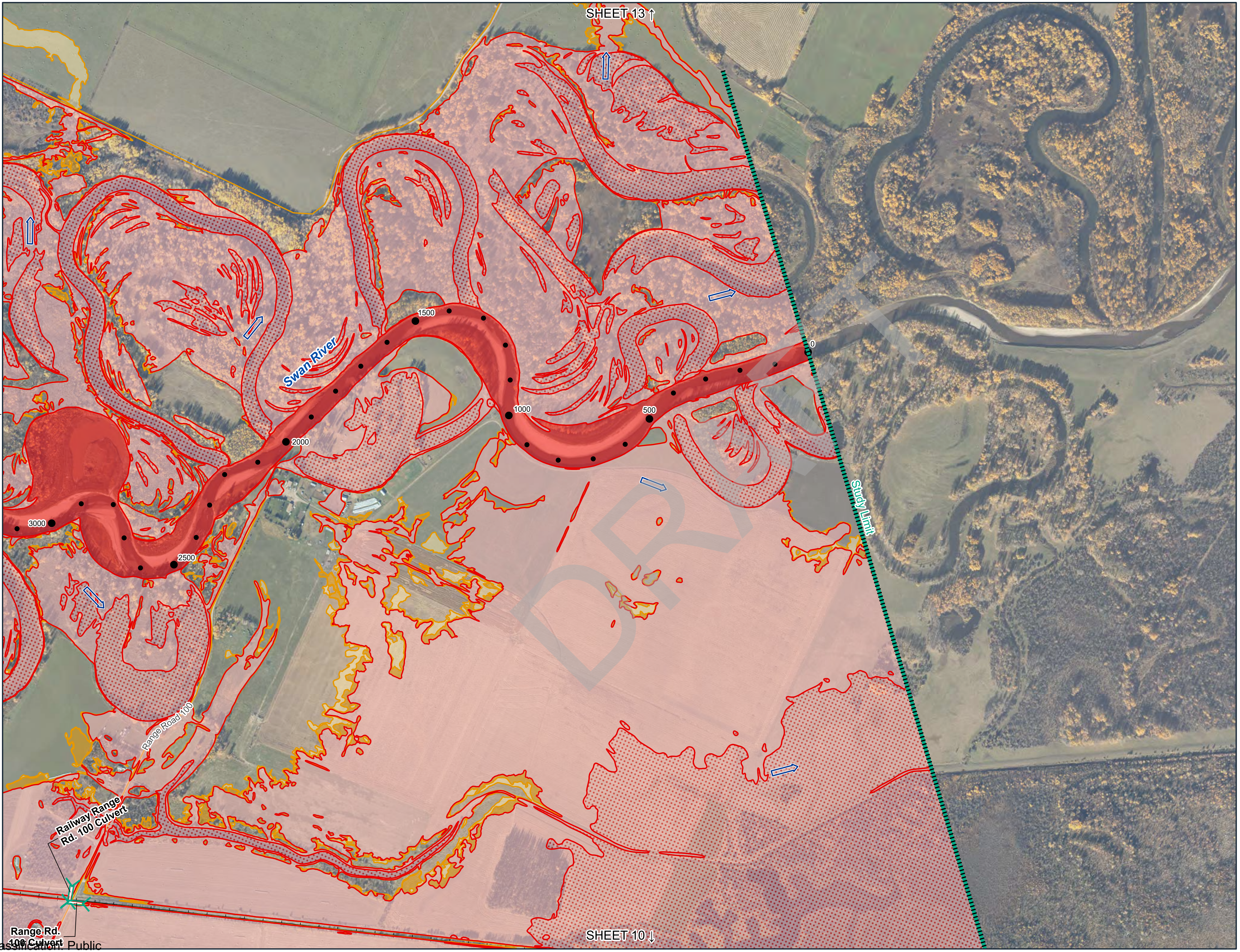
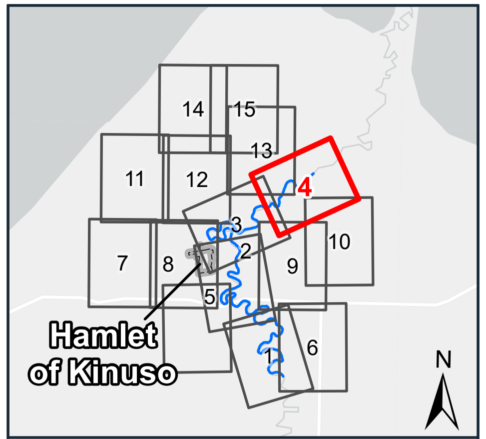




STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
HAMLET OF KINUSO BOUNDARY
FLOODWAY
PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

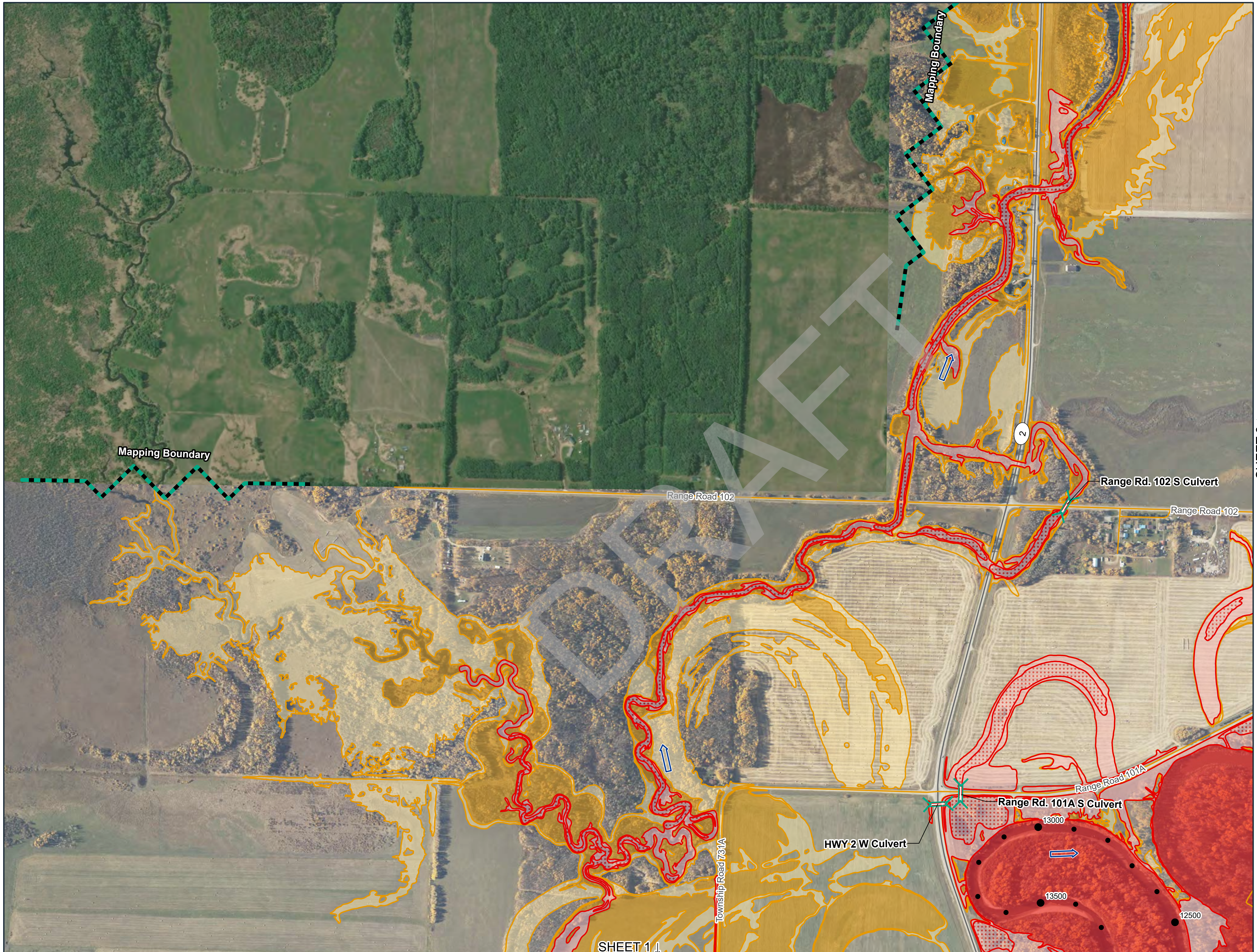
0 100 200 300
Metres
Scale: 1:10,000

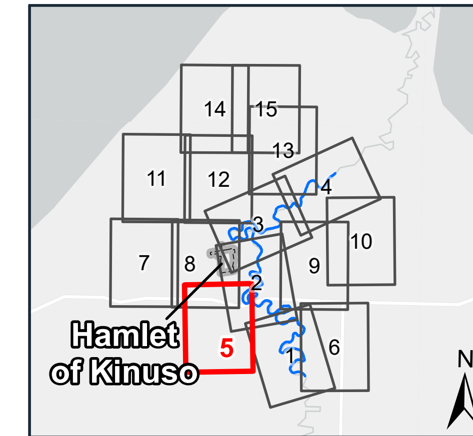
Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 4 OF 15

BARR





STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
HAMLET OF KINUSO BOUNDARY
FLOODWAY
PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
Scale: 1:10,000

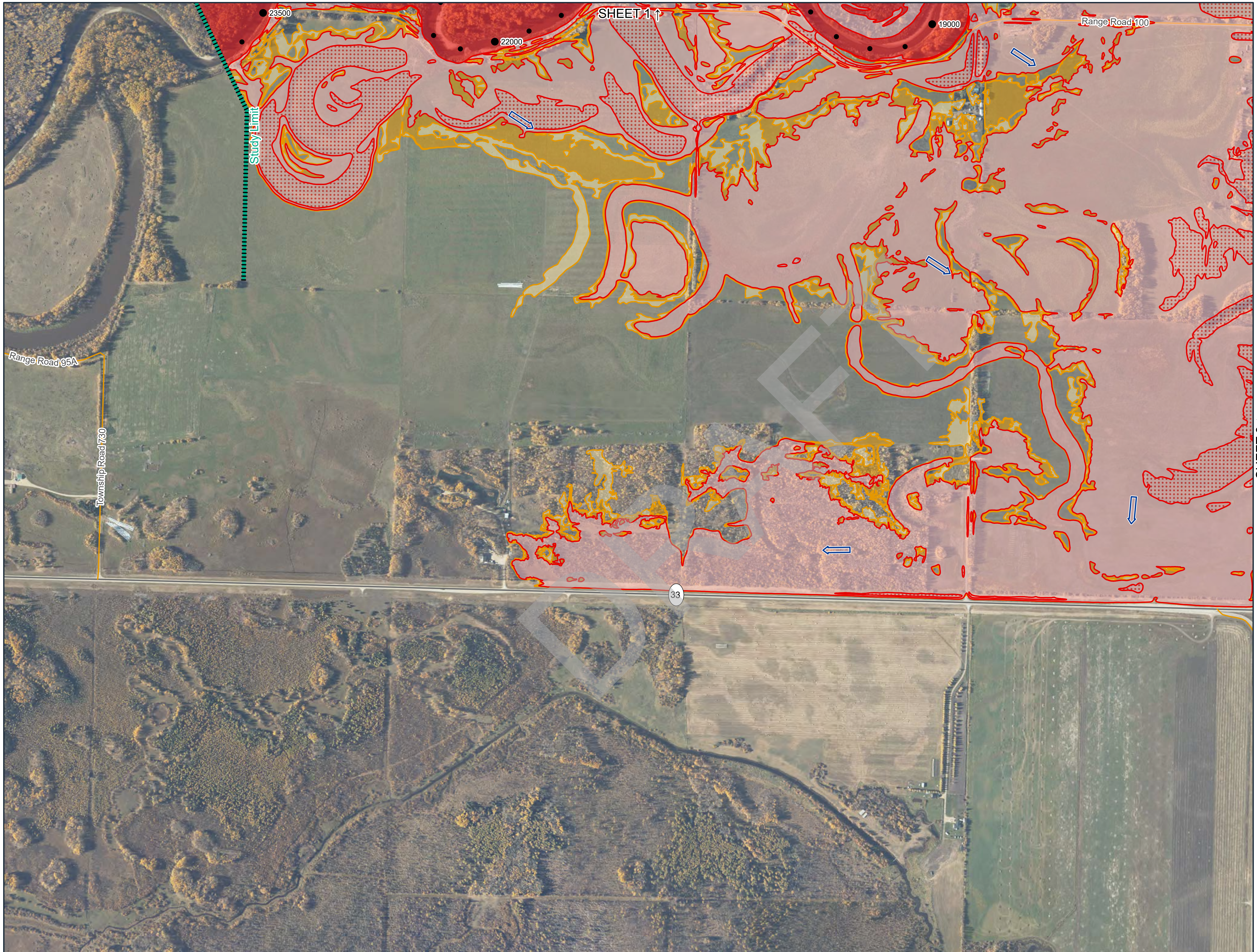
Governing Design Flood Hazard Map

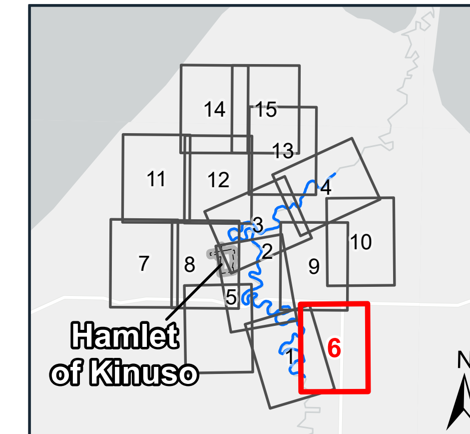
Kinuso Flood Study

SHEET 5 OF 15

BARR

Classification: Public





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- 2D MODEL PROFILE STATION
- HAMLET OF KINUSO BOUNDARY
- FLOODWAY
- PROTECTED FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta

Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
Scale: 1:10,000

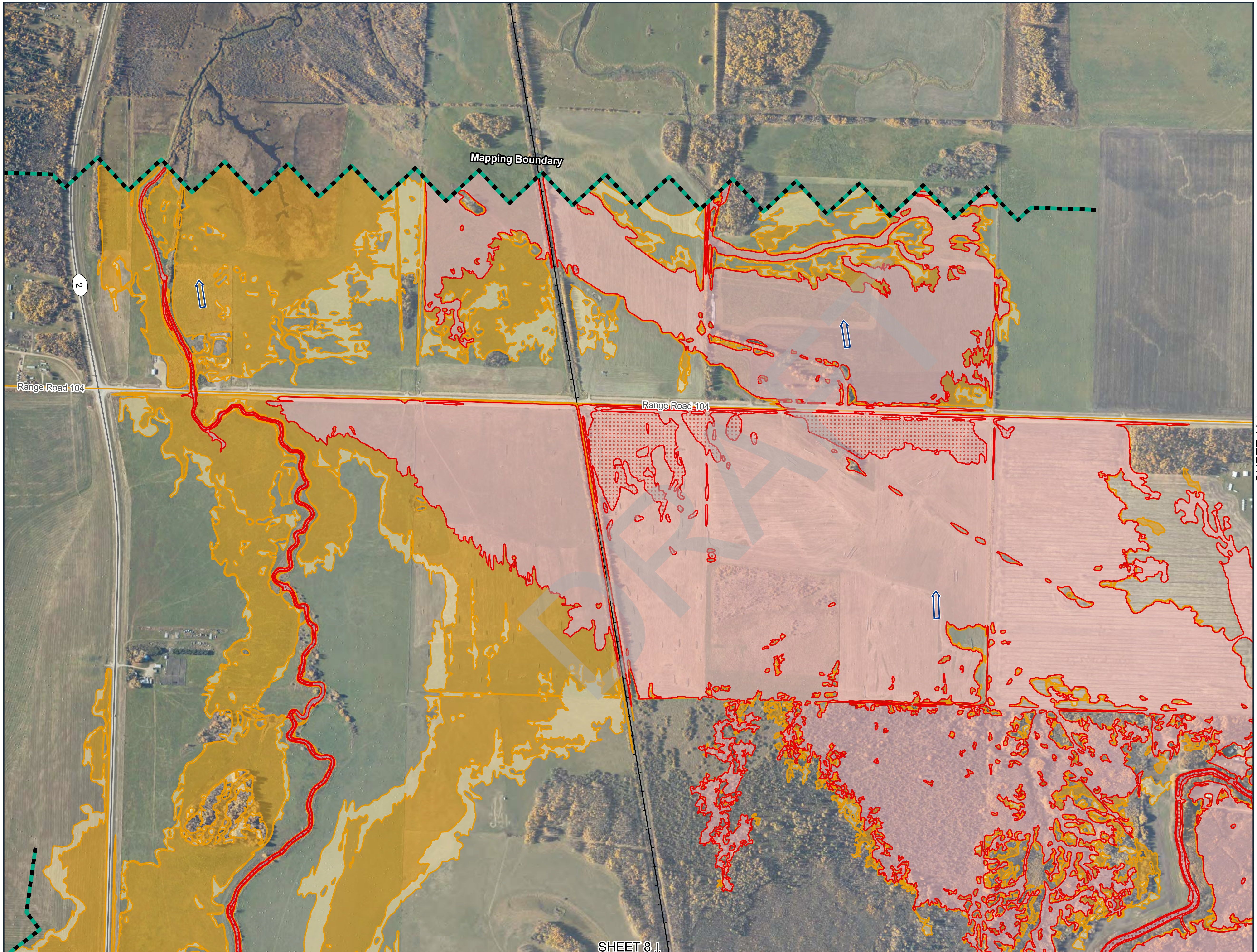
Governing Design Flood Hazard Map

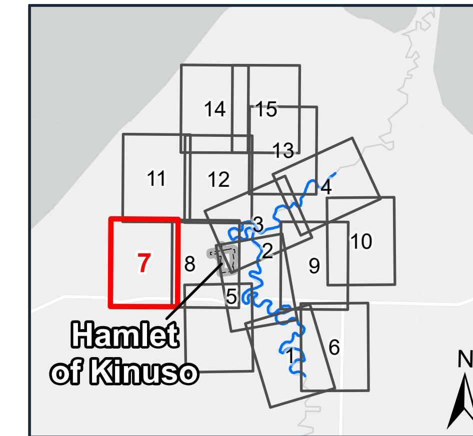
Kinuso Flood Study

SHEET 6 OF 15

BARR

Classification: Public





STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
HAMLET OF KINUSO BOUNDARY
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PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta

Canada

0 100 200 300
Metres
Scale: 1:10,000

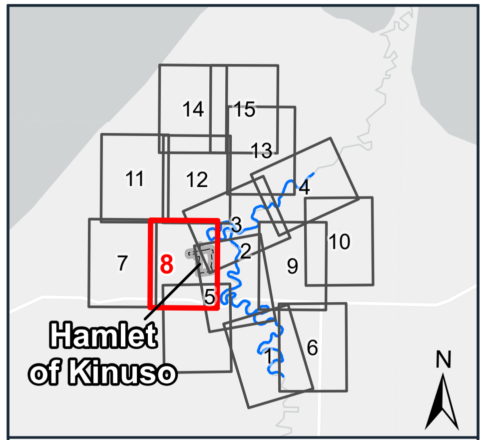
Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 7 OF 15

BARR

Classification: Public



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
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- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta

Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
N
Scale: 1:10,000

Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 8 OF 15

BARR

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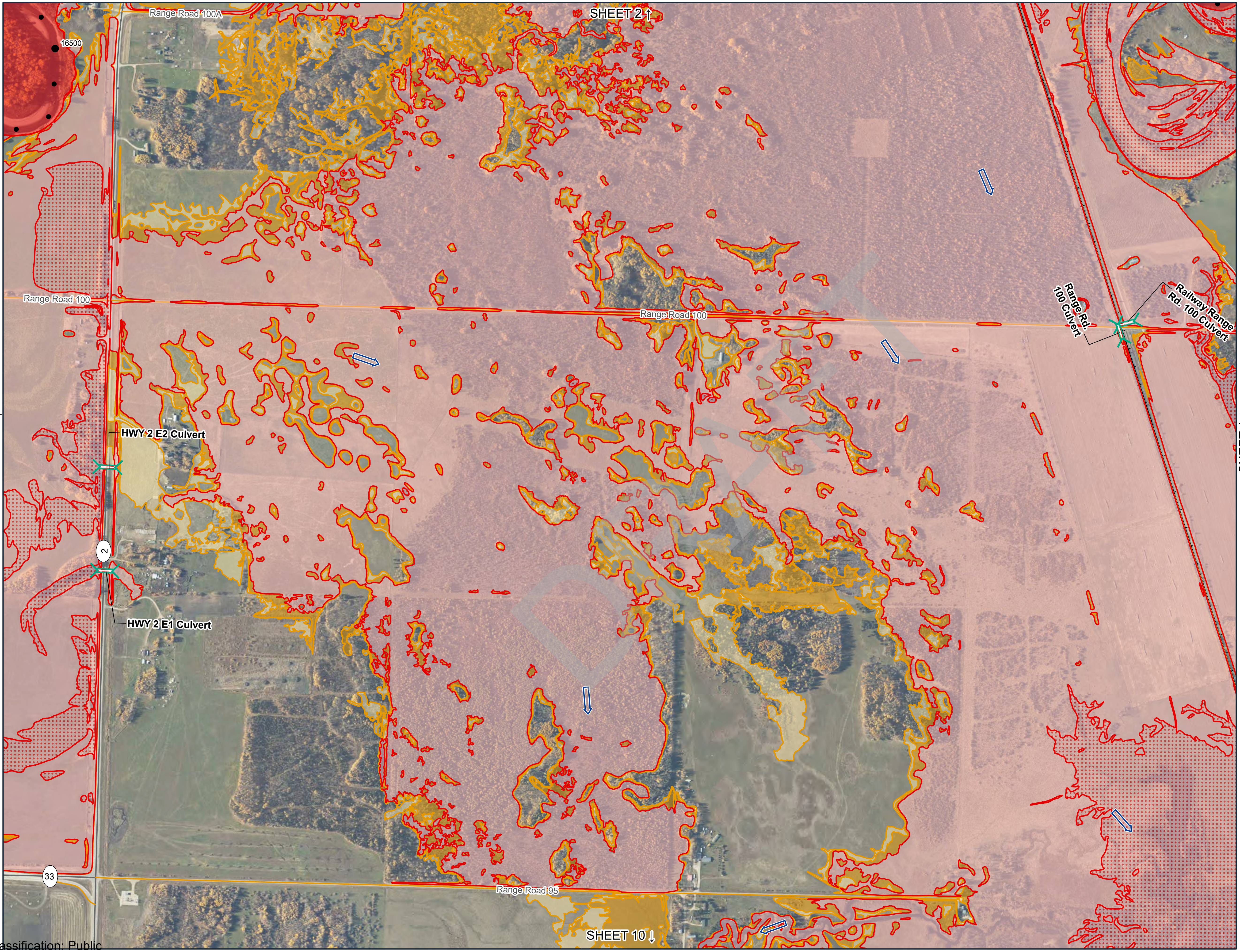

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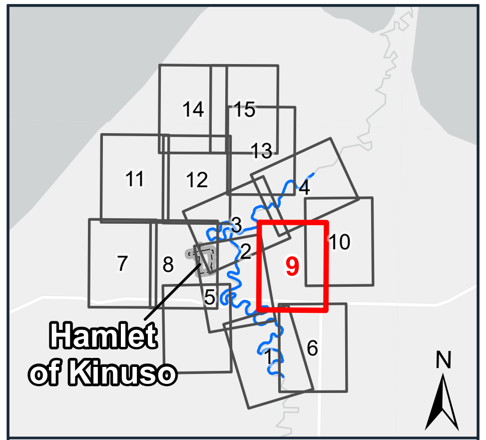

STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
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FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

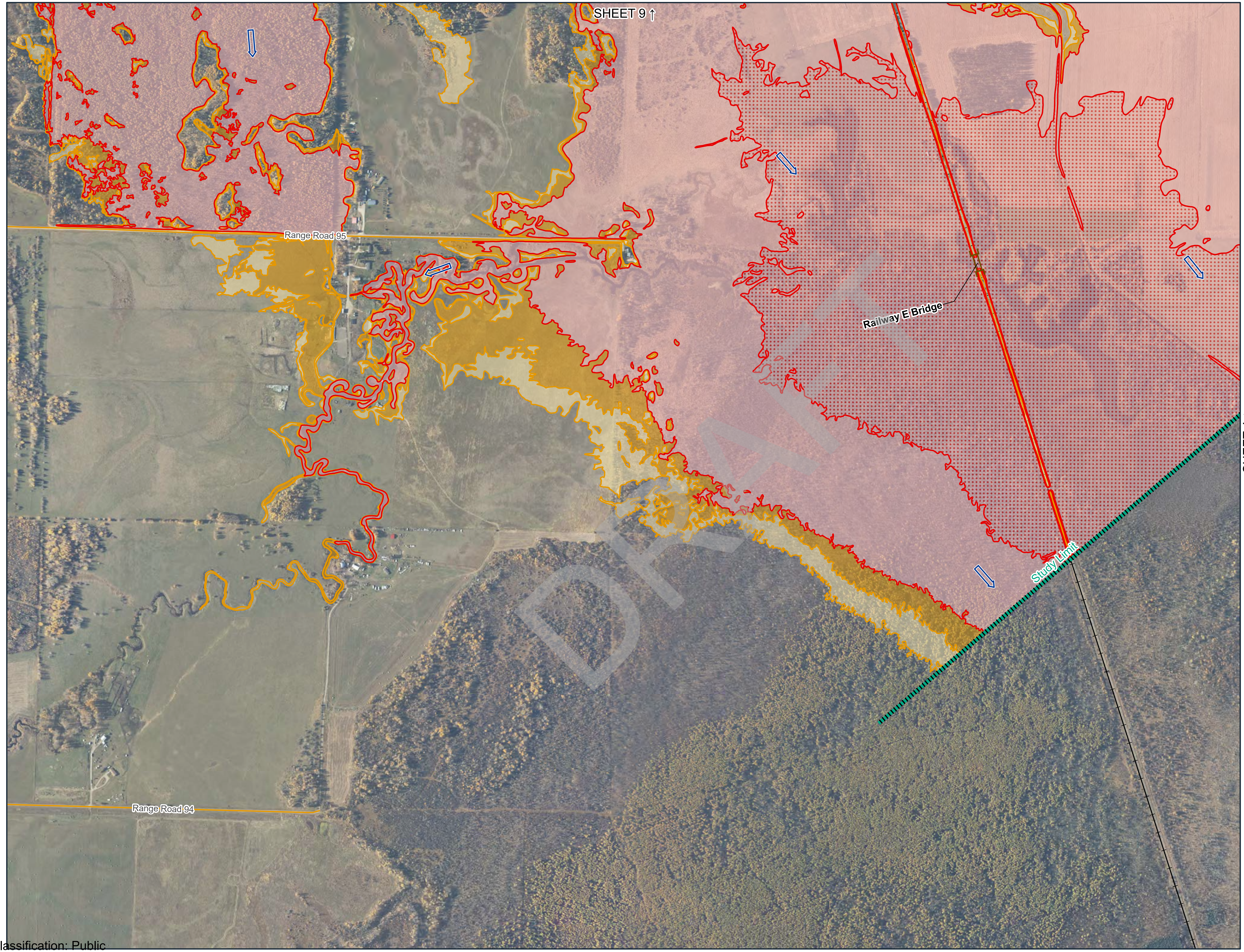
0 100 200 300
Metres
Scale: 1:10,000

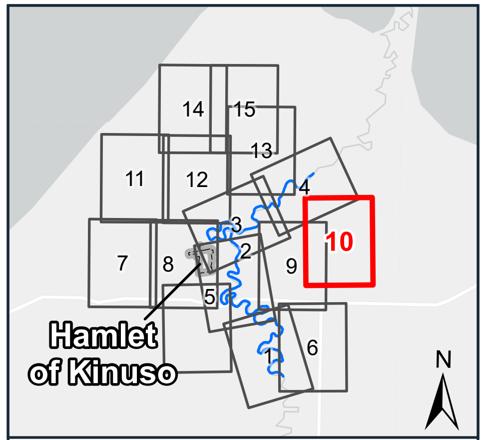
Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 9 OF 15

BARR





- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
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- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta
Canada

0 100 200 300
Metres
N
Scale: 1:10,000

Governing Design Flood Hazard Map

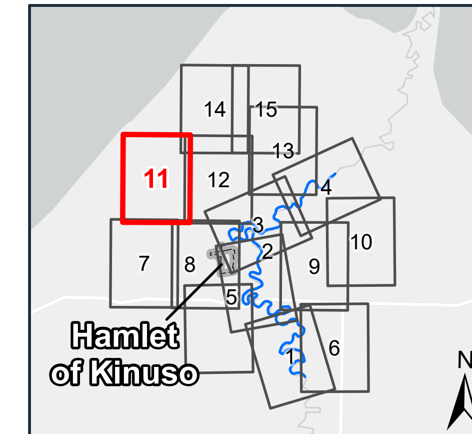
Kinuso Flood Study

SHEET 10 OF 15

BARR

Classification: Public

Classification: Public



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- HAMLET OF KINUSO BOUNDARY
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- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta
Canada

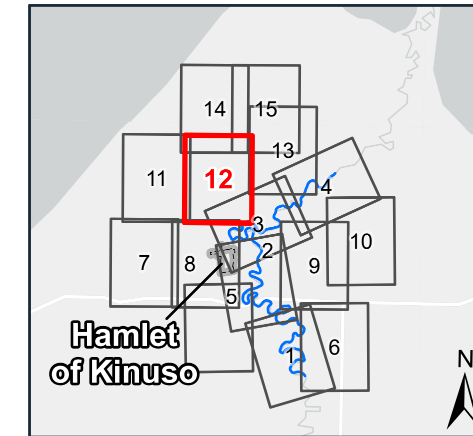
0 100 200 300
Metres
N
Scale: 1:10,000

Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 11 OF 15

BARR



- STUDY LIMIT
- FLOW DIRECTION
- BRIDGE
- CULVERT
- FLOOD CONTROL STRUCTURE
- SECONDARY HIGHWAY
- LOCAL ROAD
- RAILWAY
- 2D MODEL PROFILE STATION
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- PROTECTED FLOOD FRINGE
- HIGH HAZARD FLOOD FRINGE
- FLOOD FRINGE
- 200-YEAR FLOOD EXTENT
- 500-YEAR FLOOD EXTENT

Alberta

Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres

Scale: 1:10,000

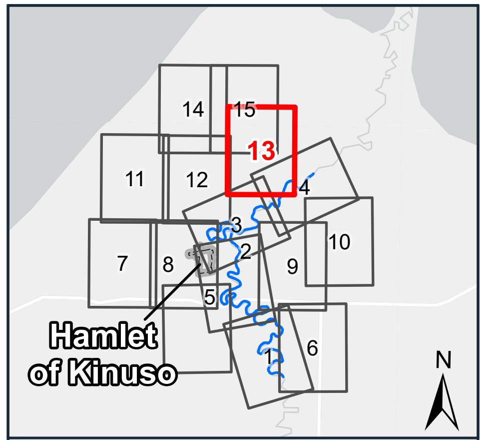
Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 12 OF 15

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
2D MODEL PROFILE STATION
HAMLET OF KINUSO BOUNDARY
FLOODWAY
PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

DISCHARGE
Swan River = 778 m^3/s

0 100 200 300
Metres
Scale: 1:10,000

Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 13 OF 15

BARR

Classification: Public

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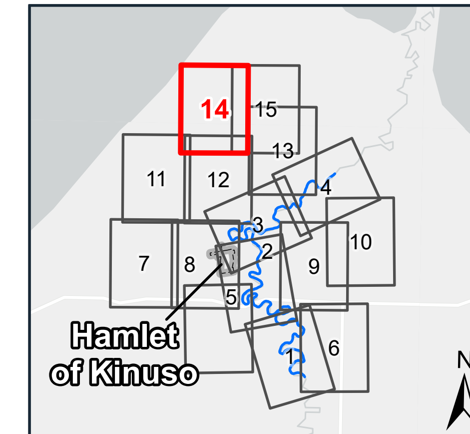

STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
HAMLET OF KINUSO BOUNDARY
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PROTECTED FLOOD FRINGE
HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

0 100 200 300
Metres
N
Scale: 1:10,000

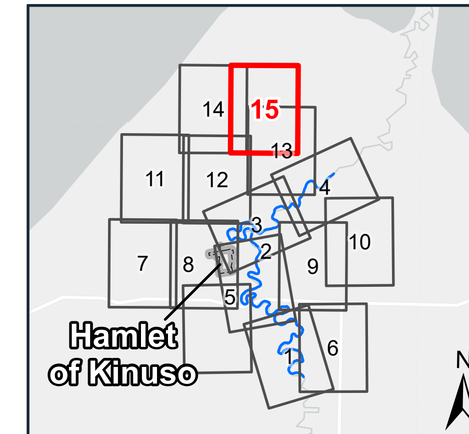
Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 14 OF 15

BARR

Classification: Public



STUDY LIMIT
FLOW DIRECTION
BRIDGE
CULVERT
FLOOD CONTROL STRUCTURE
SECONDARY HIGHWAY
LOCAL ROAD
RAILWAY
HAMLET OF KINUSO BOUNDARY
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HIGH HAZARD FLOOD FRINGE
FLOOD FRINGE
200-YEAR FLOOD EXTENT
500-YEAR FLOOD EXTENT

Alberta
Canada

0 100 200 300
Metres
N

Scale: 1:10,000

Governing Design Flood Hazard Map

Kinuso Flood Study

SHEET 15 OF 15

BARR

Appendix J

Climate Change Flood Profiles

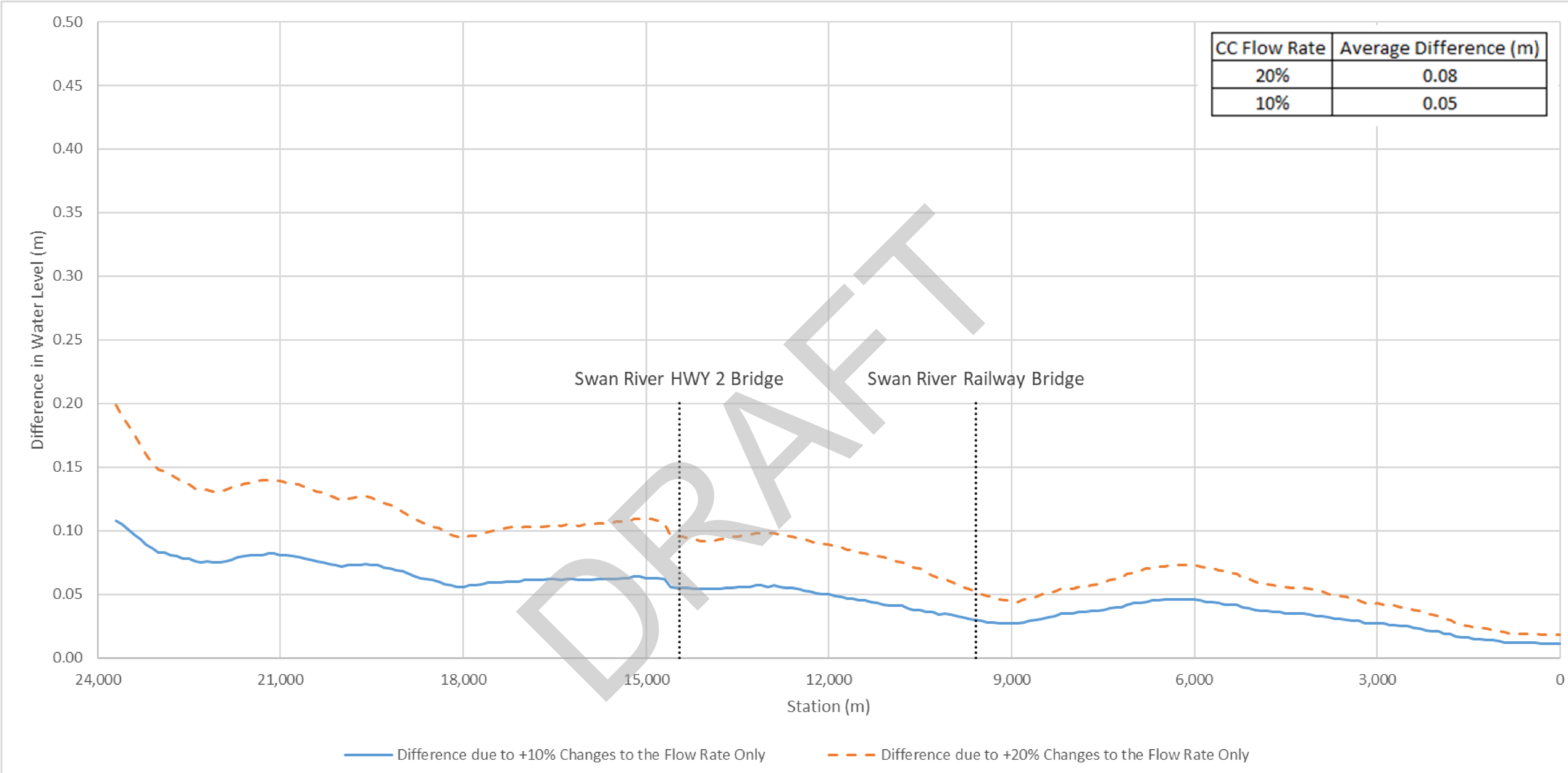

Figure J-1 Simulated Climate Change Water Surface Profiles Along Swan River

Table J-1 Swan River Climate Change Profiles

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
23,700	593.74	593.85	593.94	0.11	0.20
23,600	593.70	593.80	593.89	0.11	0.19
23,500	593.67	593.77	593.86	0.10	0.18
23,400	593.63	593.73	593.81	0.10	0.17
23,300	593.59	593.69	593.76	0.09	0.17
23,200	593.55	593.64	593.71	0.09	0.16
23,100	593.50	593.59	593.66	0.09	0.15
23,000	593.46	593.54	593.60	0.08	0.15
22,900	593.41	593.49	593.56	0.08	0.15
22,800	593.37	593.45	593.51	0.08	0.14
22,700	593.33	593.41	593.47	0.08	0.14
22,600	593.29	593.37	593.43	0.08	0.14
22,500	593.26	593.34	593.39	0.08	0.14
22,400	593.22	593.30	593.36	0.08	0.13
22,300	593.19	593.27	593.32	0.08	0.13
22,200	593.15	593.23	593.29	0.08	0.13
22,100	593.11	593.19	593.24	0.07	0.13
22,000	593.07	593.15	593.20	0.08	0.13
21,900	593.04	593.12	593.17	0.08	0.13
21,800	593.01	593.08	593.14	0.08	0.13
21,700	592.97	593.05	593.11	0.08	0.13
21,600	592.94	593.02	593.08	0.08	0.14
21,500	592.91	592.99	593.04	0.08	0.14
21,400	592.87	592.95	593.01	0.08	0.14
21,300	592.84	592.92	592.98	0.08	0.14
21,200	592.80	592.89	592.94	0.08	0.14
21,100	592.77	592.85	592.91	0.08	0.14
21,000	592.74	592.82	592.87	0.08	0.14
20,900	592.70	592.78	592.83	0.08	0.14
20,800	592.65	592.73	592.79	0.08	0.14
20,700	592.61	592.69	592.75	0.08	0.14
20,600	592.57	592.65	592.71	0.08	0.13
20,500	592.54	592.62	592.68	0.08	0.13
20,400	592.51	592.59	592.64	0.08	0.13
20,300	592.47	592.55	592.60	0.07	0.13
20,200	592.43	592.51	592.56	0.07	0.13
20,100	592.40	592.47	592.52	0.07	0.13
20,000	592.37	592.44	592.49	0.07	0.12
19,900	592.34	592.42	592.47	0.07	0.13
19,800	592.32	592.39	592.45	0.07	0.13
19,700	592.29	592.37	592.42	0.07	0.13
19,600	592.25	592.33	592.38	0.07	0.13
19,500	592.22	592.29	592.34	0.07	0.13
19,400	592.18	592.25	592.30	0.07	0.12
19,300	592.14	592.21	592.26	0.07	0.12
19,200	592.11	592.18	592.23	0.07	0.12
19,100	592.07	592.14	592.19	0.07	0.12
19,000	592.05	592.11	592.16	0.07	0.11
18,900	592.01	592.08	592.12	0.07	0.11
18,800	591.97	592.04	592.08	0.06	0.11
18,700	591.94	592.00	592.05	0.06	0.11
18,600	591.90	591.96	592.01	0.06	0.11
18,500	591.87	591.93	591.97	0.06	0.10
18,400	591.82	591.88	591.92	0.06	0.10
18,300	591.78	591.83	591.87	0.06	0.10
18,200	591.74	591.79	591.83	0.06	0.10
18,100	591.69	591.75	591.79	0.06	0.10
18,000	591.65	591.70	591.74	0.06	0.09
17,900	591.61	591.67	591.70	0.06	0.10
17,800	591.57	591.63	591.67	0.06	0.10
17,700	591.54	591.60	591.64	0.06	0.10
17,600	591.51	591.57	591.61	0.06	0.10
17,500	591.50	591.55	591.60	0.06	0.10
17,400	591.48	591.54	591.58	0.06	0.10

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
17,300	591.46	591.52	591.56	0.06	0.10
17,200	591.44	591.50	591.54	0.06	0.10
17,100	591.41	591.47	591.52	0.06	0.10
17,000	591.39	591.45	591.49	0.06	0.10
16,900	591.37	591.43	591.48	0.06	0.10
16,800	591.35	591.41	591.45	0.06	0.10
16,700	591.32	591.38	591.43	0.06	0.10
16,600	591.30	591.36	591.41	0.06	0.10
16,500	591.28	591.34	591.38	0.06	0.11
16,400	591.25	591.31	591.35	0.06	0.10
16,300	591.21	591.27	591.31	0.06	0.10
16,200	591.16	591.23	591.27	0.06	0.11
16,100	591.13	591.19	591.24	0.06	0.10
16,000	591.11	591.17	591.21	0.06	0.11
15,900	591.09	591.15	591.19	0.06	0.11
15,800	591.06	591.12	591.17	0.06	0.11
15,700	591.04	591.10	591.14	0.06	0.11
15,600	591.02	591.08	591.12	0.06	0.11
15,500	590.99	591.05	591.10	0.06	0.11
15,400	590.96	591.02	591.06	0.06	0.11
15,300	590.92	590.98	591.03	0.06	0.11
15,200	590.88	590.94	590.99	0.06	0.11
15,100	590.85	590.91	590.96	0.06	0.11
15,000	590.82	590.88	590.93	0.06	0.11
14,900	590.79	590.85	590.90	0.06	0.11
14,800	590.75	590.81	590.86	0.06	0.11
14,700	590.69	590.75	590.80	0.06	0.11
14,600	590.49	590.54	590.58	0.06	0.10
14,500	590.46	590.51	590.55	0.06	0.10
14,400	590.43	590.48	590.52	0.06	0.10
14,300	590.40	590.46	590.50	0.05	0.09
14,200	590.37	590.43	590.47	0.05	0.09
14,100	590.35	590.40	590.44	0.05	0.09
14,000	590.32	590.37	590.41	0.05	0.09
13,900	590.29	590.34	590.38	0.05	0.09
13,800	590.26	590.31	590.35	0.05	0.09
13,700	590.23	590.28	590.32	0.05	0.09
13,600	590.20	590.26	590.30	0.05	0.10
13,500	590.17	590.23	590.27	0.06	0.10
13,400	590.14	590.19	590.23	0.06	0.10
13,300	590.11	590.16	590.20	0.06	0.10
13,200	590.07	590.13	590.17	0.06	0.10
13,100	590.04	590.09	590.13	0.06	0.10
13,000	590.01	590.06	590.10	0.06	0.10
12,900	589.97	590.03	590.07	0.06	0.10
12,800	589.93	589.98	590.03	0.06	0.10
12,700	589.88	589.94	589.98	0.05	0.10
12,600	589.84	589.89	589.93	0.05	0.09
12,500	589.79	589.84	589.88	0.05	0.09
12,400	589.73	589.79	589.83	0.05	0.09
12,300	589.68	589.73	589.77	0.05	0.09
12,200	589.63	589.68	589.72	0.05	0.09
12,100	589.58	589.63	589.67	0.05	0.09
12,000	589.54	589.59	589.63	0.05	0.09
11,900	589.49	589.53	589.57	0.05	0.09
11,800	589.44	589.48	589.52	0.05	0.09
11,700	589.39	589.44	589.47	0.05	0.08
11,600	589.35	589.40	589.44	0.05	0.08
11,500	589.32	589.36	589.40	0.05	0.08
11,400	589.29	589.34	589.37	0.05	0.08
11,300	589.26	589.30	589.34	0.04	0.08
11,200	589.23	589.27	589.31	0.04	0.08
11,100	589.20	589.24	589.28	0.04	0.08
11,000	589.17	589.21	589.25	0.04	0.08
10,900	589.13	589.17	589.21	0.04	0.08

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
10,800	589.09	589.13	589.16	0.04	0.08
10,700	589.04	589.08	589.11	0.04	0.07
10,600	588.99	589.03	589.06	0.04	0.07
10,500	588.93	588.97	589.00	0.04	0.07
10,400	588.88	588.92	588.95	0.04	0.07
10,300	588.83	588.86	588.89	0.04	0.07
10,200	588.77	588.80	588.83	0.03	0.06
10,100	588.71	588.75	588.77	0.03	0.06
10,000	588.65	588.69	588.71	0.03	0.06
9,900	588.59	588.62	588.65	0.03	0.06
9,800	588.52	588.56	588.58	0.03	0.06
9,700	588.49	588.52	588.55	0.03	0.05
9,600	588.45	588.48	588.50	0.03	0.05
9,500	588.41	588.43	588.46	0.03	0.05
9,400	588.36	588.39	588.41	0.03	0.05
9,300	588.31	588.33	588.35	0.03	0.05
9,200	588.25	588.28	588.30	0.03	0.05
9,100	588.20	588.22	588.24	0.03	0.04
9,000	588.14	588.17	588.19	0.03	0.05
8,900	588.10	588.13	588.15	0.03	0.04
8,800	588.07	588.09	588.11	0.03	0.05
8,700	588.04	588.07	588.09	0.03	0.05
8,600	588.01	588.04	588.05	0.03	0.05
8,500	587.97	588.00	588.02	0.03	0.05
8,400	587.94	587.98	588.00	0.03	0.05
8,300	587.91	587.95	587.97	0.03	0.05
8,200	587.88	587.92	587.94	0.04	0.05
8,100	587.85	587.89	587.91	0.03	0.05
8,000	587.82	587.85	587.87	0.04	0.05
7,900	587.79	587.83	587.85	0.04	0.06
7,800	587.76	587.80	587.82	0.04	0.06
7,700	587.73	587.77	587.79	0.04	0.06
7,600	587.70	587.74	587.76	0.04	0.06
7,500	587.66	587.69	587.72	0.04	0.06
7,400	587.63	587.67	587.69	0.04	0.06
7,300	587.59	587.63	587.66	0.04	0.06
7,200	587.56	587.60	587.62	0.04	0.06
7,100	587.52	587.57	587.59	0.04	0.07
7,000	587.50	587.54	587.56	0.04	0.07
6,900	587.47	587.52	587.54	0.04	0.07
6,800	587.45	587.50	587.52	0.04	0.07
6,700	587.43	587.47	587.50	0.04	0.07
6,600	587.39	587.43	587.46	0.04	0.07
6,500	587.35	587.39	587.42	0.05	0.07
6,400	587.30	587.35	587.38	0.05	0.07
6,300	587.26	587.31	587.33	0.05	0.07
6,200	587.22	587.27	587.30	0.05	0.07
6,100	587.18	587.23	587.25	0.05	0.07
6,000	587.13	587.18	587.20	0.05	0.07
5,900	587.08	587.12	587.15	0.04	0.07
5,800	587.03	587.07	587.10	0.04	0.07
5,700	586.97	587.02	587.04	0.04	0.07
5,600	586.94	586.98	587.01	0.04	0.07
5,500	586.89	586.93	586.96	0.04	0.07
5,400	586.84	586.88	586.91	0.04	0.07
5,300	586.80	586.84	586.86	0.04	0.07
5,200	586.74	586.78	586.81	0.04	0.06
5,100	586.69	586.73	586.75	0.04	0.06
5,000	586.63	586.67	586.69	0.04	0.06
4,900	586.57	586.61	586.63	0.04	0.06
4,800	586.52	586.55	586.57	0.04	0.06
4,700	586.46	586.50	586.52	0.04	0.06
4,600	586.41	586.44	586.46	0.04	0.06
4,500	586.35	586.38	586.41	0.03	0.06
4,400	586.30	586.34	586.36	0.03	0.05

River Station (m)	Simulated Water Level (m)			Difference (m)	
	100-Year Flood Event	100-Year Flood Event CC+10%	100-Year Flood Event CC+20%	CC+10%	CC+20%
4,300	586.26	586.29	586.31	0.04	0.06
4,200	586.21	586.24	586.26	0.03	0.05
4,100	586.15	586.18	586.20	0.03	0.05
4,000	586.09	586.12	586.14	0.03	0.05
3,900	586.03	586.06	586.08	0.03	0.05
3,800	585.96	585.99	586.01	0.03	0.05
3,700	585.90	585.93	585.95	0.03	0.05
3,600	585.86	585.89	585.91	0.03	0.05
3,500	585.81	585.84	585.86	0.03	0.05
3,400	585.75	585.78	585.80	0.03	0.05
3,300	585.70	585.72	585.74	0.03	0.04
3,200	585.64	585.67	585.68	0.03	0.04
3,100	585.61	585.64	585.65	0.03	0.04
3,000	585.58	585.61	585.62	0.03	0.04
2,900	585.55	585.57	585.59	0.03	0.04
2,800	585.52	585.54	585.56	0.03	0.04
2,700	585.47	585.50	585.51	0.03	0.04
2,600	585.43	585.46	585.47	0.03	0.04
2,500	585.38	585.41	585.42	0.03	0.04
2,400	585.33	585.35	585.37	0.02	0.04
2,300	585.27	585.30	585.31	0.02	0.04
2,200	585.21	585.23	585.25	0.02	0.03
2,100	585.16	585.18	585.19	0.02	0.03
2,000	585.09	585.11	585.13	0.02	0.03
1,900	585.02	585.04	585.05	0.02	0.03
1,800	584.95	584.97	584.98	0.02	0.03
1,700	584.88	584.90	584.91	0.02	0.03
1,600	584.82	584.84	584.85	0.02	0.03
1,500	584.78	584.79	584.80	0.02	0.02
1,400	584.73	584.74	584.75	0.01	0.02
1,300	584.68	584.69	584.70	0.01	0.02
1,200	584.63	584.64	584.65	0.01	0.02
1,100	584.58	584.60	584.60	0.01	0.02
1,000	584.54	584.55	584.56	0.01	0.02
900	584.50	584.51	584.52	0.01	0.02
800	584.45	584.47	584.47	0.01	0.02
700	584.40	584.41	584.42	0.01	0.02
600	584.36	584.37	584.38	0.01	0.02
500	584.30	584.32	584.32	0.01	0.02
400	584.25	584.26	584.27	0.01	0.02
300	584.19	584.20	584.21	0.01	0.02
200	584.13	584.14	584.14	0.01	0.02
100	584.06	584.07	584.08	0.01	0.02
0	584.02	584.03	584.03	0.01	0.02