City of Prince Albert
Flood Plain Mapping Study

Flood Hazard Assessment

December 18, 2019

Prepared for:

City of Prince Albert
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Discipline	Sk. Reg. No.	Signature
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Executive Summary

The objective of the Prince Albert Flood Plain Mapping project was to identify and assess flood hazards within the City of Prince Albert along approximately 16 km of the North Saskatchewan River (NSR) and approximately 6.5 km of the Little Red River (LRR), also known as the Spruce River, from its confluence with the NSR. This updated 1:500 year flood plain delineation, including floodway and flood fringe, will allow the City to create new policies around development in these areas, accurately communicate risks to stakeholders, and prepare flood resilient mitigations and measures for existing infrastructure and properties.

The Prairie Farm Rehabilitation Administration (PFRA) completed a hydrology study for the NSR and LRR in 1980. A follow up hydraulic report and flood maps were later completed by PFRA in 1984. In 2010, the Saskatchewan Watershed Authority, currently the Water Security Agency (WSA), issued a flood frequency analysis update for the NSR.

The hydrology for both the NSR and LRR was updated for this study. For the NSR, gauge data at Water Survey of Canada (WSC) hydrometric station 05GG001 North Saskatchewan River at Prince Albert was used to complete a flood frequency analysis and generate a table of updated return period flows. A Log Pearson Type III distribution with Method of Moments parameter estimation aided by a “by-eye” fitting for the higher magnitude events was selected as the best fitting distribution. The results were multiplied by a calculated peaking factor to establish peak instantaneous flow estimates. The resulting flows were adopted for use in this study as shown in Table i.

Table i: Recommended Return Period Flows for North Saskatchewan River

Return Period	Peak Instantaneous Flow (m^3/s)
1:10	2,400
1:25	3,107
1:50	3,685
1:75	4,044
1:100	4,905
1:200	5,720
1:500	8,175

There is no observed flow data available for the LRR at the confluence with the NSR. Therefore, an appropriate flow estimation method was implemented to develop peak flow estimates for the LRR’s ungauged basin. The LRR hydrology was updated using basin transfer methods described in the 1993, SaskWater (now the WSA) report “Magnitude and Frequency of Peak Flows and Flow Volumes in Saskatchewan”. The Effective Drainage Area (EDA) and Gross Drainage Area (GDA) were determined based on topographical mapping and professional judgement around the impacts of the Anglin Lake Dam, a dam system in the upper reaches of the LRR watershed. The WSA was engaged to assist in the selection of an appropriate WSC gauged site for flow transposition. WSC gauging station 05GG010 Garden River near Henribourg was selected as it is immediately adjacent to the ungauged basin, is on an unregulated stream and has a drainage area similar to the ungauged site in terms of shape, topography, soils and land cover.

A flood frequency analysis was completed using the WSC gauging station 05GG010 data where a Gamma distribution with Method of Moments provided the best statistical fit and curve fitting. The updated return period flows were then transferred to the ungauged LRR watershed using provincial peak flow estimation techniques (flow transposition). These daily mean peak flow values were multiplied by established peaking factors to determine peak instantaneous flow rates. The flows adopted for use on the LRR are as shown in Table ii.

Table ii: Recommended Return Period Flows for Little Red River

Return Period	Peak Instantaneous Flow (m^3/s)
1:10	77.8
1:25	109.9
1:50	134.2
1:75	141.8
1:100	146.6
1:200	155.0
1:500	168.0

LiDAR data (acquired in October 2014) for the study area was combined with surveyed bathymetric and river cross-section data to develop a Digital Terrain Model (DTM) suitable for use in the 2D hydraulic model, HEC-RAS version 5.0.6 developed by the United States Army Corps of Engineers (USACE). Model parameters including boundary conditions, Manning's roughness coefficients, and structures were developed to represent site conditions.

Instream structures were captured by LiDAR and the survey program and incorporated into the model DTM. This DTM included all encroachments including constrictions, embankments, abutments, weirs, dykes, and bridge piers. In the absence of anticipated pressure flow through any of the bridge openings, the hydraulic effects of these structures were effectively captured in the 2D model results.

The calibration of the 2D model was based on historical flood records from 1980 (1,630 m^3/s) and 2013 (2,270 m^3/s) as well as events in 1974 (3,790 m^3/s) and 1915 (5,660 m^3/s) and verified against the WSC rating curve for the hydrometric station 05GG001 North Saskatchewan River at Prince Albert. Calibration was completed by adjusting channel roughness parameters. Channel roughness has less impact on flows as flow depth increases. For the NSR, calibration efforts determined that a lower Manning's 'n' (0.028) in the channel for flows greater than or equal to the 1:25 year provided the best calibration, while a higher Manning's 'n' (0.032) provided the best results for flows up to the 1:10 year event. For the LRR, with its shallower flow depths the channel Manning's 'n' was set to 0.032.

A sensitivity analysis was undertaken to assess the effects of scaling the model grid size. Reducing grid size resulted in significantly longer run times and minimal impacts on model results. The model sensitivity to variations in Manning's 'n' roughness factors was evaluated by varying the 'n' values for all land cover types by ±10%, ±20%, and ±30%. These varied 'n' values were applied to the high flow runs on the NSR (1:100 year to 1:500 year flows), and as expected, higher 'n' values impact the results in higher water levels, while lower 'n' values have the effect of reducing flood elevations.

Five separate model runs form the basis for the flood hazard mapping, based on five discrete flow files that are summarized in Table iii.

Table iii: Model Run Details

Model Output	Geometry File	Manning's File	Flow File	Plan Name
North Saskatchewan River flood elevations for 10 year return period	Prince Albert	Manning_19_n=0.032	NS10_S=0.0003	NS10_n=0.032
North Saskatchewan River flood elevations for 25, 50, and 75 year return period	Prince Albert	Manning_16 n=0.028	NS25to75_S=0.0003	NS25-75_n=0.028
North Saskatchewan River flood elevations for 100, 200, and 500 year return period	Prince Albert	Manning_16 n=0.028	NS100to500_S=0.0003	NS100to500 n=0.028
Little Red River flood elevations for 10, 25, 50, and 75 year return period	Prince Albert	Manning_19_n=0.032	LR10to75 S=0.0003	LR10-75_n=0.032
Little Red River flood elevations for 100, 200, and 500 year return period	Prince Albert	Manning_19_n=0.032	LR100to500 S=0.0003	LR100-500_n=0.032

The results of the 2D modelling were transferred to GIS and mapped for the various return periods. For the Regulatory flow of a 1:500 year flood, the floodway and flood fringe were identified based on the definitions in the Statement of Provincial Interest Regulations (March 29, 2012), in reference to the Planning and Development Act, 2007.

- "floodway" means the portion of the flood plain adjoining the channel where the waters in the 1:500 year flood are projected to meet or exceed a depth of one metre, or a velocity of one metre per second.
- "flood fringe" means the portion of the flood plain where the waters in the 1:500 year flood are projected to be less than a depth of one metre and have a velocity of less than one metre per second.

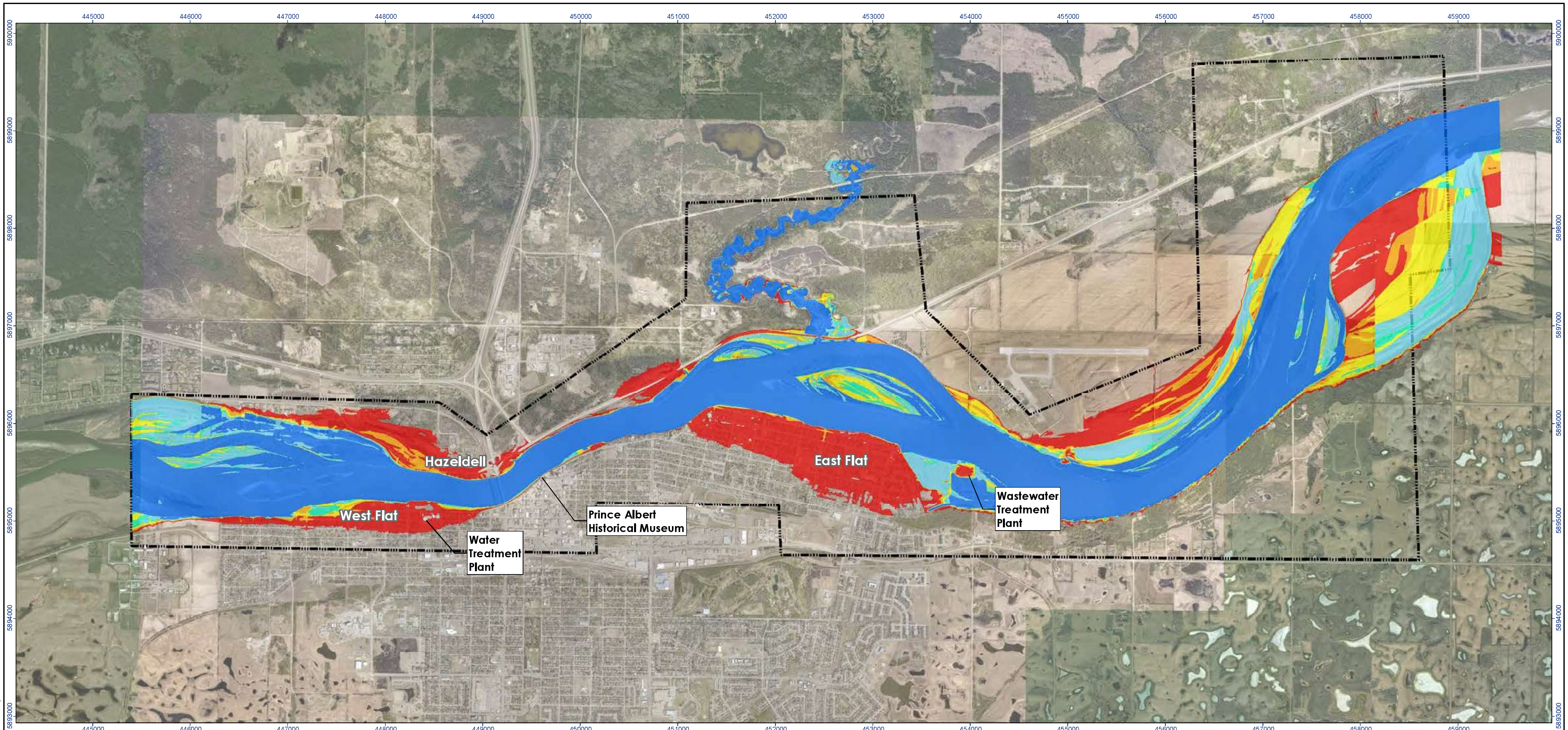
A map of the flood inundation extents for all modelled return periods (1:10, 1:25, 1:50, 1:75, 1:100, 1:200, and 1:500 year) is included as Figure A – Overall Inundation Extent.

For the 1:500 year flood, water surface elevations in the NSR range between 427.92 masl at the upstream Project boundary to 424.06 masl at the downstream City boundary. In the LRR, flood elevations are largely controlled by the NSR and range between 431.40 masl at the upstream project boundary and 425.82 masl at the confluence with the NSR.

The updated mapping confirms previous flood studies that indicated significant infrastructure and lands in the City of Prince Albert will be affected by the Regulatory flood. Specifically, the water treatment plant (WTP), wastewater treatment plant (WWTP), East Flat area, West Flat area, and Hazeldell area are impacted by the 1:500 year flood.

Options for protecting the WTP include raising the electrical and mechanical equipment above the flood elevation or purchasing a water filled barrier system that can be installed around the WTP to protect it during a flood. The WWTP could be protected similarly through retrofitting the electrical and mechanical systems or using a water filled barrier system. Additionally, it may be possible to construct an earthen berm around the WWTP for flood protection. Access to the WWTP is affected during large flood events, and to improve access, the City could consider raising the access road.

The East Flat, West Flat and Hazeldell areas could be protected by constructing a dyke system. Regulatory permissions would be required for this type of construction and the impacts of encroaching on the floodplain and reducing conveyance (possibly increasing flood elevations) would need to be examined. Alternatively, the City could develop by-laws to regulate construction in the flood plain or to allow the City first chance at purchase when properties are put up for sale. A further option to reduce flood risk to properties would be to purchase the properties at risk and convert the flood plain area to a land use that has less risk.



Legend

Inundation Extent

- 25 Year
- 50 Year
- 75 Year
- 100 Year
- 200 Year
- 500 Year
- Study Area Boundary

0 770 1,540 metres

(At original document size of 11x17)
1:40,000

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Stantec

City of Prince Albert

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by HA on 2019-12-6
IR Review by DS on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Inundation Mapping

Figure No.
A

Title
Overall Inundation Extent

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China

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Abbreviations

AEP	Annual exceedance probability
DTM	Digital Terrain Model
EDA	Effective Drainage Area
GDA	Gross Drainage Area
GIS	Geographic information system
LiDAR	Light Detection and Ranging
LRR	Little Red River
masl	Metres above sea level
NSR	North Saskatchewan River
PFRA	Prairie Farm Rehabilitation Administration
SPI	Statements of Provincial Interest
USACE	United States Army Corps of Engineers
WSA	Water Security Agency
WSC	Water Survey of Canada
WSE	Water surface elevation
WTP	Water treatment plant
WWTP	Wastewater treatment plant

1.0 INTRODUCTION

1.1 STUDY BACKGROUND AND OBJECTIVES

The objective of the Prince Albert Flood Plain Mapping project was to identify and assess flood hazards within the City of Prince Albert along approximately 16 km of the North Saskatchewan River (NSR) and approximately 6.5 km of the Little Red River (LRR), also known as the Spruce River, from its confluence with the North Saskatchewan River. This assessment has delineated the flood extents for several flood events including the 1:10, 1:25, 1:50, 1:75, 1:100, 1:200, and the 1:500 year (Regulatory event) return periods. This mapping will allow the City of Prince Albert to be in conformance with the Province of Saskatchewan's Statements of Provincial Interest (SPI), Section 6.7 "Public Safety", which requires delineation of the 1:500 year flood event and the implementation of controls on development within this area. Figure 1 illustrates the areas of focus for the flood plain mapping study.

According to previous studies (PFRA, 1984), the City of Prince Albert had significant infrastructure within the 1:500 year flood plain, including over 2,400 residential properties, the water treatment plant (WTP), and the wastewater treatment plant (WWTP), based on the 1984 results. This updated flood plain delineation will allow the City to confirm which properties are at risk and guide the City in creating new policies around development in these areas, accurately communicating risks to stakeholders, and preparing flood resilient mitigations and measures for existing infrastructure and properties.

1.2 TECHNICAL GUIDELINES

The following guidance documents were referenced for this study.

Statement of Provincial Interest (SPI) Regulations (March 29, 2012), in reference to the *Planning and Development Act*, 2007 (the Act). Under the Act, municipalities are authorized to set policies governing the development of their communities.

The SPI outlines that planning documents and decisions shall, insofar as is practical:

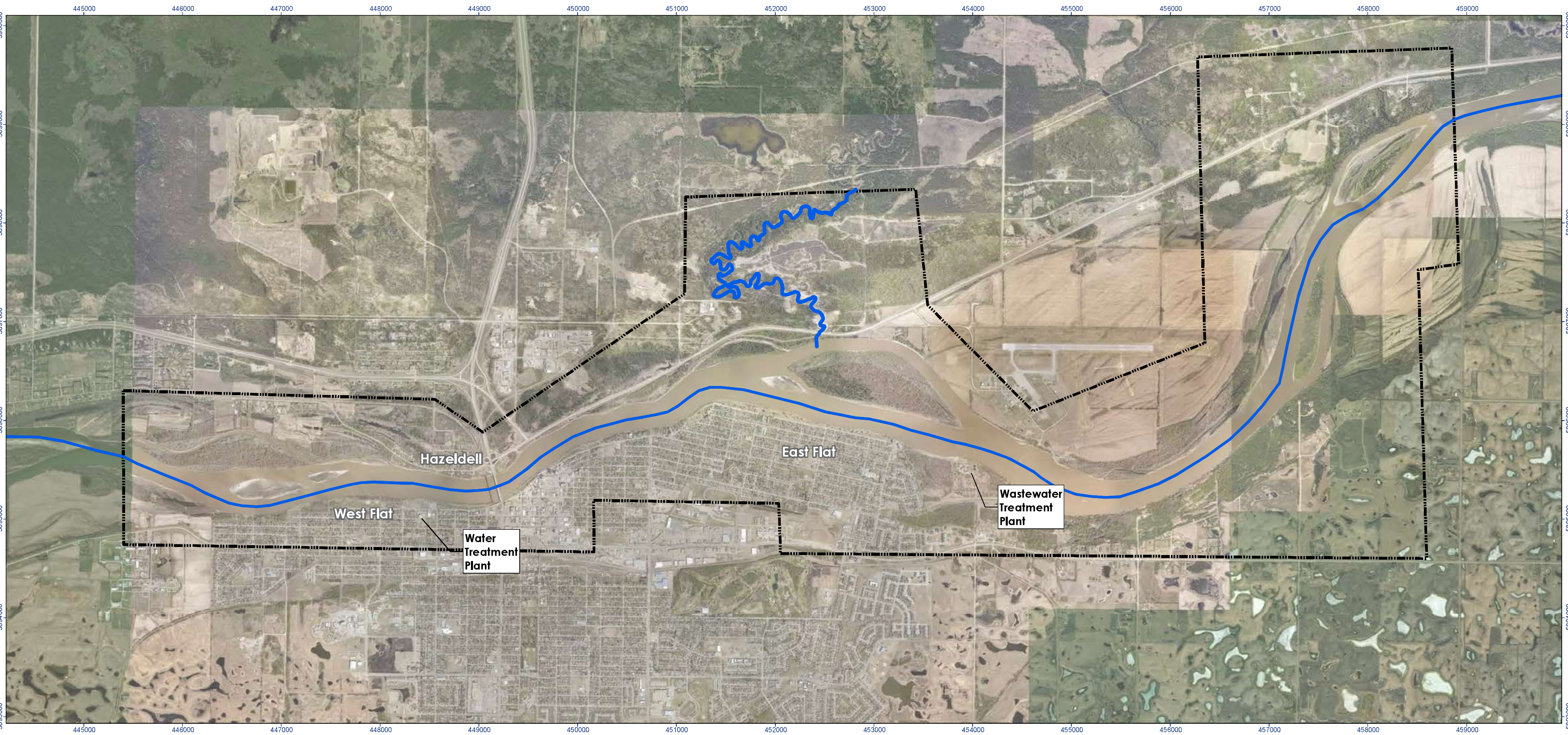
1. Identify potential hazard lands and address their management;
2. Limit development on hazard lands to minimize the risk to public or private infrastructure;
3. Prohibit the development of new buildings and additions to buildings in the floodway of the 1:500 year flood elevation of any watercourse or water body;
4. Require flood-proofing of new buildings and additions to buildings to an elevation 0.5 metres above the 1:500 year flood elevation of any watercourse or water in the flood fringe (SPI, 2012).
    - Floodway: the portion of the flood plain adjoining the channel where the waters in the 1:500 year flood are projected to meet or exceed a depth of one metre or a velocity of one metre per second.

- Flood fringe: the portion of the flood plain where the waters in the 1:500 year flood are projected to be less than a depth of one metre and have a velocity of less than one metre per second.

For example, an area of flood plain that has a depth of 1.5 m and a velocity of 0.75 m/s will be in the floodway. An area of flood plain that has a depth of 0.8 m and a velocity of 1.2 m/s will also be in the floodway.

Federal Flood Mapping Guideline Series (2019), Natural Resources Canada, Public Safety Canada:

- Federal Flood Mapping Framework (Version 2.0)
- Federal Airborne LiDAR Data Acquisition Guideline (Version 2.0)
- Bibliography of Best Practices and References for Flood Mitigation (Version 2.0)
- Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation (Version 1.0)
- Federal Geomatics Guidelines for Flood Mapping (Version 1.0)



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Legend
Study Reaches
Study Area Boundary

0 750 1,500 metres
(At original document size of 11x17)
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N

Stantec

City of Prince Albert

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by HA on 2019-12-6
IR Review by DS on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
1

Title
Site Location Plan

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2.0 BACKGROUND INFORMATION

2.1 PREVIOUS REPORTING

Previous reporting was reviewed as part of this assessment. The following section summarizes relevant background information related to the updated flood plain mapping.

2.1.1 Prince Albert Flood Damage Reduction Study Hydrology Report (PFRA, 1980)

This study undertaken by Prairie Farm Rehabilitation Administration (PFRA) determined the 1:10, 1:50, 1:100 and 1:500 flood events of the North Saskatchewan River (NSR) and the Little Red River (LRR), also known as the Spruce River, at Prince Albert. For the NSR, the instantaneous peak flow of the 1:500 year flood was estimated at 8,160 m^3/s. This was determined using a flood frequency analysis on 67 years of data (1912-1978) recorded at Water Survey of Canada (WSC) hydrometric gauging station North Saskatchewan River at Prince Albert (05GG001) as well as other flow records extending back to 1863. The effects of upstream regulation on the NSR by the Bighorn and Brazeau Dams was investigated in this study. For the LRR, the instantaneous peak flow of the 1:500 year flood was estimated at 200 m^3/s. This value was determined using a flood frequency analysis where natural peak flows were estimated for a 60 year period (1919-1978) referencing hydrometric data from upstream WSC gauging stations on the Spruce River and neighbouring streams.

2.1.2 Prince Albert Flood Damage Reduction Study Hydraulic Report (PFRA, 1984)

This study by PFRA determined floodwater elevations for flows with return periods ranging between 1:10 and 1:500 year. The analysis was done using a HEC-2 backwater model encompassing 12.3 km of the NSR and 3.4 km of the LRR (then named the Spruce River). The model limits do not cover the entire portion of the NSR within the City of Prince Albert. Approximately 10.4 km of river length within City limits were not modelled with the most downstream cross-section in the model being near the Prince Albert Airport, 8.4 km downstream of the Diefenbaker Bridge. Similarly, the most upstream cross-section on the LRR is 2.5 km downstream from a bridge belonging to the Carlton Trail Railway (formerly owned by CN Rail), which is approximately at the City limit. As such, approximately 2.5 km of the LRR located within the City limits are omitted in the 1984 model. Despite these limitations, most inhabited areas and infrastructures located within City limits were covered by the model.

Calibration of this model was based primarily on recorded flood water elevations observed during high flows in June of 1980. These water levels were used to calibrate the channel roughness coefficients, while overbank roughness was verified using observed water levels from April 23, 1974 and estimated corresponding flows. Verification of flood levels at the WSC hydrometric station was also used in model calibration.

The HEC-2 hydraulic model determined flood elevations up to the 1:500 year flood event, which was estimated at 8,160 m^3/s for the NSR and 200 m^3/s for the LRR documented in the 1980 Prince Albert

Flood Damage Reduction Study Hydrology Report, also by PFRA. Modelled flood water surface elevations were determined graphically using the charts appended to the 1984 report. For the 1:500 year flood event, these elevations range from 428.30 metres above sea level (masl) at the City western limit to 424.30 masl, at the model downstream boundary.

The LRR 1:500 year flood elevations range from 427.45 masl at the upstream boundary to 423.95 masl at its confluence with the NSR. The downstream boundary conditions for the hydraulic model were determined based on historical spring floods of record. However, it should be noted that under the 1:500 year NSR flood event, the LRR water surface increases to 425.50 masl at its confluence with the NSR, propagating approximately 1.4 km upstream.

This report also included a preliminary investigation into wind effects and concluded that the wave rush effects may be worth considering in floodproofing efforts. This hydraulic study ignored the effect of ice jams, which have caused floods in Prince Albert in the past, notably in 1943.

A vertical datum is not mentioned in the previous reporting; however, it is assumed that CGVD28 would have been used for this exercise. The difference in elevations varies spatially from the current CGVD2013, however at WSC Station 05GG001, the present datum is approximately 0.16 m higher than the value used in the previous reports.

2.1.3 Flood Frequency and Flood Hazard Maps (PFRA, 1983)

Eight 1:2000-scale flood frequency and flood hazard maps were provided separately by the PFRA to the Land Protection Branch of Saskatchewan Environment. These maps were prepared in conjunction with the 1984 Prince Albert Flood Damage Reduction Study Hydraulic Report (PFRA), but do not constitute a part of the report. The flood elevations noted on the maps were found to be in agreement with the modelled elevations noted on charts appended to the 1984 report.

2.1.4 Prince Albert Flood Frequency Update (SWA, 2010)

This document was published by the Saskatchewan Watershed Authority, currently known as the Water Security Agency (WSA), and provides recommended peak flows based on the 1980 PFRA hydrology report and an additional 30 years of gauged data. This document does not provide updated flood plain mapping results. The flow naturalization methodology and generalized watershed model developed in 1980 by PFRA was not used; instead, a revised record of naturalized flows for Prince Albert was created using data from Albert Environment for the NSR at Deer Creek. Peak instantaneous flows for the period after 1963, when a regulated flow regime may have been impacting peak flows in the NSR, were developed using a regression curve. Using HydroFreq 1.0, a flood frequency analysis software, return period flows were developed from the updated data sets. A best fit (by-eye) line was used to modify the upper range of the statistical distribution, affecting flows estimated for return periods of 1:50 and greater. Peak flows were also compared to flood frequency results of other gauged stations. The report recommended to use 8,070 m^3/s as the peak instantaneous 1:500 year flood for the NSR (1% lower than reported in 1984). Updated flows were not provided for the LRR.

2.1.5 Saskatchewan Flood and Natural Hazard Risk Assessment (SRC, 2018)

This document, prepared for the Ministry of Government Relation of Saskatchewan, discusses various environmental hazards and their impact for the Province of Saskatchewan. The sections relevant to this project (i.e. flooding risk in Prince Albert) were reviewed and summarized in this section. According to the document, Prince Albert has the highest vulnerability for mountain runoff flood in the Province. The overall risk for the City was deemed “moderate”. The document states that Prince Albert could withstand a 1:100 year flood with relatively low damage, however the effects caused by a 1:500 year flood would be notable, damaging various portions of the City and forcing large evacuations. Furthermore, being that Prince Albert is a hub for Northern Saskatchewan, the impact of a catastrophic flood would be felt throughout the region. Conversely, environmental impacts anticipated by the report would be minor. The report notes that several days of warning could be possible in this event, as the original source of flooding would be in the Rocky Mountains and it would most likely occur in early July. Finally, according to previous studies cited by the report, Prince Albert was zoned as at-risk land, but is not a designated flood zone.

2.2 WATER SURVEY OF CANADA HYDROMETRIC STATIONS

The following WSC hydrometric station data is publicly available and was referenced in the hydrologic analysis section of this study. The WSC is the national authority responsible for the collection, interpretation and dissemination of standardized water resource data and information in Canada. Station information typically referenced in hydrologic assessments include flow and level data (and datum conversions), period of record, regulation type and contributing drainage areas. A station’s data collection history is also available.

2.2.1 North Saskatchewan River

WSC Station 05GG001 – North Saskatchewan River at Prince Albert (1910-present)

This hydrometric station has been in operation from 1910 to the present day and offers over a century of valuable flow and level data. This information was used to update the existing flood frequency estimates and inform the flood plain modelling.

2.2.2 Little Red River

WSC Station 05GG002 – Spruce (Little Red) River near Prince Albert (1915-1916)

WSC Station 05GG003 – Spruce River near Outlet from Anglin Lake (1946-1964)

WSC Station 05GG007 – Spruce River below Anglin Lake Reservoir (1962-1991)

These stations provide a snapshot of flows on this tributary of the NSR; however, this data does not offer an updated record of flows and was not used to update the flood frequency analysis for the LRR in this study.

2.2.3 Additional Hydrometric Station Data

WSC Station 05GG010 – Garden River near Henribourg (1966-2016)

Available flow data and contributing drainage area information from this this hydrometric station was used to estimate peak flows for the LRR referencing basin transfer techniques as this station had comparable drainage areas and characteristics as the LRR watershed.

2.3 DAM HISTORY AND IMPACTS

2.3.1 North Saskatchewan River

The NSR begins nearly 800 km west of Prince Albert in the Columbia Icefield in the Rocky Mountains of Alberta. Its headwaters and a major upstream tributary are regulated by two important hydroelectric dams; the Brazeau Dam and the Bighorn Dam.

- The Brazeau Dam lies on the Brazeau River, a tributary of the NSR in west central Alberta. This structure was completed in 1965 and remains the largest hydro plant in Alberta. The primary function of this structure is power generation and it does not actively manage flood flows.
- The Bighorn Dam was completed in 1972 on the NSR in west central Alberta. Its impoundment forms Lake Abraham, which is Alberta's largest manmade lake. This structure is for power generation and does not actively manage flood flows.

Neither of these structures have been shown to reduce flooding potential on the NSR since their completion (Mustapha, 1981). Additionally, the dams are located near the headwaters of the NSR, and there is significant distance and tributary inflow between these structures and Prince Albert. Operations of the dams were considered in the hydrologic assessment by naturalizing the measured flows (adjusting the flows to an estimated pre-dam condition) used in the flood frequency analysis.

2.3.2 Little Red River

The LRR originates approximately 100 km northwest of the City of Prince Albert in Prince Albert National Park. It is regulated by the Anglin Lake Dam (Spruce River Dam) which was constructed in 1962 (PFRA, 1980). This dam controls Anglin Lake levels and also provides a source of water for a pump-diversion system to Emma and Christopher Lakes. The dam created some additional reservoir storage, thus reducing flows somewhat on the LRR below the dam; however, this additional storage does not have a significant impact in large flood events (Grajczyk, 2019).

2.4 RIVER AND VALLEY FEATURES

2.4.1 North Saskatchewan River

There are two bridge crossings on the NSR within City limits that include the Diefenbaker Bridge (Hwy 2/3) and the Carlton Trail Railway Bridge. The two bridges are separated by a distance of approximately 85 m.

Figure 2: Aerial view of Diefenbaker and Carlton Trail Railway bridges (Photo: Prince Albert 2011)

Figure 3: NSR Weir Construction 1939 (Photo: Prince Albert)

According to the department of Public Works for the City of Prince Albert, 33 stormwater outfalls discharge directly into the North Saskatchewan River within the City limits (Prince Albert, 2015a).

There is a rock weir in the NSR near the airport lands. The rock weir was constructed in the late 1930's in order to raise local water levels to act as a landing area for seaplanes. Its profile and effectiveness has diminished due to spring ice flows and it was approximately 0.37 m high as of 2015 (Prince Albert, 2015b). The City has evaluated the possibilities of either weir removal or weir build up, and has elected to do neither option and allow the weir to remain in place as is (Prince Albert, 2015b). Figure 3 shows the construction of the weir in 1939.

Other than bridges, several important structures are located within the NSR flood plain, including powerlines, the Prince Albert WTP and WWTP, and the Prince Albert Historical Museum.

2.4.2 Little Red River

There are seven bridge crossings on the LRR within the City limits that include Highway 55, Little Red River Park Road, 15 Ave NE, Carlton Trail Railway, and three trail bridges. The Carlton Trail Railway bridge is not included in this project study area.

The only major feature on the LRR is the Little Red River Park and associated buildings including the Cosmo Lodge. The park and associated buildings could be subject to flooding from both the LRR and backwater from NSR.

Two new pedestrian bridges are proposed to be installed across the LRR in 2020. The first new pedestrian bridge will replace the existing Sports Council Bridge and the second new bridge will replace the Sliding Hill Bridge, which was lost during the 2013 flood. The new bridges are being designed to be above the 1:50 year flood elevation.

2.5 FLOOD REGIMES AND FLOOD HISTORY

2.5.1 Flood Regimes

Prince Albert is prone to flooding from prolonged rain events in Alberta, which can be exacerbated by snowmelt in the mountains. While there is often a several days delay between these events and their downstream effects, these events can cause significant flooding in the City. The 1915, 1980 and 2013 floods in Prince Albert are believed to have been caused by this hydrologic process.

2.5.2 Ice Breakup

Prince Albert is also at risk from ice jam flooding during annual spring breakup. Ice jam flooding can cause substantial local increases in river water levels and has been the cause of major spring floods in the City (paNow, 2011 and WSA, 2013). Some recorded flood levels can be affected by ice conditions (e.g. April 1936) (WSC, 2010), which can cause high water levels under relatively low flow conditions. Ice conditions were not evaluated as a part of this study. Future studies may consider including additional evaluations of ice effects as related to peak flows and levels.

The City has tracked ice break up over the course of more than a century (See Appendix B). As indicated by data provided by the City of Prince Albert, ice break up generally occurs in mid-April. Figure 4 shows the ice breaking up at the Diefenbaker Bridge pier where a gauge is located to monitor NSR water levels. Figure 5 and Figure 6 show the annual ice break up dates for the period of record per City of Prince Albert data.

Figure 4: Spring Ice at Diefenbaker Bridge Pier, Apr 7, 2017 (Photo: Prince Albert 2017)

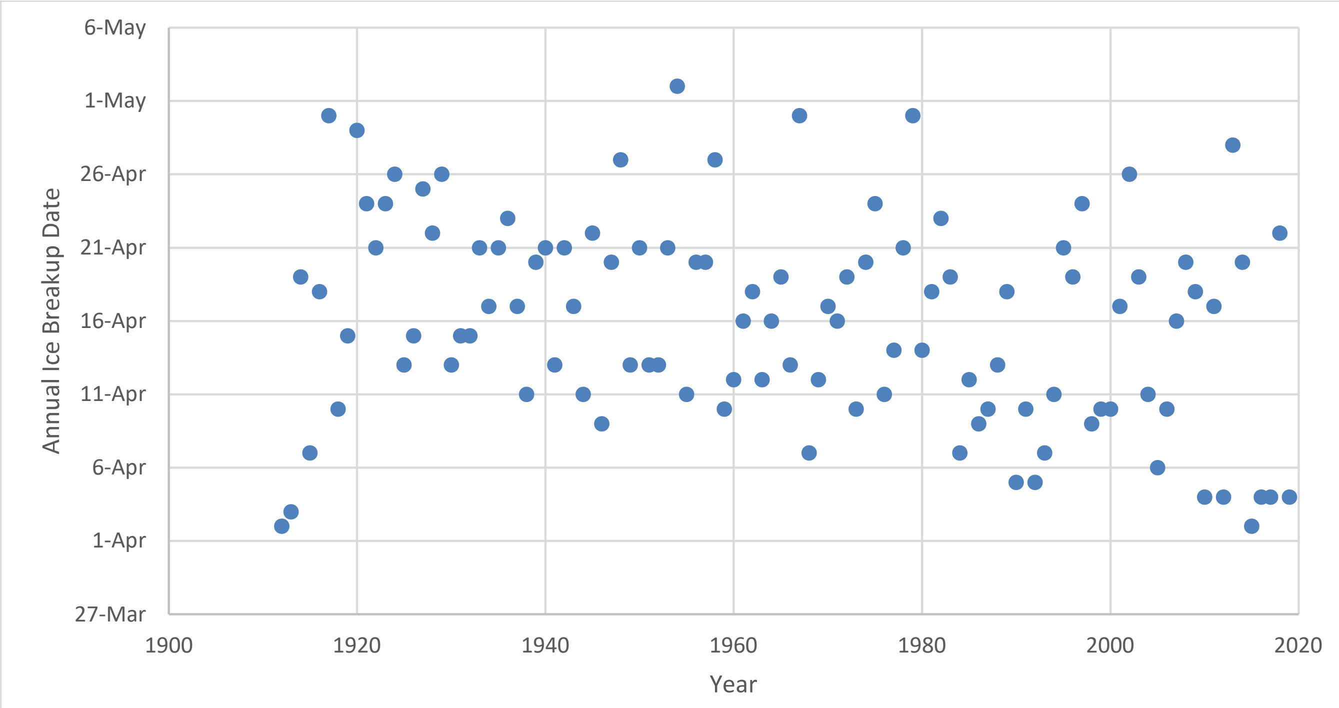


Figure 5: Annual Ice Breakup Date (1912-2019)

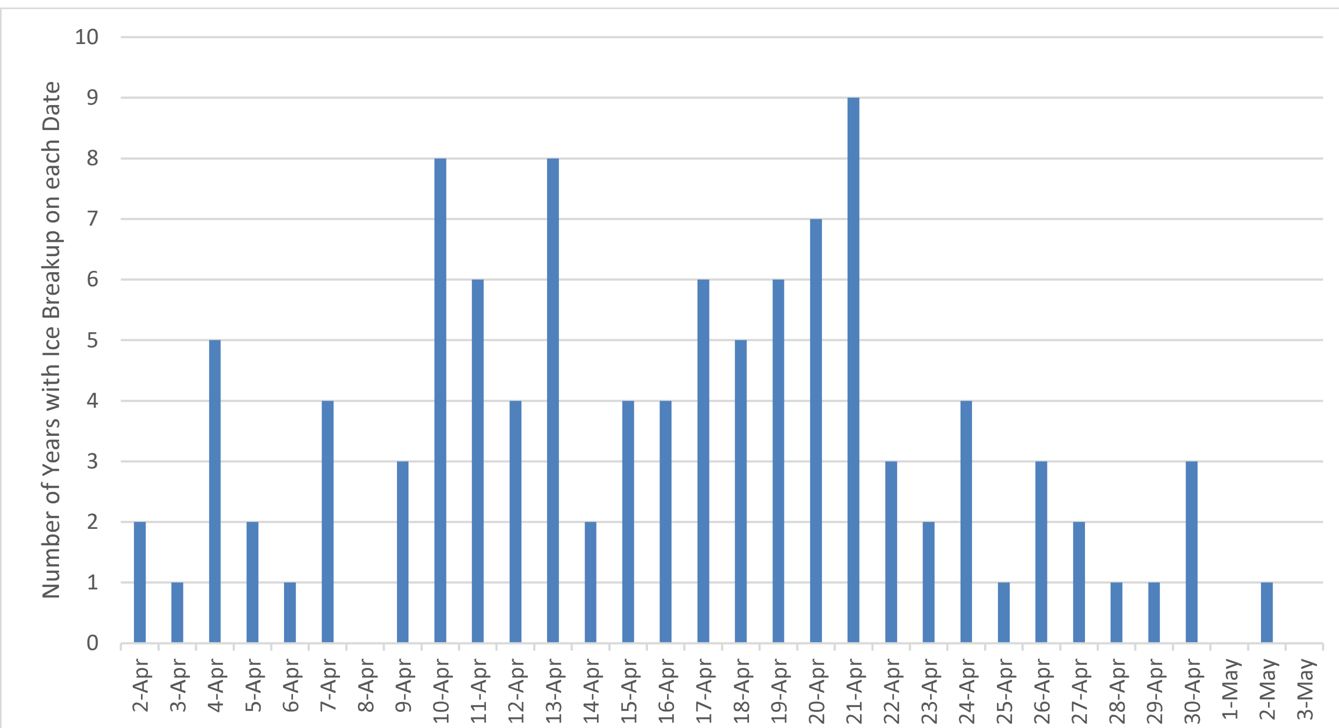


Figure 6: Years with Ice Breakup on Each Date (1912-2019)

2.5.3 North Saskatchewan River

The NSR has a well-documented history of flooding through the City of Prince Albert (Saskatchewan Water Corporation, 1986, Saskatchewan Department of the Environment, 1981) as far back as a storied 'Great Flood' in 1875 caused by ice jams. A detailed annual flood history of WSC hydrometric station 05GG001 North Saskatchewan River at Prince Albert, including recorded peak instantaneous and maximum daily mean flows from 1912 to 2016, has been included in Section 4.1.

As detailed in Section 5.4, the recorded peak flows and their associated highwater marks from flooding that occurred in 1915, 1974, 1980 and 2013 were used as calibration points for the hydraulic model.

Historic flood photos from the Prince Albert Historical Society contain imagery of the July 1915 flood event where a peak instantaneous flow rate of 5,660 m^3/s was recorded (nearly a 1:200 year flood). This flood event was cited as reaching a stage of 28 feet (8.5 m) above normal levels as shown at the Carlton Trail Railway bridge in Figure 7. In contrast, Figure 8 shows the Carlton Trail Railway bridge in 2002 under normal flow conditions.

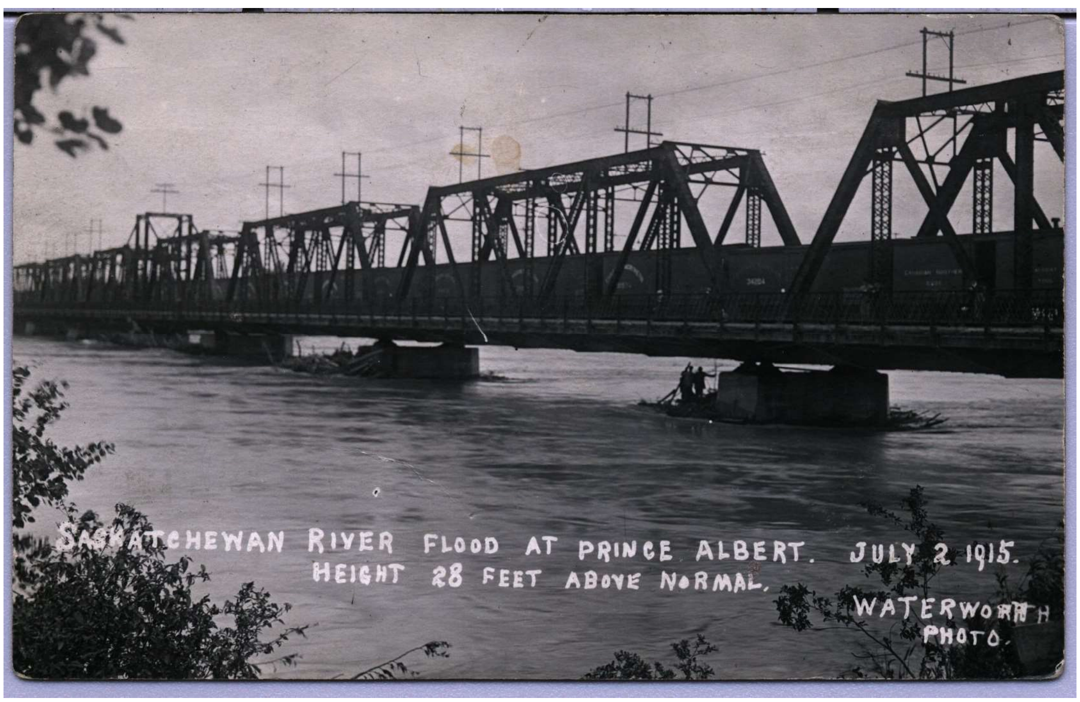


Figure 7: Looking Downstream at the Carlton Trail Railway Bridge During the July 2, 1915 Flood (Photo: WSA)

Figure 8: Looking Upstream at the Carlton Trail Railway Bridge under Normal Flow Conditions Sept 2, 2002 (Photo: Prince Albert)

Figure 9 is a photograph provided by the City of Prince Albert that shows July 1986 flood levels on the NSR at the Diefenbaker Bridge. Flows on the NSR peaked at 3,230 m^3/s, which are slightly larger than the 1:25 year flood event, as determined by this assessment. Figure 10 shows NSR water levels at the Diefenbaker Bridge under normal flow conditions.

Figure 9: Looking Upstream at Diefenbaker and Carlton Trail Railway Bridges, July 1986 Flood (Photo: Prince Albert, 1986)

Figure 10: Looking Upstream at Diefenbaker and Carlton Trail Railway Bridges Under Normal Flow Conditions June 28, 2019 (Photo: Stantec 2019)

2.5.4 Little Red River

Normal and flood flows on the LRR and their effects on a major highway and pedestrian bridge are shown in Figure 11 to 14.

Figure 11: Little Red River Park Pedestrian Bridge June 28, 2013 (Photo: Prince Albert 2013)

Figure 12: Little Red River Park Pedestrian Bridge Normal Flow Conditions Oct 15, 2017 (Photo: Stantec 2017)

Figure 13: Hwy 55 Bridge over Little Red River June 28, 2013 flood (Photo: Prince Albert 2013)

Figure 14: Highway 55 Bridge Over Little Red River Normal Flows May 9, 2019 (Photo: Stantec, 2019)

3.0 SURVEY WORK AND BASE MAPPING

Survey and mapping for this project was conducted in coordinate system NAD 1983 UTM Zone 13N, with vertical datum CGVD2013.

3.1 LIDAR DATA

LiDAR data files for the study area were provided by the City of Prince Albert and LiDAR was acquired on October 23 and 25, 2014. The following datum parameters, which were utilized for the topographic and bathymetric surveys, were used for referencing the LiDAR data.

- Horizontal Datum:
  - UTM NAD 83(CSRS) zone 13
- Vertical Datum:
  - CGVD2013
  - Geoid Model: CGG2013

Ground truthing was completed along hard surface locations to verify integration between the field survey data and the LiDAR data.

3.2 NORTH SASKATCHEWAN RIVER SURVEY

The bathymetry of the NSR was surveyed between June 3 and June 28, 2019 under the direct supervision of a Professional Land Surveyor. One hundred seventy (170) river cross-sections were surveyed using a 16 foot Jon Boat equipped with a SonarMite single beam Echosounder capable of collecting centimetre level measurements. Global Navigation Satellite Systems Real Time Kinematic (GNSS RTK) and conventional total station was used to tie in the ground survey of the water's edge. Bathymetric sounding lines were also completed alongside channels and around islands. Over 13,000 data points were collected as shown in Figure 15.

3.3 LITTLE RED RIVER SURVEY

Six cross-sections were surveyed in the LRR between June 6 and June 7, 2019 at representative sections of the channel in riffles as shown in Figure 16. Surveyed cross-sections were used in lieu of bathymetry due to the shallow, confined, and heavily vegetated nature of the LRR, which makes it impractical to survey using a SonarMite instrument mounted on a boat, therefore GNSS GPS was used to collect the cross-section data. These channel sections were assumed to be representative of the reach within the study area and were interpolated through the channel and tied into the LiDAR data for the flood plain.

The accessible cross-sections were wadeable and provided safe passage by foot, so the bathymetric survey was conducted through the bed of the creek identifying the required components of the riverbed.

As with the NSR cross-sections, the ground survey was extended to the edge of the river and from there the existing LiDAR Digital Terrain Model (DTM) was extended beyond to the study boundary.

3.4 BASE MAPPING

The elevation surface developed for the modeling portion of the project was a composite surface using a combination of the field collected survey data and the provided LiDAR data. The bathymetric and conventional survey data was first compiled and used to form the basis of the NSR channel surface. Additional points were interpolated in order to fill the gaps between the collected data. Data points representing the 6 bridge piers on each of the Diefenbaker Bridge and Carlton Trail Railway Bridge were also inserted into the surface data to capture the hydraulic effects of the instream structures. The bases of the piers were estimated based on the bathymetric survey points nearest to each pier. In addition to the bridge piers, the weir near the airport was also added to the surface as it was not captured by the bathymetric or conventional surveys. A constant elevation of 418.1 masl was assumed for the entire length of the weir. All of these data points were used to build a composite surface in AutoCAD Civil 3D 2017. This composite surface was converted to .tif format, with a 1 m pixel resolution. The exported surface from AutoCAD was then combined with the LiDAR data in ArcGIS Version 10.5 by using the Raster Calculator tool to create a DTM in .tif format of the NSR and the LRR and their flood plains.

The elevation surface for the LRR was developed separately from the NSR. The six surveyed cross-sections from the LRR were used to derive a representative channel for use in the modeling. Interpolating from the surveyed cross-sections in the LRR to create the channel surface was necessary since the water depth in the LRR was not deep enough to complete an accurate bathymetric survey by boat. A 3D river channel is important to include in a 2D model to provide reasonable results. In order to develop the 3D river channel, the LRR channel banks were digitized using the aerial imagery provided by the City, and an approximate river cross-section was interpolated between the surveyed sections to “fill-in” the gaps between the survey locations. The resulting LRR channel was then combined with the LiDAR data provided by the City and the NSR composite surface to create a seamless elevation surface to use in the modeling.

This final surface was reviewed by the City of Prince Albert and was confirmed to be suitable for use in mapping.

Additional base data that was obtained or used is listed below:

1. City of Prince Albert Aerial Imagery

   Two orthorectified aerial images were provided by the City in .ECW format. The imagery coordinate system is NAD 1983 UTM Zone 13 N, and the spatial resolution is 0.075 m x 0.075 m.

2. Study Area Boundary

   A KML (keyhole markup language) file representing the study area boundary was provided by the City. This file was converted to shapefile format and projected into the NAD 1983 UTM Zone 13 N coordinate system.

3. Study Area Reaches

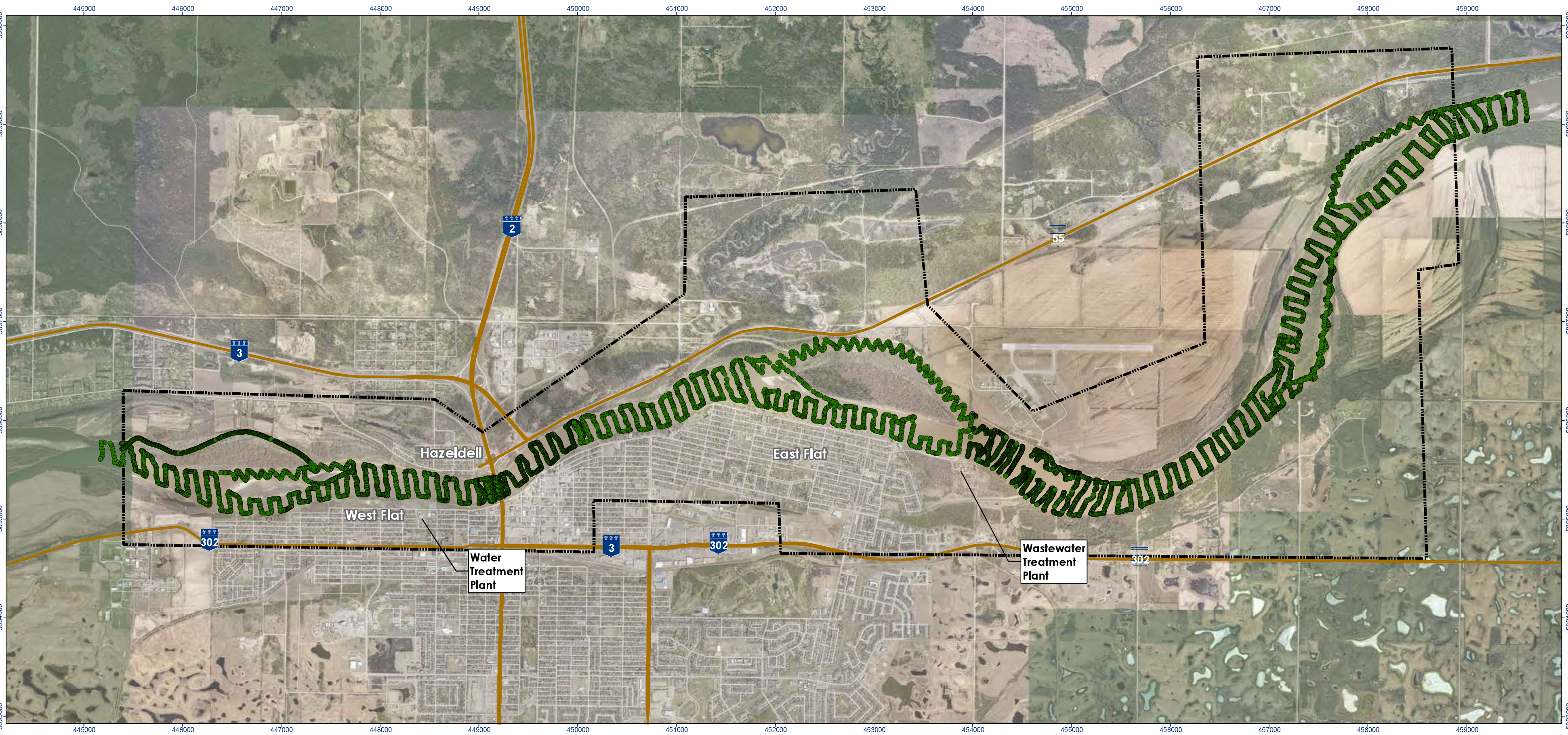
   The study area river reaches were digitized from the aerial imagery provided by the City.

4. Building Footprints

   A shapefile representing building footprints was provided by the City. This data was used for mitigation assessments discussed in Section 8.

5. Background Data

   Additional background and hydrologic data were obtained from the WSC and the Government of Canada Open Government Data portal. This includes WSC stations, major watercourses and water bodies in the vicinity of the study area, and roadway networks.



Legend

- Bathymetric Survey Points
- Study Area Boundary

0 770 1,540 metres

(At original document size of 11x17)
1:40,000

N

Stantec

City of Prince Albert

Project Location
Prince Albert, SK

Prepared by MA on 2019-11-18
TR by HA on 2019-11-18
IR Review by DS on 2019-11-18

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Bathymetric Survey

Figure No.
15

Title
Soundings from Bathymetric Survey of the North Saskatchewan River

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Vertical Datum: CGVD2013
3. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Legend

- Cross-Section Survey Points
- Study Area Boundary

0 190 380 metres

(At original document size of 11x17)
1:10,000

N

Stantec

City of Prince Albert

Project Location
Prince Albert, SK

Prepared by MA on 2019-11-18
TR by HA on 2019-11-18
IR Review by DS on 2019-11-18

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Bathymetric Survey

Figure No.
16

Title
Cross-Section Data Points on Little Red River

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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3.5 MAPPING ACCURACY

3.5.1 Spot Elevation Data Check

A sample of the survey data was compared to the LiDAR data to check the accuracy and the agreement between the two sources of data. Only points that were surveyed on the ground away from the river channels were used since the variation in water surface would make comparison of bank points impractical. This exercise included collecting a total of 58 points consisting of check shots on survey control benchmarks, survey along a pathway and boat launch adjacent to 3rd Avenue at River Street, as well as survey along Veterans Way near the airport. The results of the comparison between the survey data and the LiDAR data are shown in Table 1 below.

Table 1: Survey Data Spot Elevation Check

Parameter	Comparison Considering All Data (m)	Comparison Considering Maximum & Minimum Deviations Removed (m)
Positive delta	0.235	0.120
Negative delta	-1.725	-0.524
Range	1.960	0.644
Average	-0.127	-0.105

As shown above, the sampled survey data varied from the LiDAR data by an average of -0.127 m, with a maximum positive deviation of 0.235 and a maximum negative deviation of -1.725 m, and a range of 1.96 m when using all samples. However, when the maximum positive and negative deviations were excluded, the average drops to -0.105 m with a range of only 0.644 m.

4.0 HYDROLOGIC ANALYSIS

A hydrologic analysis was conducted for the purposes of establishing peak instantaneous flows on the NSR and LRR for the 1;10, 1:25, 1:50, 1:75, 1:100, 1:200 and 1:500 year return periods. These return periods are a statistical probability used to describe the risk of a flood of a given magnitude occurring each year. These estimates are made by using measured streamflow values to estimate the annual exceedance probability (AEP) of various flood magnitudes. A 1:100 year flood, for example, has a 1 in 100 or 1% chance of being equaled or exceeded in any given year, while a 1:10 year flood has a 10% AEP and a 1:500 year flood corresponds to an AEP of 0.2%. Based on probability theories, over a 30 year span a 1:100 year flood actually has a 26% chance of occurring (Environment Canterbury, 2019). These estimates are refined and updated as additional streamflow and flood peak data is collected. Additionally, these estimates are based on historical flow records and are assumed to be representative of future flows.

The flows resulting from the hydrologic analysis were used in the HEC-RAS 2D model to evaluate return period flood water surface elevations (WSE) and velocity profiles within the study area.

4.1 NORTH SASKATCHEWAN RIVER

4.1.1 Background

The hydrologic estimates were based on the work described in “Prince Albert Flood Damage Reduction Study Hydrology Report” (PFRA, 1980) and “Prince Albert Flood Frequency Update” (Saskatchewan Watershed Authority (SWA), 2010). Highlights of these reports include the following:

- The headwater area of the NSR contributes a large portion of the observed flow, and while the upstream Brazeau and Bighorn dams do not operate to attenuate flood peaks, they still cannot be discounted when assessing flood frequency.
- Flow estimates are based on publicly available data from WSC hydrometric station 05GG001 North Saskatchewan River at Prince Albert.
- Flood frequency estimates are based upon a naturalized peak mean daily flow data set that factors measured flows to adjust for the effects of the upstream regulation.
- A Log Pearson Type III probability distribution was used to estimate a range of flood return periods. The results were adjusted “by-eye” to fit the plotted curve more closely at higher magnitude events. These flows were subsequently multiplied by a calculated peaking factor to establish instantaneous flow estimates.
- The 2010 report recommended a slight decrease in flood frequency estimates after considering an additional 30 years of measured flow data. The results from both studies are summarized in Table 2.

Table 2: Comparison of Past Flood Frequency Estimates

Return Period	PFRA 1980 Study Peak Instantaneous Flow (m^3/s)	SWA 2010 Study Peak Instantaneous Flow (m^3/s)
1:10	2,570	2,350
1:50	4,340	3,900
1:100	5,280	4,800
1:500	8,160	8,070

4.1.2 Updated Flood Frequency Analysis

An additional 8 years (2008-2016) of recorded flows are available since the 2010 SWA report and the flood frequency analysis was updated to consider these additional data points. As per the 2010 update, the historic flood of August 1899 (approximately 4,530 m^3/s) was not included in the flood frequency analysis due to the potential inaccuracy of anecdotal flood data. The event does not have any measured values associated with it. A sensitivity analysis was completed that included this data point in the statistical analysis, which resulted in a 5% or less change in flood frequency estimates and would still require a “by-eye” fitting at the higher return periods including the Regulatory 1:500 year event. The following method was used in the updated hydrologic estimates:

1. Recorded flows from 1912 to 1962 were used since this period of record was not regulated by dams and does not require naturalization calculations.

2. From 1963 to 1978, the higher of the two naturalized maximum daily mean flows from the 1980 and 2010 reports were used to provide a more conservative estimate.

3. Values from the 2010 report were used from 1979 to 2008.

4. A ratio of naturalized to measured flows from 1963 to 2008 was established and applied to the peak mean daily flows recorded from 2008 to 2016 in order to convert these data points to naturalized flows. This naturalization allows for the effects of the upstream regulation to be factored into the flood frequency analysis and anticipated flood peaks. Naturalization provides a fixed frame of reference to compare measured flows from before and after the construction of dams to allow for an accurate comparison of long-term records of flows and flood peaks on the river. By using the entire available historic record and adjusting for regulation by naturalizing flows, a more robust flood frequency estimate can be established.

5. The following frequency analyses were applied to the 103 year data set using Hyfran+ v2.2 software: 3 Parameter Lognormal, Log Pearson Type III, Gumbel, Lognormal, Generalized Extreme Value (GEV). Fitting techniques for these series included Maximum Likelihood and Method of Moments.

Flood peaks on the NSR are available from 1912 to 2016 and are shown in Figure 17. The raw flow data has been included in Appendix B.

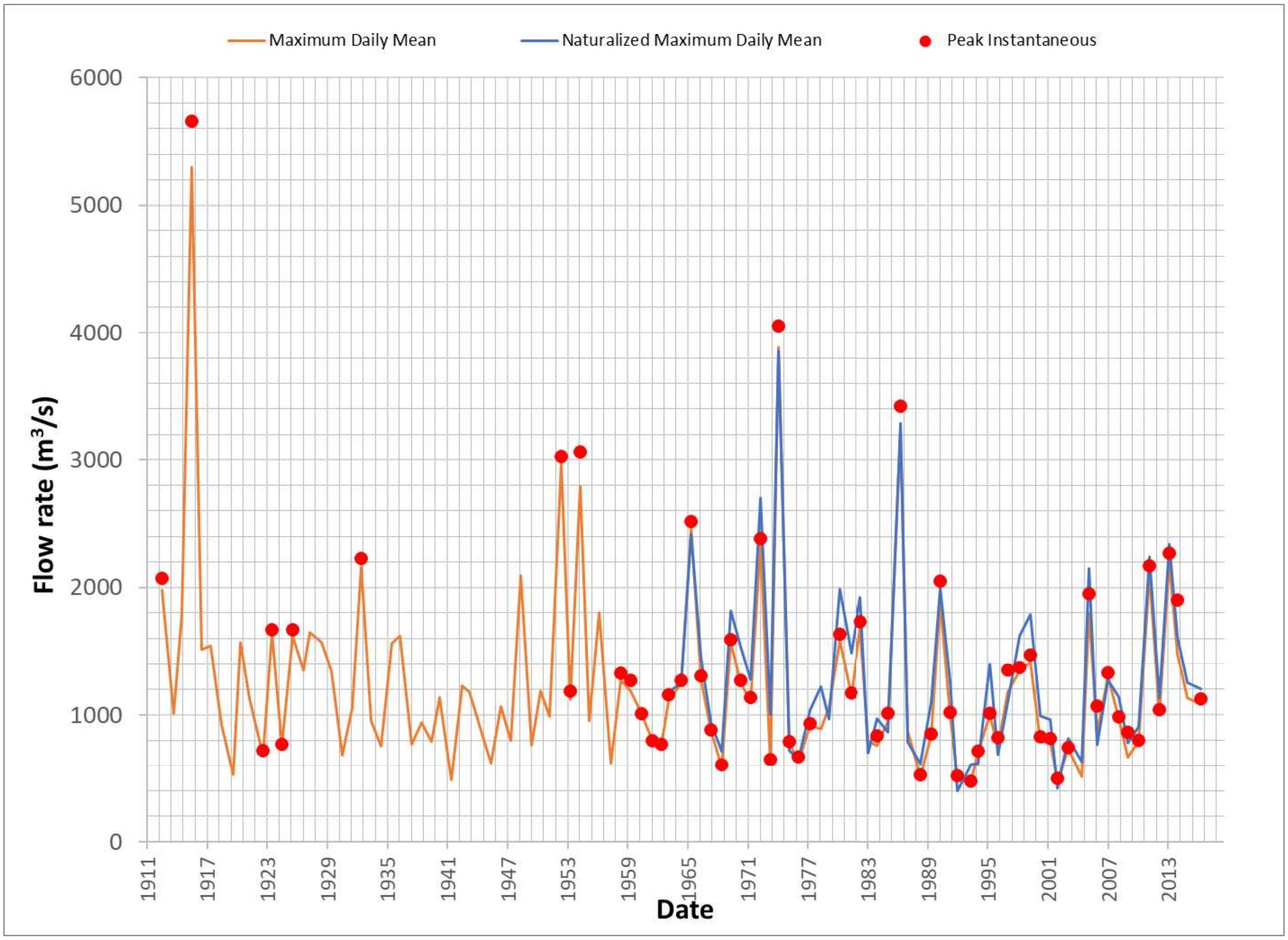


Figure 17: North Saskatchewan River Flood Peaks, 1912 – 2016

A Log Pearson Type III distribution with Method of Moments was initially selected as the best fitting distribution. However, as was found in the two previous reports, the distribution does not accurately capture higher magnitude events. A "by-eye" fitting of the curve was determined to be appropriate for higher magnitude events. The Log Pearson Type III, Method of Moments distribution is shown in red and the "by-eye" fitting for higher magnitude events is shown in green on Figure 18.

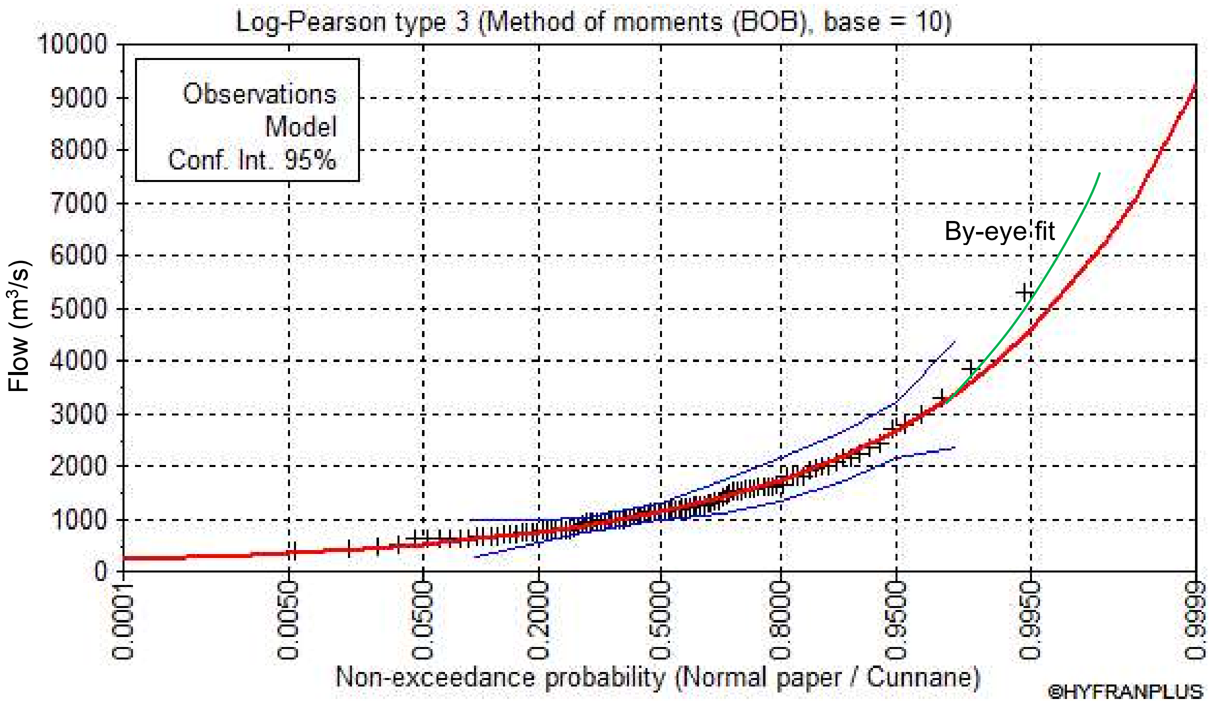


Figure 18: North Saskatchewan River Flood Frequency Analysis

These results were multiplied by a peaking factor of 1.09 as described in the previous reports to calculate peak instantaneous flood flows. This peaking factor value was reviewed by Stantec and accepted as conservative and appropriate. Updated return period flows, including additional flood frequency events (1:25, 1:75, 1:200 year) are summarized below in Table 3.

Table 3: Updated Return Period Flows

Return Period	Daily Mean Peak Flow (m³/s)	"By-Eye" Estimate Flow (m³/s)	Peak Instantaneous Flow (m³/s)
1:10	2,200		2,400
1:25	2,850		3,107
1:50	3,380		3,685
1:75	3,710		4,044
1:100	3,950	4,500	4,905
1:200	4,570	5,250	5,720
1:500	5,470	7,500	8,175

4.1.3 Recommendation

The additional measured flows available from 2008 to 2016 result in slightly different return period flows when compared to the 2010 SWA report results (range of approximately 1% to 5%). The recommended updated flood frequency peak instantaneous flow estimates to be carried forward for use in the hydraulic model are summarized in Table 4. The flows from the 1980 and 2010 studies are included in Table 4 for comparison.

Table 4: Recommended Return Period Flows for North Saskatchewan River

Return Period	PFRA 1980 Study Peak Instantaneous Flow (m^3/s)	SWA 2010 Study Peak Instantaneous Flow (m^3/s)	NSR Peak Instantaneous Flow (m^3/s)
1:10	2,570	2,350	**2,400**
1:25			**3,107**
1:50	4,340	3,900	**3,685**
1:75			**4,044**
1:100	5,280	4,800	**4,905**
1:200			**5,720**
1:500	8,160	8,070	**8,175**

4.2 LITTLE RED RIVER

4.2.1 Background

The hydrology and flood frequency estimates for the LRR were outlined in the "Prince Albert Flood Damage Reduction Study Hydrology Report" (PFRA, 1980). A summary of their methods is as follows:

- Flow data from 1919 to 1961 was estimated using various neighbouring gauged streams using a regressions analysis and an effective drainage area ratio of 0.7 to transfer these flows to the mouth of the LRR.
- Natural peak flows on the LRR were available from 1962 to 1978 at WSC hydrometric station 05GG007 Spruce River below Anglin Reservoir.
- The report estimated the Gross Drainage Area (GDA) of the LRR at the mouth to be 1,667 km^2.
- The report estimated the Effective Drainage Area (EDA) of the LRR at the mouth by reducing the initial estimation of 1,196 km^2 to 949 km^2 following findings that major flood peaks downstream of Anglin Lake would be smaller due to natural storages upstream of the lake.

- Recorded peaks were considered to be natural for WSC hydrometric station 05GG003 Spruce River near Outlet from Anglin Lake referencing a 1959 PFRA Hydrology Division investigation of flows at this station "West Anglin Lake… is shallow and small in area so has very little regulatory effect on Spruce River flood peaks".
- The flow data was fit to several statistical distributions to estimate flood frequency return periods. A Lognormal fitting was selected as the most appropriate, and the results were multiplied by a calculated ratio of instantaneous to daily means flows (ratio ranged between 1.3 to 1.35), resulting in the following flood frequency estimates presented in Table 5.

Table 5: PFRA 1980 Study Flood Frequency Estimates

Return Period	Daily Mean Peak Flow (m^3/s)	Peak Instantaneous Flow (m^3/s)
1:10	28.2	38.0
1:50	64.0	84.8
1:100	85.2	113
1:500	153	200

4.2.2 Updated Flood Frequency Analysis

Stantec attempted to recreate the LRR datasets described for the period of 1919 to 1961, however, except for 11 years, data points from these WSC stations were not available. Furthermore, the WSA investigated whether the missing data points from WSC hydrometric station 05GG007 could be located to supplement the 11 years of data available from this site. The WSA confirmed that this data was not available, therefore it could not be included in the flood frequency analysis.

In 1993, Saskatchewan Water Corporation (SaskWater at that time) updated the report and appendices titled "Magnitude and Frequency of Peak Flows and Flow Volumes in Saskatchewan". This document describes the procedures for estimating peak flows for various flood occurrences in ungauged areas using flow transposition and is currently used by the WSA's Hydrology Branch as the preferred method for peak flow estimation. These documented procedures were followed for peak flow estimation at the mouth of the LRR.

4.2.2.1 GDA and EDA Estimation

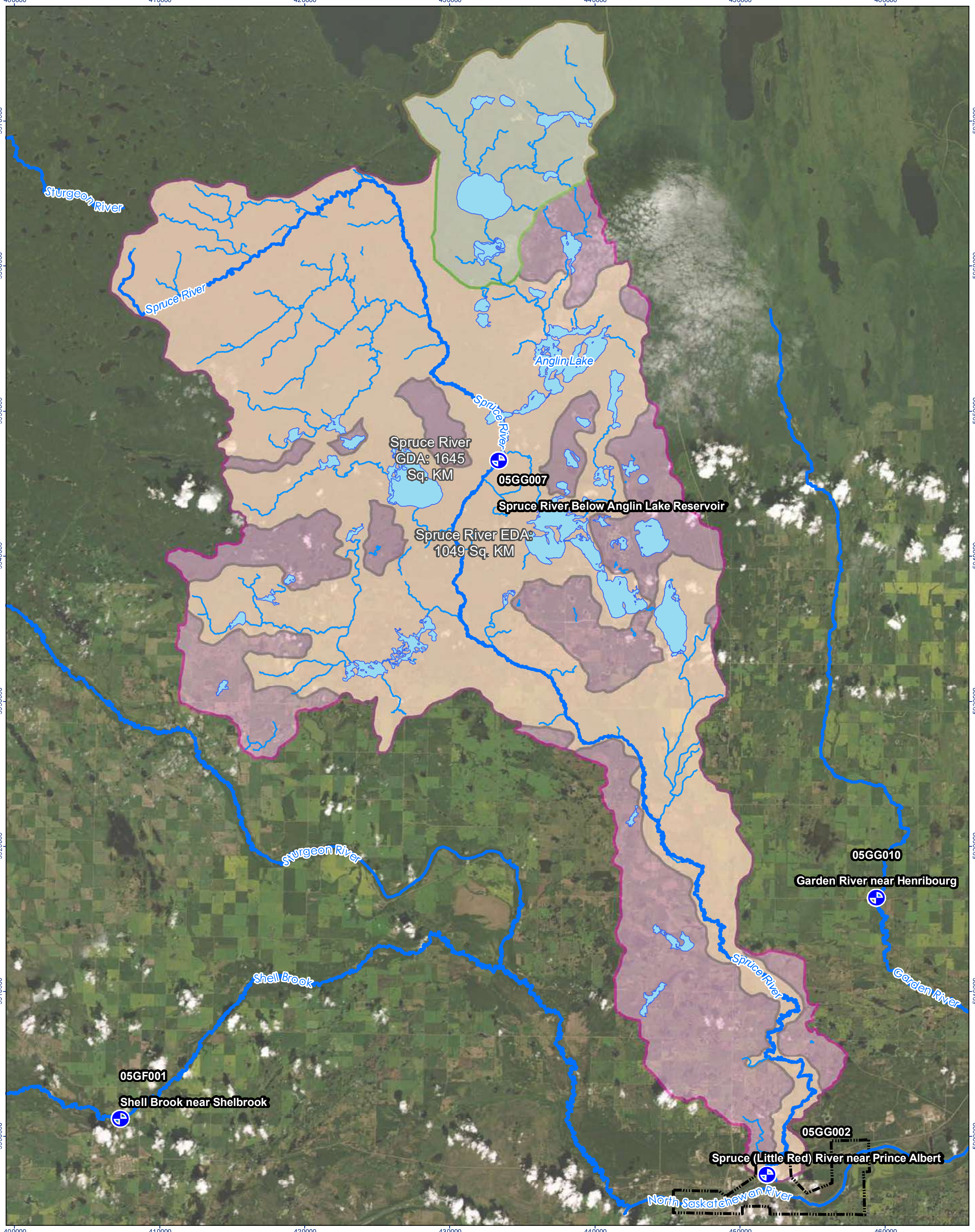
The GDA and EDA were reviewed and updated for the LRR basin referencing current PFRA boundaries for gross and non-effective drainage areas as per Figure 19. Definitions of GDA and EDA (Godwin and Martin, 1975) are as follows:

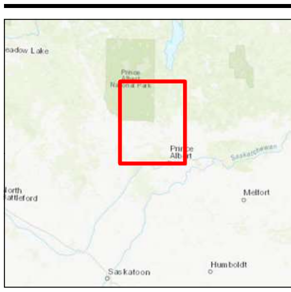
- **Gross Drainage Area (GDA):** The gross drainage area of a stream at a specified location is that plane area, enclosed by its drainage divide, which might be expected to entirely contribute runoff to that specified location under extremely wet conditions. The gross drainage boundary is the drainage divide or the height of land between adjoining watersheds.
- **Effective Drainage Area (EDA):** The effective drainage area is that portion of a drainage basin which might be expected to entirely contribute runoff to the main stream during a flood with a return period of 2 years. This area excludes marsh and slough areas and other natural storage areas which would prevent runoff from reaching the main stream in a year of average runoff.

The Non-effective Drainage Area can be considered the difference between the GDA and the EDA.

The GDA based on the PFRA boundaries is estimated to be 1,640 km^2.

Considering the sum of the non-effective PFRA drainage areas (424 km^2), the resultant EDA would be 1,216 km^2. Considering the methods of the 1980 PFRA report, the estimated drainage area north of Anglin Lake (156 km^2) was subtracted from 1,216 km^2 to provide a reduced EDA of 1,060 km^2, based on the report's statement that major flood peaks downstream of Anglin Lake would be smaller due to natural storages upstream of the lake. Stantec also assessed the drainage area north of Anglin Lake and, applying professional judgement, concluded that this area should be excluded from the defined EDA.





Legend
- WSC Gauging Stations
- Study Area Boundary
- Waterbodies
- Assumed Non-Effective Drainage Area North of Lake Anglin
- Spruce River EDA
- Spruce River GDA

0 5,000 10,000 metres

(At original document size of 11x17)
1:275,000

N

Stantec

City of Prince Albert

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 13N
2. Data Sources: Water Survey of Canada; GeoBase - National Hydrological Network; GeoBase - National Road Network
3. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Project Location
Prince Albert, SK

Prepared by MA on 2019-10-24
TR by HA on 2019-10-24
IR Review by DS on 2019-10-24

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
19

Title
WSC Station Locations and Litte Red River GDA and EDA

U:\113101975\report\figures\map_mxd\fig_19_WSC_locations.mxd Revised: 2019-12-06 By: MaAnderson

4.2.2.2 Single Station Basin Transfer Techniques

As outlined in “Magnitude and Frequency of Peak Flows and Flow Volumes in Saskatchewan” (SaskWater, 1993), the following equation is used for return periods from 1:2 year to 1:50 year:

$$Q_{est} = Q_{gauged}\left(\frac{EDA_{ungauged}}{EDA_{gauged}}\right)^{0.7}$$

where:

Q_{est}	Estimated flow - ungauged watershed
Q_{gauged}	Ranked flow for design frequency – gauged watershed
EDA_{gauged}	EDA of the gauged watershed
$EDA_{ungauged}$	EDA of the ungauged watershed

Peak flow values for flood events less frequent than the 1:50 year return period are estimated using the following procedure (SaskWater, 1993):

- The effective and gross drainage area ratios are plotted on normal probability paper (SWA, Figure 30, 18 September 1986), so that the EDA ratio ($EDA_{ungauged}$ / EDA_{gauged}) corresponds with the 1:50 year probability position and the GDA ratio ($GDA_{ungauged}$ / GDA_{gauged}) corresponds with the 1:1000 year probability position.
- The two plotted positions are joined with a straight line. The line yields drainage area ratios for intermediate probability positions between 1:50 year and 1:1000 year.
- The peak flows for these flood occurrences at the hydrometric gauging station are multiplied with the drainage area ratios obtained from the straight line plot, raised to the power of 0.7.

4.2.2.3 WSC Gauging Station Selection

The WSA was engaged to assist in the selection of an appropriate WSC gauged site for flow transposition. WSC hydrometric station 05GG010 Garden River near Henribourg was selected as it is immediately adjacent to the ungauged basin, is on an unregulated stream and has a drainage area similar to the ungauged site in terms of shape, topography, soils and land cover. It is noted the EDA and GDA of WSC gauging station 05GG010 is 372 km^2 and 903 km^2, respectively, which is less than the ungauged basin of the LRR.

Stantec initially reviewed WSC hydrometric stations 05GF001 Shell Brook near Shellbrook and 05GG007 Spruce River Below Anglin Reservoir whose locations are shown on Figure 19. These stations were selected since they have similar basin characteristics, were close in proximity to the study area, and had recently available data. A flood frequency analysis update was completed for each station using hydrologic frequency analysis Hyfran+ v2.2 software, where several statistical distributions to estimate flood frequency return periods were reviewed. After selection of the best fit statistical distribution, the flows were then transposed to the ungauged site.

These transposed results produced significantly different peak flow estimates compared to the 1980 PFRA report and were therefore not included in the analysis.

The hydrometric records for WSC gauging station 05GG010 Garden River near Henribourg were reviewed and assessed for an updated flood frequency analysis. Flow data is included in Appendix B, while a visualization of flood peaks in the available hydrometric record for this station is shown in Figure 20.

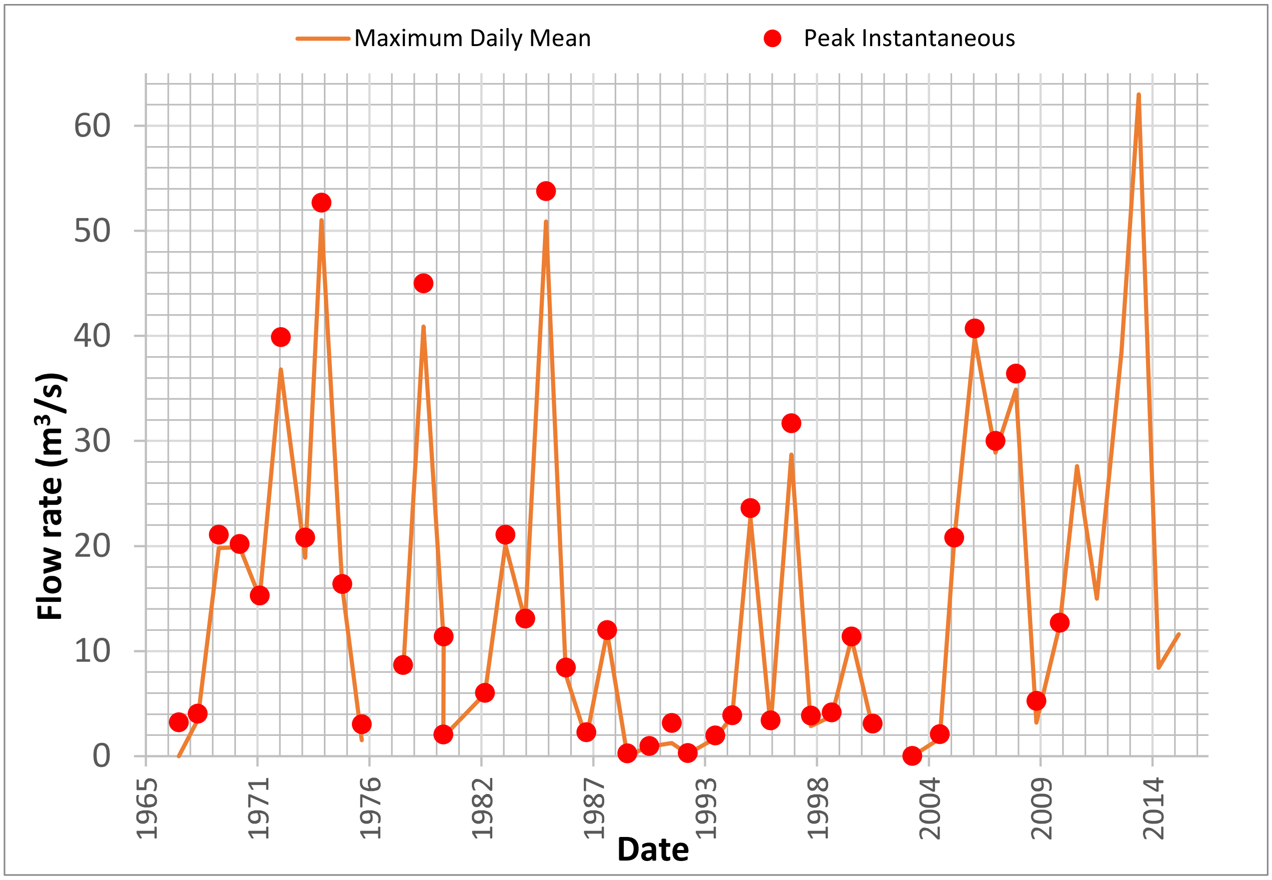


Figure 20: Garden River Peak Flow History, 1962 – 2016

4.2.2.4 Flood Frequency Distribution Selection

The flow data was fit to several statistical distributions including Lognormal, 3 Parameter Lognormal, Log Pearson Type III, Gumbel, Gamma and Normal using various methods including maximum likelihood or Method of Moments, depending on the parameters. A Gamma distribution with Method of Moments provided the best statistical fit and curve fitting, as shown in Figure 21, and was selected to form the basis for the flood frequency estimates.

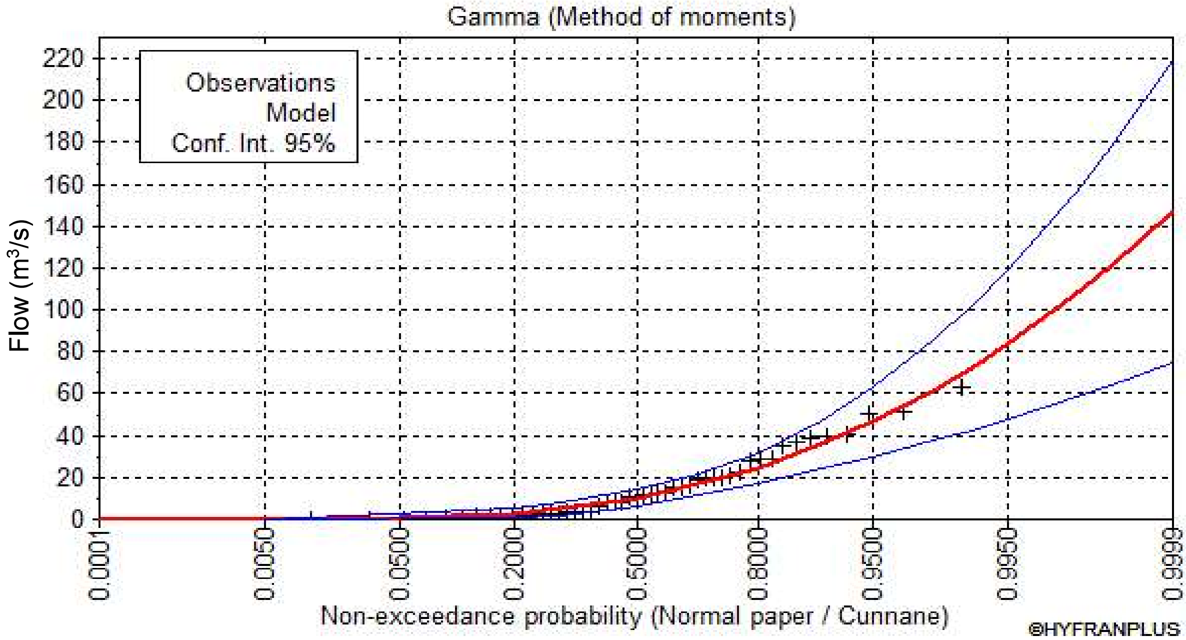


Figure 21: Little Red River Flood Frequency Analysis

The updated flood frequency results for WSC hydrometric station 05GG010 Garden River near Henribourg are summarized in Table 6.

Table 6: Updated Flood Frequency Results for WSC Hydrometric Station 05GG010 Garden River near Henribourg

Return Period	Daily Mean Peak Flow (m³/s)
1:10	35.6
1:25	50.3
1:50	61.4
1:75	67.9
1:100	72.5
1:200	83.7
1:500	98.5

4.2.2.5 Peaking Factor

The WSA completed a flood frequency analysis update in 2017 for WSC 05GG010 Garden River near Henribourg, which considered the average of the peak instantaneous to peak mean daily flow ratios for the three (3) highest recorded peak flows for an estimated peaking factor of 1.05. A peaking factor of 1.05 was also estimated by Stantec based on the average of the peak instantaneous to peak mean daily flow ratios for the ten (10) highest recorded peak flows from the WSC 05GG010 Garden River near Henribourg hydrometric station dataset between 1967 – 2016. These results vary significantly from the

1980 PFRA ratios, which ranged from 1.31 to 1.35 based on the Fuller Formula (Fuller, 1914) and ratios of instantaneous to daily mean flows from four (4) adjacent hydrometric stations that included WSC 05GG010 Garden River near Henribourg, 05GF001 Shell Brook near Shellbrook, 05GF002 Sturgeon River near Prince Albert and 05KE005 White Fox River near Garrick. Based on the current practices adopted by the WSA, the recommended peaking factor is 1.05.

4.2.2.6 Flow Transposition Results

Following the procedures described in Section 4.2.2.2, the flood frequency results at WSC station 05GG010 presented in Table 6, were transposed to the mouth of the LRR. The peaking factor of 1.05 was used to estimate peak instantaneous flows, and the results are presented in Table 7.

Table 7: Peak Flows Estimated at the Mouth of the Little Red River

Return Period	Daily Mean Peak Flow (m^3/s)	Peak Instantaneous Flow (m^3/s)
1:10	74.1	77.8
1:25	104.7	109.9
1:50	127.8	134.2
1:75	135.0	141.8
1:100	139.6	146.6
1:200	147.7	155.0
1:500	160.0	168.0

4.2.3 Recommendation

Current provincially accepted methodologies for peak flow estimation at ungauged stations resulted in different results compared to the 1980 PFRA assessment with higher flow estimates at lower return periods and lower flow estimates at higher return periods. The 1980 PFRA study adopted flow transposition methodologies; however, used significantly larger river systems in this analysis including the Battle River, which could have skewed flood frequency estimates.

Based on consultation with the WSA for selection of WSC gauging stations and using the procedures described above, it is recommended that the updated flood frequency estimates summarized in Table 8 are carried forward for use in the hydraulic model. The 1980 PFRA flows are in included in Table 8 for comparison.

Table 8: Recommended Return Period Flows for Little Red River

Return Period	PFRA 1980 Study Peak Instantaneous Flow (m^3/s)	LRR Peak Instantaneous Flow (m^3/s)
1:10	38	77.8
1:25		109.9
1:50	84.8	134.2
1:75		141.8
1:100	113	146.6
1:200		155.0
1:500	200	168.0

5.0 HYDRAULIC ANALYSIS

A two-dimensional (2D) hydraulic model was built for the project area using the United States Army Corps of Engineers (USACE) software HEC-RAS version 5.0.6. HEC-RAS 2D is suited to complex flow situations, especially around obstructions such as instream structures, flow splits, and buildings. These capabilities make it a useful tool for understanding flood plain interactions and informing flood hazard mapping.

5.1 MODEL SURFACE

The DTM surface described in Section 3.4 was imported into the model to develop the terrain that forms the basis for the hydraulic analysis and assessment. The surface was composed of combined LiDAR, survey, and bathymetric data and also included bridge piers as instream obstructions for the model. The terrain was imported as a .tif file, with a cell size of 1 m.

A computational grid was developed over the surface, and cell spacing was initially assigned at 50 m given the size of the modelled area. This density was increased around important features such as bridges and dykes using breaklines. These breaklines also served to demarcate elevation features to increase model and cell computational accuracy.

The river's edge was delineated by additional breaklines to ensure sufficient cell spacing to capture flows as they spilled from the river channel under flood conditions. Breaklines were included at the major bridges over the NSR, the Highway 55 bridge over the LRR, at the weir on the NSR, and at the confluence of the two rivers to increase cell density and capture flow patterns at these important locations. An additional breakline was added to follow the channel of the LRR in order to decrease the cell spacing from the 50 m used through the majority of the rest of the model and more accurately model lower return period flows in this tributary that are not driven by NSR backwater. Minimum cell spacing at these breaklines ranged from 30 m at the banks to 10 m at the major bridges and along the centreline of the LRR. Cell size variance around important features can be seen in Figure 22.

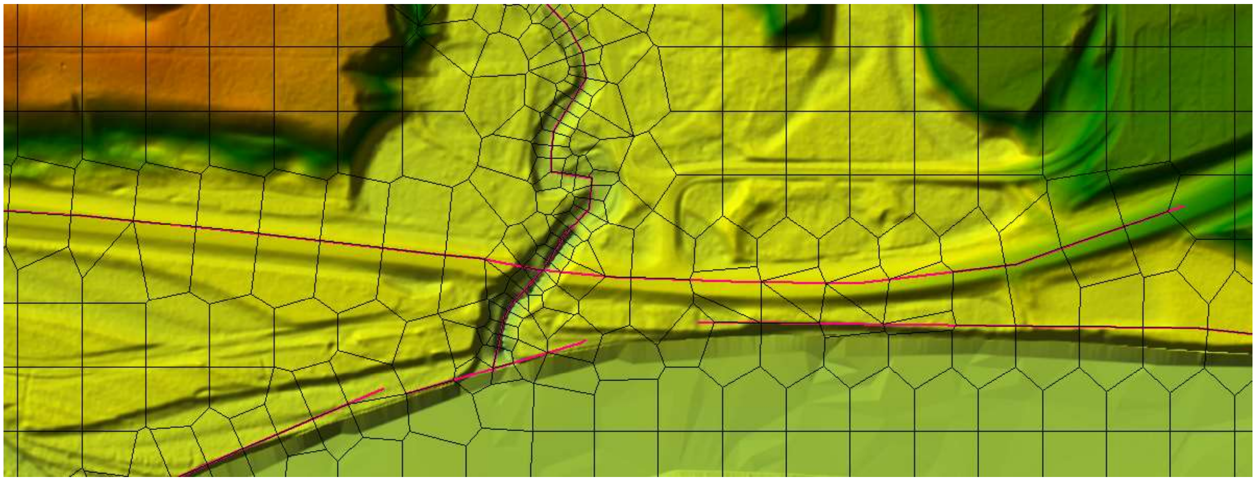


Figure 22: Cell Spacing Standard Grid and Variation at Confluence of Little Red River and North Saskatchewan River

5.2 MANNING'S N VALUES

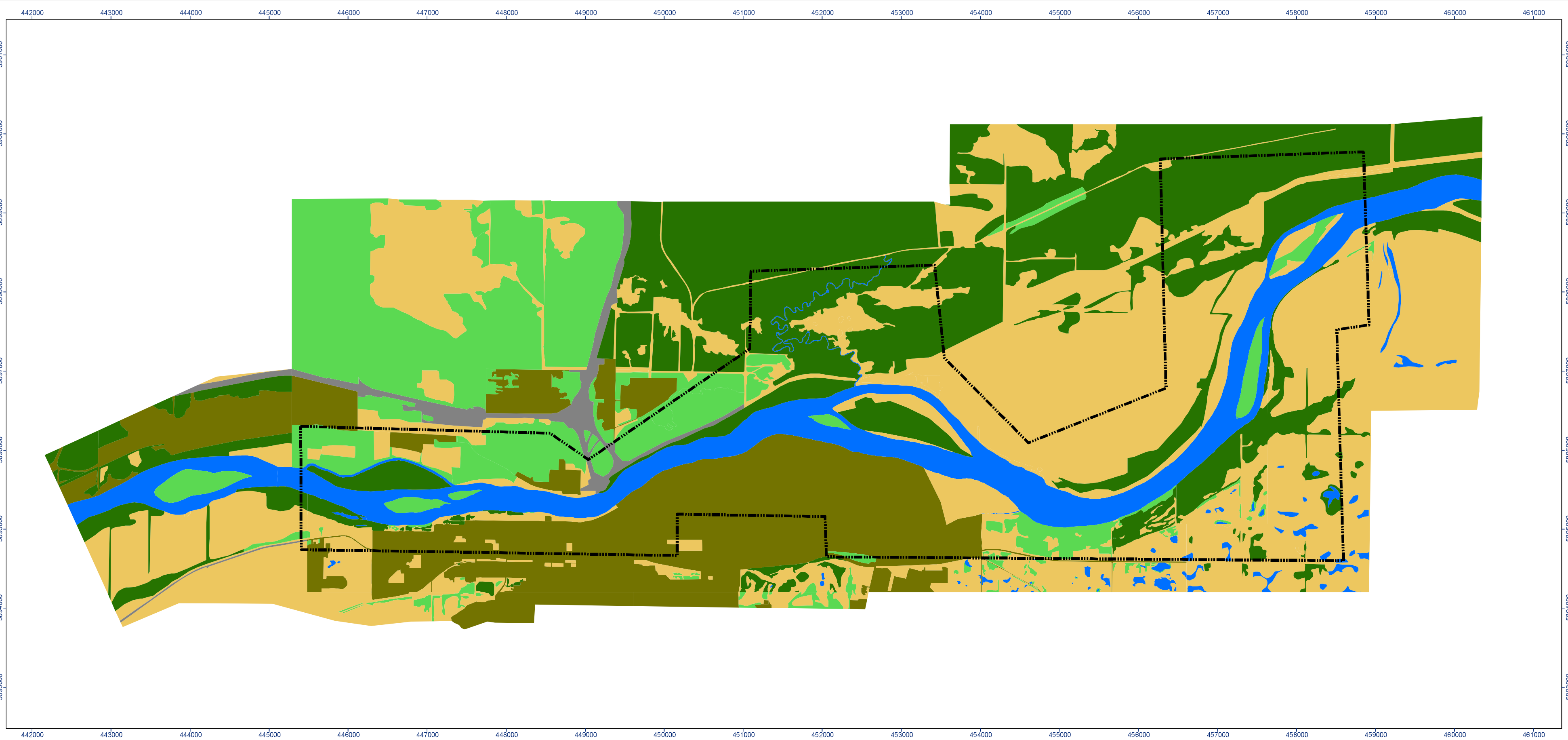
A land cover map of the project area was delineated using ArcGIS Version 10.5 software. The dominant land uses of the project area are Heavy Trees, Pasture, Trees, Transportation/Utility Corridor (TUC), Urban and Water. The default Manning's 'n' roughness values were chosen for these different landcovers based on Table 5-6 of "Open Channel Hydraulics" (Chow, 1959) and following a calibration exercise (see Section 5.4), were finalized as per Table 9. Manning's 'n' values for the Urban land cover were based on the United States Geological Survey (USGS) Water-Supply Paper 2339 "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" (USGS, 1989). Table 3 of the USGS document provides adjustment values for factors that affect roughness of flood plains and gives ranges of 'n' value adjustments to calculate an aggregate roughness for an urbanized flood plain. It considers degree of irregularity (n_1), effect of obstructions (n_3), and amount of vegetation (n_4), and is shown in Figure 23. For an urban flood plain, the n values used include n_1 = Severe, n_3 = Appreciable, and n_4 = Small, to estimate an Urban roughness of 0.04.

Table 3. Adjustment values for factors that affect roughness of flood plains
[Modified from Aldridge and Garrett, 1973, table 2]

Flood-plain conditions		*n* value adjustment	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest, flattest flood plain attainable in a given bed material.
	Minor	0.001–0.005	Is a flood plain slightly irregular in shape. A few rises and dips or sloughs may be visible on the flood plain.
	Moderate	0.006–0.010	Has more rises and dips. Sloughs and hummocks may occur.
	Severe	0.011–0.020	Flood plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pastureland and furrows perpendicular to the flow are also included.
Variation of flood-plain cross section (n_2)		0.0	Not applicable.
Effect of obstructions (n_3)	Negligible	0.000–0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, or isolated boulders, occupy less than 5 percent of the cross-sectional area.
	Minor	0.005–0.019	Obstructions occupy less than 15 percent of the cross-sectional area.
	Appreciable	0.020–0.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area.
Amount of vegetation (n_4)	Small	0.001–0.010	Dense growth of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation, or supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.011–0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation, or moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season.
	Large	0.025–0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation, or 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft, or mature row crops such as small vegetables, or mature field crops where depth of flow is at least twice the height of the vegetation.
	Very large	0.050–0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation, or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
	Extreme	0.100–0.200	Dense bushy willow, mesquite, and saltcedar (all vegetation in full foliage), or heavy stand of timber, few down trees, depth of flow reaching branches.
Degree of meander (m)		1.0	Not applicable.

Figure 23: Table 3 from USGS, 1989 for Estimating Urban Flood Plain Roughness

Land cover delineation through the project area is shown in Figure 24.



Legend

Landcover

- Channel / Water
- Heavy Trees
- Trees
- Pasture
- Transportation/Utility Corridor
- Urban Area
- Study Area Boundary

0 960 1,920 metres

(At original document size of 11x17)
1:50,000

N

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Stantec

City of Prince Albert

Project Location
Prince Albert, SK

Prepared by MA on 2019-11-15
TR by HA on 2019-11-15
IR Review by DS on 2019-11-15

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
24

Title
Project Area Land Cover Delineation

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Table 9: Manning's 'n' Value by Land Type

Land Cover Type	Final Manning's 'n' Range
Heavy Trees	0.06 - 0.1
Pasture	0.035
Trees	0.06
TUC	0.015
Urban	0.04
Channel / Water	0.028 - 0.032

5.3 MODEL RUN

Unsteady flow model runs were carried out at a 10 second interval with a 10 minute mapping output interval. The hydrograph output interval and detailed results output interval were both set at 1 hour. The geometry preprocessor, unsteady flow simulation, and post processor modules were each selected at every model run.

Unsteady computation parameters 2D flow options were all kept at their default values, including using the Diffusion Wave equation set to calculate results.

5.4 MODEL CALIBRATION

The calibration of the 2D model was based on several large flood events that occurred on the NSR, as described below:

1. One of the events occurred in 1980 and was used to calibrate the floodplain model developed in 1984 (PFRA, 1984). This 1980 flood was recorded in detail with a variety of measured elevations at points along the river during the flood. The first calibration flood is the June 12, 1980 flood which had a peak flow of 1,630 m^3/s as per WSC historical flood records presented on their website in October 2019. This peak flow corresponded with a flood elevation of 422.16 masl at WSC hydrometric station 05GG001 North Saskatchewan River at Prince Albert. The 1984 report had used a slightly lower flow value of 1,540 m^3/s for the 1980 flood (PFRA, 1984).

2. The second calibration flow was based on the 2,268 m^3/s flood that occurred on June 29, 2013. WSC provided a measured water surface for this flood at the WSC 05GG001 hydrometric station, which recorded the peak flow of 2,268 m^3/s on June 29, 2013 at 20:35. The peak water level of 5.477 m was converted to elevation 422.971 masl using the WSC datum elevation of 417.494 masl.

3. A flood flow of 3,790 m^3/s was measured on April 23, 1974. Water levels at the WSC 05GG001 hydrometric station were measured at 424.28 masl.

4. The highest flow ever recorded by WSC at Prince Albert was the 5,660 m^3/s (nearly 1:200 year) flood recorded on July 2, 1915. Based on photos and records and the peak flood elevation presented in the 1984 report by PFRA, a water surface elevation of 425.75 masl (converts to 425.49 masl using modern 2013 datum) was observed at the Carlton Trail Rail Bridge (which is approximately 575 m downstream of the WSC 05GG001 hydrometric station).

Modelled flood elevations were compared to measured flood elevations at specific locations based on the cross-section locations and measurement sites presented in the 1984 PFRA report. Cross-section locations are identified on Figure 26.

The 2D model was calibrated using channel slope and Manning's 'n' values for the channel and adjacent land uses. The energy grade line slope for the downstream boundary condition was adjusted around the approximate energy grade line of the system in combination with adjustments to the channel roughness. The Manning's 'n' roughness values and channel boundary condition slope were adjusted until the model data aligned with the measured flood elevations. Boundary conditions slopes used in calibration ranged between 0.0001 to 0.006 m/m. Figure 25 shows the WSE impacts of adjusting the downstream boundary condition for slopes from 0.0002 m/m to 0.0004 m/m. A boundary condition slope of 0.0003 m/m provided the best calibration and corresponded well with a measured water surface slope of 0.00027 m/m at the downstream end of the model.

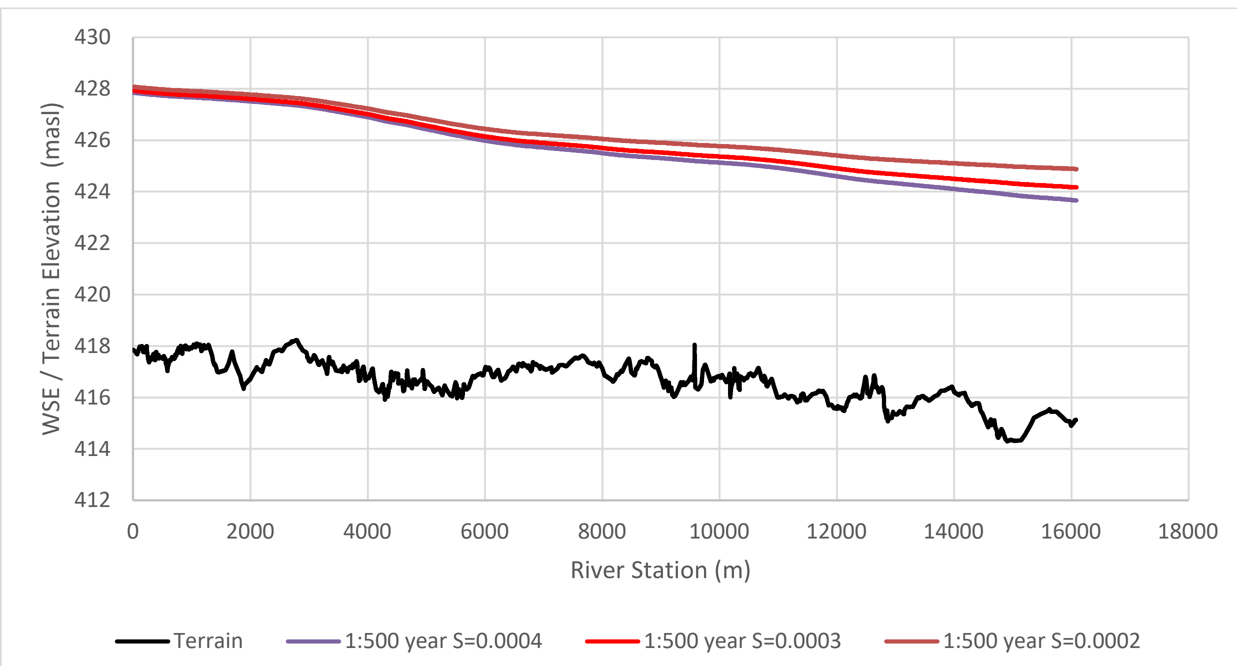
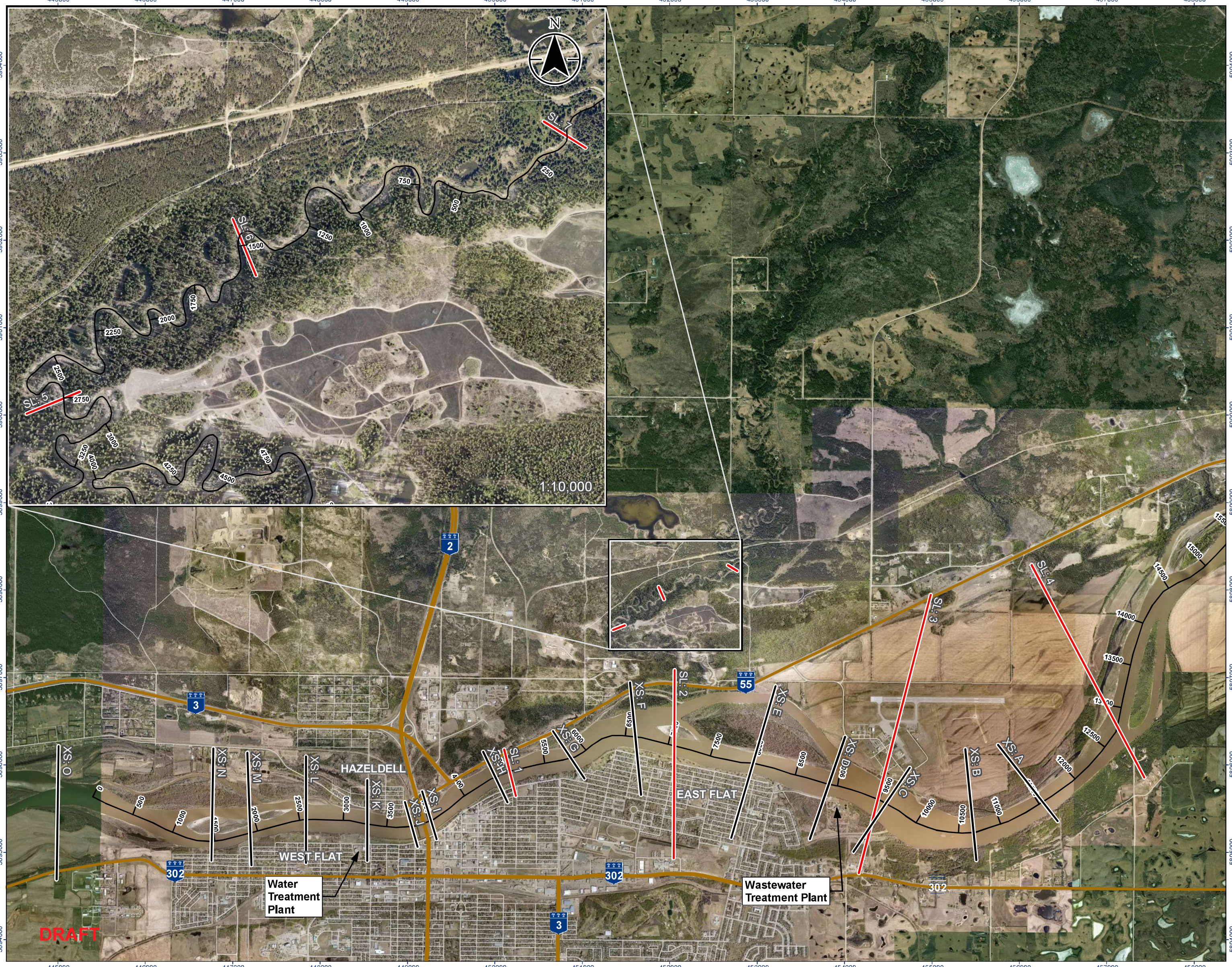


Figure 25: Calibration of Downstream NSR Boundary Condition Slope

The ranges of Manning's 'n' values used in calibration are shown in Table 10. As outlined in the USGS paper "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" *(*Arcement*,* 1989*)*: "Depth of flow must be considered when selecting 'n' values for channels. If the depth of flow is shallow in relation to the size of the roughness elements, the 'n' value can be large. The 'n' value decreases with increasing depth." Flows in the NSR range from approximately 5 m depths during the 1:10 year flood to greater than 10 m depths under the 1:500 year flood. Calibration efforts show that for flows up to the 1:10 year event, calibration is best with a higher channel Manning's 'n', while flows from the 1:25 year flow and greater calibrate best with a lower channel Manning's 'n' value. The Manning's 'n' values for the LRR were kept at the higher channel roughness as flood depths in this system are shallower than those observed in the NSR.

Table 10: Manning's 'n' Values Used in Calibration Runs

Land Cover Type	Maximum Value Tested	Minimum Value Tested	Final NSR Manning's 'n' Flow ≤ 1:10 year	Final NSR Manning's 'n' Flow ≥ 1:25 year	Final LRR Manning's 'n' All flows
Heavy Trees	0.1	0.05	0.1	0.06	0.1
Pasture	0.035	0.025	0.035	0.035	0.035
Trees	0.06	0.04	0.06	0.06	0.06
TUC	0.015	0.015	0.015	0.015	0.015
Urban	0.4	0.04	0.04	0.04	0.04
Channel	0.035	0.024	0.032	0.028	0.032



Stantec

City of Prince Albert

Legend

- Highways
- Local Road Network
- Sensitivity Line (SL)
- Cross Section (XS)

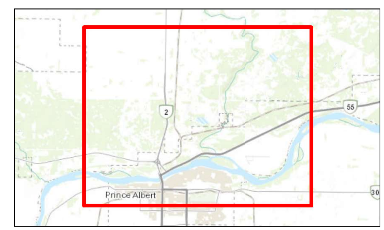
N

0 0.5 1 1.5 2 Km

(At original document size of 11x17)
1:45,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 13N; Canadian Geodetic Vertical Datum of 1928
2. Data Sources: Water Survey of Canada; GeoBase - National Hydrological Network; GeoBase - National Road Network; Cross sections (A-O) based on PFRA Prince Albert Flood Damage Reduction Study Hydraulic Report (1984).
3. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS,



Project Location
Prince Albert, SK

Prepared by MA on 2019-11-18
TR by LM on 2019-11-18
IR Review by HA on 2019-11-18

113101975

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
26

Title
Cross Sections and Sensitivity Lines

Disclaimer: This document has been prepared based on information provided by others as cited in the Notes section. Stantec has not verified the accuracy and/or completeness of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result. Stantec assumes no responsibility for data supplied in electronic format, and the recipient accepts full responsibility for verifying the accuracy and completeness of the data.

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Table 11 shows the results of the calibration for the 1980 and 2013 floods.

Table 11: Model Calibration Results for 1980 and 2013 Flood Events

Cross-Section ID (Based on 1984 Cross-Section Mapping)	Location	Water Surface Elevations (masl)					
		June 12, 1980 Flow = 1,630 m³/s			June 29, 2013 Flow = 2,268 m³/s		
		Recorded	Calibrated 2019 Model	Delta Recorded /2019	Recorded	Calibrated 2019 Model	Delta Recorded /2019
A		420.38	420.44	0.06			
D		420.89	420.89	0.00			
E	Bateman Island	421.06	421.05	-0.01			
J		422.08	422.04	-0.04			
K	WSC Station	422.16	422.18	0.02	422.971	423.07	0.10
N	15th Ave West	422.56	422.60	0.04			

The April 23, 1974 flood elevations used for calibration were taken in the river approximately 10 to 16 hours after the flood peaked. The 1984 report estimated the flow that correlated with the time flood elevations were recorded to be approximately 3,790 m^3/s, which was carried forward for review as part of the calibration efforts. Using the NSR calibration for flows greater than the 1:25 year event, the modelled water surface elevations from the 1974 flood flow of 3,790 m^3/s were found to be close to measured levels; between -0.01 and 0.29 m higher for this study (see Table 12), compared to between 0.31 and 0.61 m higher in the 1984 report results.

Table 12: Model Results for 1974 Flood Event

Cross-Section ID (Based on 1984 Cross-Section Mapping)	Location	Water Surface Elevation (masl) for April 23, 1974 Estimated Flow = 3,790 m³/s		
		Recorded	Calibrated 2019 Model	Delta Recorded /2019
E	Bateman Island	422.71	423.00	0.29
K	WSC Station	424.28	424.27	-0.01
N	15th Avenue West	424.64	424.67	0.03

On July 2, 1915, the WSC recorded a peak flow of 5,660 m3/s (nearly 1:200 year). Based on photos (See Figure 27) and records and the peak flood elevation presented in the 1984 PFRA report, a water surface elevation of 425.75 masl (converts to 425.49 masl using modern 2013 datum) was observed at the Carlton Trail Railway Bridge (which is approximately 575 m downstream of the WSC station).

Table 13 presents the results of the modelled 5,660 m^3/s flow.

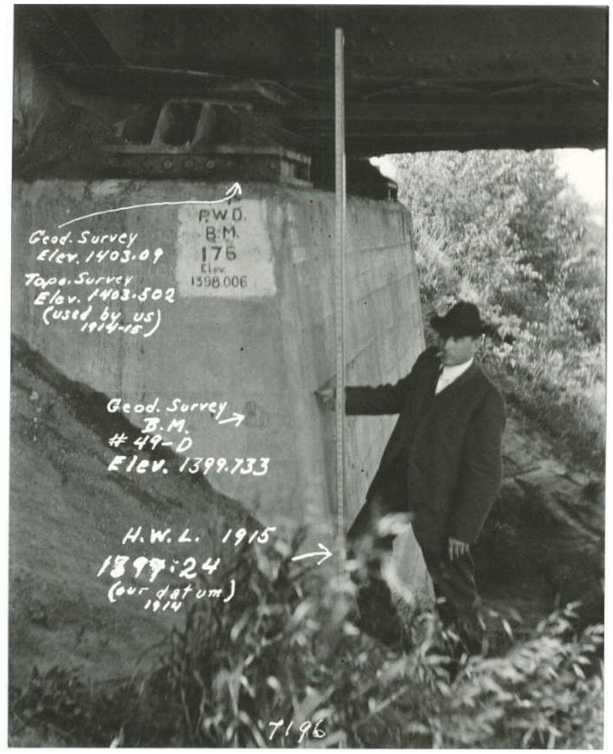


Figure 27: 1915 Flood Stage at Carlton Trail Railway Bridge (Source WSA)

Table 13: Model Results for 1915 Flood Event

Cross-Section ID (Based on 1984 Cross-Section Mapping)	Location	Water Surface Elevation (masl) for July 2, 1915 Estimated Flow = 5,660 m^3/s		
		Recorded 1915 (at Carlton Trail Railway Bridge)	Calibrated 2019 Model	Delta Recorded /2019
K	WSC Station	425.49	425.76	0.27

The WSC rating curve for station 05GG001 was used as a calibration check for all modelled flows up to the peak curve flow of 6,800 m^3/s. Figure 28 and Table 14 show the calibration results of modelled flows at cross-section K (WSC station 05GG001 - North Saskatchewan River at Prince Albert) compared to the rating curve and measured flood elevations. In Figure 28 the red dots represent the measured flood events used for calibration. The solid purple dots represent the results of the modelled results based on a calibration using channel ‘n’ = 0.032 for flows up to the 1:10 year return period. The solid orange dots represent the results of the modelled results based on a calibration using channel ‘n’ = 0.028 for flows ≥ 1:25 year return period. The hollow purple and orange dots show the trend for each of the Manning’s ‘n’ calibration and indicate why it was necessary to use two different ‘n’ values to calibrate. The use of two separate roughness values for calibration has been verified with the WSA. The 1984 modelled elevations (solid green dots) are included in Figure 28 for interest.

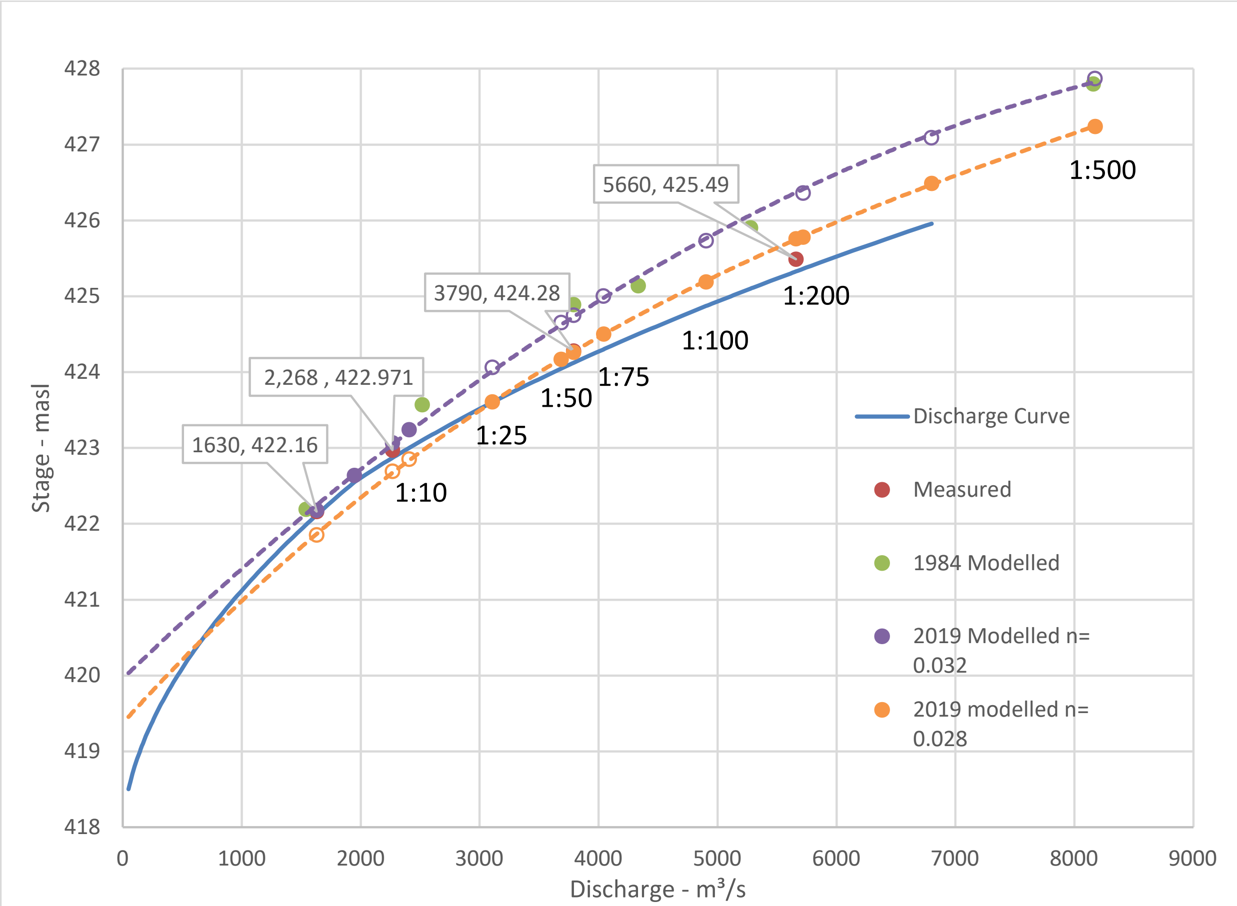


Figure 28: Comparison of Stage-Discharge Curve - WSC 05GG001 - North Saskatchewan River at Prince Albert to 1984 and 2019 Modelled Results

Table 14: Calibration Check Using WSC 05GG001 Gauge Stage-Discharge Curve

Flow (m³/s)	WSC Curve Water Surface Elevation (masl)	Model Water Surface Elevation (masl)	Difference (m)
1,947	422.55	422.64	0.09
3,790	424.12	424.27	0.15
4,050	424.31	424.50	0.18
6,800	425.96	426.51	0.55

In the absence of additional measured flow events with reliable measured water surface elevations for flows greater than the 1:25 year event, the Manning's 'n' values selected for the calibrated model remain as described above, based on literature.

The LRR did not have any calibration points to scale to and so the larger roughness coefficient (channel n= 0.032) was assigned to the LRR channel based on lower flow depths, while land use Manning's 'n' values remained consistent for both river systems.

5.5 SENSITIVITY ANALYSIS

A sensitivity analysis was undertaken to assess the effects of variations in Manning's 'n' roughness factors. The 'n' values for all land cover types were varied by ±10%, ±20%, and ±30% and applied to the Regulatory flood (1:500 year) on the NSR and LRR. As expected, varying the roughness resulted in change to the water surface elevations and variations throughout the project reach. Average changes in water surface elevations at the 1:500 year flood event are summarized in Table 15. The cross-section locations of the sensitivity analysis site are shown in Figure 26.

The sensitivity analysis for the NSR showed a greater variance in the confined upstream reach of the project area and decreased as it entered the lower reaches with an undeveloped flood plain and wider valley.

The LRR is also sensitive to variations in roughness but, due to the smaller size of the system and its smaller flows, the average water surface elevations variances are smaller compared to the NSR.

Overall this model showed significant sensitivity to changes in roughness.

Table 15: Sensitivity Analysis Results (1:500 year Flow)

Change in Manning's 'n'	North Saskatchewan River Average Water Surface Elevation Variance (m)	Little Red River Average Water Surface Elevation Variance (m)
+30%	1.01	0.33
+20%	0.69	0.23
+10%	0.36	0.11
-10%	-0.40	-0.13
-20%	-0.84	-0.26
-30%	-1.33	-0.40

An additional sensitivity exercise was undertaken by increasing the cell spacing to assess its effect on flood levels. The grid spacing was decreased globally to 35 m which increased processing time by approximately a factor of 2. The resultant change in water surface due to the increased cell density was a decrease of 0.01 m for the NSR and a decrease of 0.02 to 0.04 m for the LRR at the 1:500 year return period. Therefore, the 50 m grid spacing was deemed sufficient to capture flood extents, especially given the increased cell density around important features.

5.6 MODEL RUNS

Five separate model runs form the basis for the flood hazard mapping, based on five discrete flow files. The model geometry and flow files for each model run are summarized in Table 16.

Table 16: Model Run Details

Model Output	Geometry File	Manning's File	Flow File	Plan Name
North Saskatchewan River flood elevations for 1:10 year return period	Prince Albert	Manning_19_n=0.032	NS10_S=0.0003	NS10_n=0.032
North Saskatchewan River flood elevations for 1:25, 1:50, and 1:75 year return period	Prince Albert	Manning_16 n=0.028	NS25to75_S=0.0003	NS25-75_n=0.028
North Saskatchewan River flood elevations for 1:100, 1:200, and 1:500 year return period	Prince Albert	Manning_16 n=0.028	NS100to500_S=0.0003	NS100to500 n=0.028
Little Red River flood elevations for 1:10, 1:25, 1:50, and 1:75 year return period	Prince Albert	Manning_19_n=0.032	LR10to75 S=0.0003	LR10-75_n=0.032
Little Red River flood elevations for 1:100, 1:200, and 1:500 year return period	Prince Albert	Manning_19_n=0.032	LR100to500 S=0.0003	LR100-500_n=0.032

The model runs each included the grid surface described in Section 5.1, the calibrated Manning's 'n' values described in Sections 5.2 and 5.4, the hydrographs described in Section 5.7.1 and 5.8.1, and used the computation parameters described in Section 5.3.

5.7 NORTH SASKATCHEWAN RIVER

5.7.1 Flow Data

HEC-RAS 2D only runs in unsteady state, therefore it requires input hydrographs to run simulations. As only peak flows were developed for this project, flow was input as an artificial hydrograph, ramping up from an initial low flow over 12 hour steps to reach each return period flow which was then maintained at a steady flow for another 12 hours to allow the model to reach equilibrium for each peak flood flow. This stepping was achieved in three separate model runs, the first was the 1:10 year, then the 1:25 to 1:75 year, and the third from 1:100 year to 1:500 year. The hydrographs are displayed in Figure 29 and Figure 30.

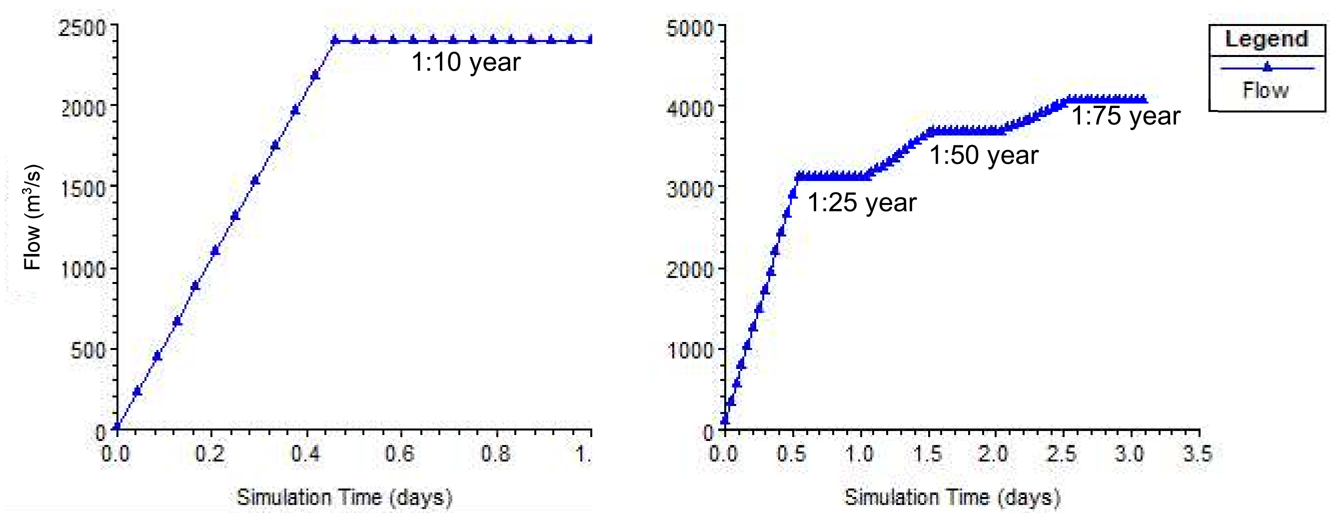


Figure 29: Input Hydrographs for NSR 1:10 to 1:75 Year Flows

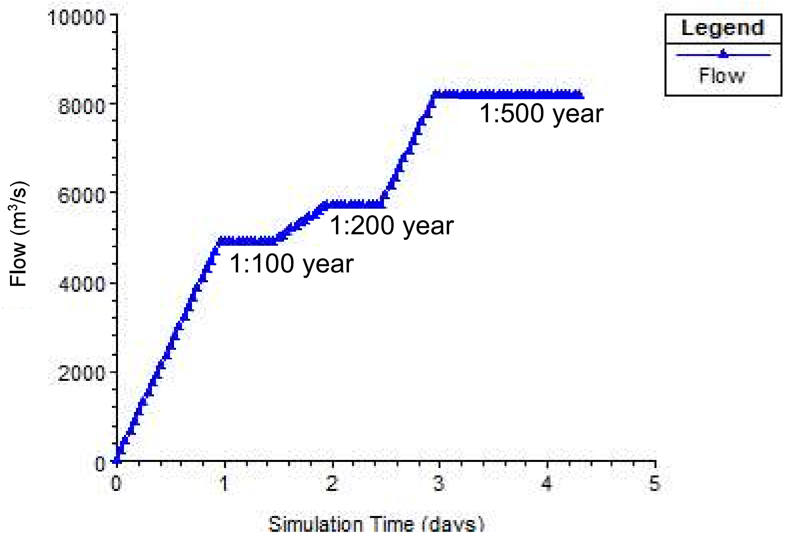


Figure 30: Input Hydrograph for NSR 1:100 to 1:500 Year Flows

Flows in the LRR were maintained at 10 m^3/s, which is roughly analogous to a mean springtime flow and acted as a base level tributary inflow for those model runs. These results were combined with those from the LRR during map preparation to assume coincident flood peaks.

5.7.2 Boundary Conditions

Both upstream and downstream model extents were extended beyond the project area to eliminate any potential for erratic flows or instability caused by any of the boundary conditions. In this way the boundaries established outside of the project area allowed the model to stabilize by the time calculations reached the study area.

Upstream boundary conditions on the NSR were governed by the inflow hydrograph and an energy slope at the boundary condition line of 0.0003 m/m for each given model run.

The downstream boundary condition was Normal Depth and was driven by a friction slope value of 0.0003 m/m or 0.03%. A channel slope of 0.00012 m/m was measured from the bathymetric surface as an average of the approximately 3 km section at the downstream end of the model reach. Water surface slope measured from calibration and return period events were used as a surrogate for energy slopes. These slopes were in the range of 0.00014 to 0.00027 m/m. Based on a variety of calibration runs, the model results were able to best match the recorded water surface elevations when using a slope of 0.0003 m/m (see Figure 25 in Section 5.4). This boundary condition slope was then used for all scenarios.

5.7.3 Structure Modelling

5.7.3.1 Diefenbaker Bridge (1960)

The bridge pier geometry was measured as part of the survey program and was incorporated into the model surface. The bridge deck was not included in the geometry and the hydraulic effects of the bridge piers are captured in the 2D model. The bridge deck was not included because, per the 1984 PFRA hydraulic report, the low chord elevation of the Diefenbaker Bridge is 431.3 masl and at the 1:500 year flood event, the maximum water surface elevation was 427.04 masl, which leaves significant freeboard available beneath the bridge deck and verifies the assumption that hydraulic effects through the bridge are appropriately captured in the model calculations.

HEC-RAS 2D does not have the same bridge modeling capabilities as a 1D model, and as such, low flow bridge modelling approaches such as Energy, Momentum, and Yarnell equations cannot be replicated. Similarly, Energy and Pressure/Weir high flow calculation approaches are not a feature of this 2D model. The design flows for this investigation are high without reaching a pressure flow through the bridge opening, however the surface geometry that includes the piers and their instream obstruction allow for the constriction and pier effects on river flows and hydraulics to be captured in this model through its 2D St. Venant equations that compute stages and flows through the bridge opening.

Figure 31: Construction of the Diefenbaker Bridge, 1960 (Photo: Saskatchewan Archival Information Network)

5.7.3.2 Carlton Trail Railway Bridge (1910)

The six bridge piers of this rail crossing were incorporated into the model surface following capture during the survey program. Detailed bridge information was not made available to Stantec. Based on the 1984 PFRA hydraulic report, the low chord elevation is estimated to be at approximately 428.4 masl. At the 1:500 year flood event, the maximum water surface elevation is 427.65 masl, which allows enough freeboard to avoid hydraulic impacts from the bridge deck and associated pressure flow.

Constriction and pier effects are captured in the 2D model by way of the inclusion of piers and abutments in the model surface.

Figure 32: Carlton Trail Railway Bridge, 1915 (Photo: Prince Albert)

5.7.3.3 Weir (1939)

The weir was not effectively captured by the bathymetric survey; however, this low head structure was input into the model surface with a top elevation of 418.1 masl using information available in the 1984 PFRA hydraulic report. A photo of recent conditions at the weir is shown in Figure 33.

Figure 33: NSR Weir Under Normal Flow Conditions May 15, 2015 (Photo: Prince Albert 2015)

5.8 LITTLE RED RIVER

5.8.1 Flow Data

Similar to the NSR, the LRR flows were input as two artificial hydrographs, increasing in 12 hour steps to each return period flow which is maintained for another 12 hours to reach equilibrium in the model. This was modelled in two separate runs, the first ranging from the 1:10 year to 1:75 year, and the second from 1:100 year to 1:500 year. The hydrographs are displayed in Figure 34 and Figure 35.

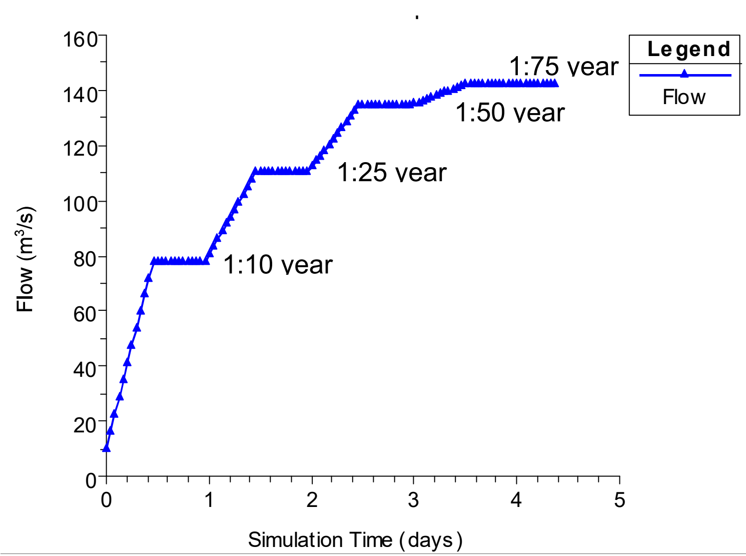


Figure 34: Input Hydrograph for LRR 1:10 to 1:75 Year Flows

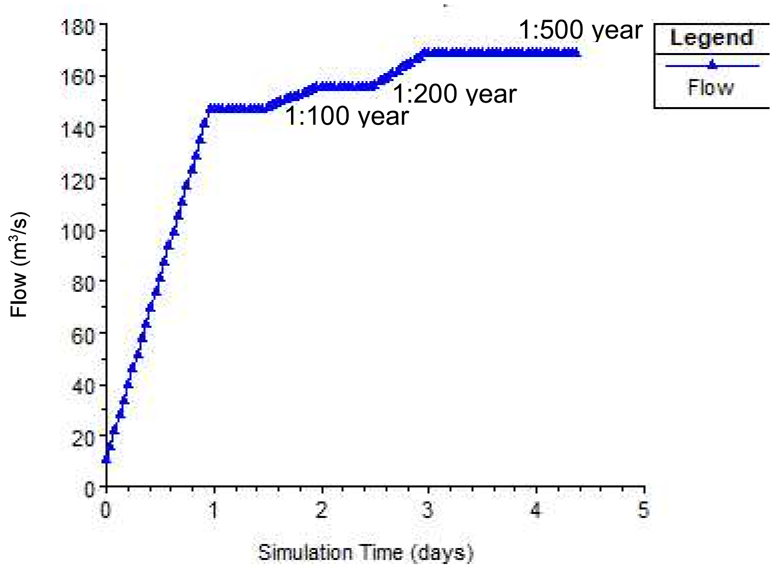


Figure 35: Input Hydrograph for LRR 1:100 to 1:500 Year Flows

Flows in the NSR were maintained at 1,100 m^3/s during this model run to assess flows in the LRR alone and not have the lower reach driven by backwater caused by NSR flooding. The results were combined during mapping to assume coincident flood peaks.

5.8.2 Boundary Conditions

The upstream boundary condition was delineated at the upper end of the model and governed by an inflow hydrograph. Two hydrographs were created, one to assess flows from 1:10 year to 1:75 year and another for 1:100 to 1:500 year flooding, both with an energy slope at the boundary condition line of 0.0003 m/m.

There is no separate downstream boundary condition for the LRR as it is a tributary of the NSR and the NSR acts as the downstream boundary for the LRR.

5.8.3 Structure Modelling

5.8.3.1 Highway 55 Bridge (1966)

The Highway 55 Bridge was not included in the 2D model since water levels at this location and through the bridge opening are driven by the backwater effects of the NSR in flood stage. These effects begin to influence flows from the LRR before the 1:10 year return period flows and reduce velocities to approximately 0.1 m/s while eliminating the possibility of orifice flow through the bridge opening. Overtopping of the bridge from the NSR backwater occurs at approximately a 1:200 year return period event. The bridge deck itself does not cause a significant backwater or water surface elevation change since flood levels are dominated by NSR levels. The hydraulic effects of the constriction through the bridge opening due to the abutments are captured in the 2D model surface.

5.8.3.2 Little Red River Park Bridge (1975)

The Little Red River Park Bridge also experiences the influence of backwater effects from the NSR, with this occurring at return periods less than 25 years. Flood flows in the LRR alone reach the bridge deck at a 1:75 year event, which is concurrent with a backwater effect from the NSR that reaches all the way to the City boundary upstream of the bridge. This flat water has the effect of reducing velocities to 0.15 m/s and eliminating the influence of the LRR inflow, thereby removing the possibility of pressure flow occurring through the bridge opening. The embankments are captured in the model which validates the effects of constriction through the bridge opening at flood flows, but the deck was deemed unnecessary for this flood mapping exercise. There are no instream piers at this bridge and its abutments are captured in the 2D model. The bridge is overtopped by the backwater of the 1:500 year event on the NSR, but not by any event on the LRR alone.

5.8.3.3 Pedestrian Bridges

The pedestrian bridges were not included in the model under the assumption that their slender geometry would not result in any significant impacts to low flows and under flood flows it is likely that they would be overtopped and/or destroyed.

5.9 MODEL RESULTS

The NSR stays predominantly confined within its channel for floods up to the 75 year return period. Some exceptions include a backwater forming in the low lying area around the WWTP, and some gravel bars and small channel islands are also overtopped. At the 1:100 year flood event, the NSR has spilled its banks in the upstream reaches of the project area, causing some overland flooding in the west part of the City, both north and south of the river. Under the 200 year flood some roadways in the East Flat area are flooded, and there is flooding in the low lying area surrounding the WWTP including the access road to the facility. At the 1:200 year flood, overland flooding on the west side of the City has also increased, and flood effects can also start to be seen to the north of the river in the Hazeldell area as well as in the West Flat area. The WWTP is surrounded by flood waters during the 1:200 year event. During the 1:500 year flood, Highway 55 is also inundated at points, including the bridge crossing of the LRR. The 1:500 year flood event causes significant flooding in the Hazeldell, East Flat and West Flat Areas. Flood effects appear around the interchange of Highways 2 and 3 as well. The NSR stays relatively contained in its channel through the rail and highway bridges and downstream until it spills into the East Flat area covering a large area of land. The entire WTP and WWTP are also inundated during this flood. Table 17 shows the modelled water surface elevations for a range of floods at select locations in the City (sections shown on Figure 26).

Table 17: Flood Elevations at Select Locations on North Saskatchewan River

NSR Main Channel Location (River Station)	Water Surface Elevation (masl)			
	1:10 year	1:50 year	1:100 year	1:500 year
XS N (1+465)	423.66	424.57	425.59	427.68
XS M (1+915)	423.55	424.48	425.51	427.61
XS L (2+570)	423.40	424.35	425.38	427.50
XS K (WSC Station) (3+275)	423.24	424.18	425.20	427.30
XS J (3+785)	423.09	424.02	425.03	427.10
XS I (Downstream of Highway 3 Bridge) (4+020)	423.02	423.95	424.96	427.00
XS H (4+910)	422.75	423.65	424.36	426.61
XS G (5+800)	422.50	423.37	424.32	426.22
XS F (6+615)	422.32	423.17	424.11	425.97
XS E (Bateman Island) (7+990)	422.05	422.91	423.85	425.70
XS D (8+900)	421.89	422.76	423.70	425.54
XS C (Weir) (9+585)	421.77	422.63	423.85	425.42
XS B (10+670)	421.63	422.49	423.43	425.25
XS A (11+540)	421.42	422.27	423.22	425.04

Figure 36 presents a profile view of the water surface elevations (WSE) along the NSR for selected return period floods and the 1:500 year energy grade line from the 1984 PFRA hydraulic report results.

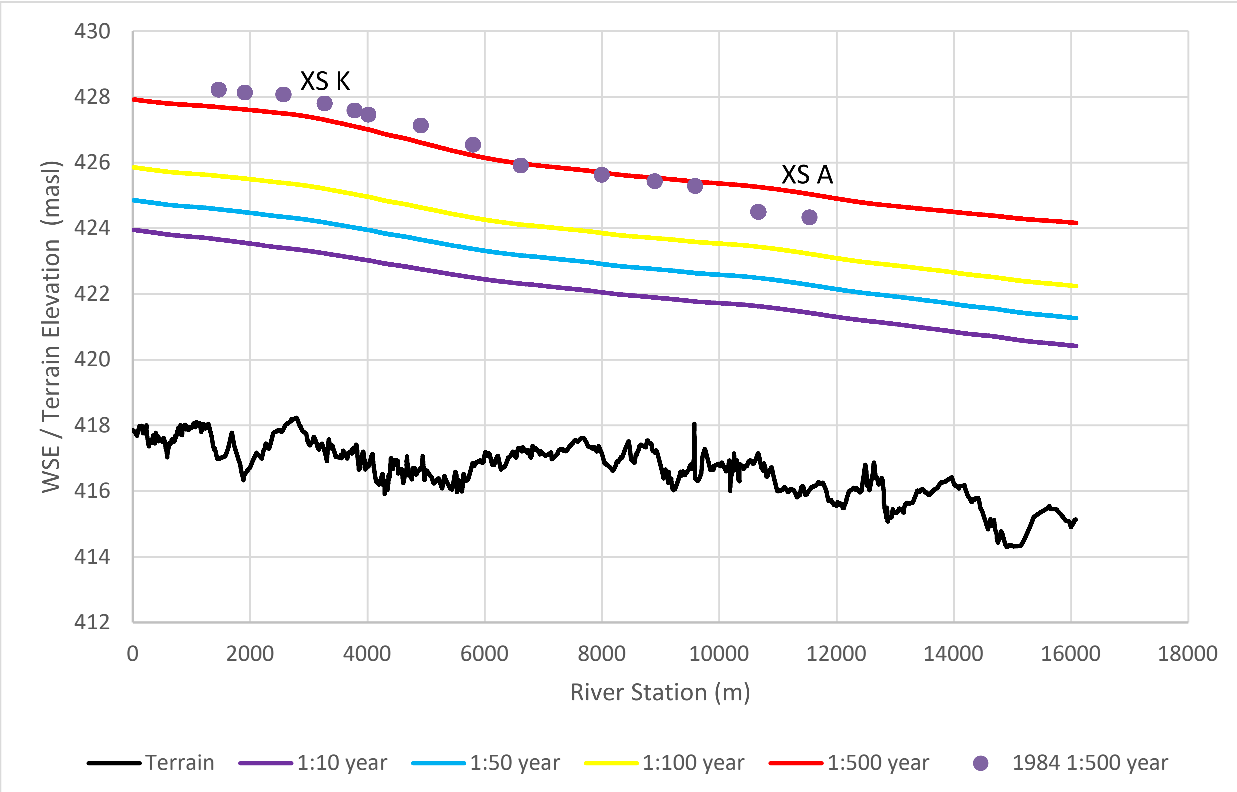


Figure 36: NSR WSE Profile for 1:10, 1:50, 1:100 and 1:500 Year Flood

Figure 37 to Figure 42 show the modelled flood WSE conditions at selected locations in the NSR and LRR. Cross-sections are presented looking downstream.

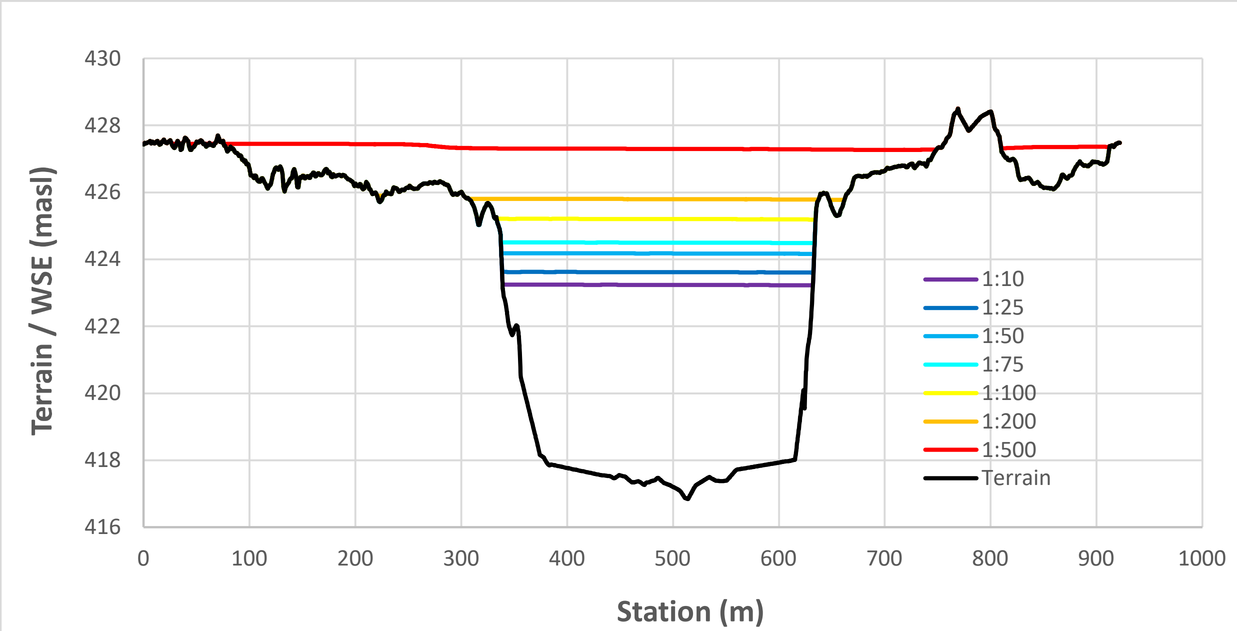


Figure 37: NSR WSE Profile – Cross-Section K at WSC Gauge Station

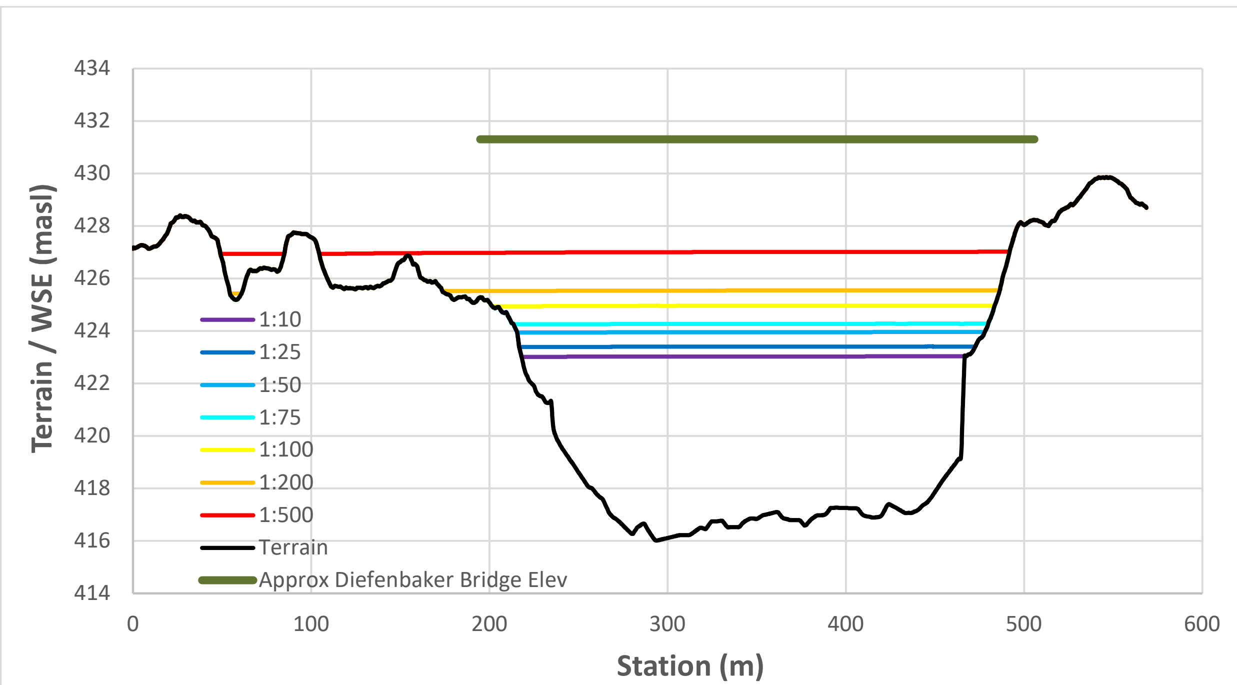


Figure 38: NSR WSE Profile - Cross-Section I – 80 m Downstream of Diefenbaker Bridge

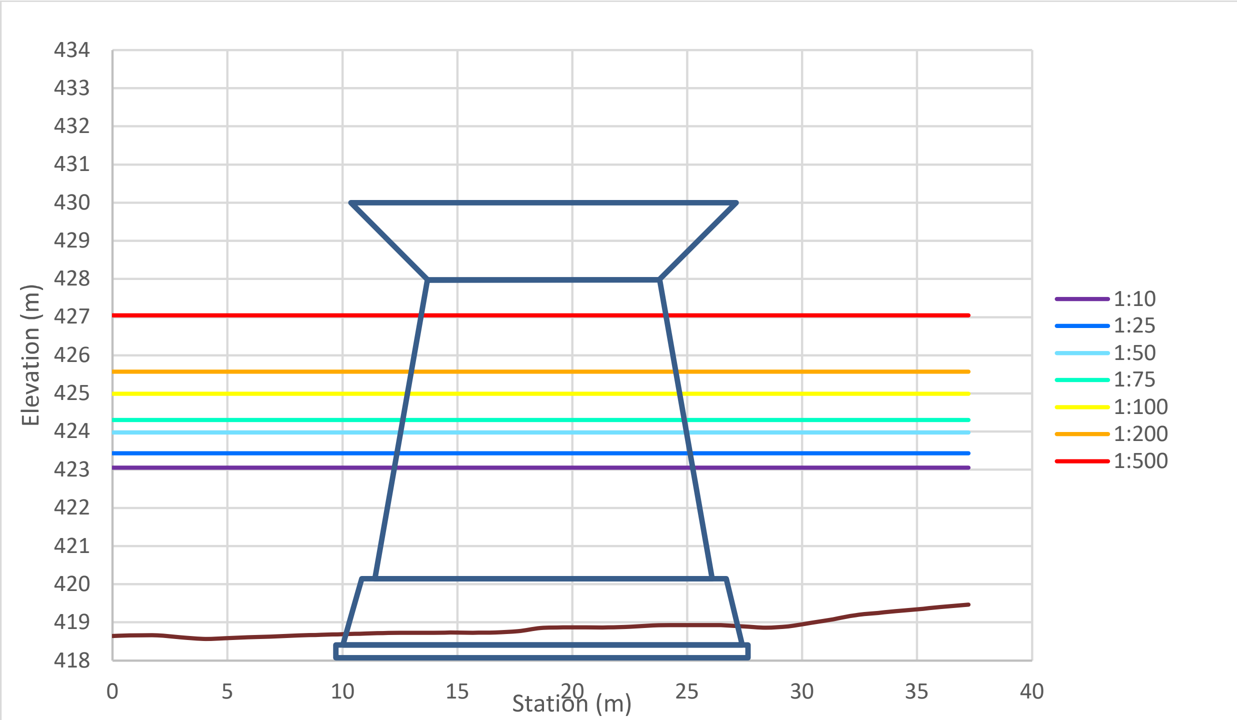


Figure 39: NSR WSE at Typical Diefenbaker Bridge Pier

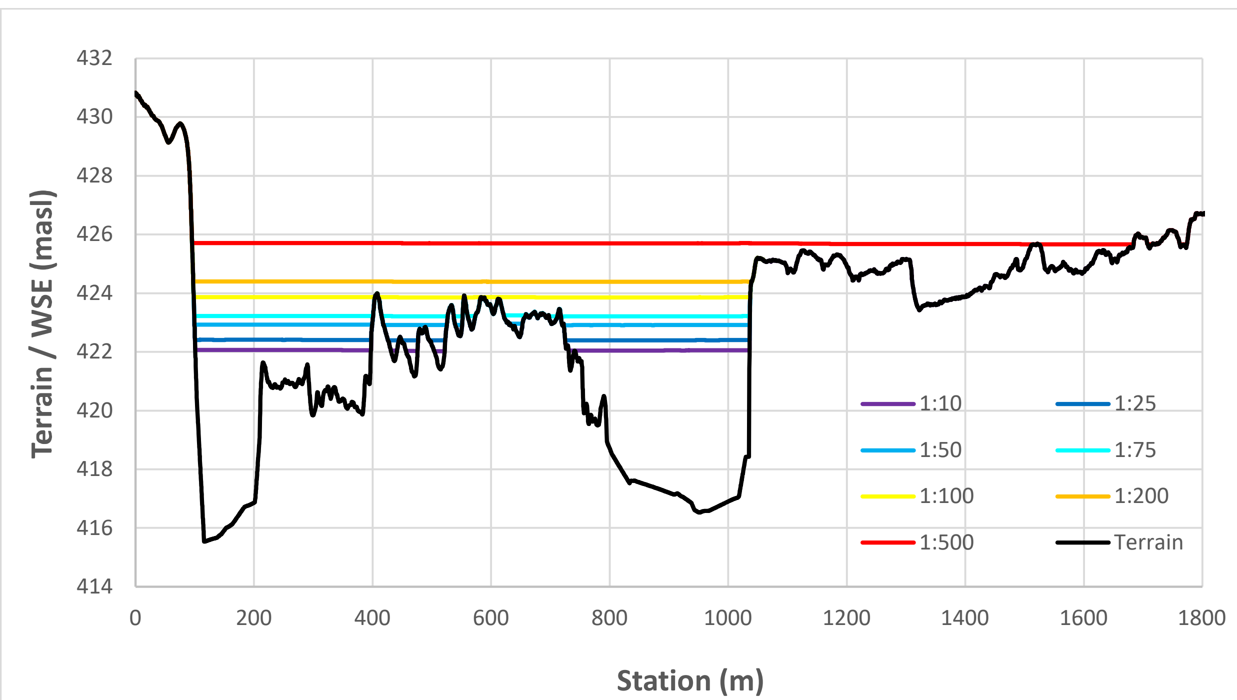


Figure 40: NSR WSE Profile - Cross-Section E - Section through Bateman Island

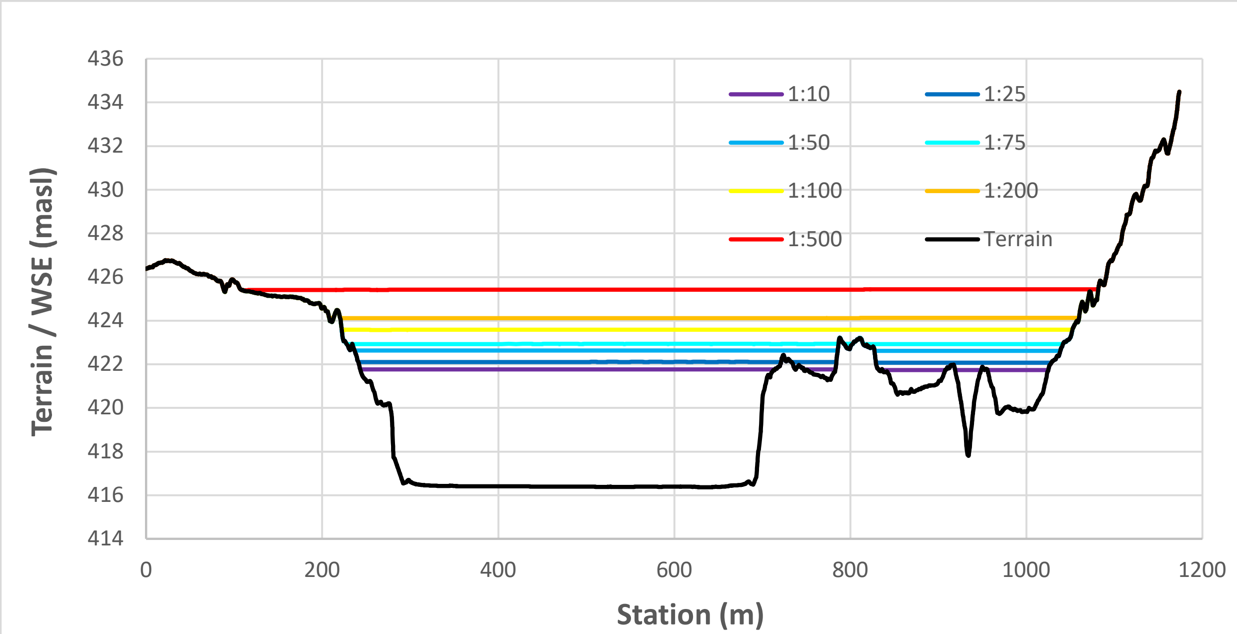


Figure 41: NSR WSE Profile - Cross-Section C at Weir

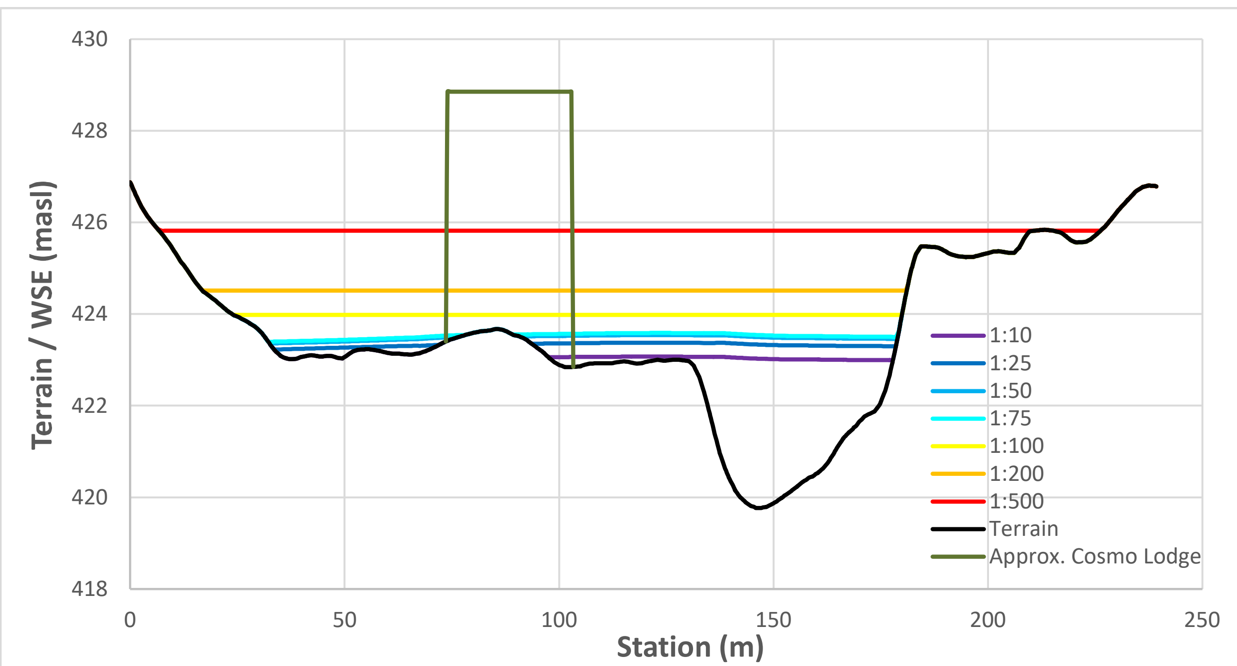


Figure 42: LRR WSE Profile - Downstream of LRR Park Road Bridge at Cosmopolitan Lodge

Table 18 presents a comparison at select locations on the NSR of Total Energy Elevations from the 1984 PRFA report to the WSE 2019 results from this analysis for a range of flood events.

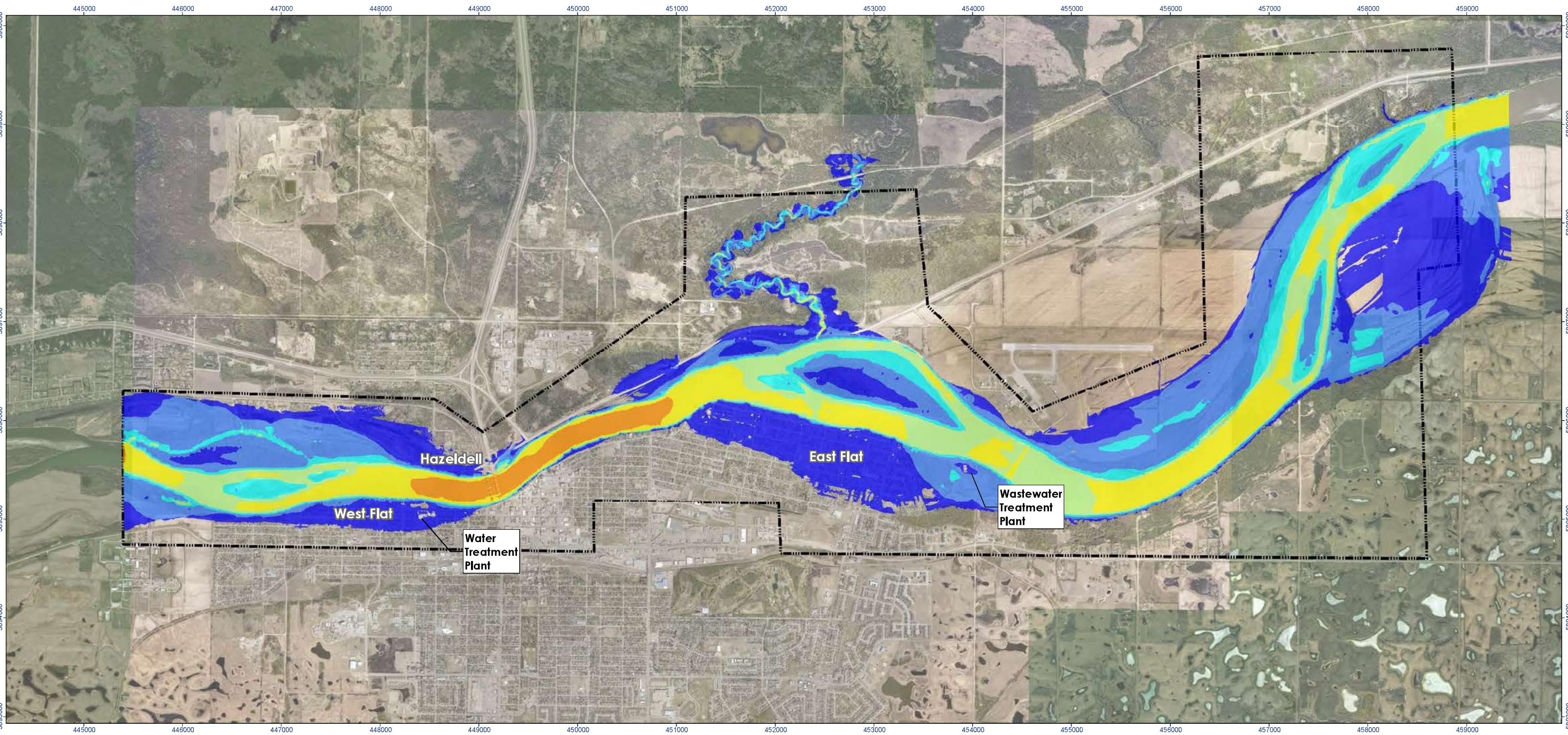
Table 18: 1984 Total Energy Elevation (masl) compared to 2019 Water Surface Elevation (masl)

NSR Main Channel Location	1984 Total Energy Elevation/2019 Water Surface Elevation (masl)							
	1:10 year		1:50 year		1:100 year		1:500 year	
	1984	2019	1984	2019	1984	2019	1984	2019
WSC gauge station (XS K)	423.57	423.24	425.14	424.18	425.90	425.20	427.80	427.30
Downstream of Diefenbaker Bridge (XS I)	423.38	423.02	424.89	423.95	425.63	424.96	427.48	427.30
Weir (XS C)	422.18	421.77	423.23	422.63	423.86	423.85	425.43	425.42

Velocities in the NSR under the 1:500 year event range from approximately 2 m/s in the main channel in areas where the floods have access to conveyance in the flood plain to over 3.5 m/s in the most confined reaches. Overland flooding velocities are generally less than 0.5 m/s. Figure 43 illustrates flood velocities for the 1:500 year flood.

The 1:500 year flood is predicted to result in depths over 10 m in the main channel. Depths over land range from up 0.5 to 1.5 m in residential areas to over 4 m in low lying areas. Figure 44 illustrates flood depths for the 1:500 year flood.

The LRR has mostly filled its flood plain by the 1:25 year event. There is no major infrastructure in this river valley besides the Cosmo Lodge, which is cut off by water during a 1:25 year flood and inundated by the backwater of a 1:75 year flood on the NSR.



Legend

500 Year Velocity

- 0 m/s - 0.5 m/s
- > 0.5 m/s - 1.0 m/s
- > 1.0 m/s - 1.5 m/s
- > 1.5 m/s - 2.0 m/s
- > 2.0 m/s - 3.0 m/s
- > 3.0 m/s - 5.0 m/s
- > 5.0 m/s
- Study Area Boundary

0 770 1,540 metres

(At original document size of 11x17)
1:40,000

N

Stantec

City of Prince Albert

Project Location
Prince Albert, SK

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City of Prince Albert
Flood Plain Mapping
Report

Figure No.
43

Title
1:500 Year Flood Velocities

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China

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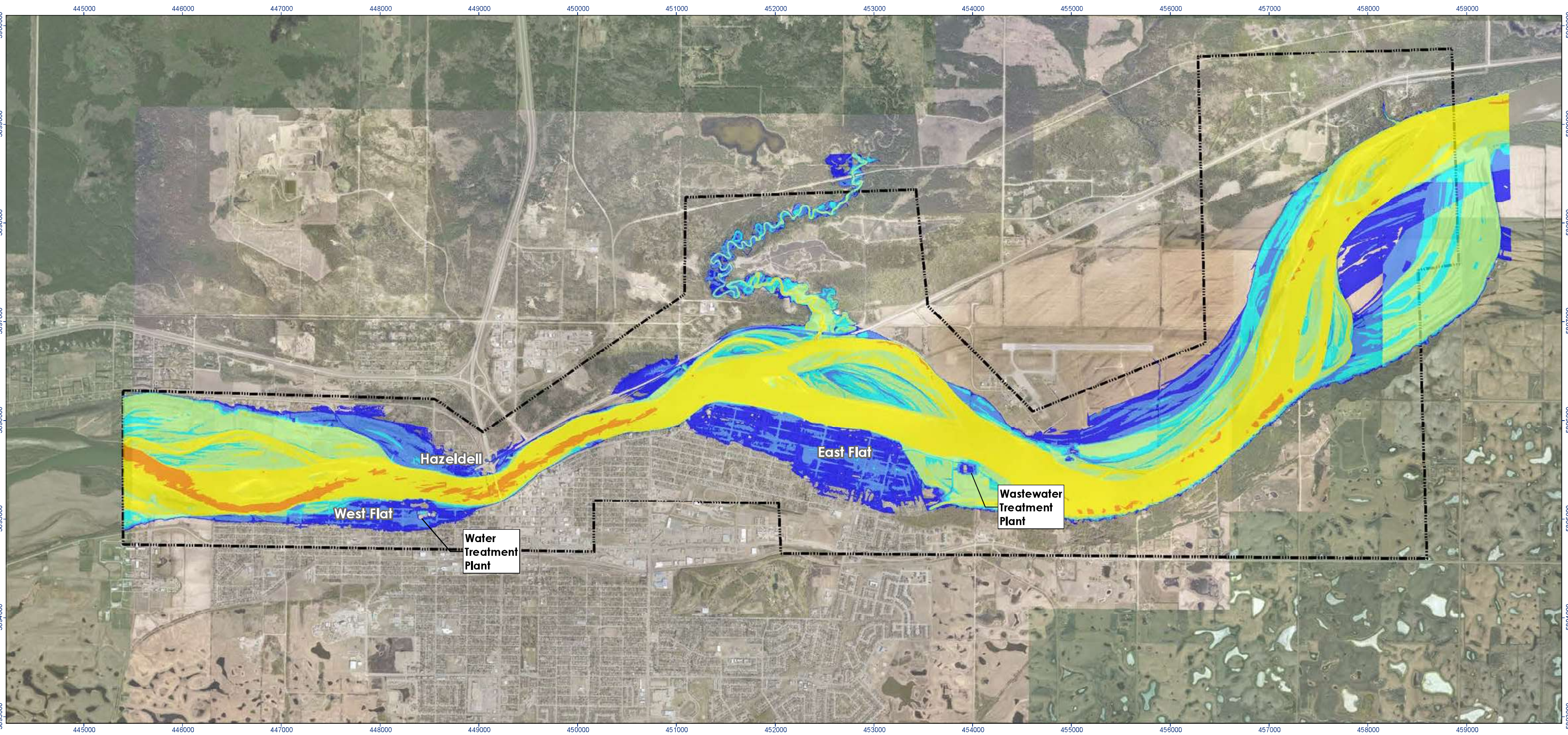

Legend

500 Year Depth

- 0 - 1.0 m
- > 1.0 m - 2.0 m
- > 2.0 m - 3.0 m
- > 3.0 m - 5.0 m
- > 5.0 m - 10.0 m
- > 10.0 m - 15.0 m
- > 15.0 m
- Study Area Boundary

0 770 1,540 metres

(At original document size of 11x17)
1:40,000

N

Notes

1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China

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Flood Plain Mapping
Report

Figure No.
44

Title
1:500 Year Flood Depths

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6.0 FLOOD INUNDATION MAPPING

Raster files representing the floodwater depths and velocities were exported from the RAS Mapper tool in HEC-RAS. Polygon shapefiles representing the floodwater inundation extent were also exported for each return period. This exercise was completed for seven different time steps for each river, for a total of 42 files to inform the GIS mapping. The maximum inundation extent for each return period was mapped for the entire study area and these maps are included in Appendix C. The data exported from the RAS Mapper tool in HEC-RAS underwent a series of edits and cleaning to provide a more aesthetically pleasing and accurate product. For each return period, the following was completed:

- Any disconnected "wet" areas (areas not hydraulically connected) were removed from the results.
- Any "dry islands" with a total area of 100m² or less were removed from the results.
- The boundaries of the inundation extents were smoothed, using the PAEK method with a 20 m tolerance.

The raster files were used to delineate the floodway and the flood fringe based on velocity and depth model outputs. These areas were mapped within the flood boundary. The Study Area floodway and flood fringe areas (as described in Section 1.2) are shown in Appendix C. These results underwent the same data editing and cleaning described above.

Comparing the results of this study to the 1984 study by PFRA shows that generally flood lines and effects appear to be similar to the flood hazard maps produced in the 1980's with some variations that can be attributed to additional development in the City, updated flow estimates, different model calibrations, and more accurate land cover data in the updated study. The updated 2D model provides better estimates of complex flow around the many obstructions present in this flood assessment.

7.0 MITIGATION SITES AND MITIGATION OPTIONS

As shown by the flood inundation maps, several floods for the return period flows are anticipated to have significant impacts on lands and properties within the City of Prince Albert. Of note are the East and West Flat areas of the City as well as the WTP and WWTP.

The City's Official Community Plan (Prince Albert, 2015c) includes section 10.9: Flood Plain Risk Areas, which states "Any development on lands within the flood risk areas need to provide suitable area wide or site specific mitigation measures and preclude flood vulnerable development to prevent injury, loss of life and minimize property damage." The City is in the process of developing a by-law to amend Section 10.9 which will include three zones: the Flood Fringe of the 1:500 year flood event, the Floodway of the 1:500 year flood event, and the Restricted Floodway of the 1:100 year flood event elevation.

The by-law will retain a clause that states "No residential, commercial, institutional or industrial development shall be allowed within the Floodway below the 1:100 year flood event elevation except for recreational and agricultural related development in accordance with the Flood Risk Regulations in the Zoning By-law and other development by-law's. Covenants or land title restrictions may be established to manage non-habitable areas and equipment or storage materials that could be affected by flooding." The updates will also allow existing development to continue in the Flood Risk Area, including regular maintenance. The proposed update will retain a policy that states "Determine the infrastructure and mitigation measures necessary to protect planned or affected development in flood risk areas".

Possible options for mitigating against flood damage are outlined below along with conceptual opinion of probable construction costing estimates to a Class 5 estimate class (-35% to +50% accuracy range) in accordance with ASTM E 2516-06 - Standard Classification for Cost Estimate Classification System. Some project costs are not accounted for in the estimates such as design, permitting, and land acquisition. The costs presented in this report are high level and it is expected costs will be refined in future studies. High level cost assumptions for the estimates are included in Appendix B.

7.1 WATER TREATMENT PLANT SITE

The City's WTP is located on River Street (see Figure 47). The WTP facility will not be affected by any of the return period flood conditions except the 1:500 year event. Under the 1:500 year return period flood condition, access via 6th Avenue and River Street will be inundated. Access is cut off by 1.35 m deep water, and 0.28 m/s velocities for the 1:200 year event. The WTP facility buildings will see inundation under the 1:500 year return period flood. See Figure 45 for inundation extents.

Legend

Inundation Extent

- 25 Year
- 50 Year
- 75 Year
- 100 Year
- 200 Year
- 500 Year

Flood Mitigation

- Dyke
- Water Filled Barrier

Notes

1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

0 10 20 30 40 50 metres

(At original document size of 11x17)
1:1,500

N

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TR by HA on 2019-12-6
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Inundation Extent

Figure No.
45

Title
Inundation Extent - Water Treatment Plant Site

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7.1.1 WTP Mitigation Options

7.1.1.1 Water Filled Barriers and Pumps/Generators to Protect Site

Water filled barriers are large tube-like structures that are filled with water. These barriers can be installed around a facility and pumped full of water to isolate the treatment facility building or other key infrastructure from the flooded lands. The WTP could be completely protected by isolating it from the flooded land using a system of water filled barriers. The City would need to determine if additional pumping or generator capacity will be needed beyond existing backup generator capacity for filling the dams and dewatering within the isolated area during operation to account for leakage. A perimeter of approximately 240 m would be required to protect the main building only. Preparation of the site, including grading and other infrastructure modifications may be necessary prior to effective deployment of the waterfilled barriers during an event. In addition to site-preparation it is recommended that a deployment plan be developed and tested regularly.

A dam system (water filled barriers only – not including pumps) to protect the WTP building only (290 m) against up to 0.9 m of water depth would cost approximately $52,000. A dam system to protect the entire facility not including north of River Street (600 m) would cost approximately $185,000 for up to 1.5 m of flood depth.

7.1.1.2 Elevate Electrical and Mechanical Systems

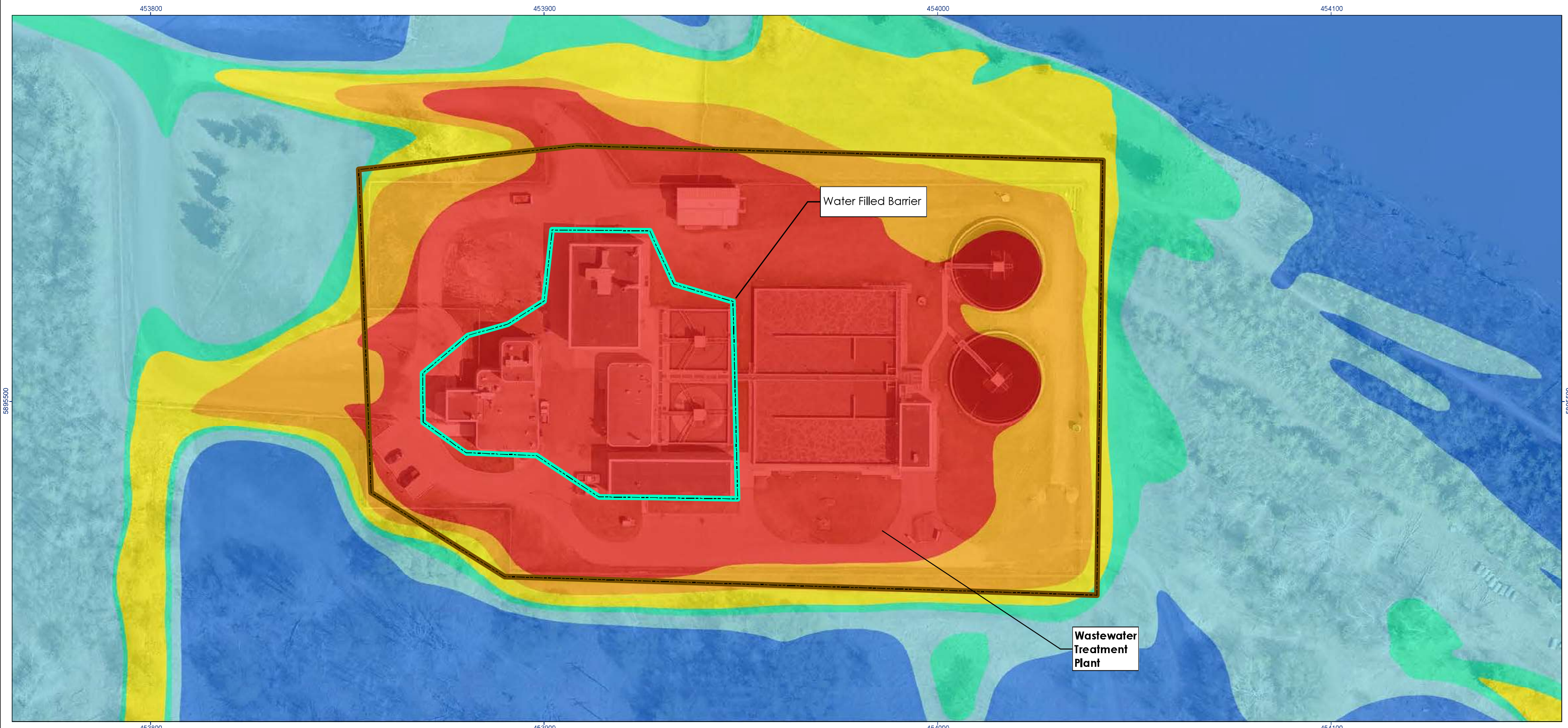
To protect against loss of the electrical and mechanical systems following a flood, it may be possible to elevate these systems above a given flood elevation. At the WTP, the 1:500 year flood elevation is 427.37 masl (or approximately 0.5 - 1.0 m water depth). A detailed assessment of equipment and retrofitting needs would be required to determine a cost for this mitigation option.

7.2 WASTEWATER TREATMENT PLANT

The WWTP is located at the east end of 1st Street E, there is a single access road leading to the WWTP. The site (buildings and treatment infrastructure) is not affected until the 1:100 year flood. However, access is affected on 1st Street E under all return periods greater than the 1:25 year flood. Table 19 lists the depths of flood water and velocities observed on 1st Street E for each return period greater than the 1:25 year event. See Figure 46 for inundation extents.

Table 19: Effects of Flooding on Access to Wastewater Treatment Plant

Return Period	1st Street E		
	Maximum Depth (m)	Maximum Velocity (m/s)	Length of road affected from closest access point (m)
1:50	0.12	0.41	300
1:75	0.42	0.65	470
1:100	1.06	0.76	550
1:200	1.59	0.84	590
1:500	2.89	1.05	675



Legend

Inundation Extent

- 25 Year
- 50 Year
- 75 Year
- 100 Year
- 200 Year
- 500 Year

Flood Mitigation

- Berm
- Water Filled Barrier

0 10 20 metres
(At original document size of 11x17)
1:1,000

N

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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City of Prince Albert

Project Location
Prince Albert, SK

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Report

Inundation Extent

Figure No.
46

Title
Inundation Extent - Wastewater Treatment Plant Site

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The WWTP plant building is above all return period flood lines except the 1:500 year flood. A portion of the WWTP plant site is above the 1:200 year flood line, however land surrounding the tanks is inundated, and site access is inundated by 2-3 m deep water, with 1.05 m/s velocity under the 1:500 year event.

7.2.1 WWTP Mitigation Options

7.2.1.1 Water Filled Barriers and Pumps/Generators to Protect Site

Water filled barriers are waterfilled barriers that can be installed around a facility and pumped full of water to isolate the treatment facility building or other key infrastructure from the flooded lands. The main WWTP building could be completely protected by isolating it from the flooded land using a system of water filled barriers. The City would need to determine if additional pumping or generator capacity will be needed beyond existing backup generator capacity for filling the dams and dewatering within the isolated area during operation to account for leakage. A perimeter of approximately 220 m would be required to protect the main building and facilities. Protecting the entire plant site (575 m) with water filled barriers is not feasible due to water depths of over 2.5 m around the site.

A dam system (water filled barriers only – not including pumps) to protect the main building against up to 1.5 m of water depth would cost approximately $70,000.

7.2.1.2 Earth Berm Flood Protection

An earth berm could be used to isolate the entire WWTP site from floodwaters. To encircle the perimeter of the WWTP site, the berm would need to be approximately 575 m long and a maximum of 3.0 m high to protect against the 1:500 year event, with 0.5 m of freeboard. Unless the access road was also modified the site would still not be accessible by road under flood events larger than the 1:25 year event.

Conceptual costs to construct a berm around the entire WWTP site is estimated to be $950,000 (3:1 side slopes and 3 m top width).

7.2.1.3 Access Road Improvements

To improve site access to the facility under flood conditions, the access road would need to be elevated or a new access road constructed. Under the 1:100 year flood 1st Street E would need to be elevated 1.5 m and under the 1:500 year flood 1st Street E and other access streets would need to be elevated 3.5 m.

Elevating the access road may cost approximately $1,000,000 to provide access under the 1:100 return period flood and $1,900,000 to elevate 675 m of access road to provide access under the 1:500 year return period flood condition. These costs are based on an assumed 8 m wide road with 3:1 side slopes on the roadway.

7.2.1.4 Elevate Electrical and Mechanical Systems

An additional option could include elevating critical electrical and mechanical systems above a specific flood elevation threshold through retrofitting existing systems or applying a flood elevation standard to any new systems. At the WWTP, the 1:500 year flood elevation is 426.05 masl (or approximately 1.0 to 1.5 m water depth). A detailed assessment of equipment and retrofitting needs would be required to determine a cost for this mitigation option.

7.3 WEST FLAT AREA

The West Flat area is the topographically low area to the west of the Diefenbaker Bridge, south of the NSR. A number of properties (13) in the West Flat area are affected by the 1:75 year flood that include the rear lots of homes on 12th Street W, west of 13th Avenue W.

Residential properties in the West Flat area (west of the Diefenbaker Bridge) are affected by the 1:100 year, 1:200 year and 1:500 year return period floods. Only rear lot areas are affected in the 1:75 and 1:100 year flood, but the depth and extent of flooding become progressively larger up to the 1:500 year. Approximately 31.9 ha of land are inundated by the 1:500 year flood. The table below provides the number of properties impacted, and the depth and velocities observed for the 1:100 year, 1:200 year and 1:500 year return period floods for the West Flat area. The property counts include any residential, industrial, commercial or institutional properties located in the inundation area.

Table 20: Effects of Flooding on West Flat Area

	West Flat Area		
Return Period	**Number of Properties**	**Maximum Depth (m)**	**Maximum Velocity (m/s)**
1:100	27	1.25	0.11
1:200	46	1.84	0.26
1:500	378	3.36	0.49

7.3.1 West Flat Area Mitigation Options

7.3.1.1 Development Regulation and By-Law

It is recommended that the City by-law be finalized to provide governance around reducing impacts to development in flood areas. Specific types of development such as parks and trails may be exceptions to this development guideline.

The City may consider implementing a by-law to allow the City to have the first option to purchase properties in the flood plain when they go up for sale. In this way, over time, the City could remove properties at risk of flooding and redevelop flood plain areas into recreational areas, nature reserves, or wetlands.

7.3.1.2 Property Acquisition

The City could consider select property acquisition as a method of reducing risk to property.

7.3.1.3 Dyke Protection

To protect all the West Flat area from 1:500 year flooding on the south side of the NSR, a 2.9 km long, 2.0 – 4.0 m high earth dyke would be required. Implementing a solution such as this would require property acquisition and buy-in from regulators and the public. Dykes have the potential to increase flood elevations and further study would be required prior to implementation. A dyke that protects the West Flat area would also protect the WTP. A 1 m high dyke would provide flood protection for floods up to and including the 1:75 year flood. Figure 47 shows proposed mitigation options for the West Flat area.

The conceptual cost to construct an earth dyke with 3:1 side slopes and 3 m top width to protect the West Flat area on the south side of the NSR is estimated to be $3,500,000, excluding property acquisition.

It may be possible for a lower dyke to be combined with water filled barriers to provide flood protection for the West Flat area.

7.4 EAST FLAT AREA

The East Flat area is the topographically low area to the east of the Diefenbaker Bridge, south of the NSR. In this area, buildings are not affected by the 1:100 year flood as floodwaters are confined to the river channel, however the rear lots of 7 properties and 1 building will be affected by the 1:200 year flood event. Flooding impact to properties for the 1:200 and 1:500 year flood condition are presented in Table 21. The total area of the East Flat area that is inundated by the 1:500 year flood is 112.7 ha.

Table 21: Effects of Flooding on East Flat Area

	East Flat Area		
Return Period	**Number of Properties**	**Maximum Depth (m)**	**Maximum Velocity (m/s)**
1:200	7	0.35	0.29
1:500	1139	2.15	0.55

7.4.1 East Flat Area Mitigation Options

7.4.1.1 Development Regulation and By-Law, Property Acquisition

Similar to the options presented in section 7.3.1, the City could implement a development regulation or By-law or consider select property acquisition.

7.4.1.2 Dyke Protection

To protect all the East Flat area from flooding under the 1:500 year flood, a 1.5 m high 600 m long earth dyke combined with a 2.1 km long 2.0 m high dyke and a 3.5 m high 100 m long dyke would be required.

Implementing a solution such as this would require property acquisition and buy-in from regulators and the public. A 1 m high dyke would provide flood protection for floods up to and including the 1:200 year flood. Figure 48 shows proposed mitigation options for the West Flat area.

The conceptual cost to construct an earth dyke with 3:1 side slopes and 3 m top width to protect the East Flat area is estimated to be $2,800,000, excluding property acquisition.

It may be possible for a lower dyke to be combined with water filled barriers to provide flood protection for the East Flat area.

7.5 HAZELDELL AREA

The Hazeldell area is a largely residential neighborhood on a topographically low area to the west of the Diefenbaker Bridge, on the north side of the NSR. This region will see flooding for the 1:200 year flood events and above, and flooding impacts are presented in Table 22.

Table 22: Effects of Flooding on Hazeldell Area

	Hazeldell Area		
Return Period	**Number of Properties**	**Maximum Depth (m)**	**Maximum Velocity (m/s)**
1:200	18	0.85	0.37
1:500	82	2.35	0.41

7.5.1 Hazeldell Area Mitigation Options

7.5.1.1 Development Regulation and By-Law, Property Acquisition

Similar to the options presented in section 7.3.1 and 7.4.1, the City could implement a development regulation or By-law or consider select property acquisition.

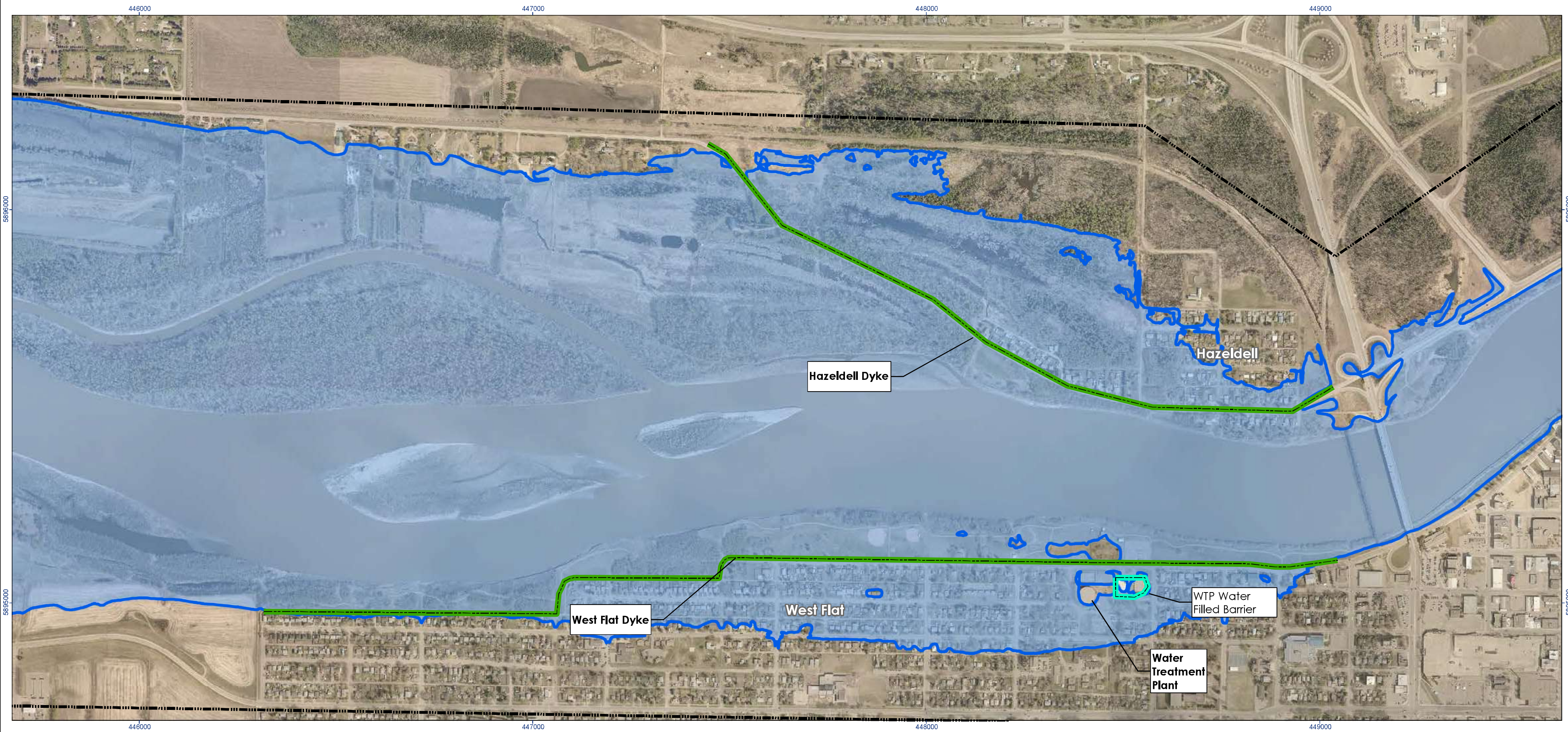
7.5.1.2 Dyke Protection

To protect all of the Hazeldell Area from flooding a 1.0 km long, 1.5 m high earth dyke combined with 550 m long, 2.5 m high earth dyke would be required. The dyke would follow Shellbrook Road / Riverside Drive. Implementing a solution such as this would require property acquisition and buy-in from regulators and the public. A 1 m high dyke would provide flood protection for floods up to and including the 1:200 year flood. Figure 47 shows proposed mitigation options for the Hazeldell area.

The conceptual cost to construct an earth dyke to protect the Hazeldell Area is estimated to be $2,000,000, excluding property acquisition. It may be possible for a lower dyke to be combined with water filled barriers to provide flood protection for the Hazeldell area.

7.6 IMPACTS OF MITIGATION OPTIONS

The impacts of protecting properties on both the north and south sides of the NSR (West Flat, East Flat and Hazeldell areas) at the same time would require further investigation into the effects of any dykes or berm systems on the modelled flood elevations. Regulatory approvals would be required for this type of construction and the impacts of encroaching on the floodplain and reducing conveyance (possibly increasing flood elevations) would need to be examined in detail.



Legend

Flood Mitigation

- Dyke
- Water Filled Barrier
- Flood Inundation Extent - 500 Year
- Study Area Boundary

0 190 380 metres

(At original document size of 11x17)
1:10,000

N

Stantec

City of Prince Albert

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by HA on 2019-12-6
IR Review by DS on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Flood Mitigation

Figure No.
47

Title
West Mitigation Options

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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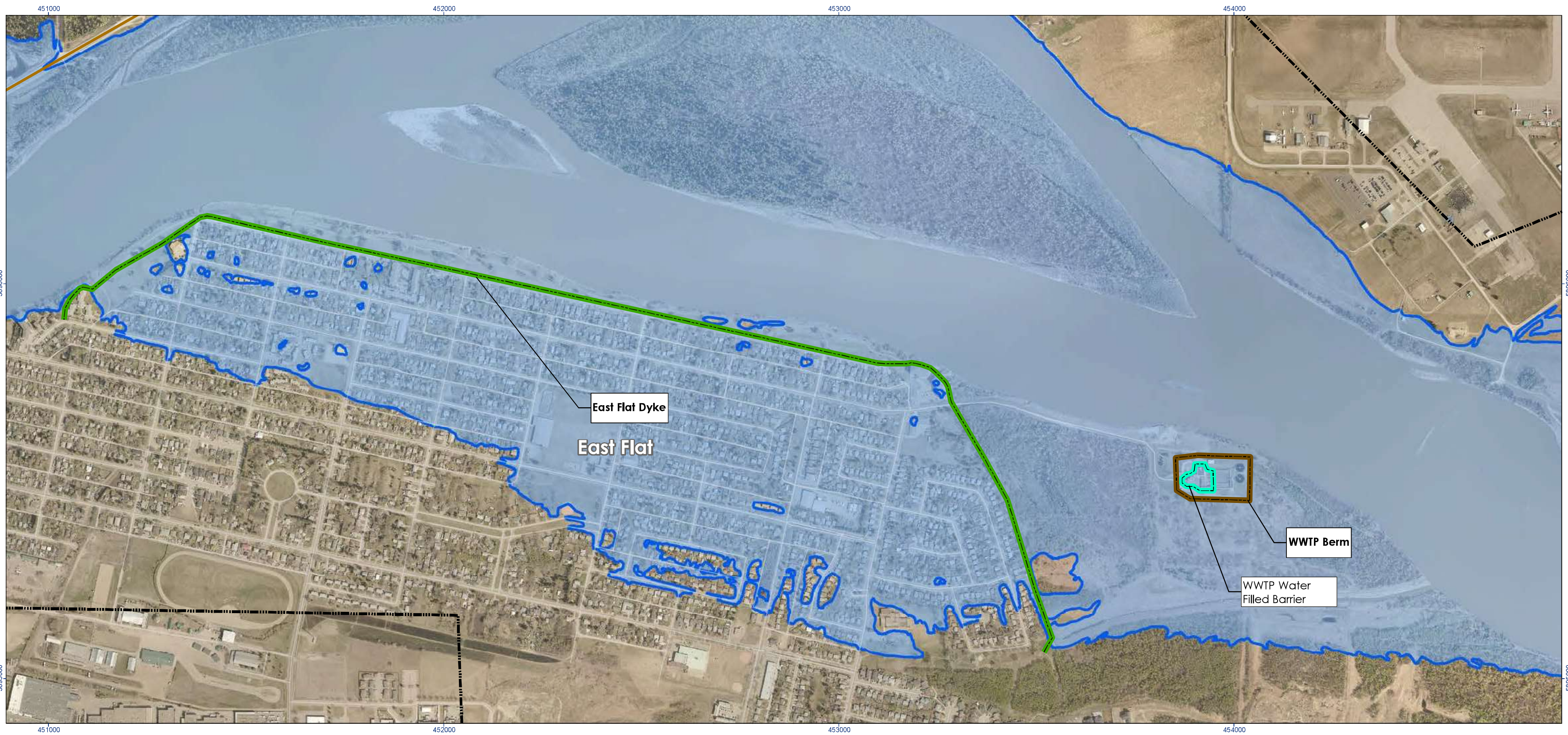

Legend

Flood Mitigation

- Dyke
- Berm
- Water Filled Barrier
- Flood Inundation Extent - 500 Year
- Study Area Boundary

0 190 380 metres

(At original document size of 11x17)
1:10,000

N

Stantec

City of Prince Albert

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by HA on 2019-12-6
IR Review by DS on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Flood Mitigation

Figure No.
48

Title
East Mitigation Options

Notes
1. Coordinate System: NAD 1983 UTM Zone 13N
2. Data Sources:
3. Background: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

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8.0 CONCLUSIONS AND RECOMMENDATIONS

Mapping for the 1:500 year flood has been developed using updated hydrology, topography, bathymetry and modelling software as described in this report. Comparing the updated hydrology shows that the recommended flows are relatively close to flows used in previous mapping studies (Table 23 and Table 24).

Table 23: Return Period Hydrology for North Saskatchewan River

Return Period	Recommended Peak Instantaneous Flow (m^3/s)
1:10	2,400
1:50	3,685
1:100	4,905
1:500	8,175

Table 24: Return Period Hydrology for Little Red River

Return Period	Recommended Peak Instantaneous Flow (m^3/s)
1:10	77.8
1:50	134.2
1:100	146.6
1:500	168.0

The flood plain extents resulting from the 2D modelling analysis are presented on the maps included in Appendix C. Flood elevations in the NSR for the 1:500 year event range between 427.92 masl at the upstream Project boundary to 424.04 masl at the downstream Project boundary. In the LRR flood elevations are largely controlled by the NSR and for the 1:500 year event range between 431.26 masl at the upstream City boundary and 425.82 masl at the confluence with the NSR.

Floodway and flood fringe extents have been delineated for the 1:500 year flood to support local policy development. Overall, there are 27 properties affected by the 1:100 year flood and 1599 properties affected by flooding under the 1:500 year flood event.

Conceptual mitigation options and associated opinion of probable costs have been provided for further consideration.

It is recommended that the return period flood flows and the flood lines as shown on the mapping in Appendix C be adopted for use by the City of Prince Albert and the WSA.

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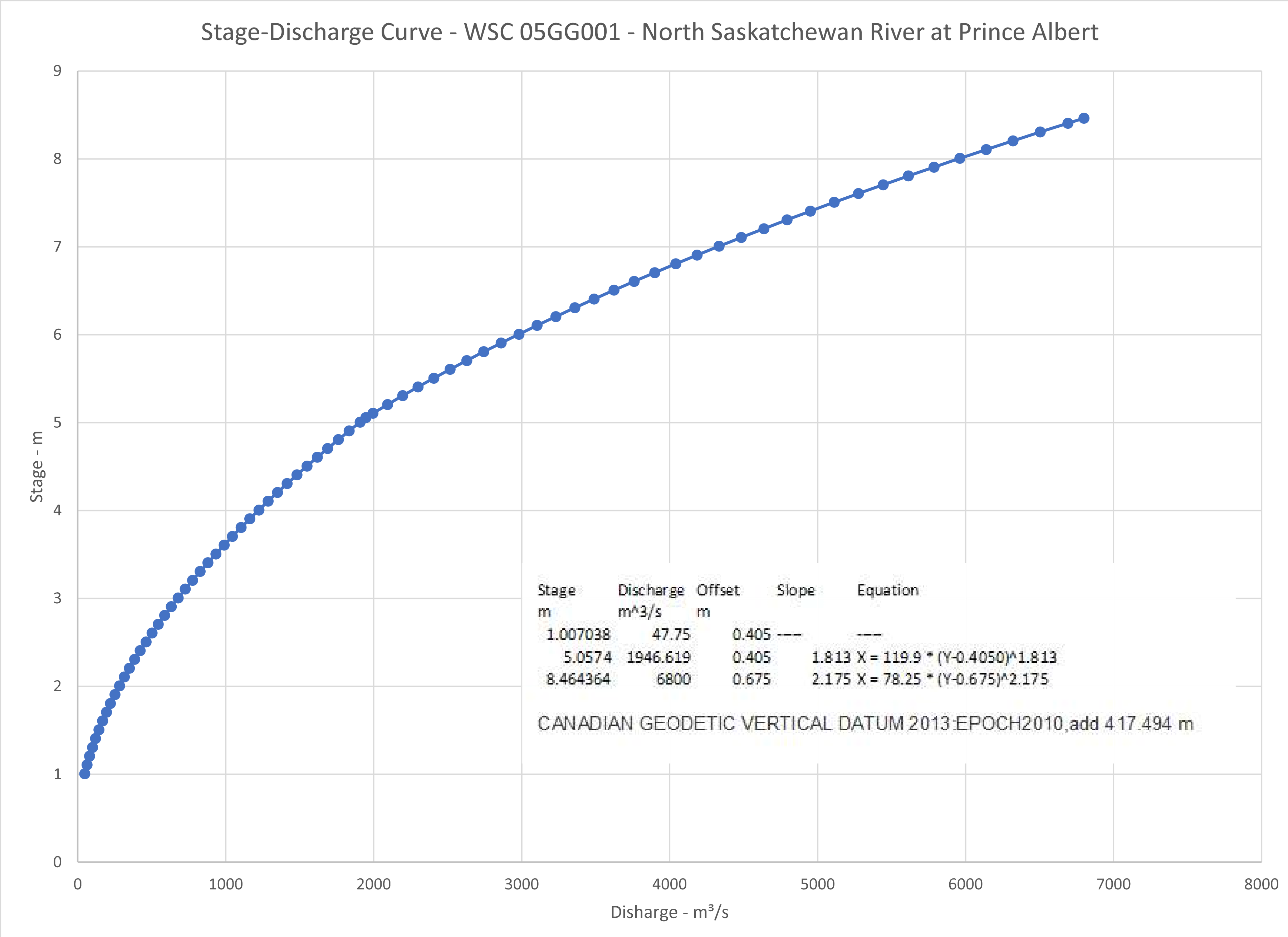
APPENDIX A

Stage-Discharge Curve for WSC Station 05GG001 (North Saskatchewan River at Prince Albert)



Stage-Discharge Curve - WSC 05GG001 - North Saskatchewan River at Prince Albert
Stage - m
Disharge - m³/s
0
1
2
3
4
5
6
7
8
9
0
1000
2000
3000
4000
5000
6000
7000
8000
Stage Discharge Offset Slope Equation
m m^3/s m
1.007038 47.75 0.405 ---- ----
5.0574 1946.619 0.405 1.813 X = 119.9 * (Y-0.4050)^1.813
8.464364 6800 0.675 2.175 X = 78.25 * (Y-0.675)^2.175
CANADIAN GEODETIC VERTICAL DATUM 2013:EPOCH2010,add 417.494 m

APPENDIX B

Historic Flood Data & Ice Data

Cost Assumptions

North Saskatchewan River at Prince Albert (05GG001) Flow Data

Year	Peak Flow Date	Peak Instantaneous Flow (m^3/s)	Maximum Daily Mean Flow (m^3/s)	Naturalized Maximum Daily Mean Flow (m^3/s)	Approximate Return Period
1912	14-Jul	2070	1980		
1913			1010		
1914			1790		
1915	2-Jul	5660	5300		1:200
1916			1510		
1917			1540		
1918			926		
1919			527		
1920			1570		
1921			1130		
1922	25-Aug	719	682		
1923	30-Jun	1670	1640		
1924	12-Jul	767	765		
1925	23-Aug	1670	1620		
1926			1350		
1927			1650		
1928			1570		
1929			1340		
1930			685		
1931			1050		
1932	10-Jun	2230	2160		1:10
1933			954		
1934			756		
1935			1560		
1936			1620		
1937			770		
1938			940		
1939			790		
1940			1140		
1941			487		
1942			1230		
1943			1180		
1944					
1945			620		
1946			1070		
1947			796		
1948			2090		
1949			762		

North Saskatchewan River at Prince Albert (05GG001) Flow Data

Year	Peak Flow Date	Peak Instantaneous Flow (m^3/s)	Maximum Daily Mean Flow (m^3/s)	Naturalized Maximum Daily Mean Flow (m^3/s)	Approximate Return Period
1950			1190		
1951			991		
1952	29-Jun	3030	2970		1:25
1953	10-Jun	1190	1120		
1954	12-Jun	3060	2790		1:25
1955			951		
1956			1800		
1957			623		
1958	6-Jul	1330	1270		
1959	4-Jul	1270	1190		
1960	9-Jul	1010	1010		
1961	7-Aug	799	799		
1962	21-Jul	767	759		
1963	22-Apr	1160	1110	1179	
1964	26-Jun	1270	1250	1250	
1965	4-Jul	2520	2460	2420	1:10
1966	12-Jul	1310	1280	1450	
1967	26-Jun	883	875	937	
1968	16-Aug	603	589	714	
1969	13-Jul	1590	1570	1820	
1970	24-Jun	1270	1250	1536	
1971	17-Jun	1140	1110	1280	
1972	2-Jul	2380	2340	2700	1:10
1973	3-Jul	646	620	1000	
1974	23-Apr	4050	3880	3853	1:75
1975	1-May	790	787	722	
1976	14-Apr	668	629	648	
1977	6-Jun	929	915	1040	
1978			889	1220	
1979			1060	970	
1980	12-Jun	1630	1580	1989	
1981	2-Aug	1170	1150	1482	
1982	13-Jul	1730	1680	1925	
1983			790	700	
1984	8-Apr	835	754	965	
1985	14-Apr	1010	944	862	
1986	24-Jul	3420	3230	3287	1:25
1987			871	784	

North Saskatchewan River at Prince Albert (05GG001) Flow Data

Year	Peak Flow Date	Peak Instantaneous Flow (m^3/s)	Maximum Daily Mean Flow (m^3/s)	Naturalized Maximum Daily Mean Flow (m^3/s)	Approximate Return Period
1988	15-Jul	529	515	615	
1989	12-Aug	849	834	1098	
1990	10-Jul	2050	1890	1996	
1991	14-Jul	1020	996	1260	
1992	6-Apr	520	491	400	
1993	6-Aug	477	474	609	
1994	21-Apr	716	709	613	
1995	13-Jul	1010	997	1399	
1996	20-Apr	817	749	686	
1997	22-Apr	1350	1180	1102	
1998	8-Jul	1370	1340	1616	
1999	23-Jul	1470	1410	1789	
2000	18-Jul	829	787	990	
2001	6-Aug	809	781	957	
2002	2-May	501	487	424	
2003	4-May	744	729	814	
2004			514	630	
2005	27-Jun	1950	1800	2148	
2006	14-Apr	1070	859	761	
2007	12-May	1330	1300	1275	
2008	20-Jun	982	965	1134	
2009	19-Apr	859	666	778	
2010	19-Jun	801	790	905	
2011	26-Jun	2170	2100	2242	
2012	18-Jun	1040	1010	1129	
2013	29-Jun	2270	2200	2344	1:10
2014	24-Apr	1900	1480	1609	
2015			1130	1252	
2016	31-Aug	1120	1080	1201	

Garden River at Henribourg (05GG010) Flow Data

Year	Peak Flow Date	Peak Instantaneous Flow (m^3/s)	Maximum Daily Mean Flow (m^3/s)
1919			0.623
1920			13.3
1921			37.4
1922			33.1
1923			5.83
1924			9.83
1925			11.6
1926			4.97
1927			19.1
1928			9.07
1929			8.7
1930			8.65
1931			3.67
1955			16.7
1956			25
1957			43.4
1958			8.85
1959			4.47
1960			11.6
1961			1.74
1962			9.37
1963			5.35
1964			6.45
1965			7.16
1966			9.08
1967		3.23	2.07
1968		4.05	3.45
1969		21.1	19.8
1970		20.2	19.9
1971		15.3	15.1
1972		39.9	36.8
1973		20.8	18.9
1974		52.7	51
1975		16.4	16.1
1976		3.03	1.53
1977			0.156
1978		8.67	7.96
1979		45	40.9

Garden River at Henribourg (05GG010) Flow Data

Year	Peak Flow Date	Peak Instantaneous Flow (m^3/s)	Maximum Daily Mean Flow (m^3/s)
1980		11.4	11
1981		2.07	1.83
1982		6.03	5.95
1983		21.1	20.1
1984		13.1	12.9
1985		53.8	50.9
1986		8.45	7.74
1987		2.29	1.68
1988		12	11.8
1989		0.274	0.06
1990	11-May	0.982	0.896
1991	17-Jun	3.17	1.25
1992	29-Mar	0.286	0.209
1993	26-Jul	1.98	1.7
1994	29-May	3.9	3.82
1995	21-Apr	23.6	22.7
1996	18-Apr	3.41	2.84
1997	21-Apr	31.7	28.7
1998	6-Apr	3.87	2.86
1999	14-Apr	4.18	3.79
2000	2-Apr	11.4	11.2
2001	15-Apr	3.11	2.74
2002			
2003	27-Mar	0.013	0.01
2004	29-Jul	2.1	1.67
2005	9-Apr	20.8	20.5
2006	14-Apr	40.7	39.8
2007	19-Apr	30	28.9
2008	18-Apr	36.4	34.9
2009	20-Apr	5.26	3.2
2010	11-Jun	12.7	12.5
2011	15-Apr	29.3	27.6
2012	5-Apr	15.2	15
2013	18-Jun	39.5	38.5
2014	26-Apr	63.6	63
2015	15-Apr	8.54	8.42
2016	7-Apr	12.5	11.6

Aunnual Ice Breakup dates on NSR at Prince Albert

Data Source: City of Prince Albert

Year	Date	Adjusted
1912	5-Apr	2-Apr
1913	6-Apr	3-Apr
1914	22-Apr	19-Apr
1915	10-Apr	7-Apr
1916	21-Apr	18-Apr
1917	3-May	30-Apr
1918	13-Apr	10-Apr
1919	18-Apr	15-Apr
1920	2-May	29-Apr
1921	27-Apr	24-Apr
1922	24-Apr	21-Apr
1923	27-Apr	24-Apr
1924	29-Apr	26-Apr
1925	16-Apr	13-Apr
1926	18-Apr	15-Apr
1927	28-Apr	25-Apr
1928	25-Apr	22-Apr
1929	29-Apr	26-Apr
1930	16-Apr	13-Apr
1931	18-Apr	15-Apr
1932	18-Apr	15-Apr
1933	24-Apr	21-Apr
1934	20-Apr	17-Apr
1935	24-Apr	21-Apr
1936	26-Apr	23-Apr
1937	20-Apr	17-Apr
1938	14-Apr	11-Apr
1939	23-Apr	20-Apr
1940	24-Apr	21-Apr
1941	16-Apr	13-Apr
1942	24-Apr	21-Apr
1943	20-Apr	17-Apr
1944	14-Apr	11-Apr
1945	25-Apr	22-Apr
1946	12-Apr	9-Apr
1947	23-Apr	20-Apr
1948	30-Apr	27-Apr
1949	16-Apr	13-Apr
1950	24-Apr	21-Apr
1951	16-Apr	13-Apr
1952	16-Apr	13-Apr
1953	24-Apr	21-Apr
1954	5-May	2-May
1955	14-Apr	11-Apr
1956	23-Apr	20-Apr
1957	23-Apr	20-Apr
1958	30-Apr	27-Apr
1959	13-Apr	10-Apr
1960	15-Apr	12-Apr
1961	19-Apr	16-Apr
1962	21-Apr	18-Apr
1963	15-Apr	12-Apr
1964	19-Apr	16-Apr
1965	22-Apr	19-Apr
1966	16-Apr	13-Apr
1967	3-May	30-Apr
1968	10-Apr	7-Apr
1969	15-Apr	12-Apr
1970	20-Apr	17-Apr
1971	19-Apr	16-Apr
1972	22-Apr	19-Apr
1973	13-Apr	10-Apr
1974	23-Apr	20-Apr
1975	27-Apr	24-Apr
1976	14-Apr	11-Apr
1977	17-Apr	14-Apr
1978	24-Apr	21-Apr
1979	3-May	30-Apr
1980	17-Apr	14-Apr
1981	21-Apr	18-Apr
1982	26-Apr	23-Apr
1983	22-Apr	19-Apr
1984	10-Apr	7-Apr
1985	15-Apr	12-Apr
1986	12-Apr	9-Apr
1987	13-Apr	10-Apr
1988	16-Apr	13-Apr
1989	21-Apr	18-Apr
1990	8-Apr	5-Apr
1991	13-Apr	10-Apr
1992	8-Apr	5-Apr
1993	10-Apr	7-Apr
1994	14-Apr	11-Apr
1995	24-Apr	21-Apr
1996	22-Apr	19-Apr
1997	27-Apr	24-Apr
1998	12-Apr	9-Apr
1999	13-Apr	10-Apr
2000	13-Apr	10-Apr
2001	20-Apr	17-Apr
2002	29-Apr	26-Apr
2003	22-Apr	19-Apr
2004	14-Apr	11-Apr
2005	9-Apr	6-Apr
2006	13-Apr	10-Apr
2007	19-Apr	16-Apr
2008	23-Apr	20-Apr
2009	21-Apr	18-Apr
2010	7-Apr	4-Apr
2011	20-Apr	17-Apr
2012	7-Apr	4-Apr
2013	1-May	28-Apr
2014	23-Apr	20-Apr
2015	5-Apr	2-Apr
2016	7-Apr	4-Apr
2017	7-Apr	4-Apr
2018	25-Apr	22-Apr
2019	7-Apr	4-Apr

*Adjusted 3 days (since last days are very slushy) per Environment Canada

Flood Plain Mapping Study

City of Prince Albert

Cost Estimating Assumptions

Opinion of probable construction cost

Road Costs	$	86	/m^2
Earth moving costs	$	18	/m^3
Site Preparation	$	15	/m^2
Site Restoration	$	28	/m^2
Aqua Dam for 0.9 m depth protection	$	5,700	/ 30 m
Aqua Dam for 1.5 m depth protection	$	14,500	/ 30 m

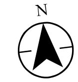
Earth Dykes - Unit Cost Estimate

1 m high, 3 m wide, 3:1 side slopes	$	5,000	/10 m
2 m high, 3 m wide, 3:1 side slopes	$	10,000	/10 m
3 m high, 3 m wide, 3:1 side slopes	$	16,000	/10 m

*Costs not included:

- Property Acquisition
- Design
- Permitting
- Pumps & Generators
- Contract administration

APPENDIX C
Flood Plain Maps



Legend

Study Area Boundary

Highways

Local Road Network

Flood Inundation Extent - 10 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes
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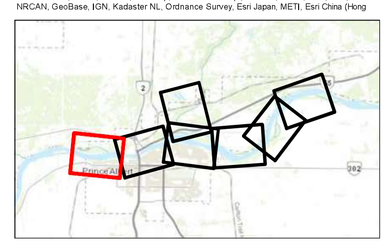

Project Location
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City of Prince Albert

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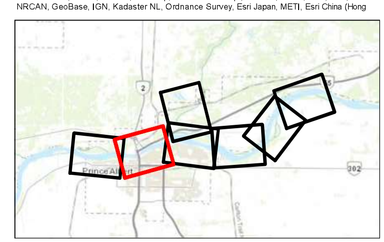

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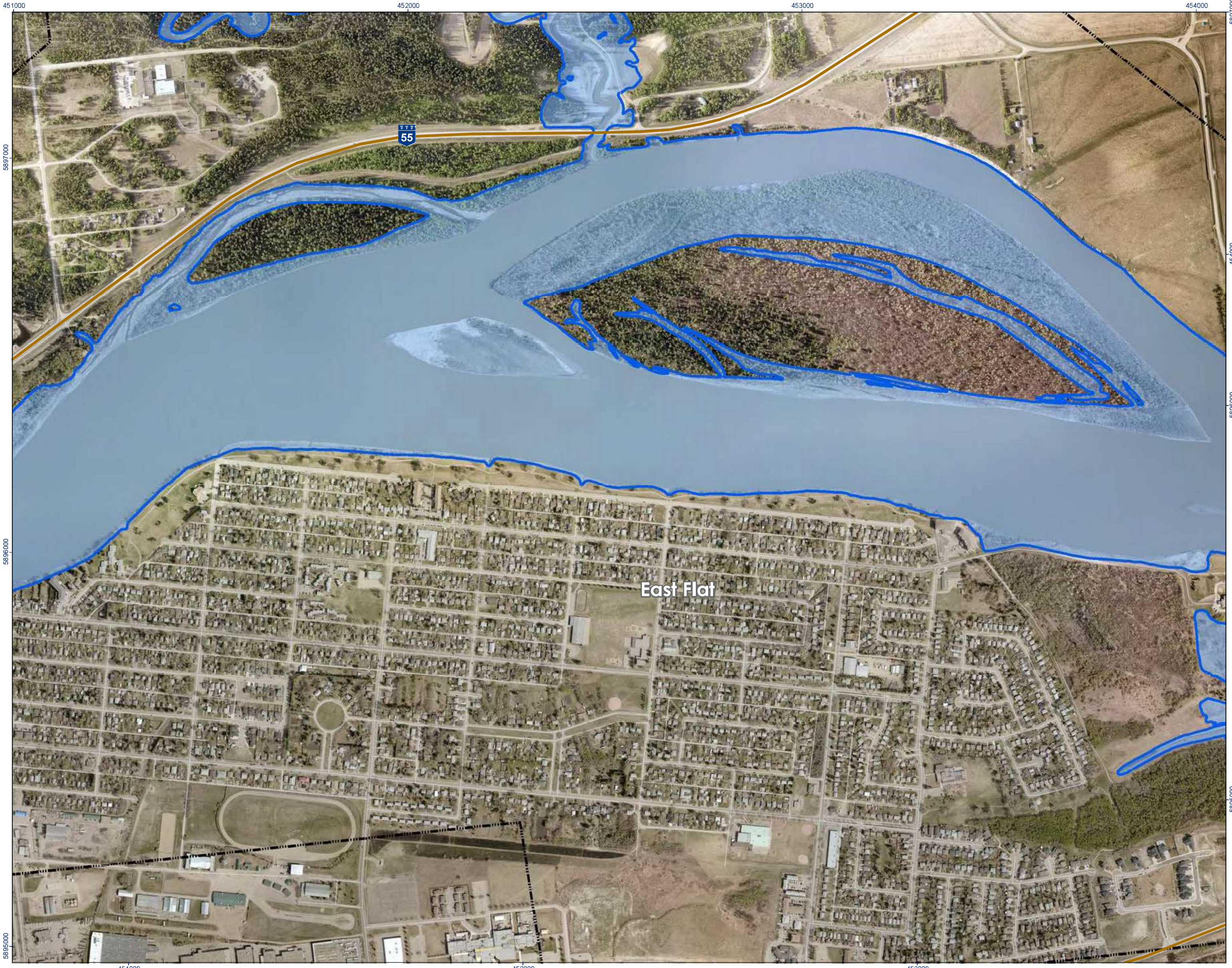

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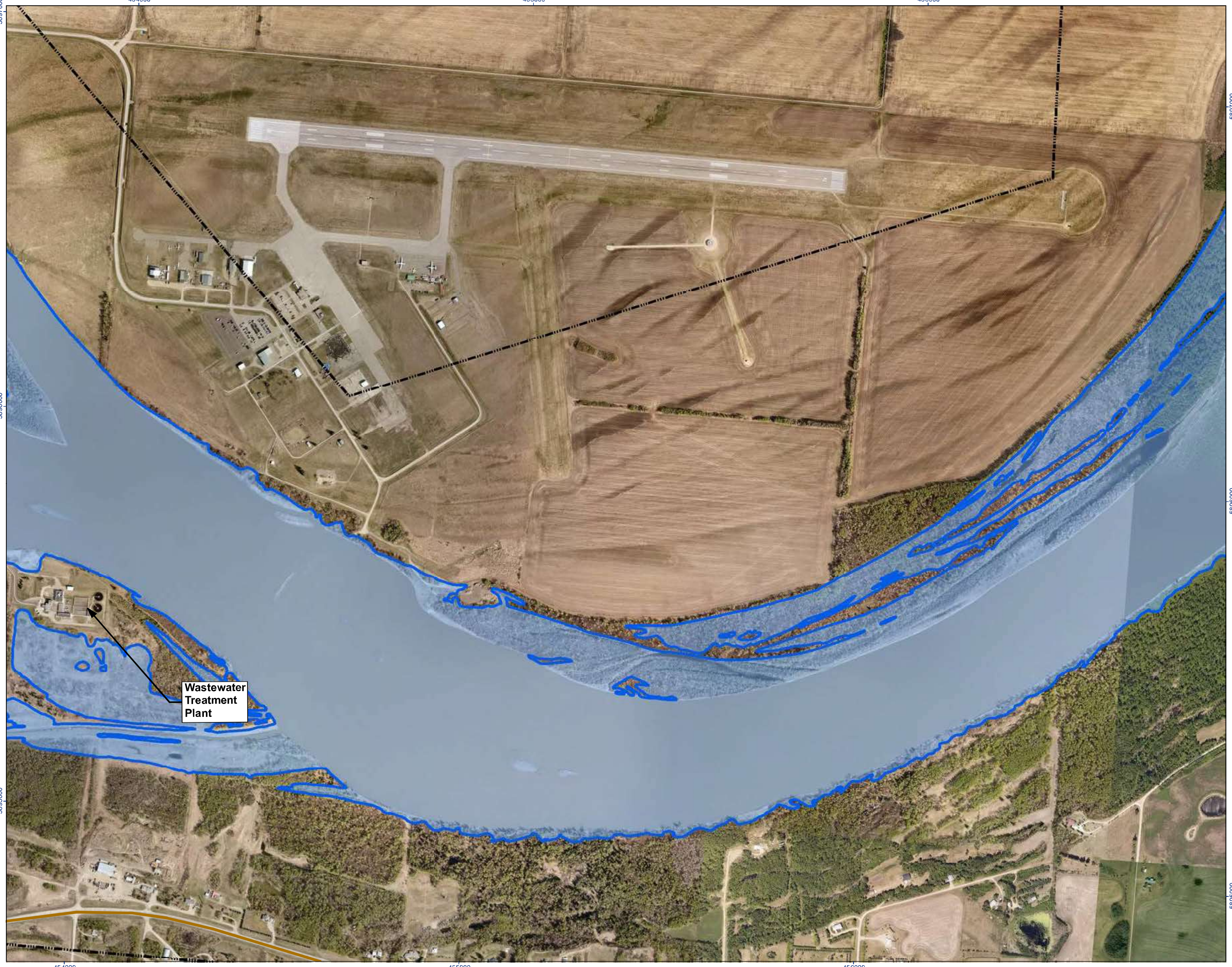

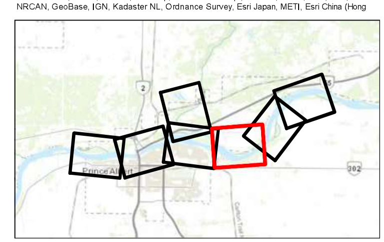

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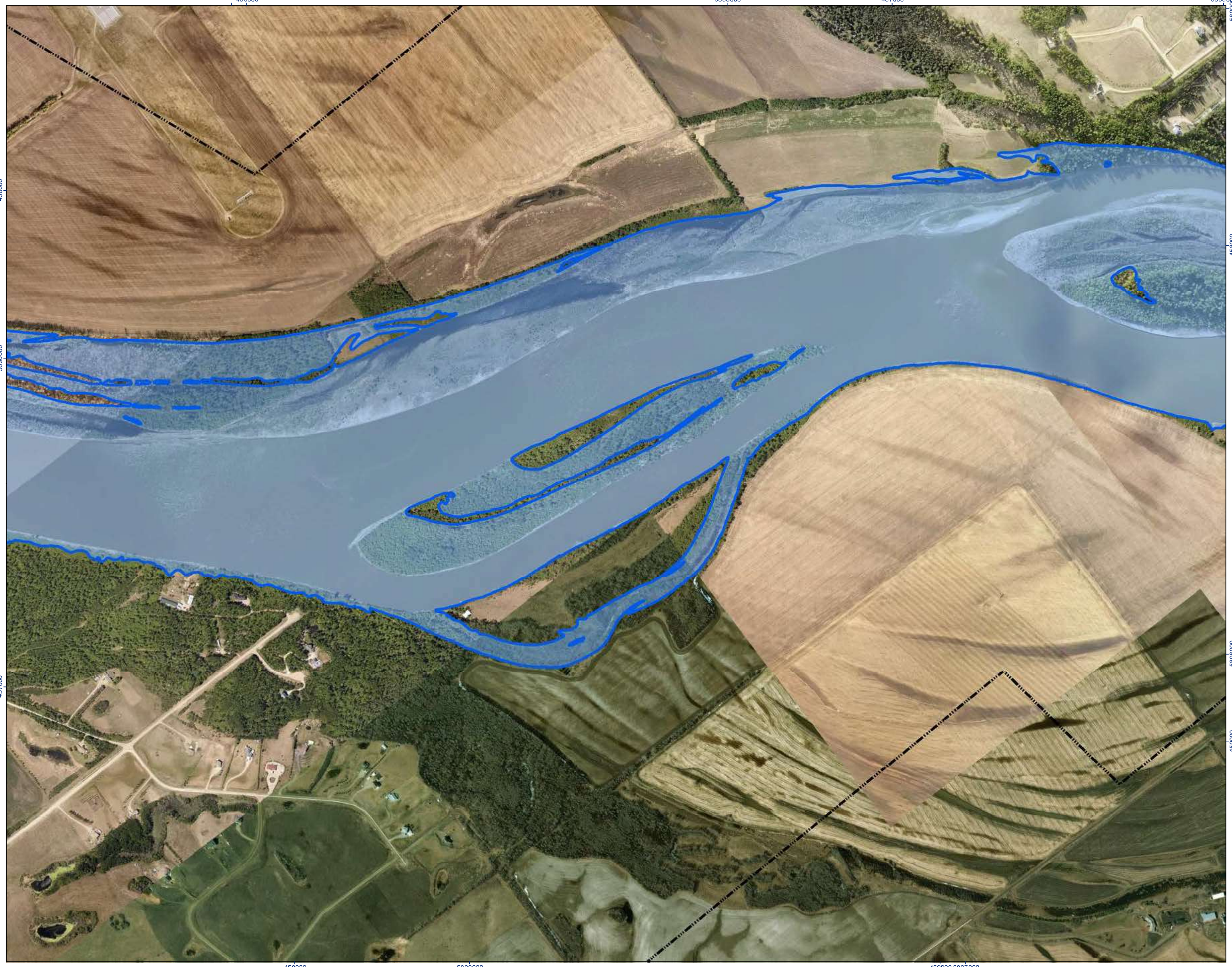

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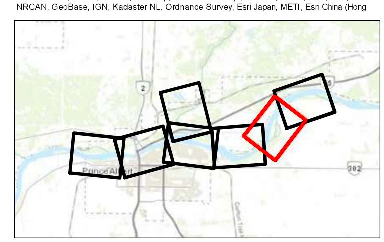

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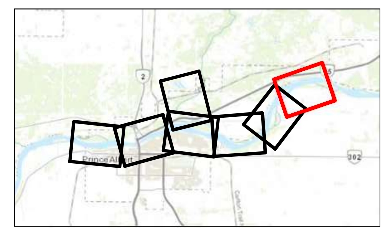

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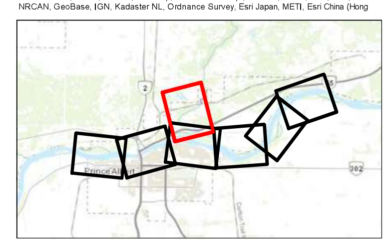

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City of Prince Albert

Legend

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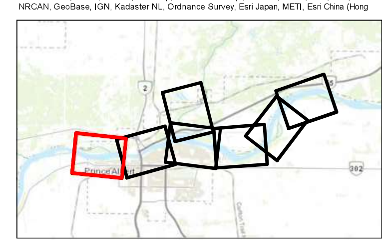

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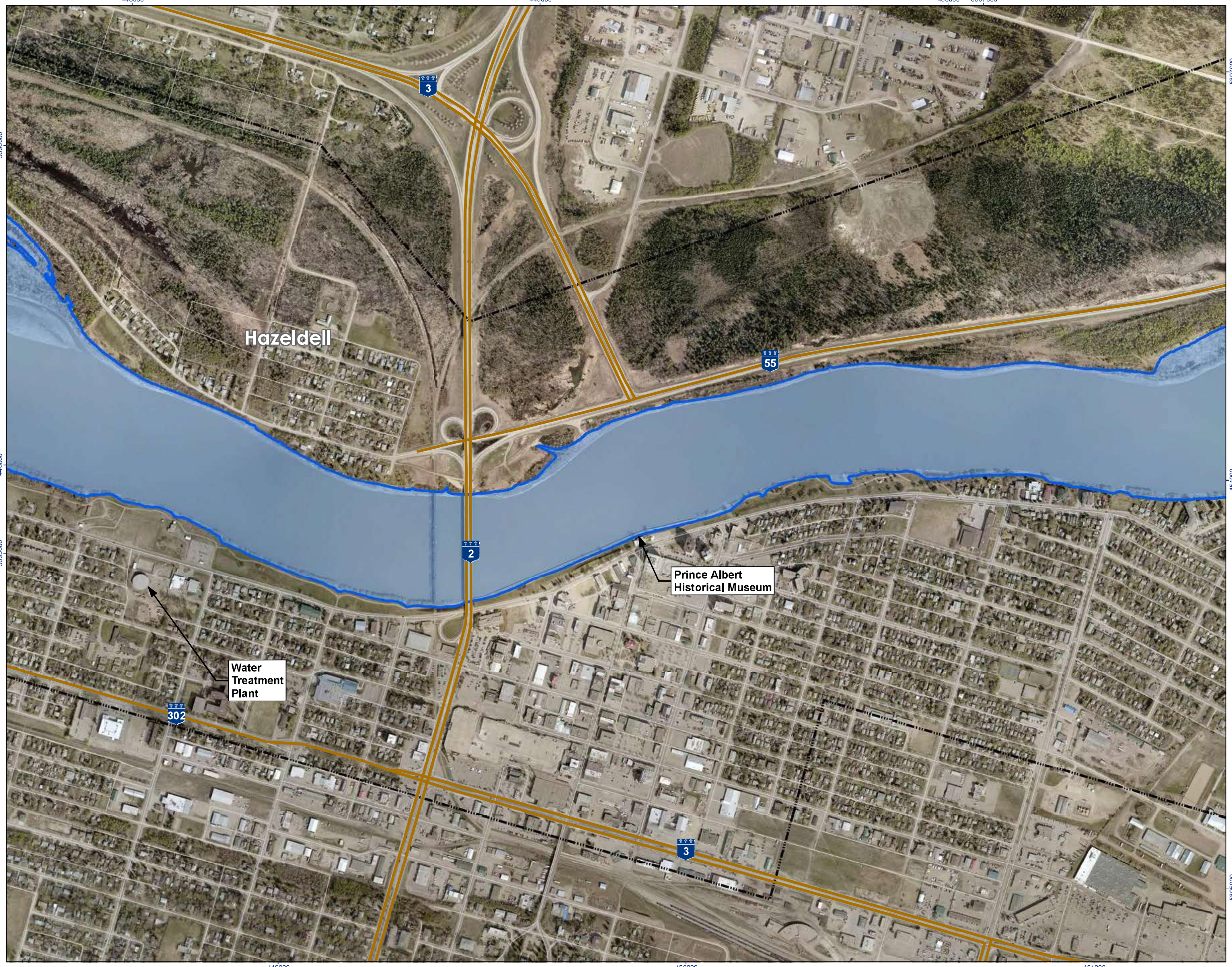

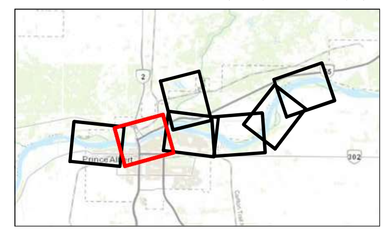

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City of Prince Albert

Legend

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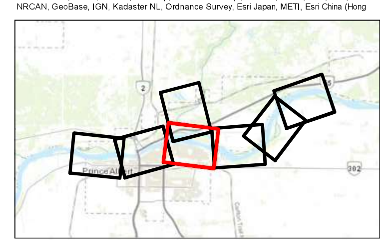

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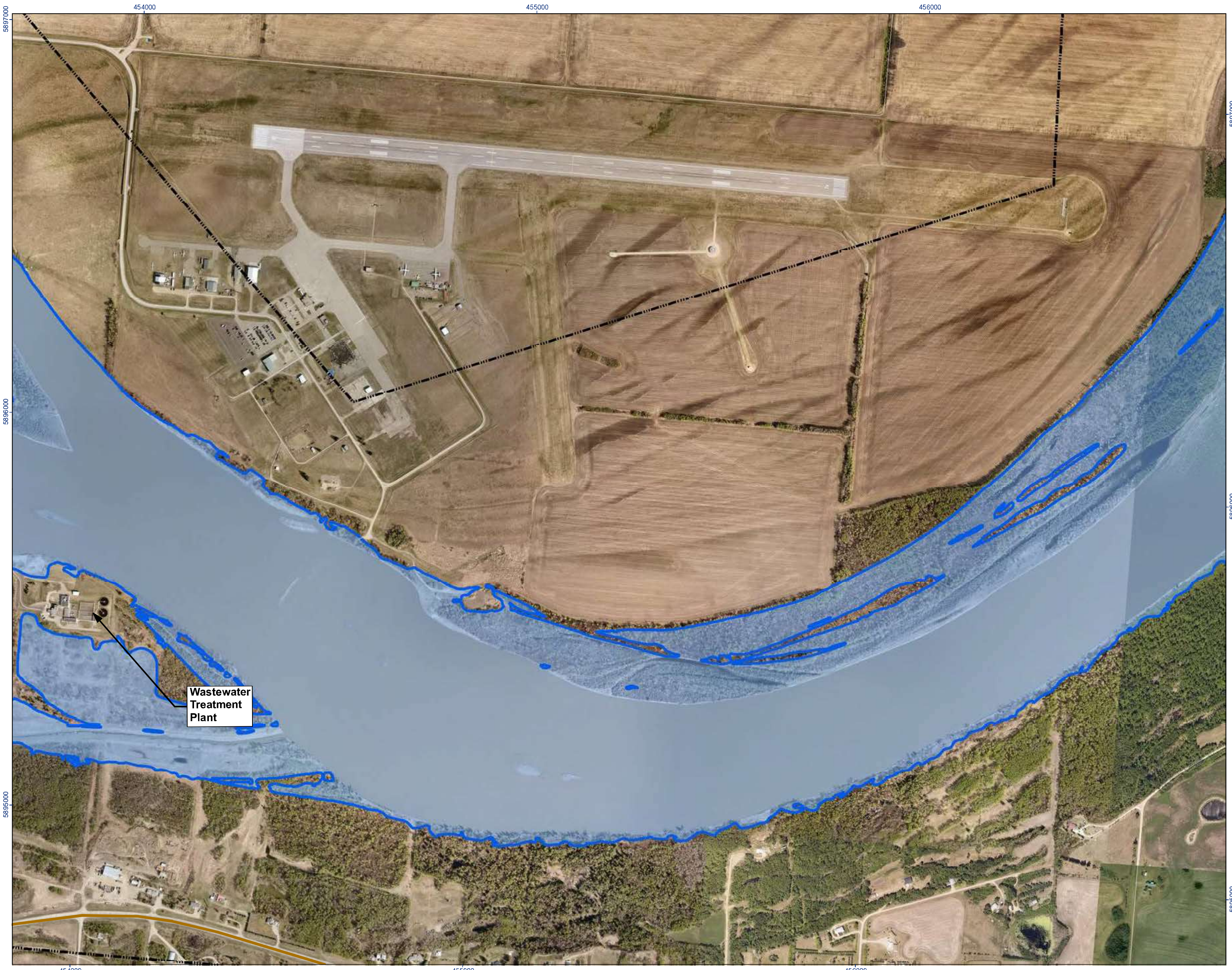

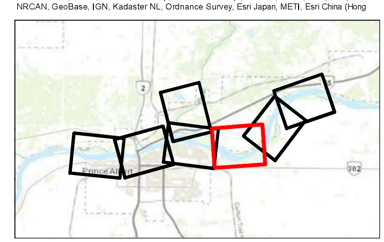

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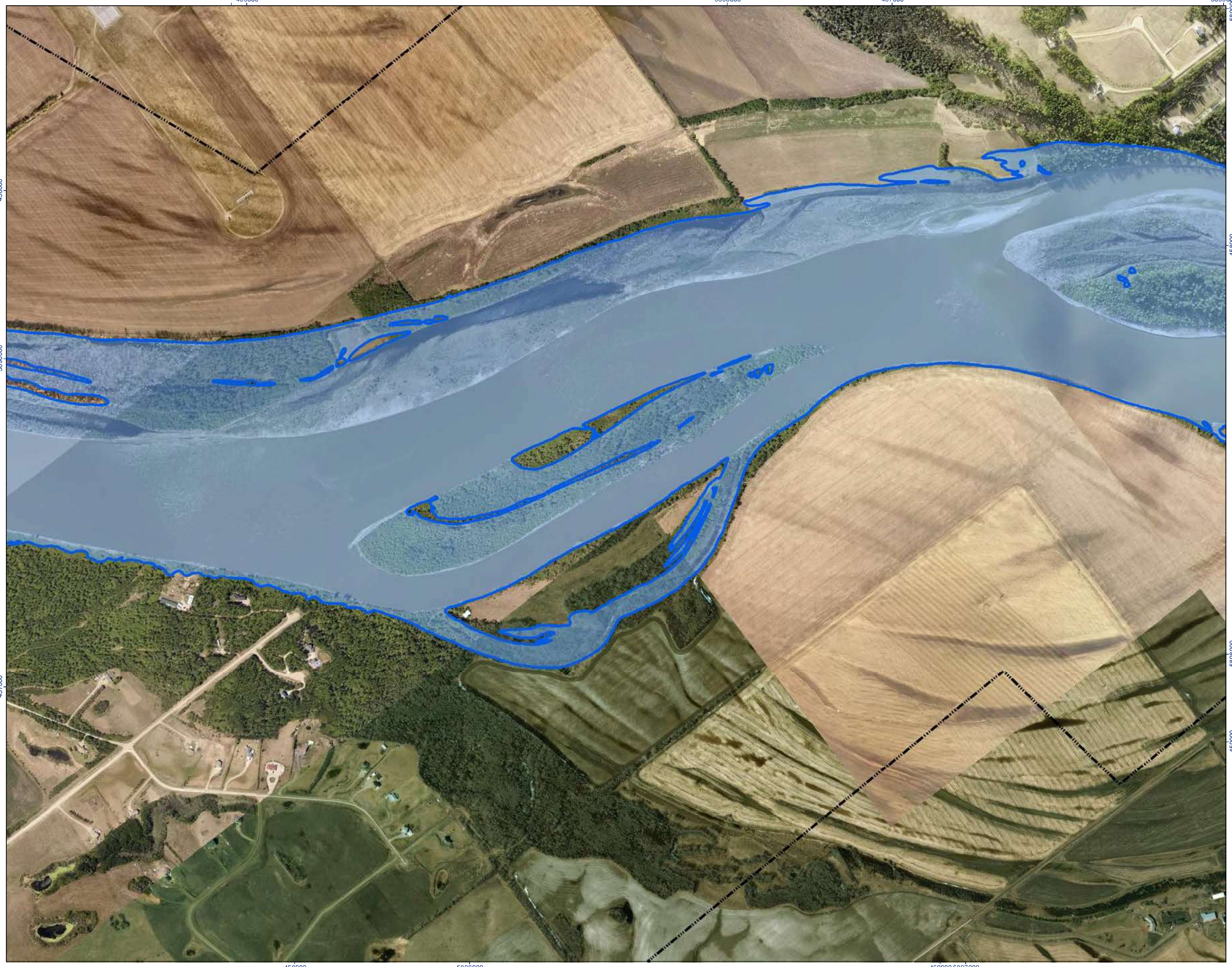

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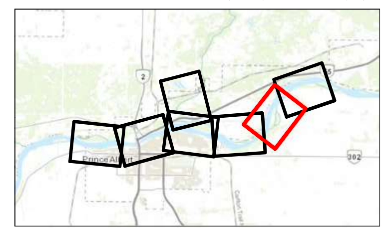

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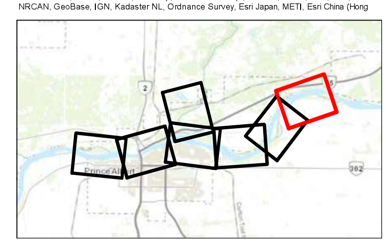

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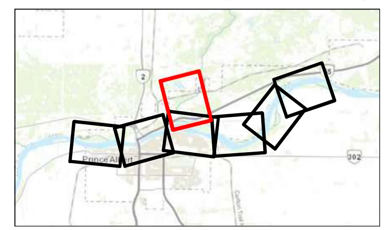

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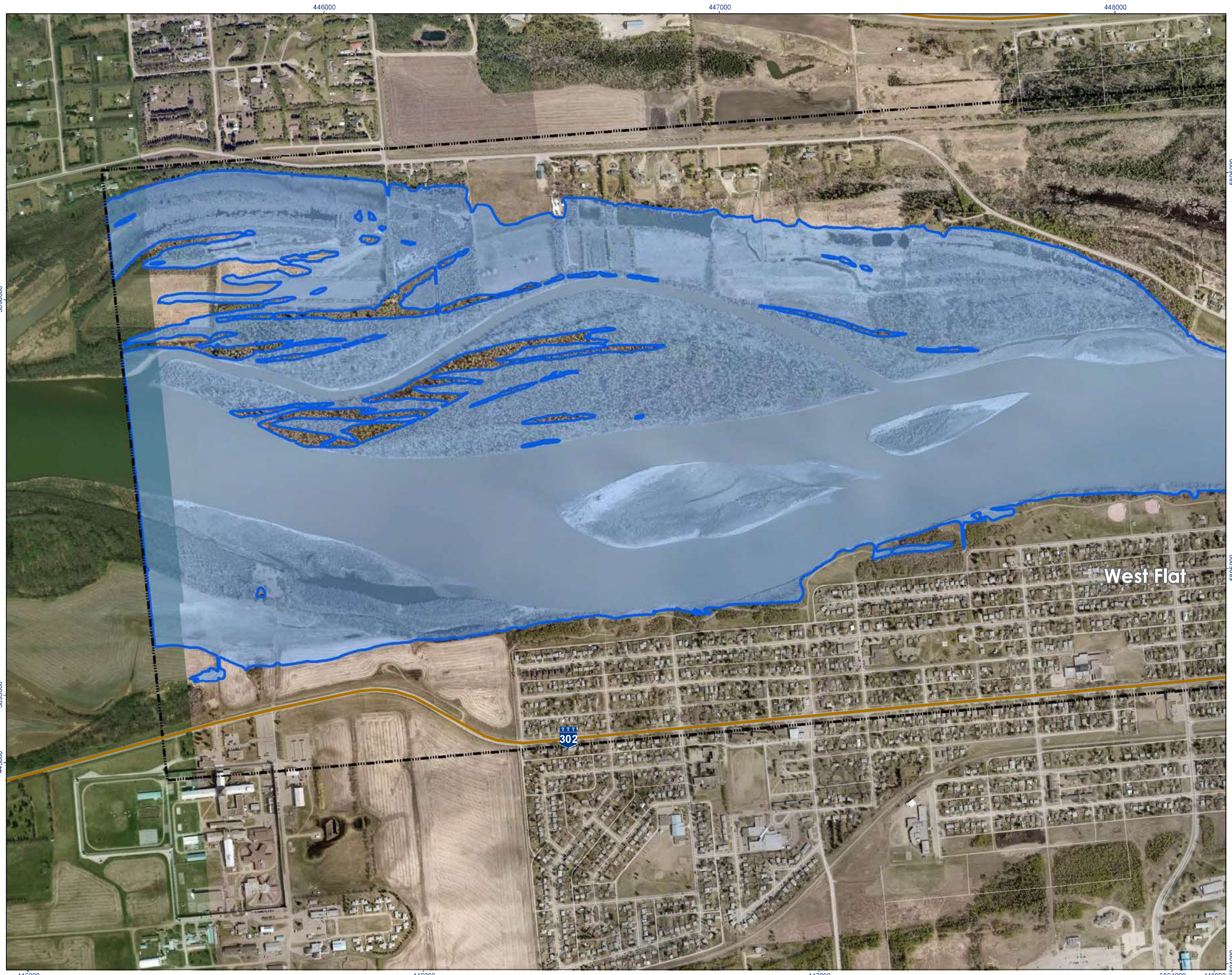

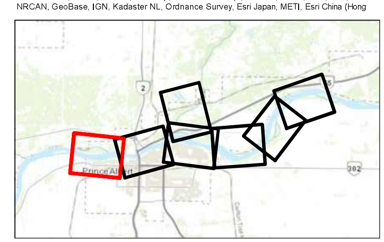

Stantec

City of Prince Albert

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 50 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes
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Project Location Prince Albert, SK	Prepared by MA on 2019-12-6 TR by LM on 2019-12-6 IR Review by HA on 2019-12-6
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Flood Plain Model - Inundation Results
50 Year Return Period

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City of Prince Albert

Legend

Study Area Boundary

Highways

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Flood Inundation Extent - 50 Year

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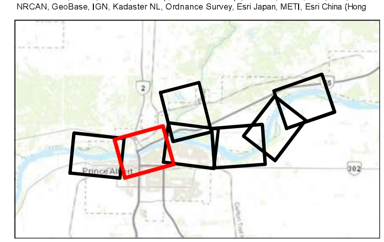

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
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City of Prince Albert
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Flood Plain Model - Inundation Results
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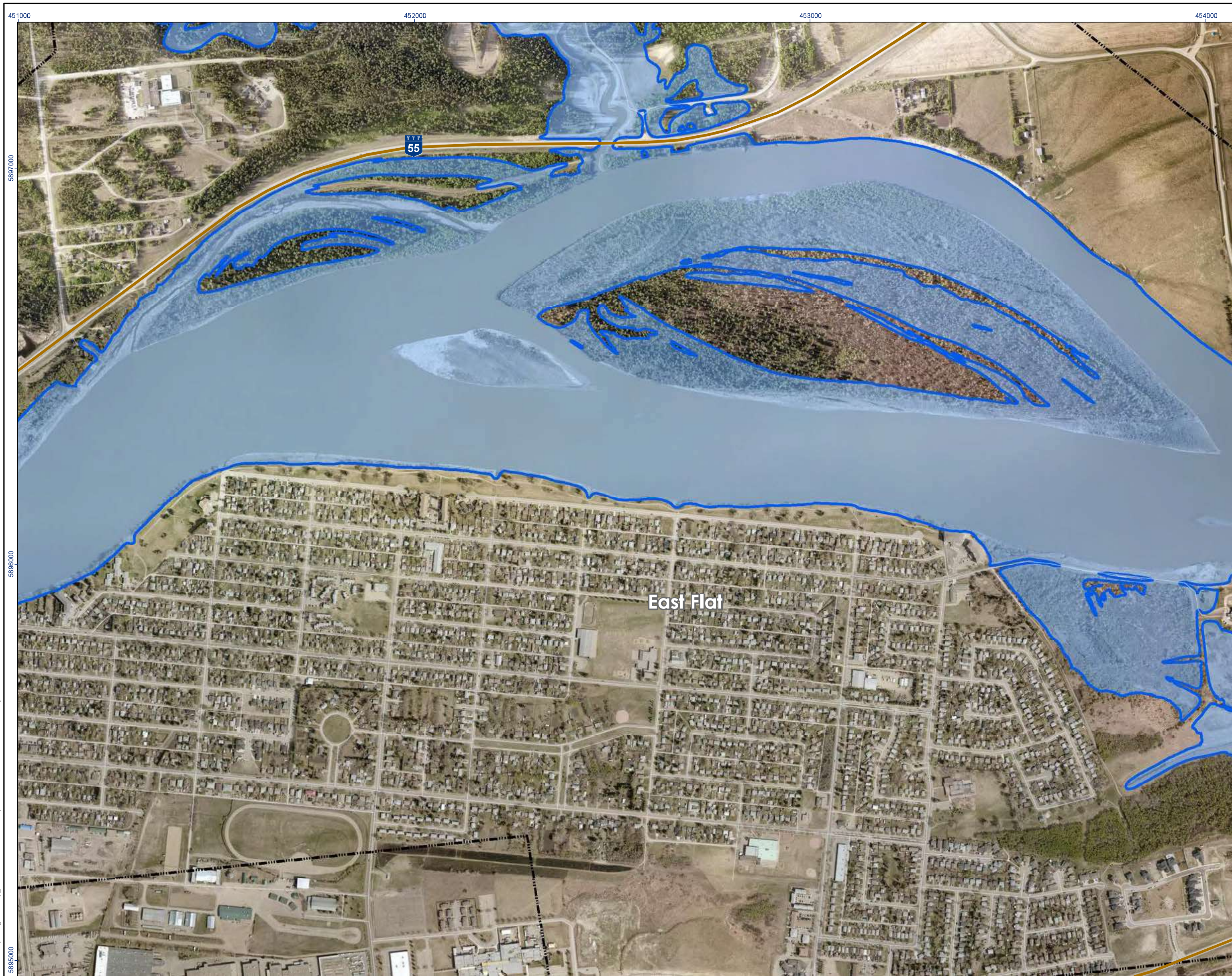

Stantec

City of Prince Albert

Legend
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- Flood Inundation Extent - 50 Year

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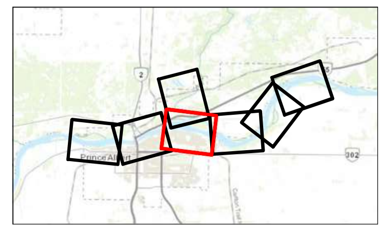

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Flood Plain Model - Inundation Results
50 Year Return Period

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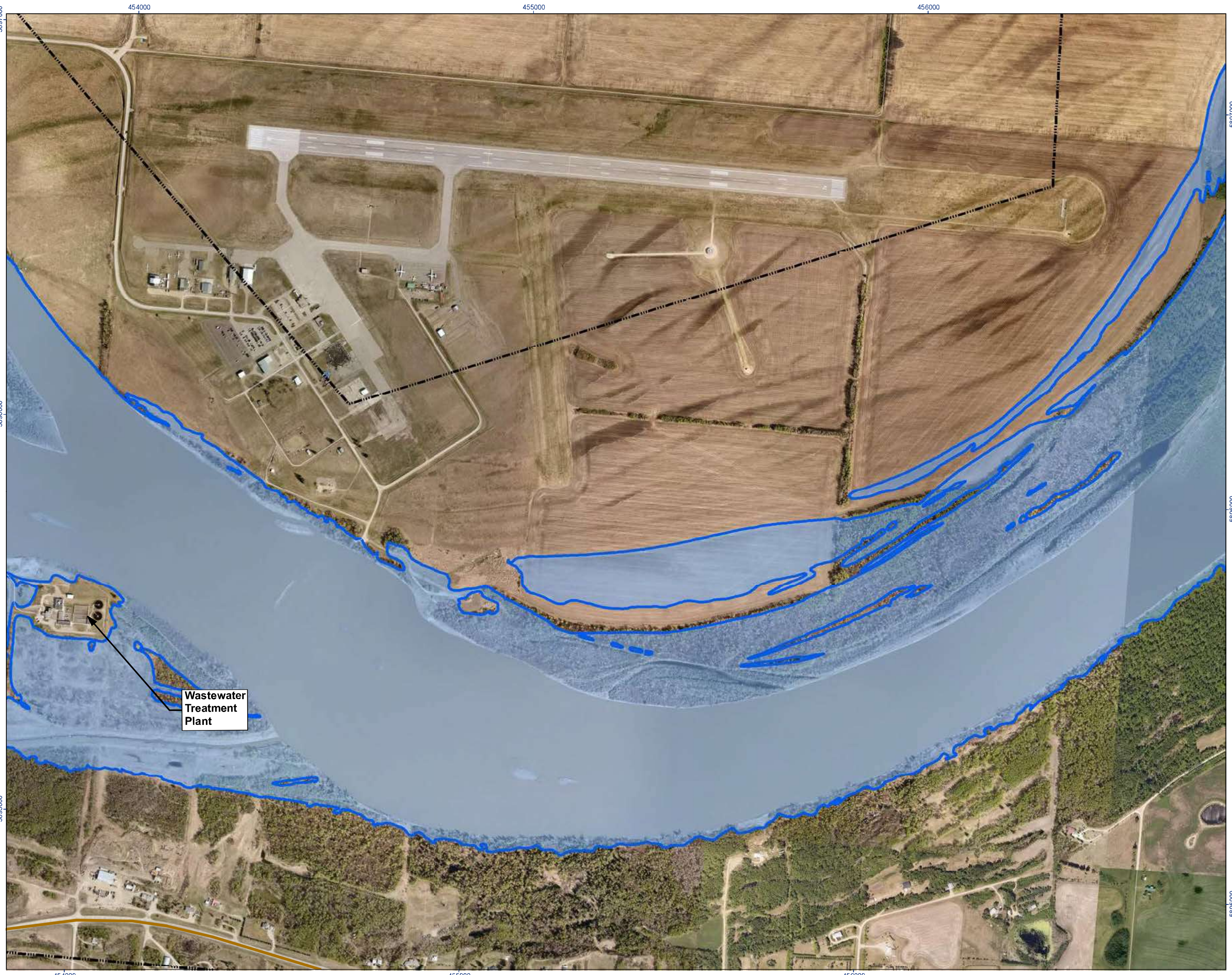

Stantec

City of Prince Albert

Legend

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N

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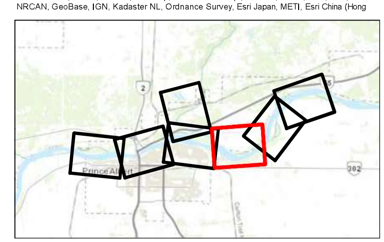

Project Location

Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project

City of Prince Albert
Flood Plain Mapping
Report

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Figure No.

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Title

Flood Plain Model - Inundation Results
50 Year Return Period

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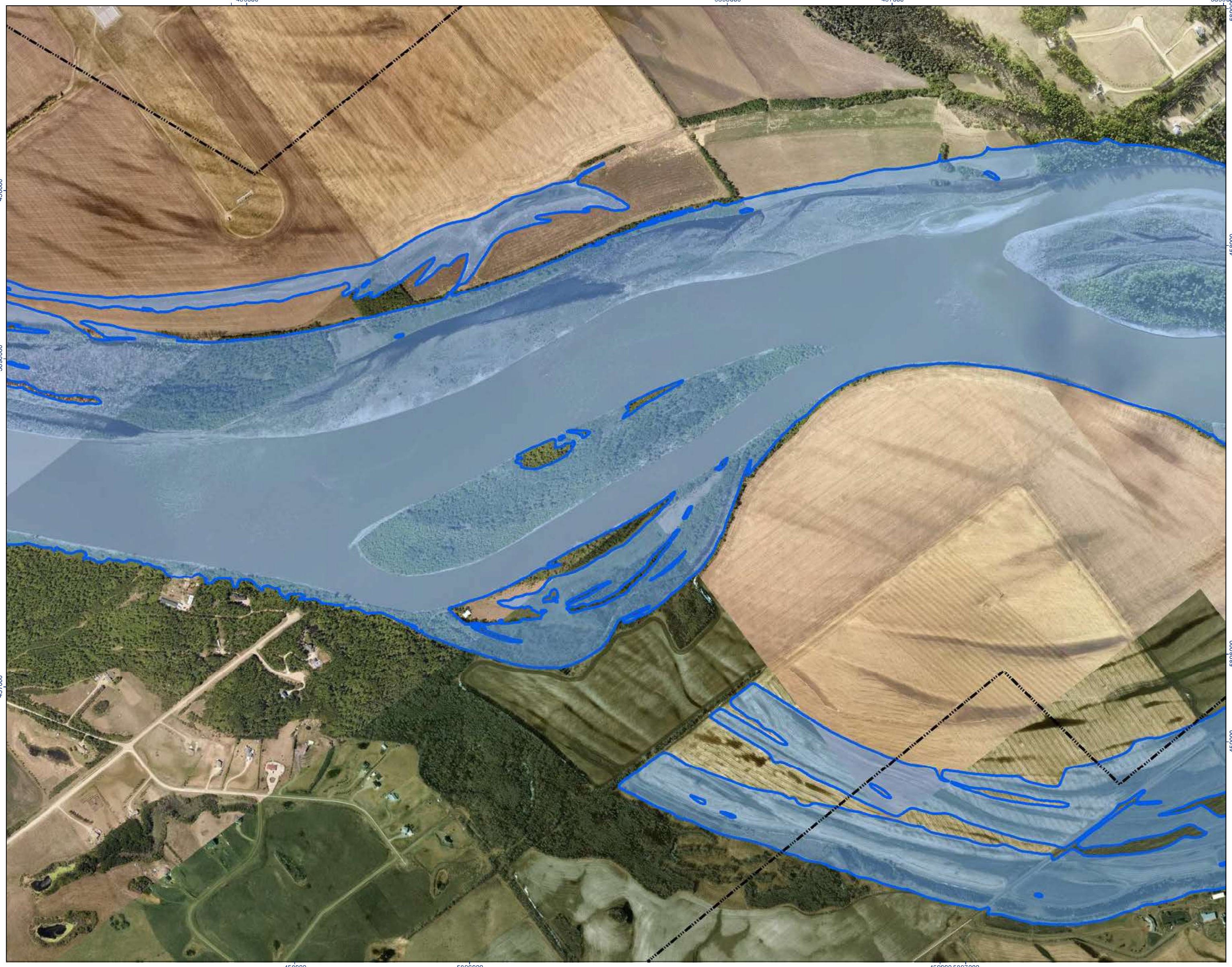

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 50 Year

0 190 380 metres
(At original document size of 11x17)
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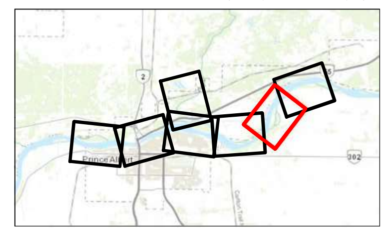

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
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Client/Project
City of Prince Albert
Flood Plain Mapping
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Title
Flood Plain Model - Inundation Results
50 Year Return Period

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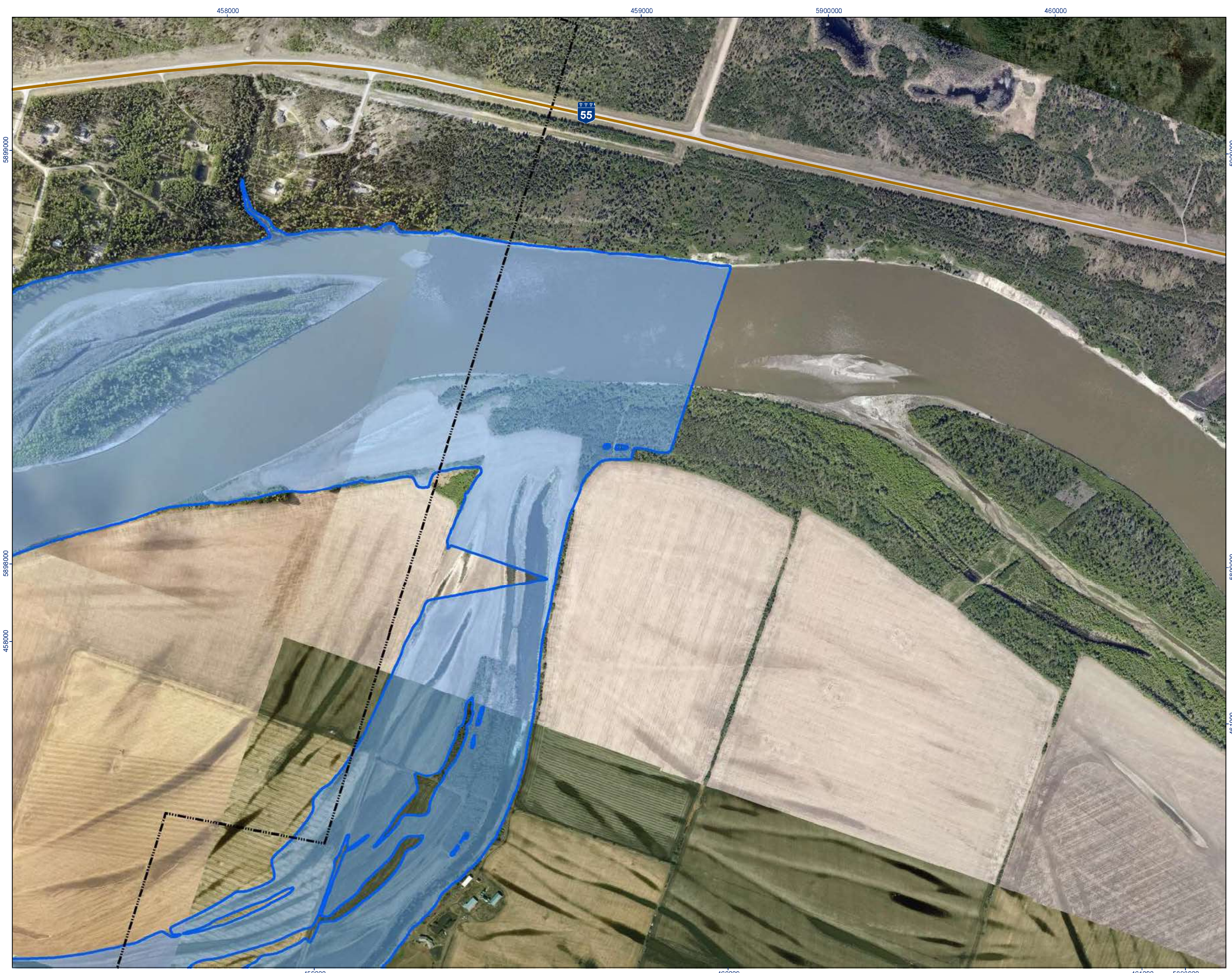

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City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 50 Year

N

0 190 380 metres

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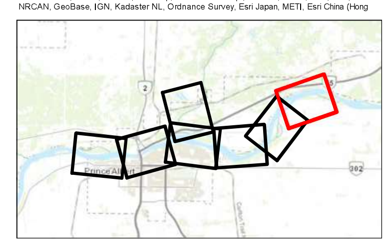

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City of Prince Albert
Flood Plain Mapping
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Flood Plain Model - Inundation Results
50 Year Return Period

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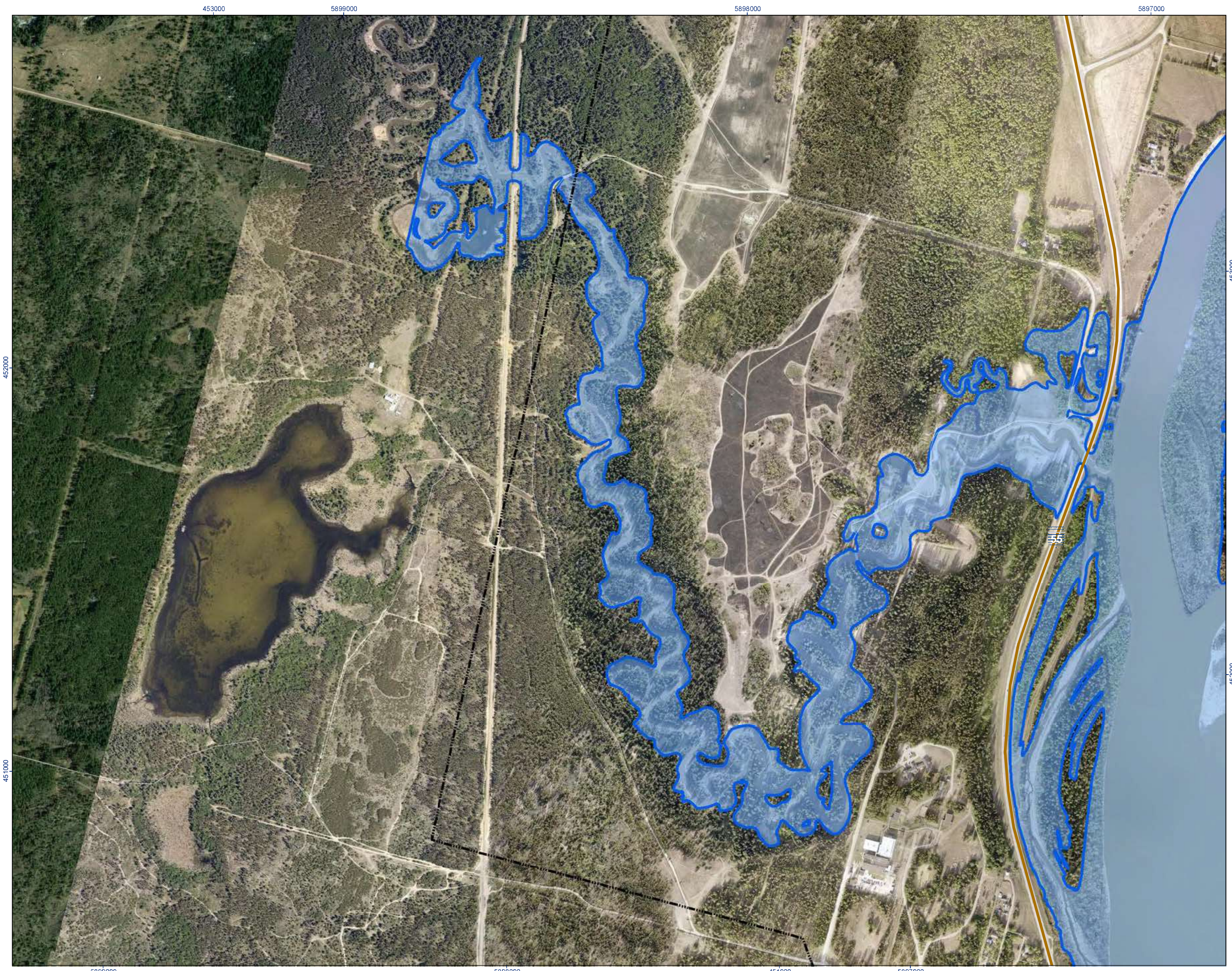

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City of Prince Albert

Legend
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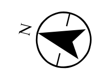

0 190 380 metres
(At original document size of 11x17)
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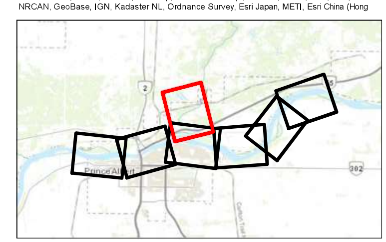

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

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Figure No.

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Title
Flood Plain Model - Inundation Results
50 Year Return Period

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Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 75 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes

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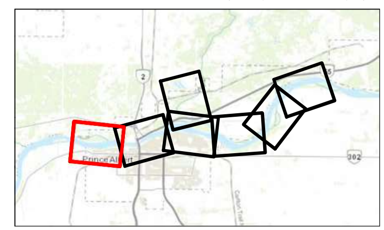

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Client/Project
City of Prince Albert
Flood Plain Mapping
Report

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Figure No.

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Title
Flood Plain Model - Inundation Results
75 Year Return Period

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Legend
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- Local Road Network
- Flood Inundation Extent - 75 Year

0 190 380 metres
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Notes
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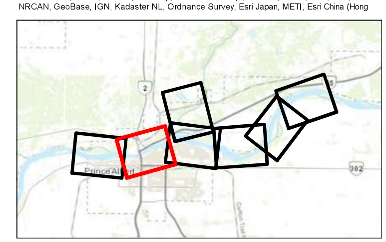

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City of Prince Albert
Flood Plain Mapping
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Title
Flood Plain Model - Inundation Results
75 Year Return Period

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City of Prince Albert

Legend

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N

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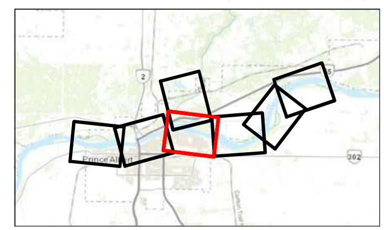

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City of Prince Albert
Flood Plain Mapping
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Figure No.

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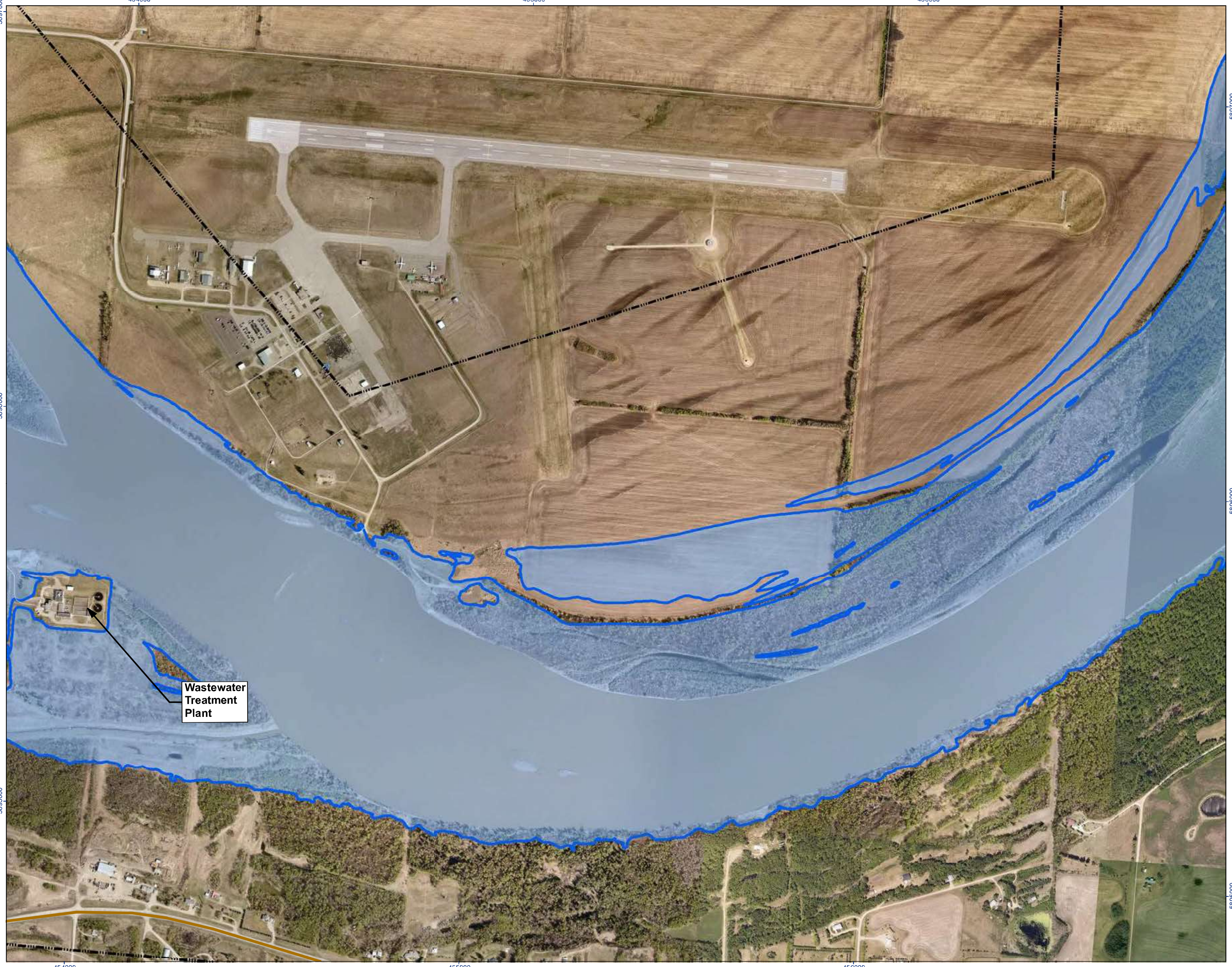
3 of 7

Title
Flood Plain Model - Inundation Results
75 Year Return Period



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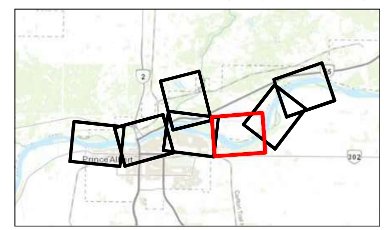

Project Location
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Client/Project
City of Prince Albert
Flood Plain Mapping
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Figure No.

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Title
Flood Plain Model - Inundation Results
75 Year Return Period

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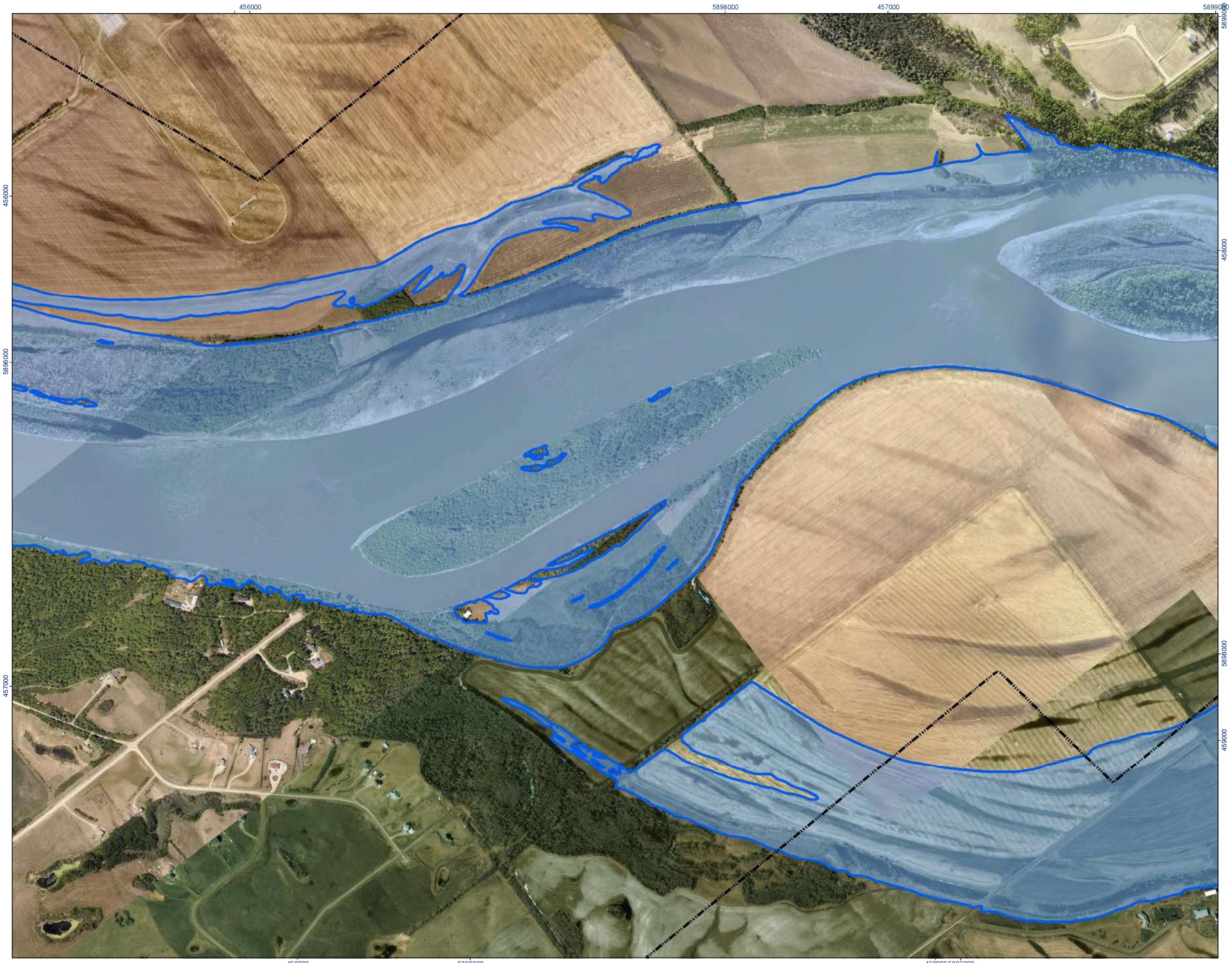

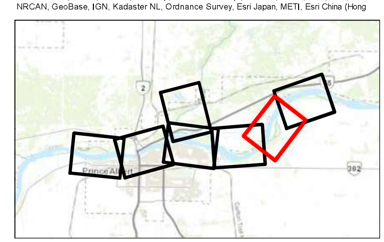

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City of Prince Albert

Legend
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Title
Flood Plain Model - Inundation Results
75 Year Return Period

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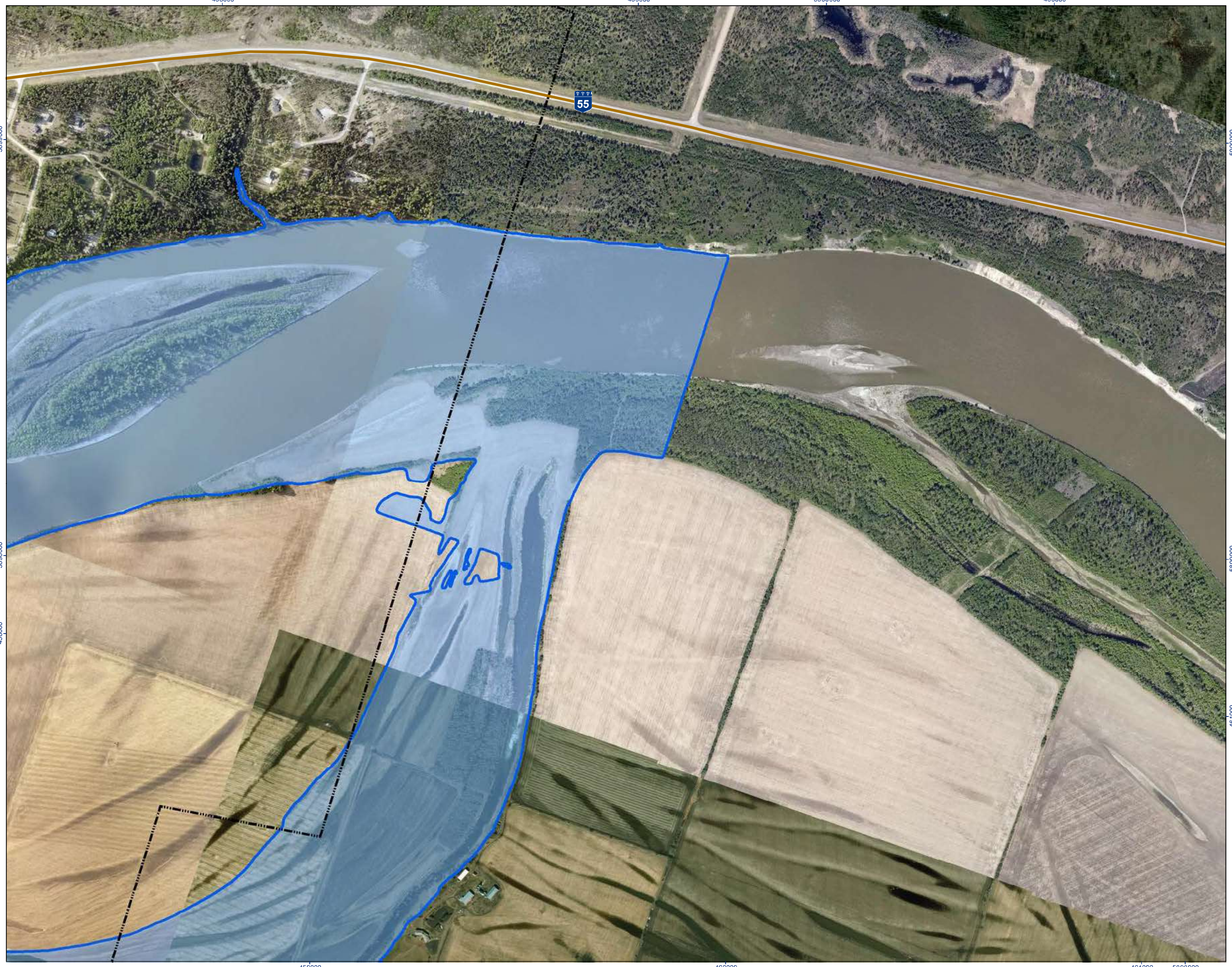

Stantec

City of Prince Albert

Legend
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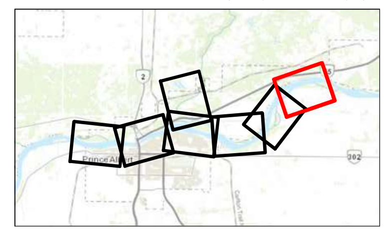

Project Location
Prince Albert, SK

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Client/Project
City of Prince Albert
Flood Plain Mapping
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Figure No.

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Title
Flood Plain Model - Inundation Results
75 Year Return Period

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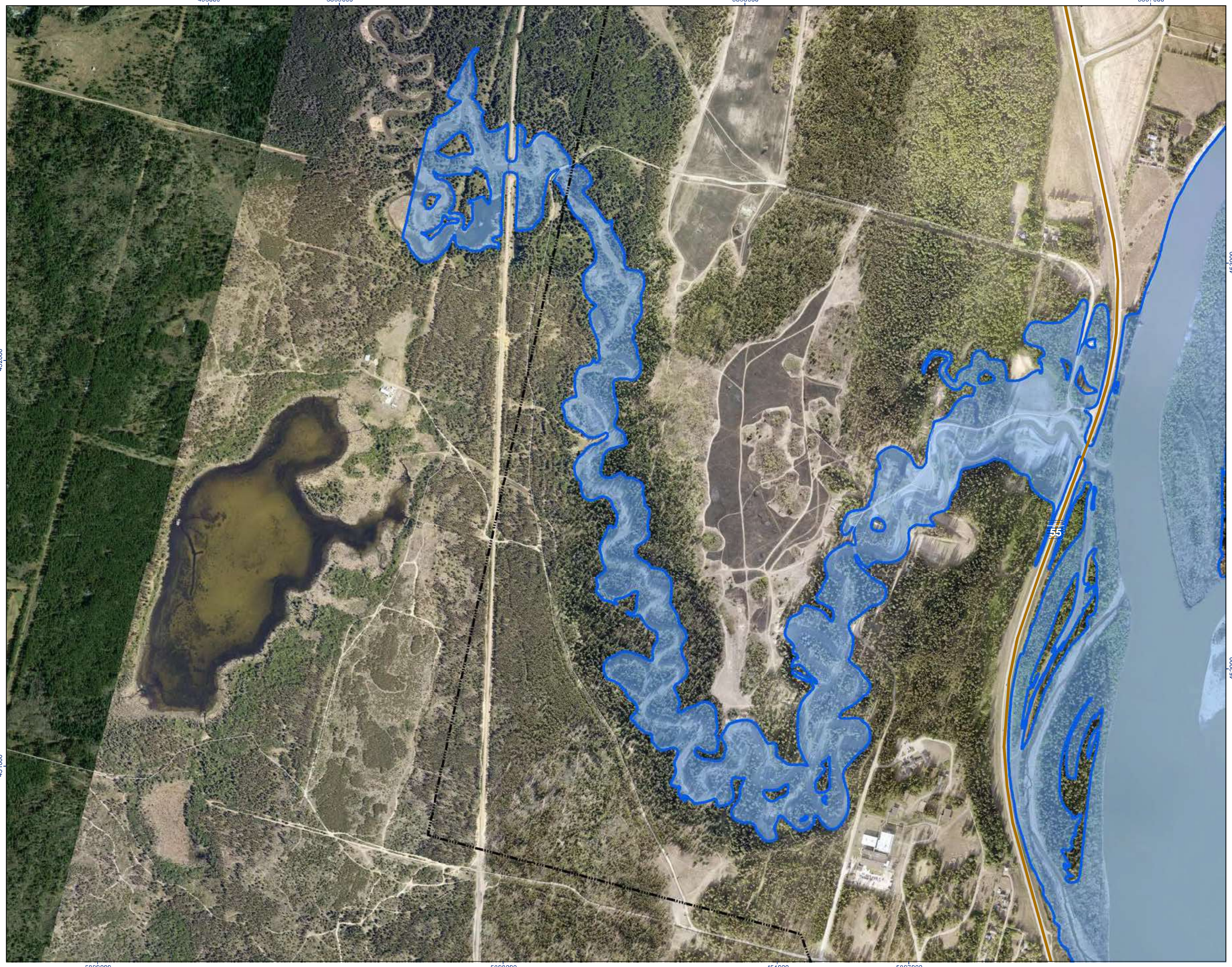

Stantec

City of Prince Albert

Legend

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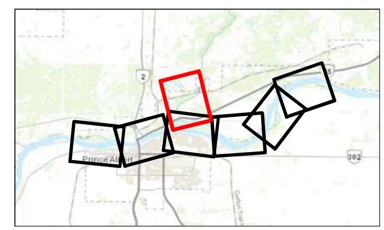

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City of Prince Albert
Flood Plain Mapping
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Sheet No.
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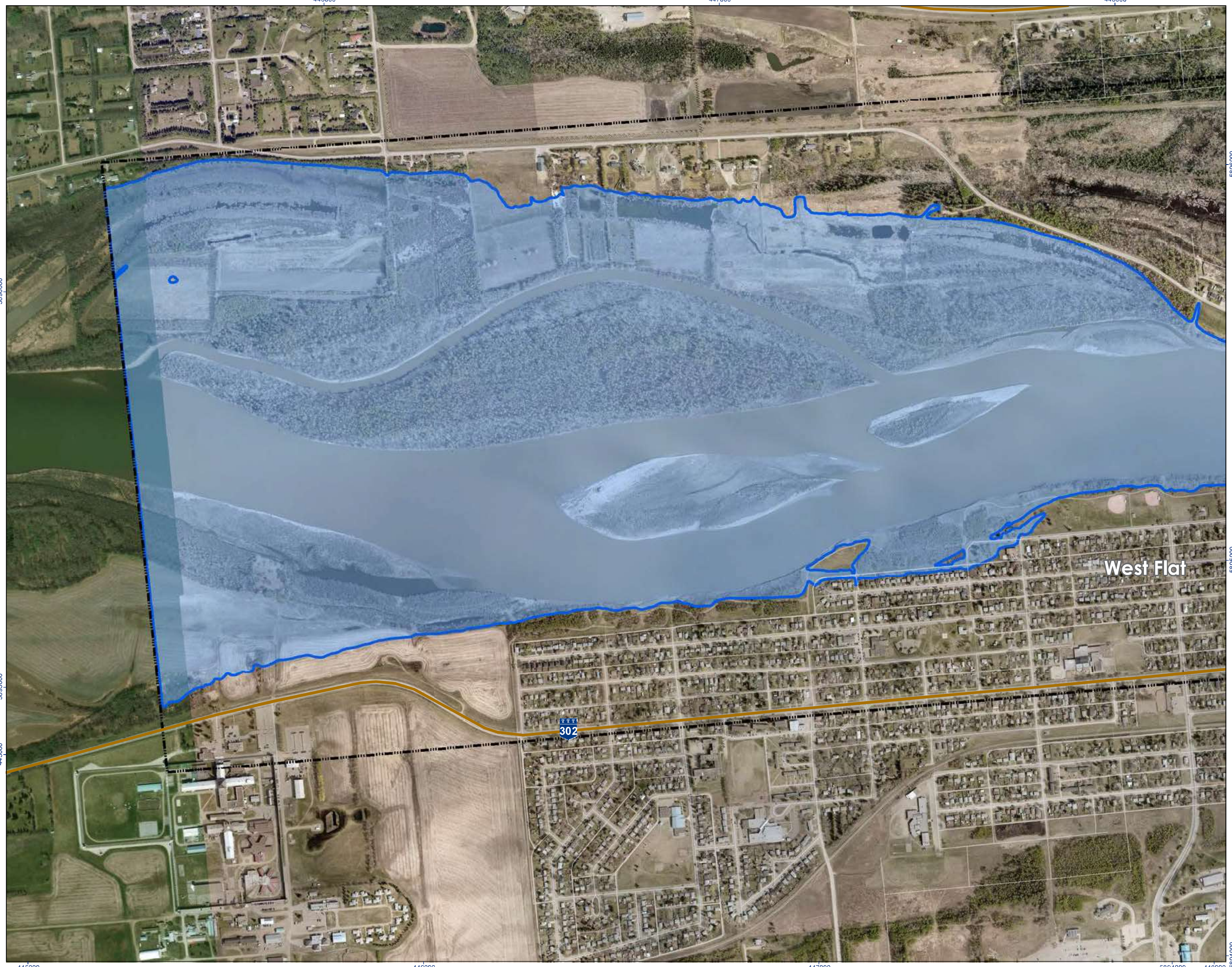
Title
Flood Plain Model - Inundation Results
75 Year Return Period

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson



Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 100 Year

N

0 190 380 metres
(At original document size of 11x17)
1:10,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 13N; Canadian Geodetic Vertical Datum of 2013
2. Data Sources: Water Survey of Canada; GeoBase - National Hydrological Network; GeoBase - National Road Network
3. Background: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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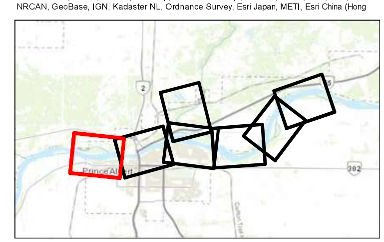


Project Location
Prince Albert, SK

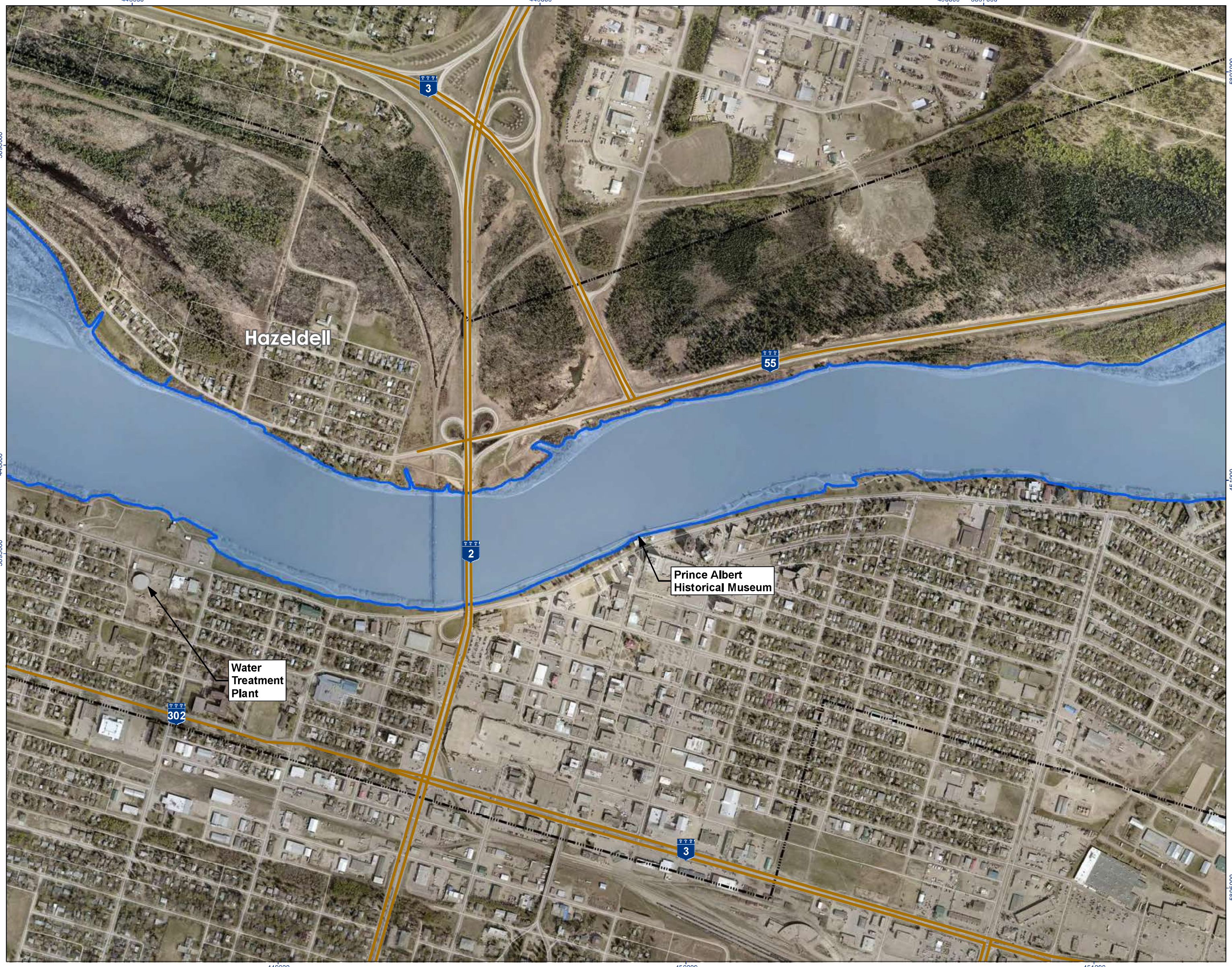
Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
Sheet No.
1 of 7

Title
Flood Plain Model - Inundation Results
100 Year Return Period

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson



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City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 100 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

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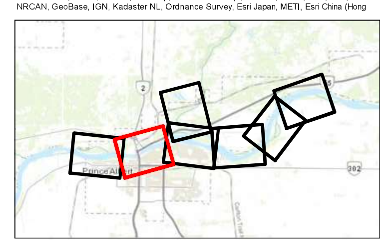

Project Location Prince Albert, SK	Prepared by MA on 2019-12-6 TR by LM on 2019-12-6 IR Review by HA on 2019-12-6
Client/Project City of Prince Albert Flood Plain Mapping Report	113101975
Figure No.	Sheet No. 2 of 7

Title
Flood Plain Model - Inundation Results
100 Year Return Period

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson

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City of Prince Albert

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 100 Year

N

0 190 380 metres

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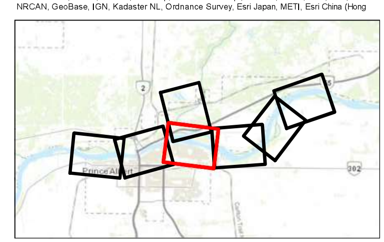


Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

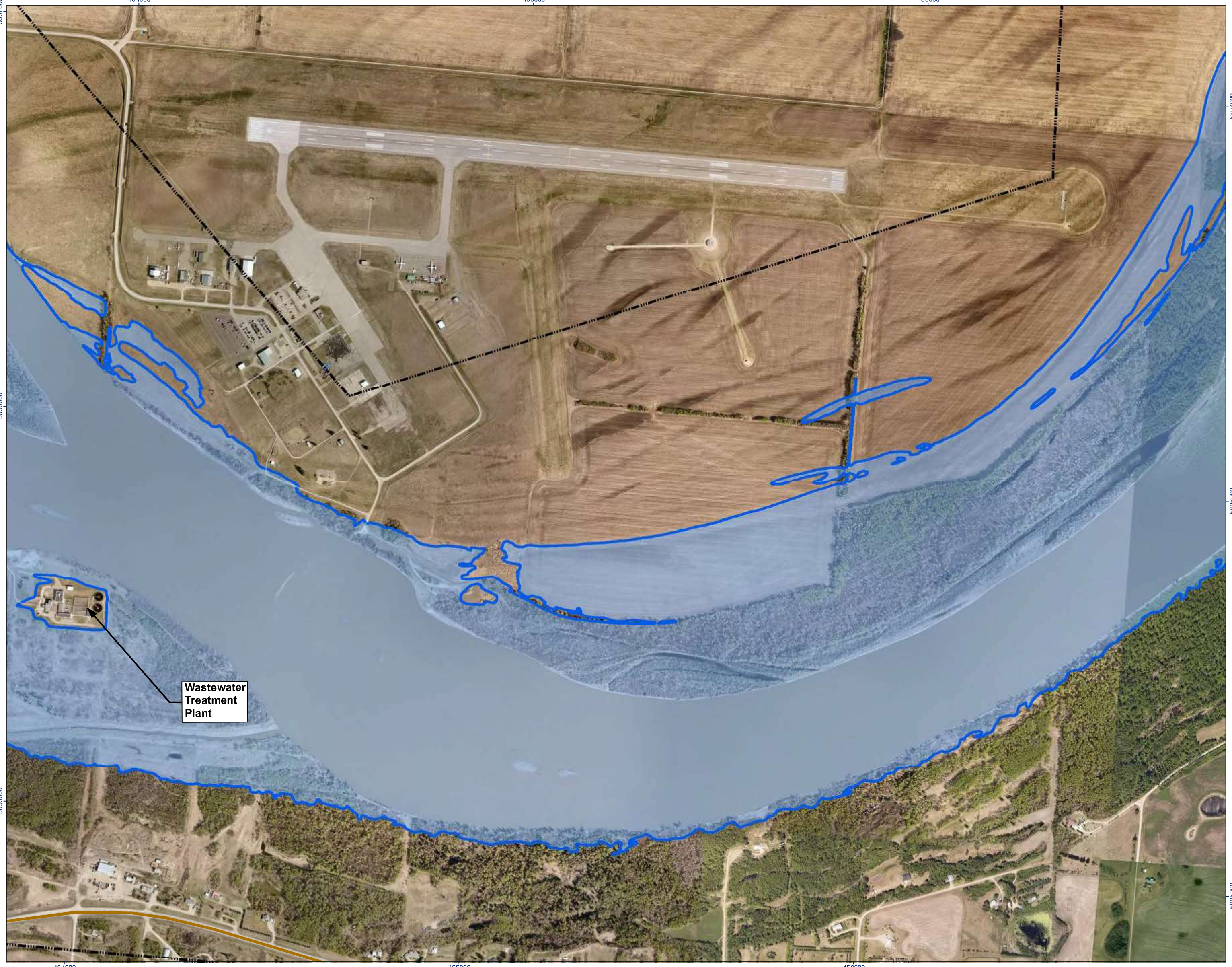
113101975

Figure No.

Sheet No.
3 of 7

Title
Flood Plain Model - Inundation Results
100 Year Return Period

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson



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City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 100 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes

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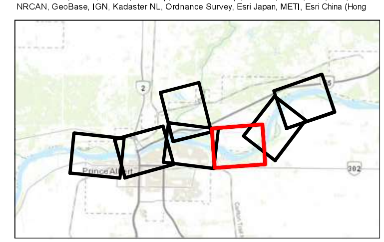

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
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IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
4 of 7

Title
Flood Plain Model - Inundation Results
100 Year Return Period

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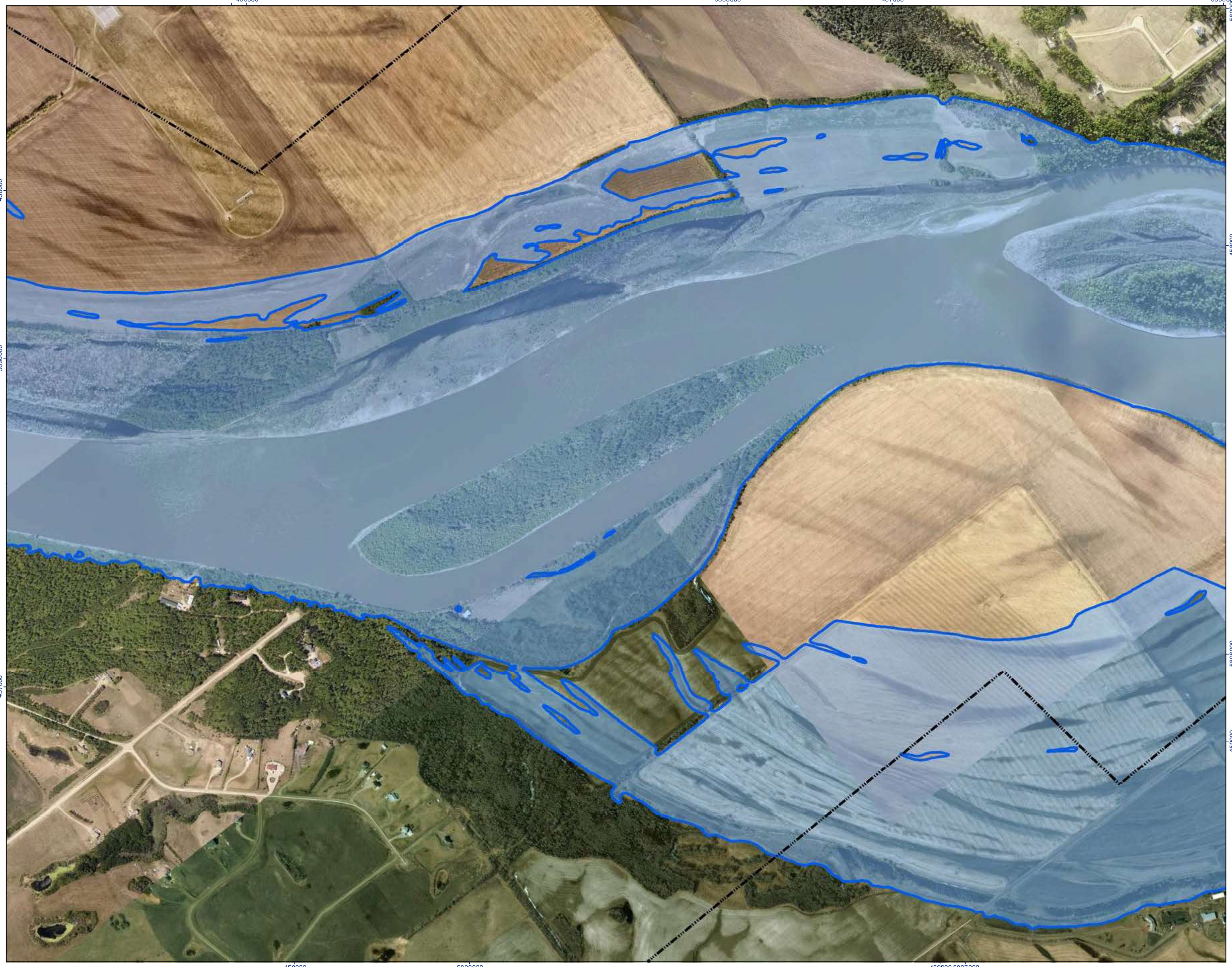

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City of Prince Albert

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 100 Year

0 190 380 metres
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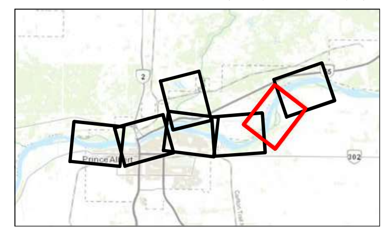

Project Location Prince Albert, SK	Prepared by MA on 2019-12-6 TR by LM on 2019-12-6 IR Review by HA on 2019-12-6
Client/Project City of Prince Albert Flood Plain Mapping Report	113101975
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Title
Flood Plain Model - Inundation Results
100 Year Return Period

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson

Stantec

City of Prince Albert

Legend

Study Area Boundary

Highways

Local Road Network

Flood Inundation Extent - 100 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes

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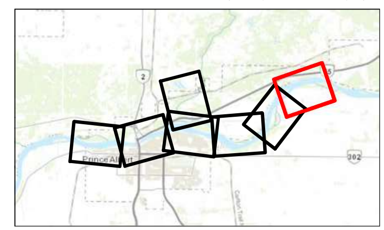

Project Location
Prince Albert, SK

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TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.

Sheet No.
6 of 7

Title
Flood Plain Model - Inundation Results
100 Year Return Period

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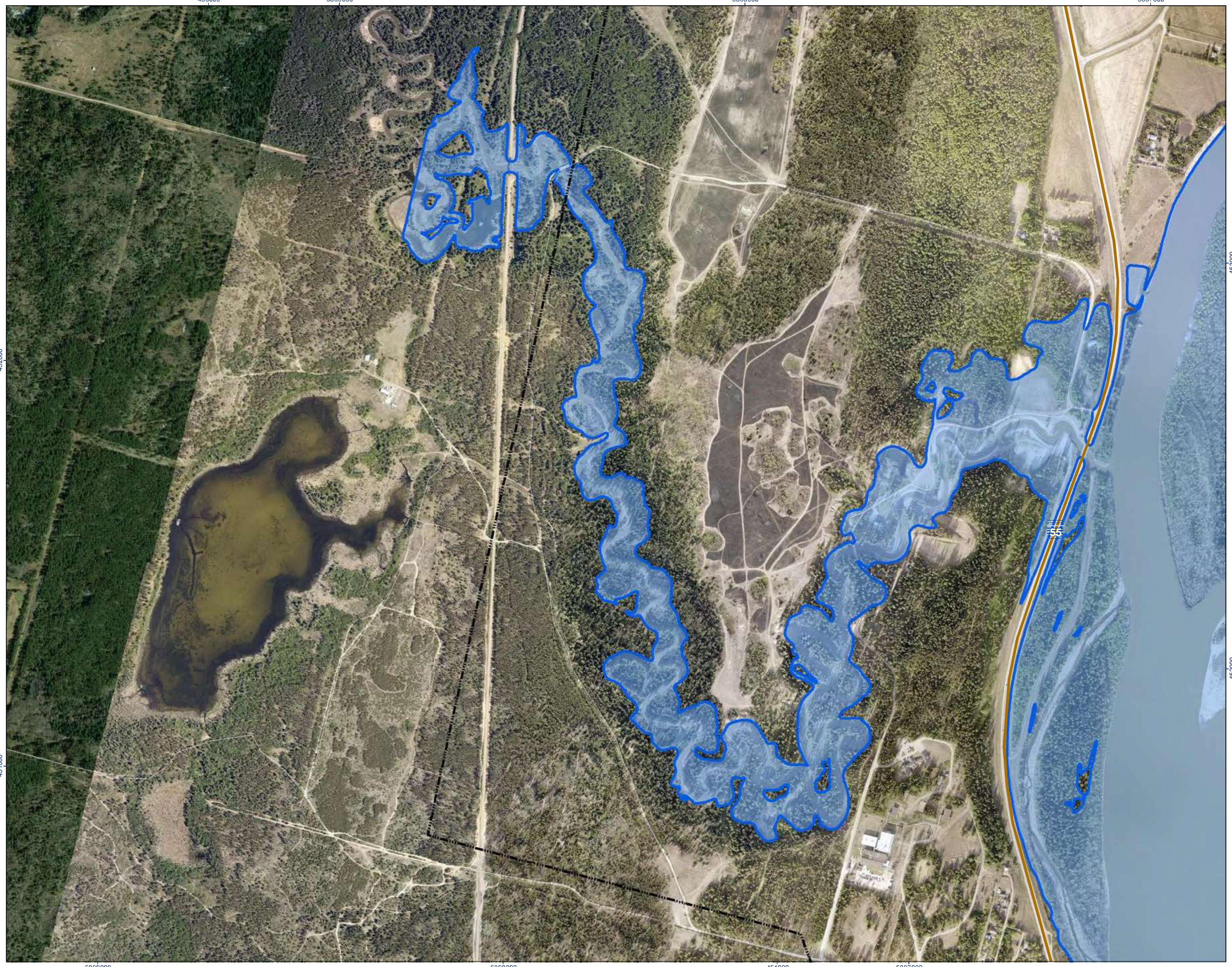

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 100 Year

N

0 190 380 metres
(At original document size of 11x17)
1:10,000

Notes
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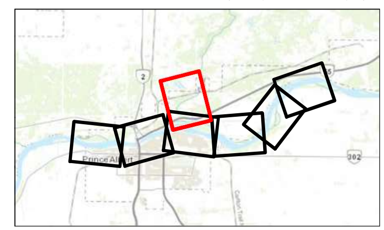

Project Location
Prince Albert, SK

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Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
7 of 7

Title
Flood Plain Model - Inundation Results
100 Year Return Period

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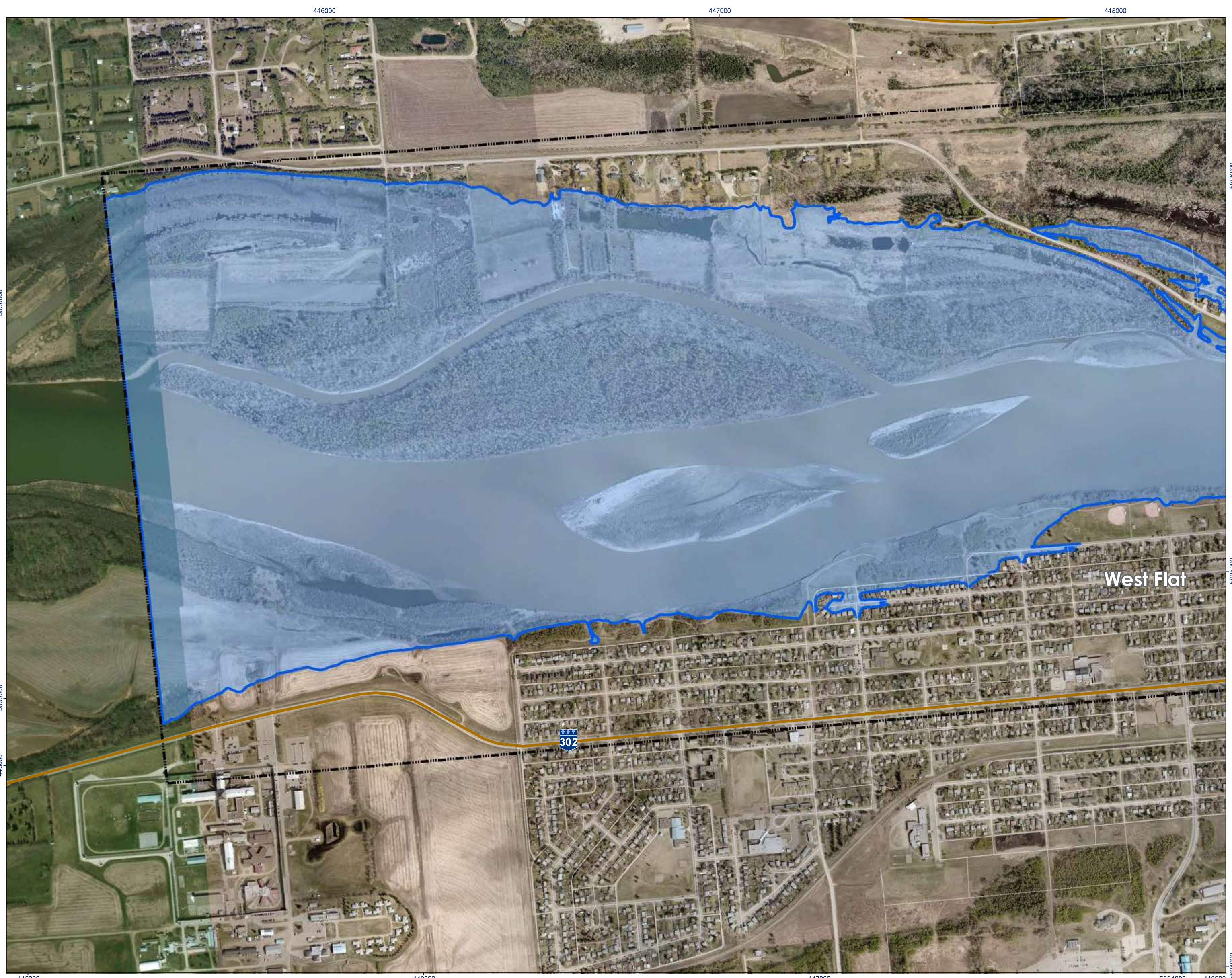

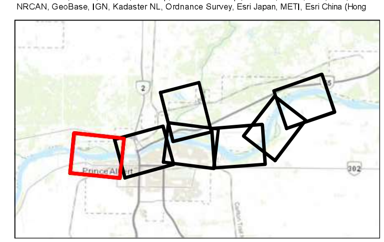

Stantec

City of Prince Albert

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 200 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

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Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

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1 of 7

Title
Flood Plain Model - Inundation Results
200 Year Return Period

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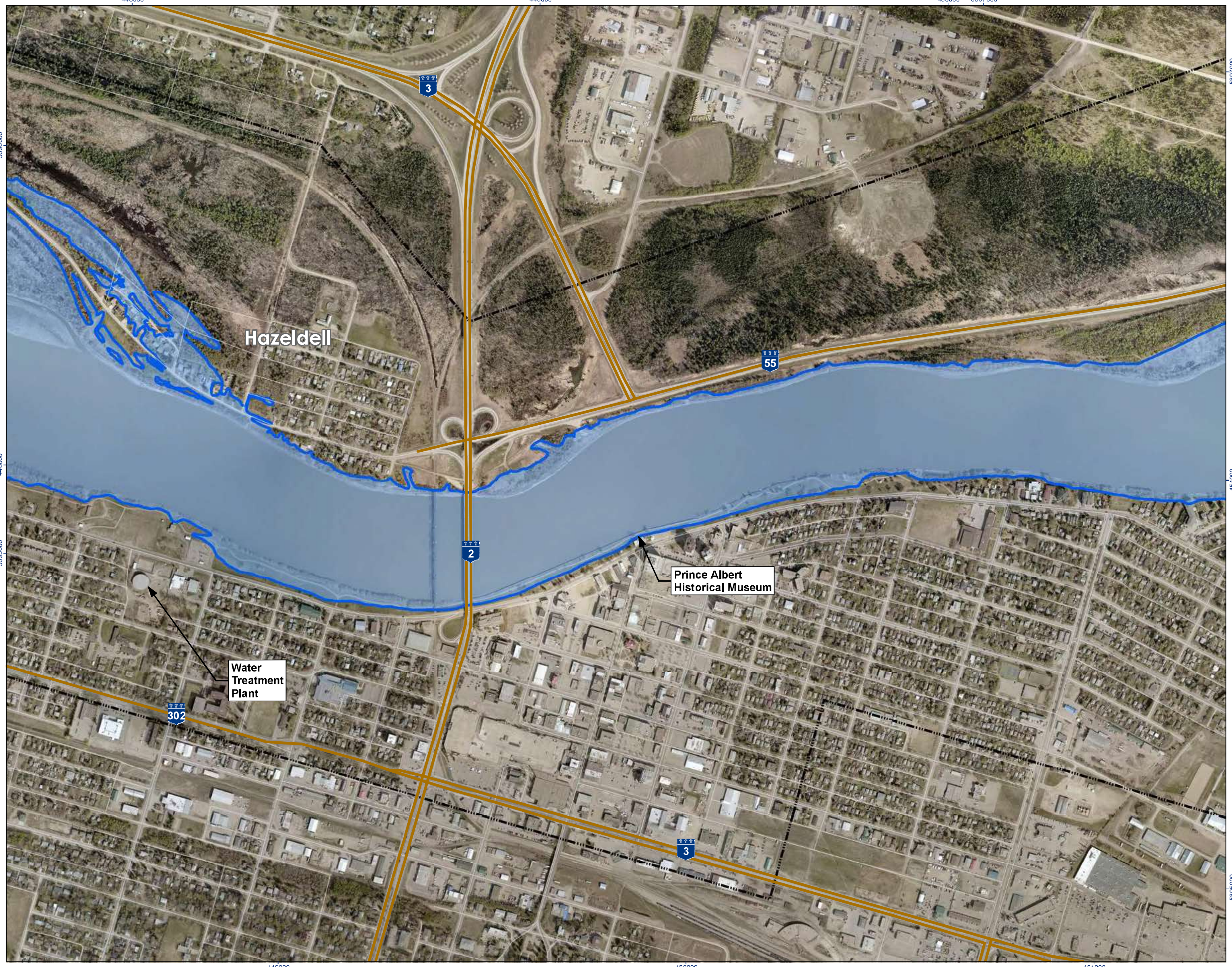

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 200 Year

N

0 190 380 metres

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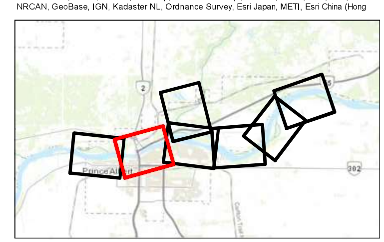

Project Location
Prince Albert, SK

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TR by LM on 2019-12-6
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113101975

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Figure No.

Sheet No.
2 of 7

Title
Flood Plain Model - Inundation Results
200 Year Return Period

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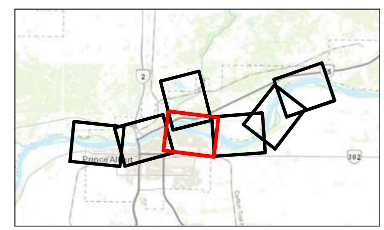

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City of Prince Albert

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 200 Year

N

0 190 380 metres

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Notes
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Project Location
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Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
Sheet No.
3 of 7

Title
Flood Plain Model - Inundation Results
200 Year Return Period

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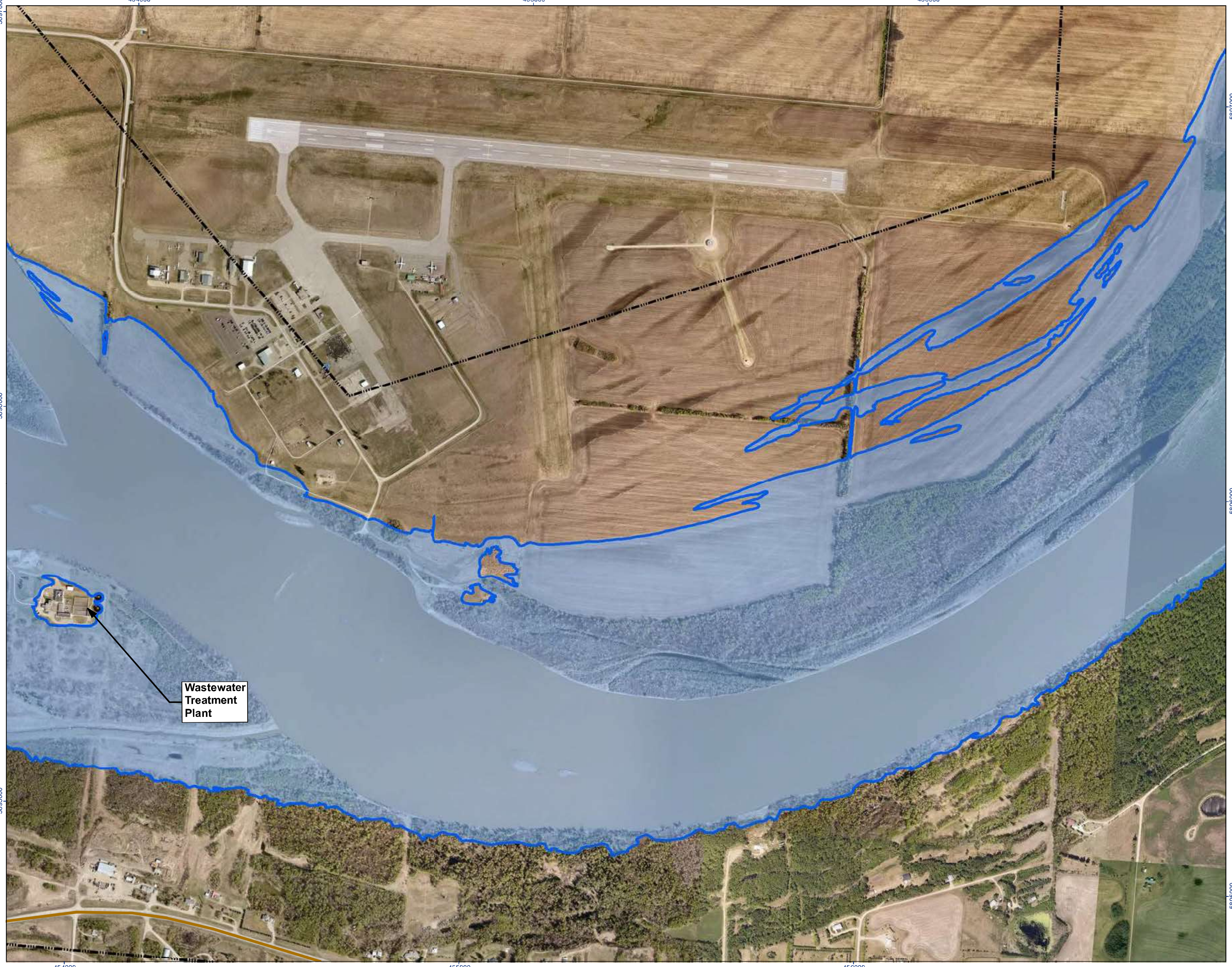

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City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 200 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes

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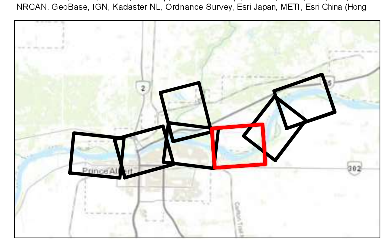

Project Location

Prince Albert, SK

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Client/Project

113101975

City of Prince Albert
Flood Plain Mapping
Report

Figure No.

Sheet No.

4 of 7

Title

Flood Plain Model - Inundation Results
200 Year Return Period

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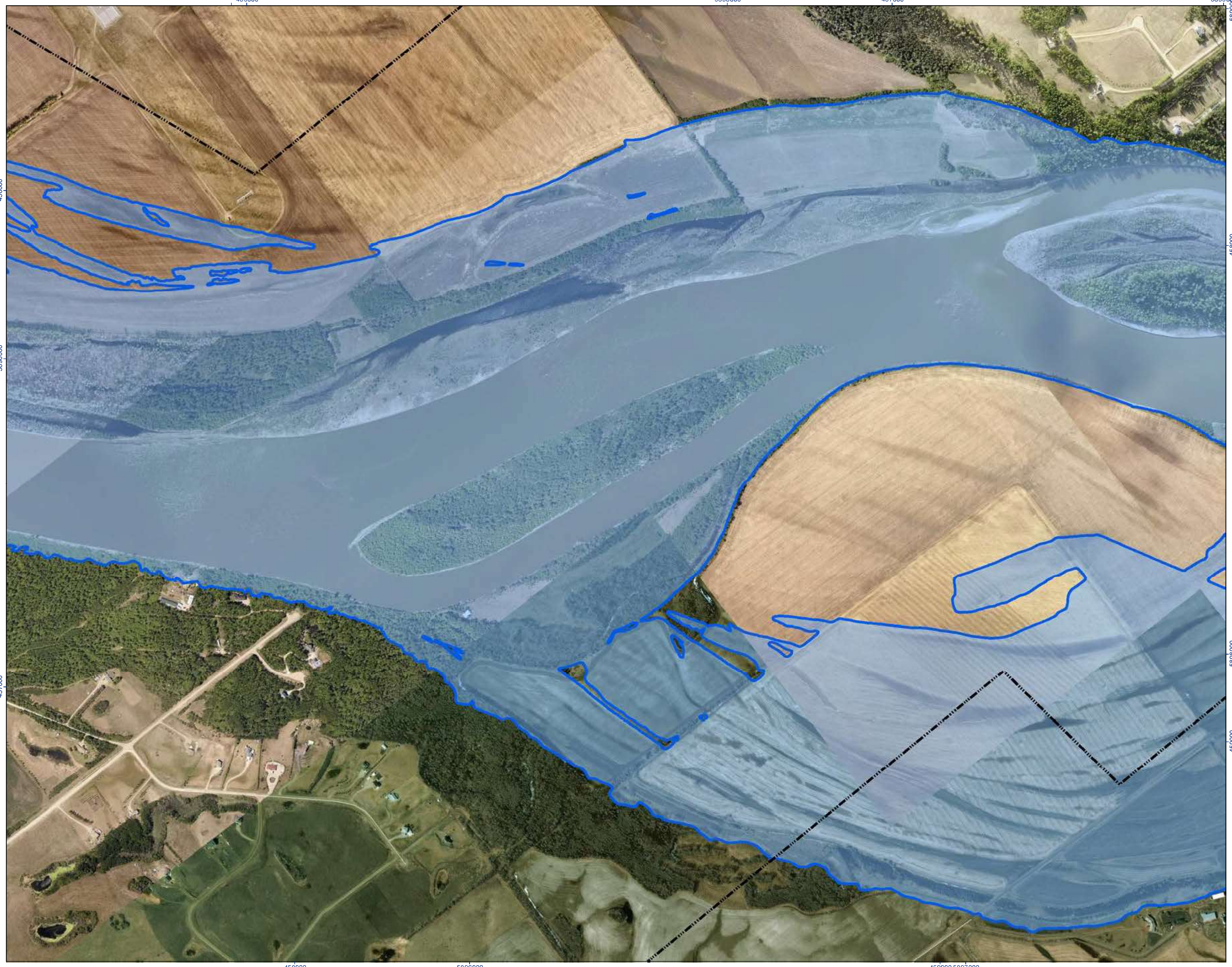

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 200 Year

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes
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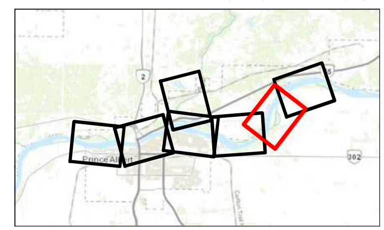

Project Location
Prince Albert, SK

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IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
5 of 7

Title
Flood Plain Model - Inundation Results
200 Year Return Period

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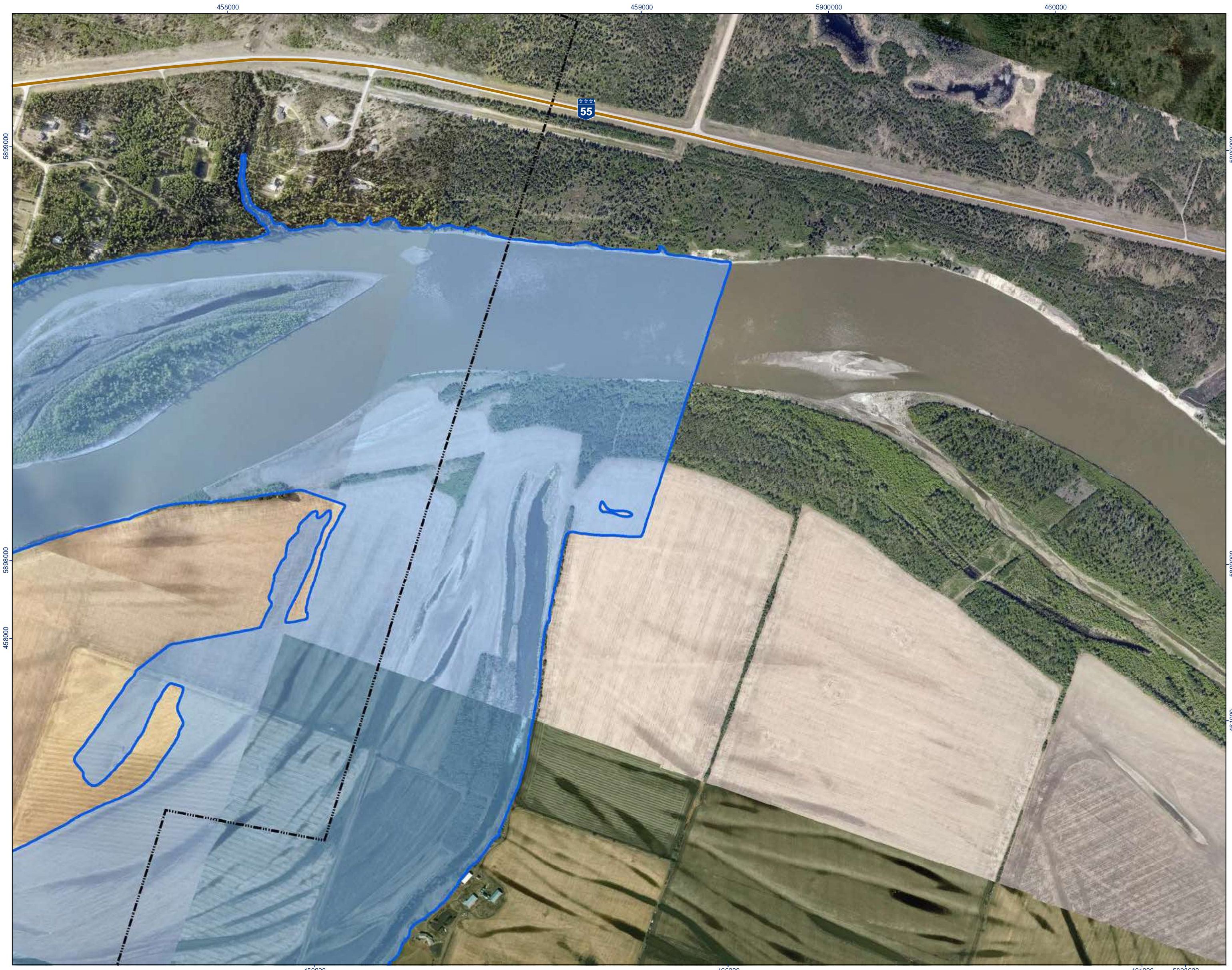

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 200 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

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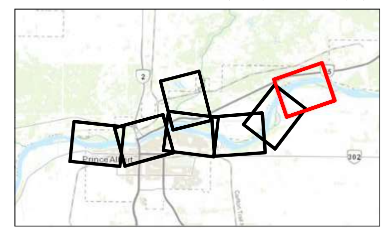

Project Location
Prince Albert, SK

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Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
6 of 7

Title
Flood Plain Model - Inundation Results
200 Year Return Period

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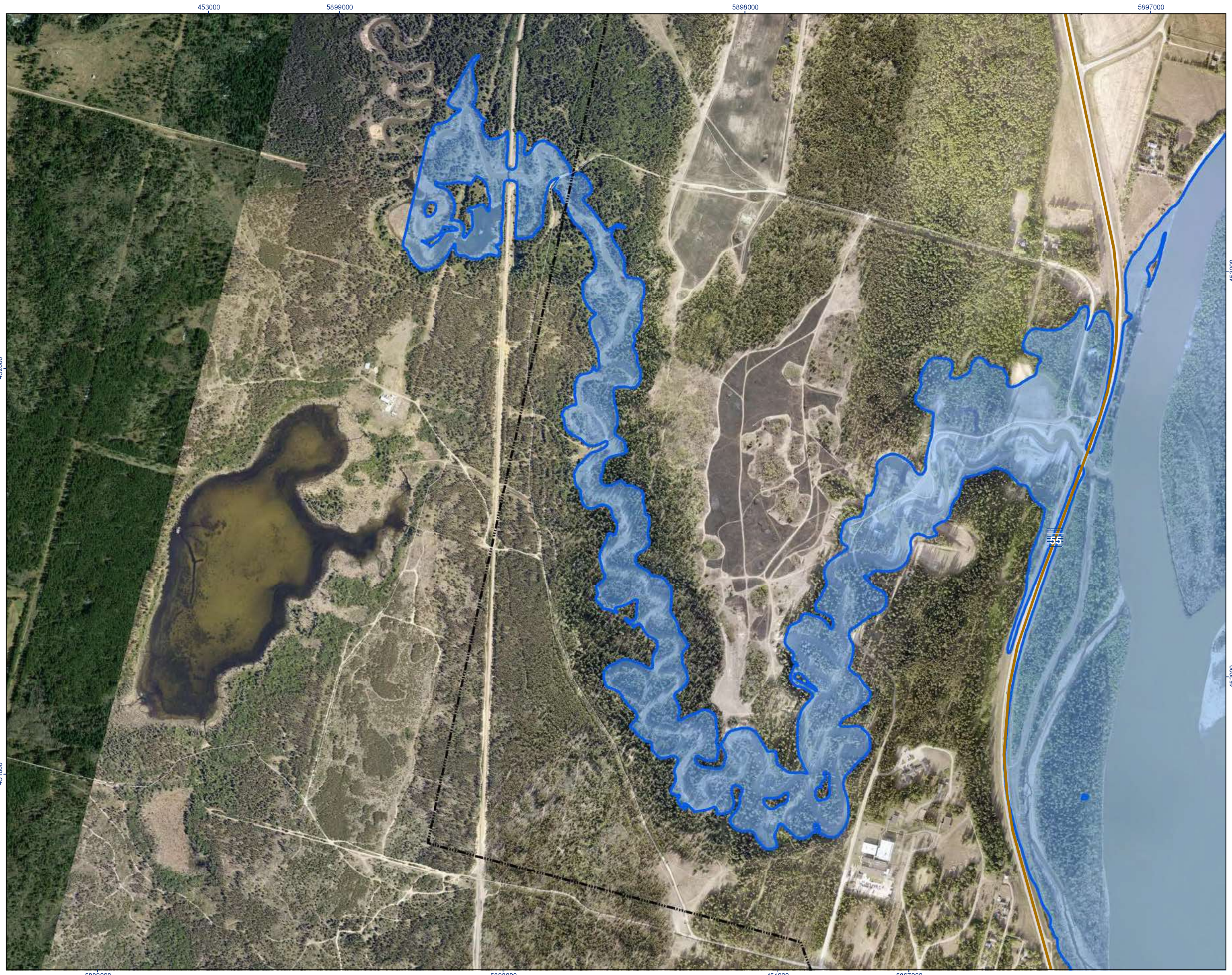

Stantec

City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 200 Year

N

0 190 380 metres

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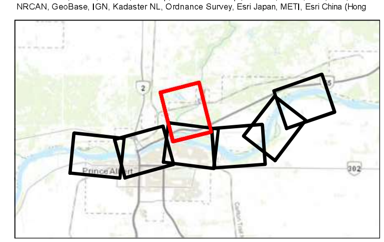

Project Location
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Client/Project
City of Prince Albert
Flood Plain Mapping
Report

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Figure No.

Sheet No.
7 of 7

Title
Flood Plain Model - Inundation Results
200 Year Return Period

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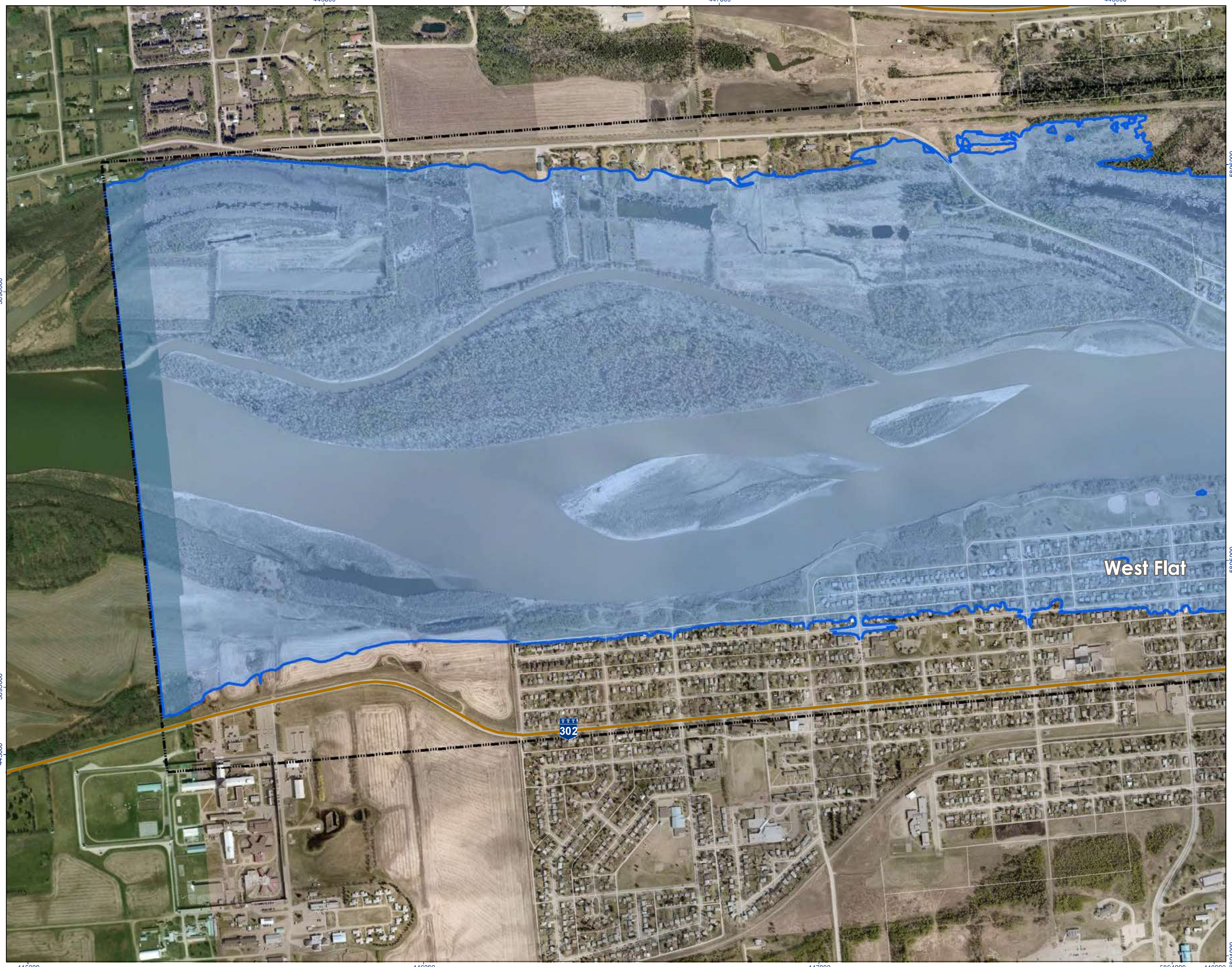

Stantec

City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 500 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 13N; Canadian Geodetic Vertical Datum of 2013
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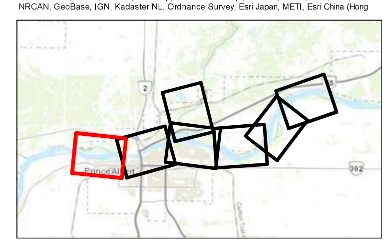


Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

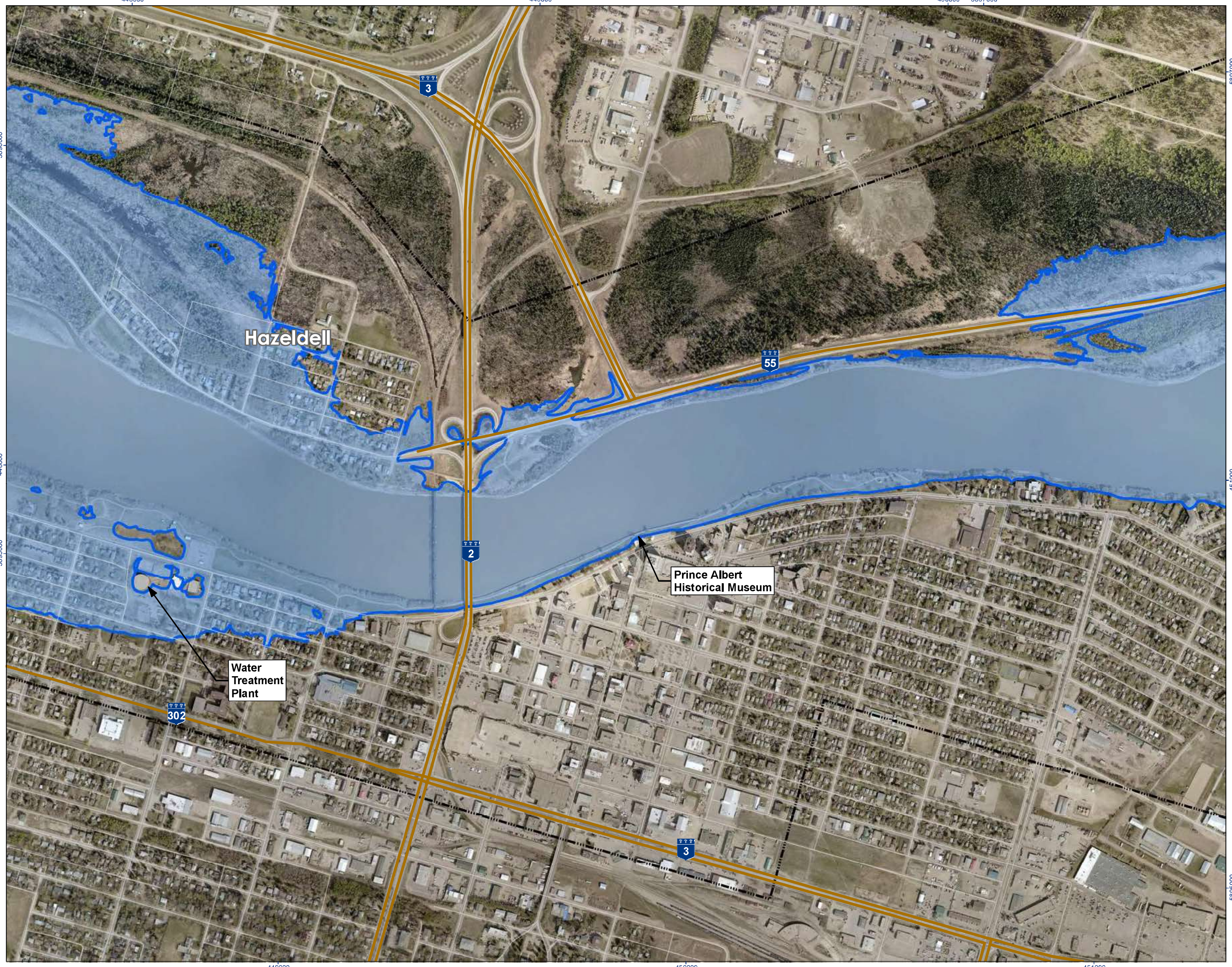
Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.

Sheet No.
1 of 7

Title
Flood Plain Model - Inundation Results
500 Year Return Period

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson



Stantec

City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 500 Year

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 13N; Canadian Geodetic Vertical Datum of 2013
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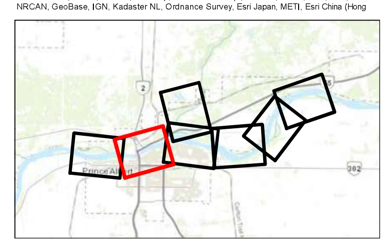

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
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IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

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Title
Flood Plain Model - Inundation Results
500 Year Return Period

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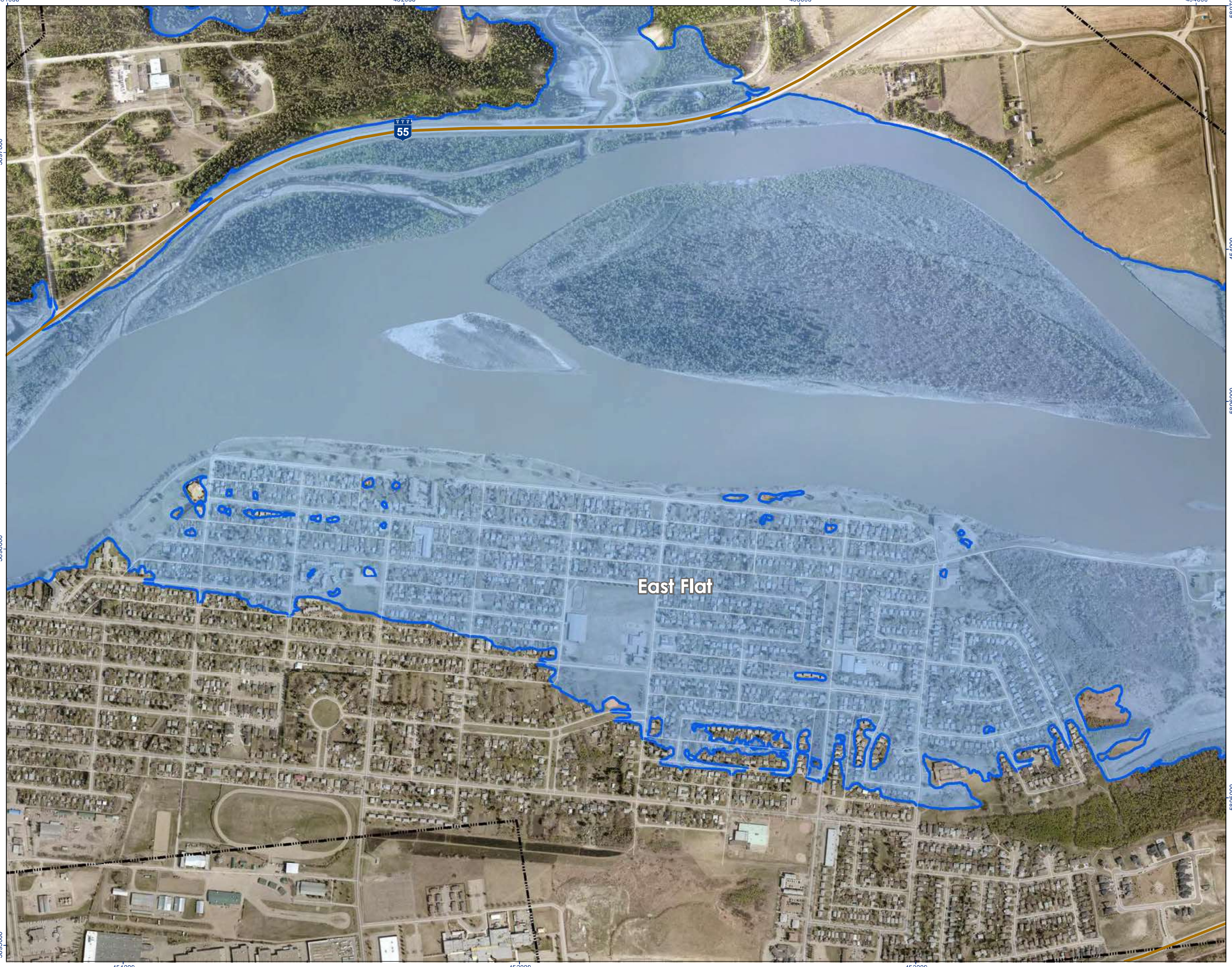

Stantec

City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 500 Year

N

0 190 380 metres

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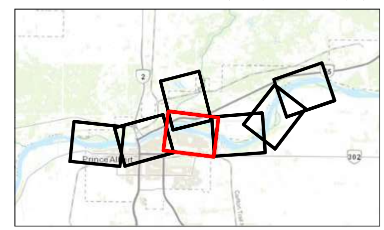

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
3 of 7

Title
Flood Plain Model - Inundation Results
500 Year Return Period

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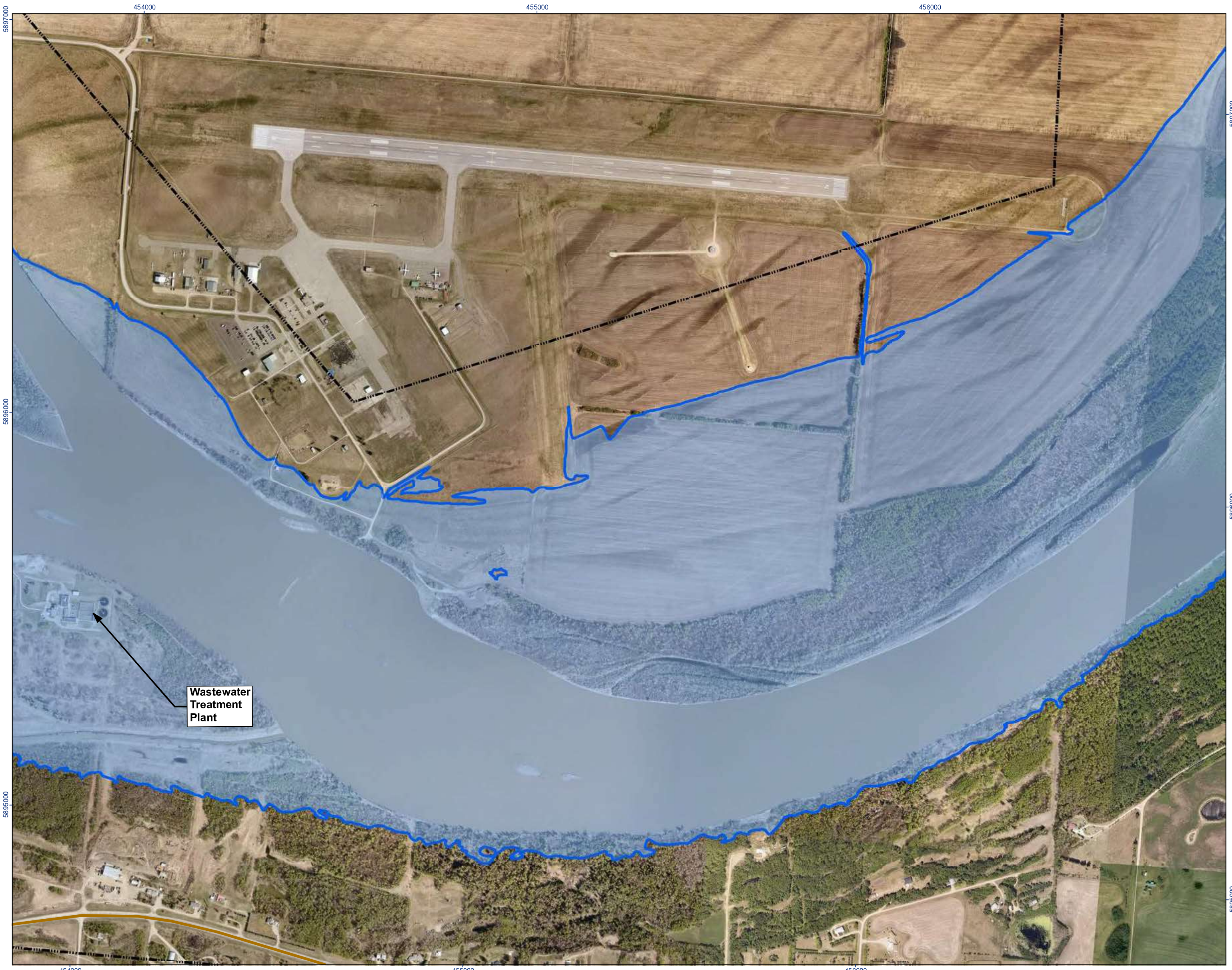

Legend
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- Highways
- Local Road Network
- Flood Inundation Extent - 500 Year

N

0 190 380 metres
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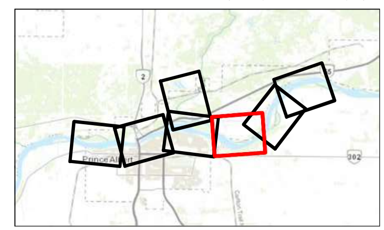

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
4 of 7

Title
Flood Plain Model - Inundation Results
500 Year Return Period

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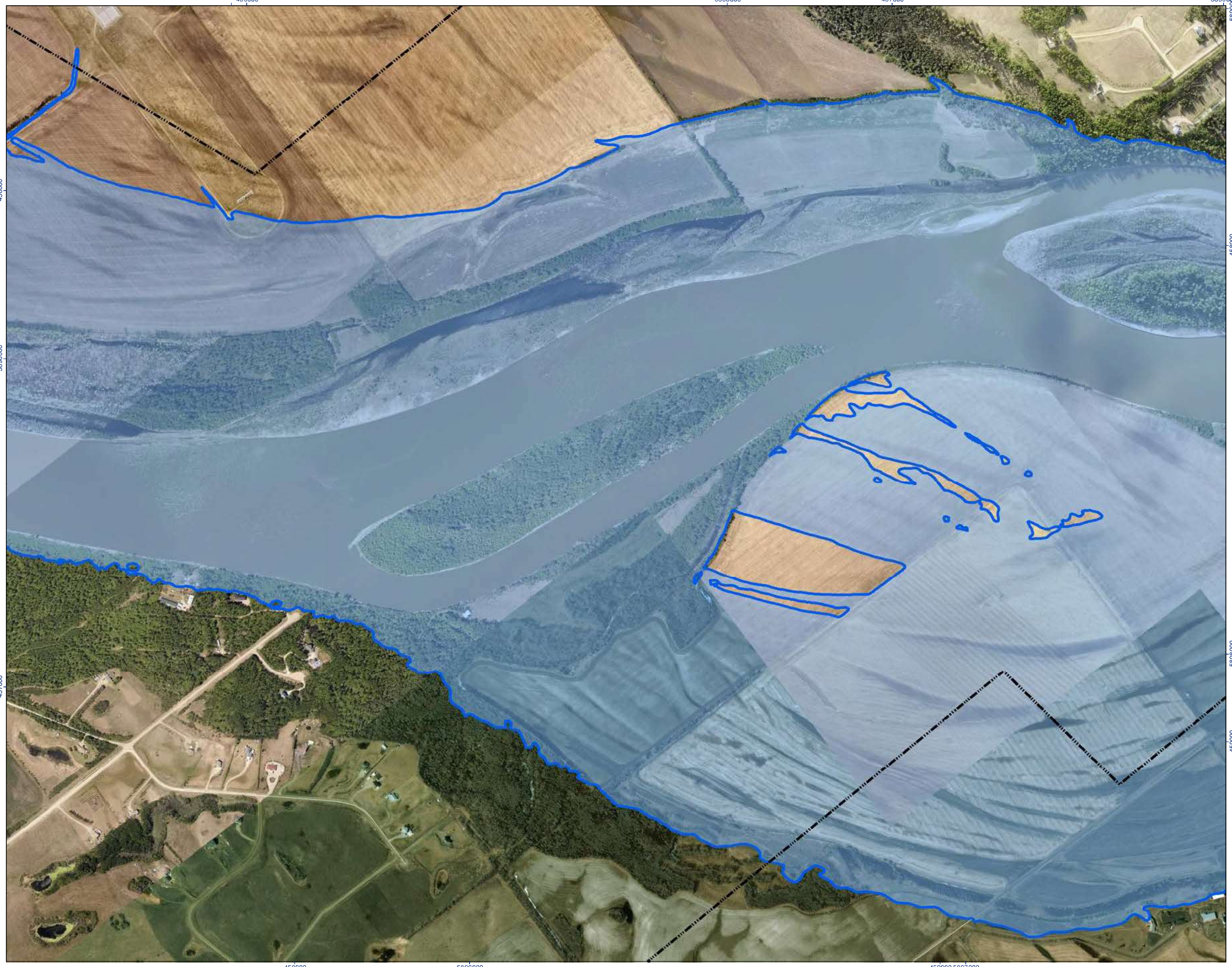

Stantec

City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 500 Year

N

0 190 380 metres

(At original document size of 11x17)
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Notes

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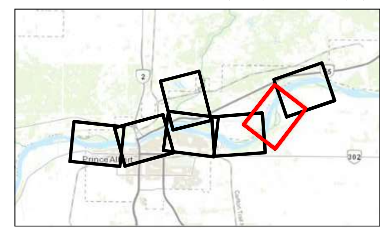

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
5 of 7

Title
Flood Plain Model - Inundation Results
500 Year Return Period

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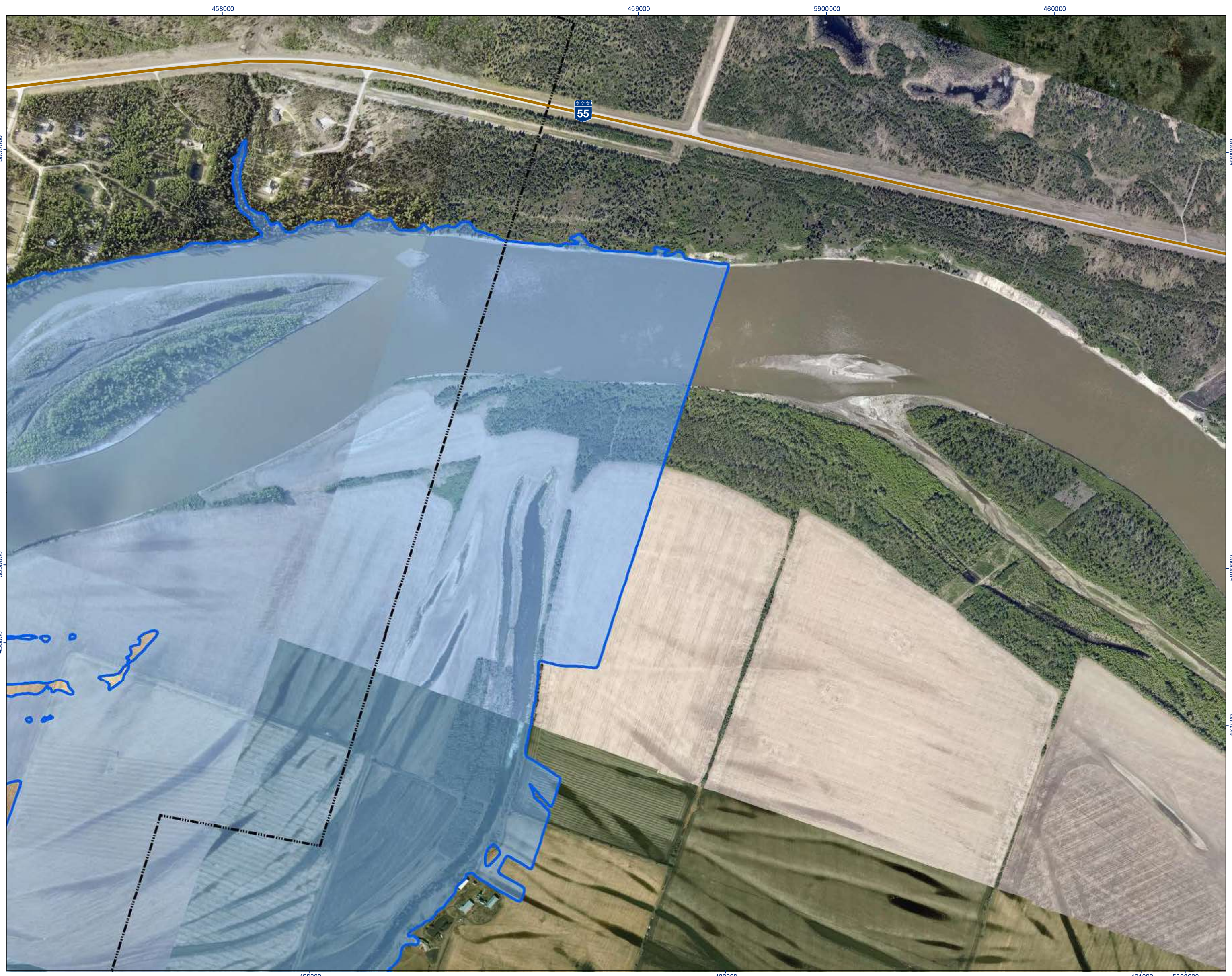

Stantec

City of Prince Albert

Legend
- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 500 Year

N

0 190 380 metres

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1:10,000

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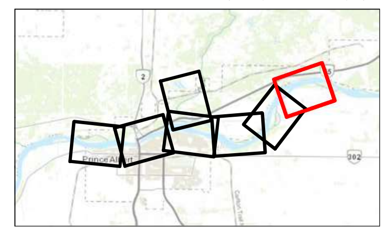

Project Location
Prince Albert, SK

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TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
Sheet No.
6 of 7

Title
Flood Plain Model - Inundation Results
500 Year Return Period

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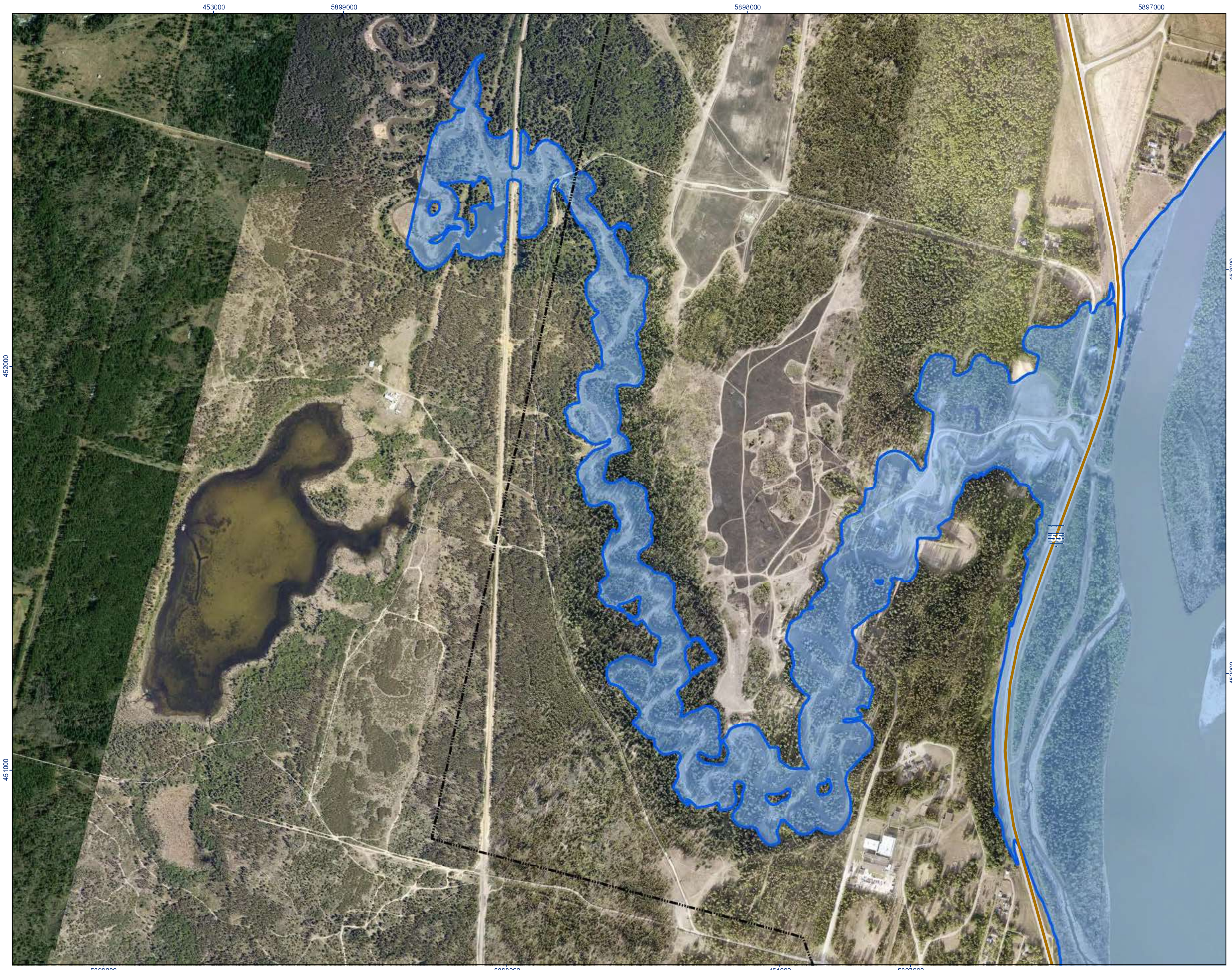
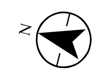


Stantec

City of Prince Albert

Legend

- Study Area Boundary
- Highways
- Local Road Network
- Flood Inundation Extent - 500 Year



0 190 380 metres
(At original document size of 11x17)
1:10,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 13N; Canadian Geodetic Vertical Datum of 2013
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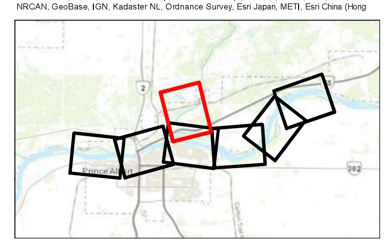

Project Location
Prince Albert, SK

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TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
7 of 7

Title
Flood Plain Model - Inundation Results
500 Year Return Period

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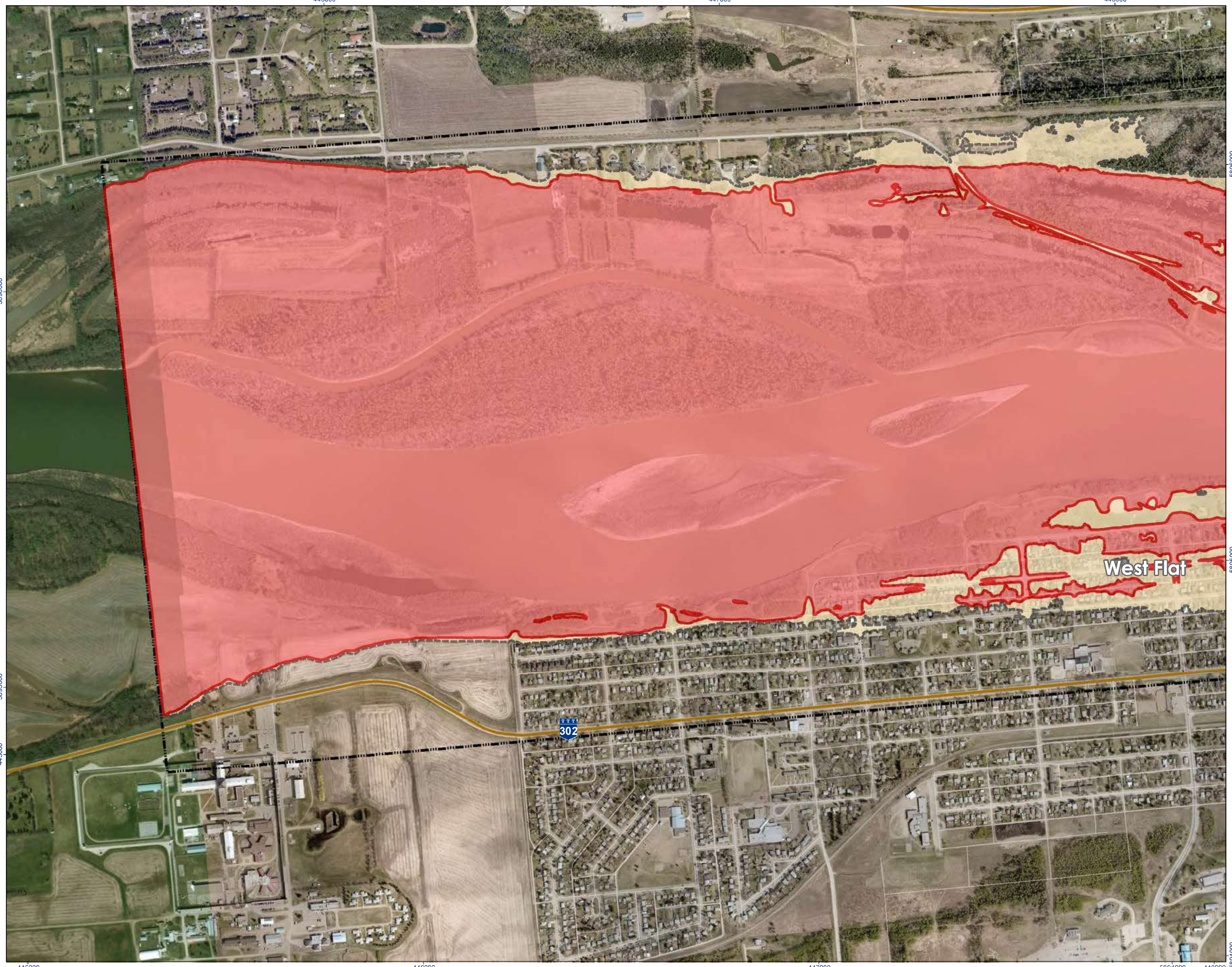

Stantec

City of Prince Albert

Legend

- Flood Fringe
- Floodway
- Study Area Boundary
- Highways
- Local Road Network

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes
1. Coordinate System: NAD 1983 CSRS UTM Zone 13N; Canadian Geodetic Vertical Datum of 2013
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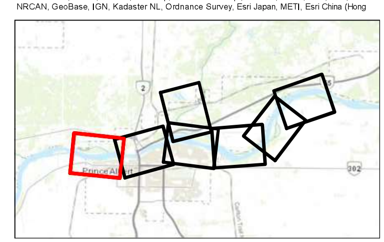

Project Location
Prince Albert, SK

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TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

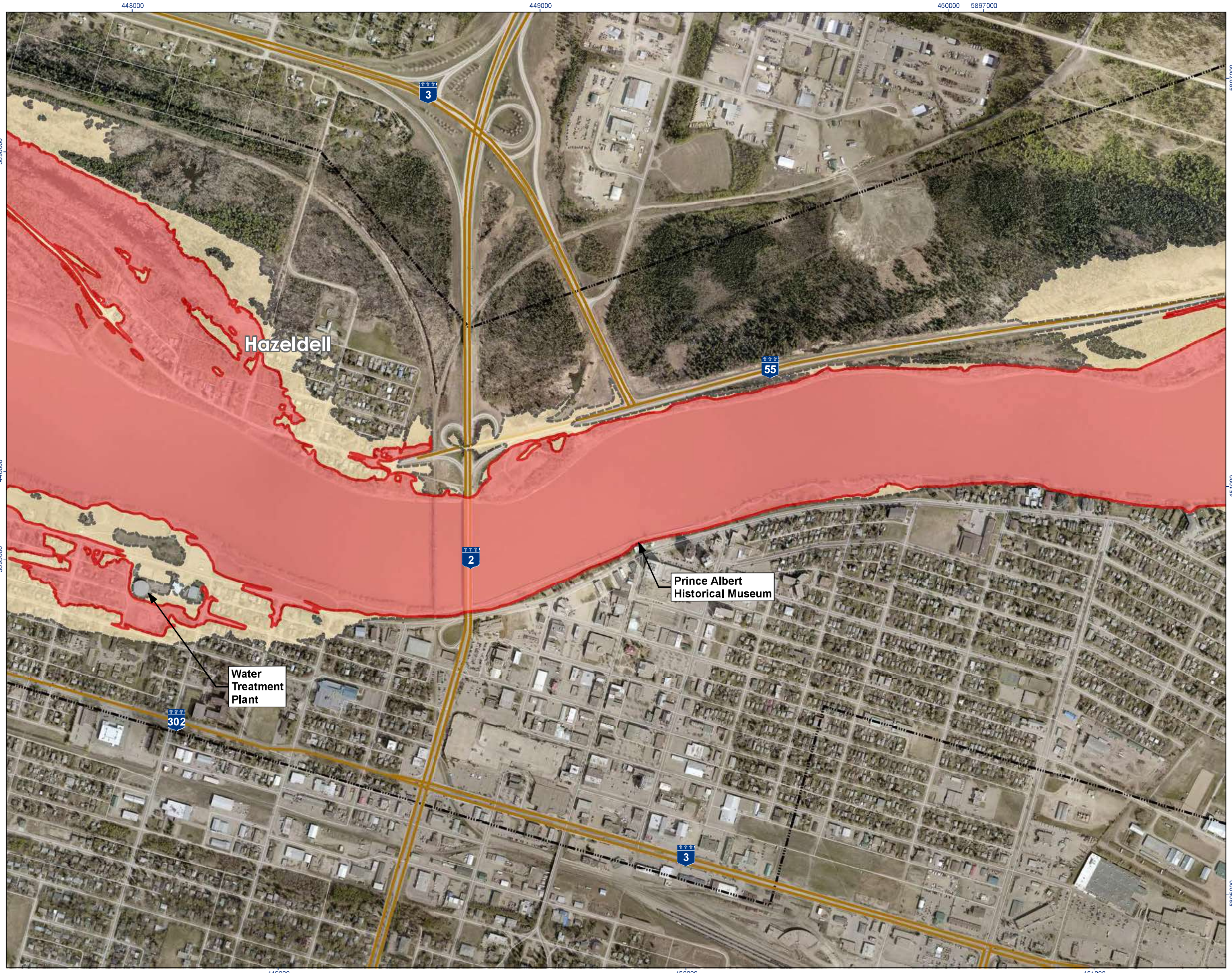
113101975

Figure No.

Sheet No.
1 of 7

Title
Flood Plain Model - Inundation Results
Floodway / Flood Fringe

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson



Legend

- Flood Fringe
- Floodway
- Study Area Boundary
- Highways
- Local Road Network

N

0 190 380 metres

(At original document size of 11x17)
1:10,000

Notes

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Project Location
Prince Albert, SK

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TR by LM on 2019-12-6
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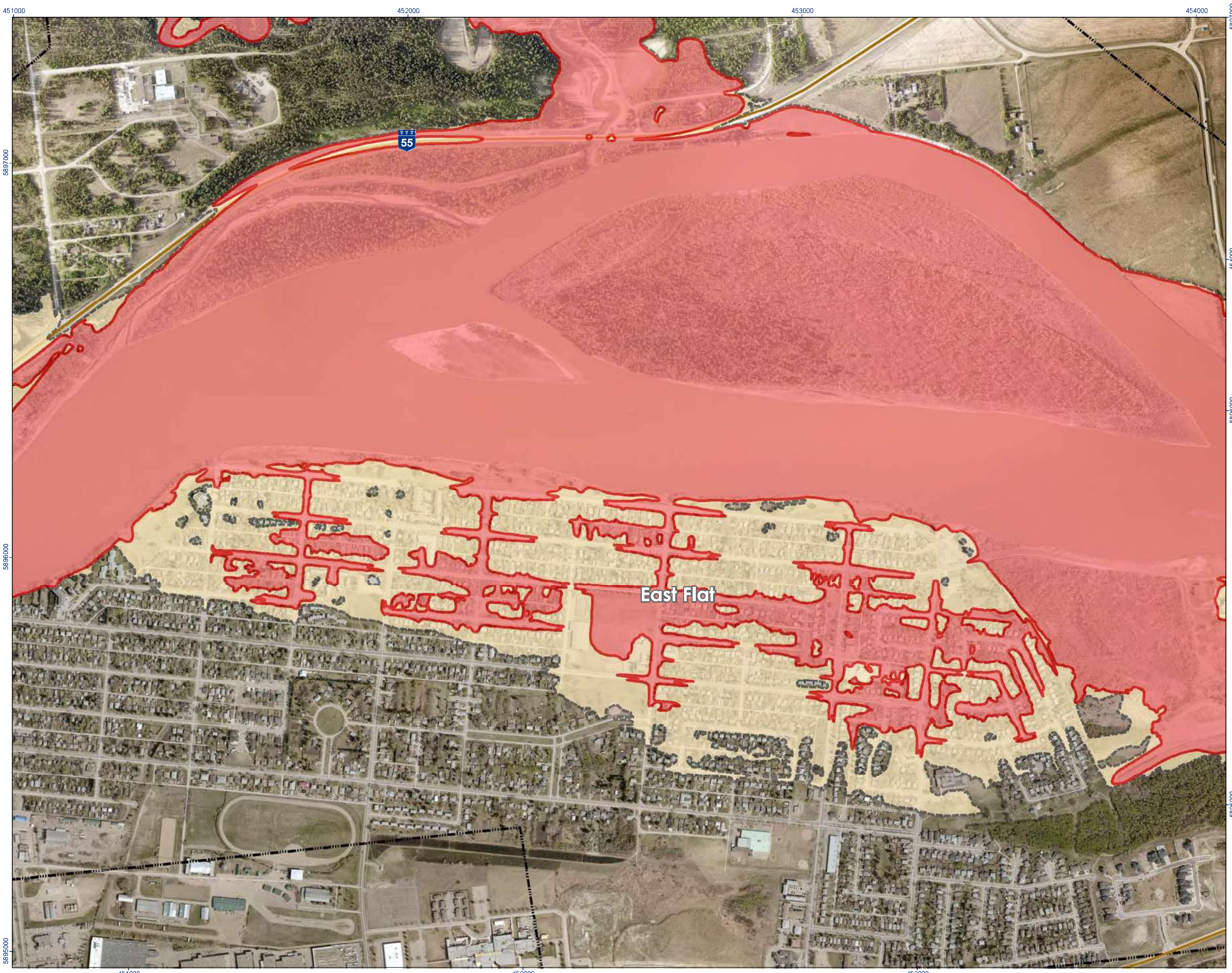
Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.

Sheet No.
2 of 7

Title
Flood Plain Model - Inundation Results
Floodway / Flood Fringe

U:\113101975\report\figures\map_mxd\FloodInundationTemplate.mxd Revised: 2019-12-06 By: MaAnderson



Stantec

City of Prince Albert

Legend

- Flood Fringe
- Floodway
- Study Area Boundary
- Highways
- Local Road Network

N

0 190 380 metres

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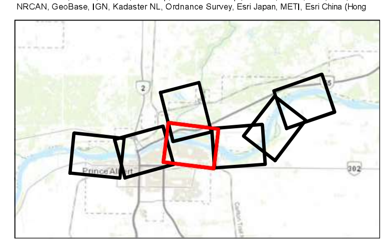

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
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Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.

Sheet No.
3 of 7

Title
Flood Plain Model - Inundation Results
Floodway / Flood Fringe

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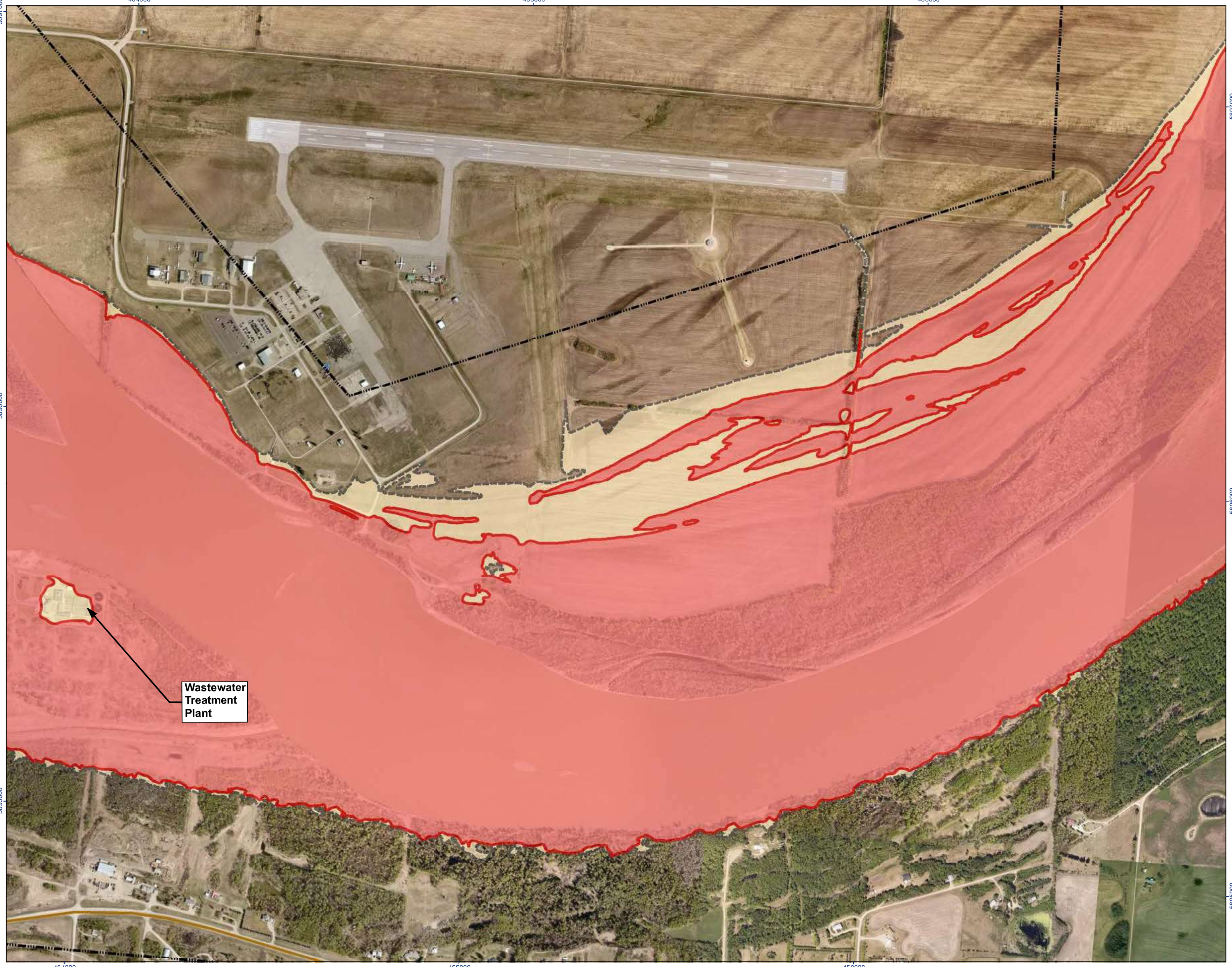

Stantec

City of Prince Albert

Legend

- Flood Fringe
- Floodway
- Study Area Boundary
- Highways
- Local Road Network

N

0 190 380 metres

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1:10,000

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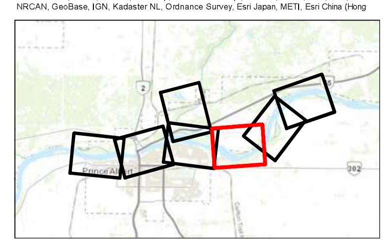

Project Location
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Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
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Client/Project
113101975
City of Prince Albert
Flood Plain Mapping
Report

Figure No.
Sheet No.
4 of 7

Title
Flood Plain Model - Inundation Results
Floodway / Flood Fringe

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City of Prince Albert

Legend

- Flood Fringe
- Floodway
- Study Area Boundary
- Highways
- Local Road Network

0 190 380 metres

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1:10,000

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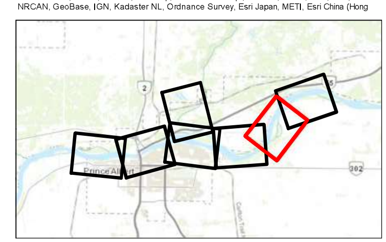

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
TR by LM on 2019-12-6
IR Review by HA on 2019-12-6

Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
5 of 7

Title
Flood Plain Model - Inundation Results
Floodway / Flood Fringe

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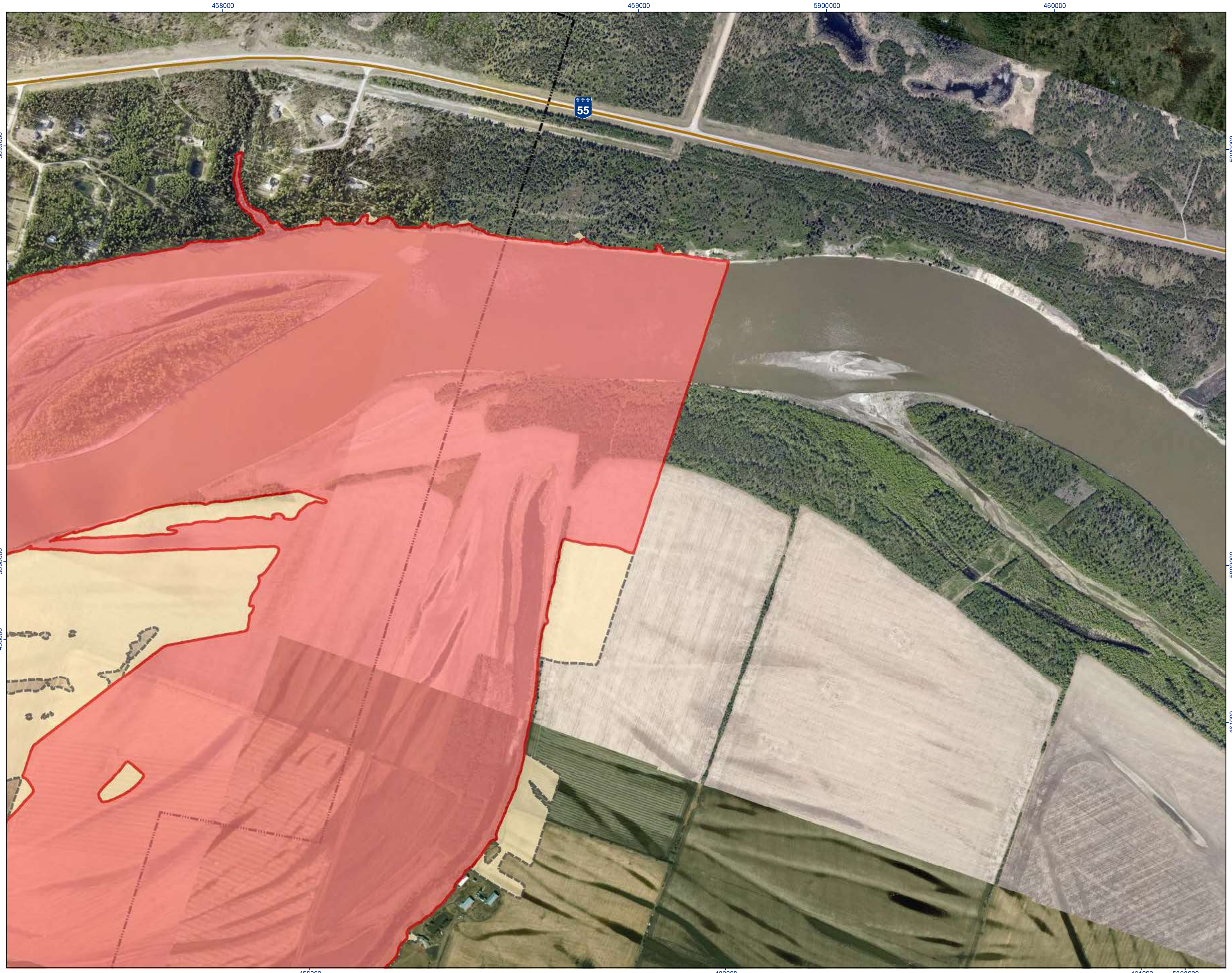

Stantec

City of Prince Albert

Legend
- Flood Fringe
- Floodway
- Study Area Boundary
- Highways
- Local Road Network

N

0 190 380 metres
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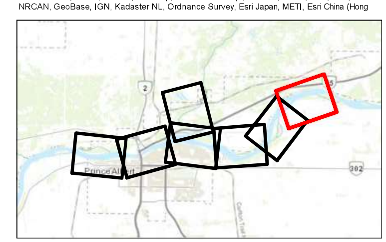

Project Location
Prince Albert, SK

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Client/Project
City of Prince Albert
Flood Plain Mapping
Report

113101975

Figure No.

Sheet No.
6 of 7

Title
Flood Plain Model - Inundation Results
Floodway / Flood Fringe

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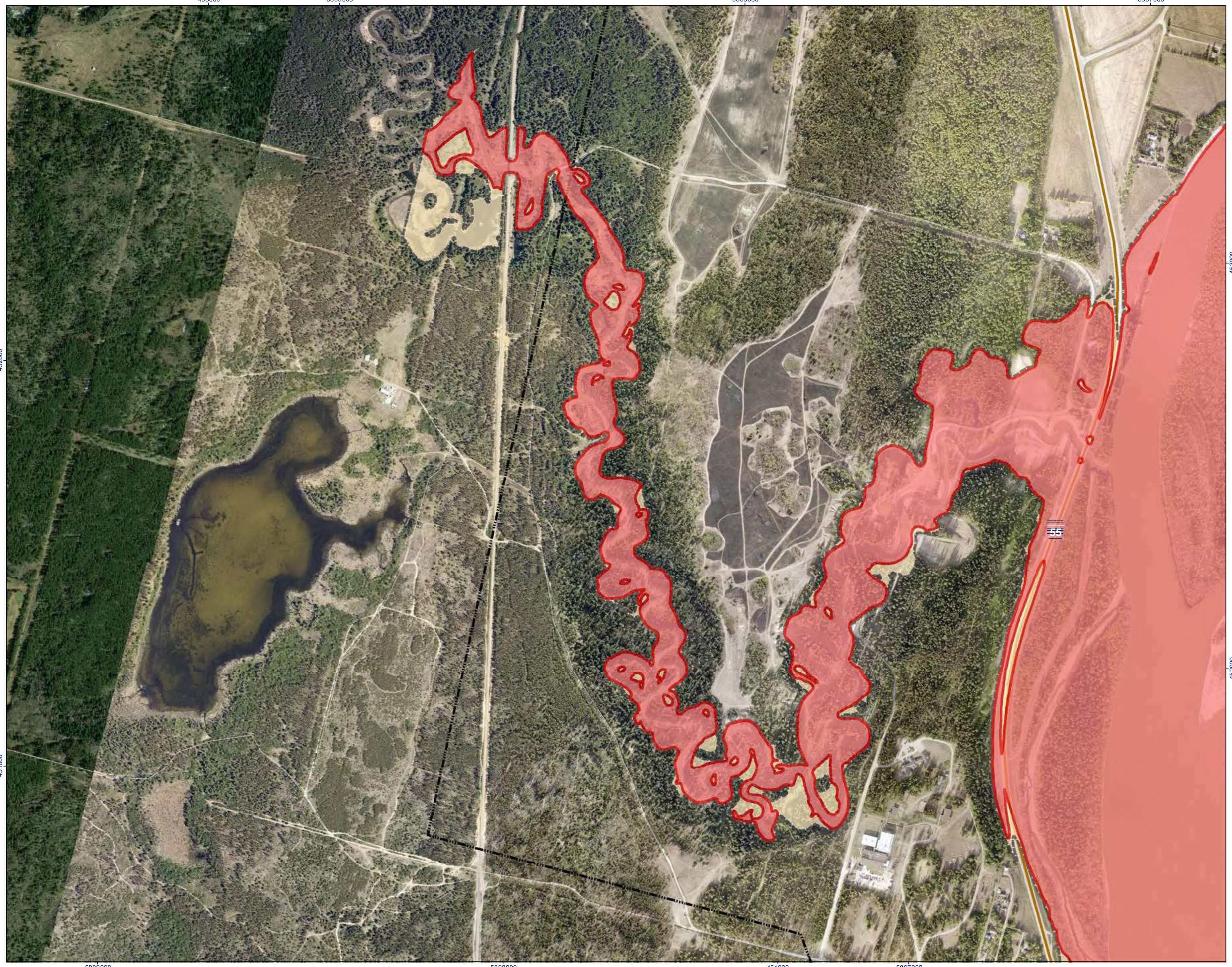

Stantec

City of Prince Albert

Legend

- Flood Fringe
- Floodway
- Study Area Boundary
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- Local Road Network

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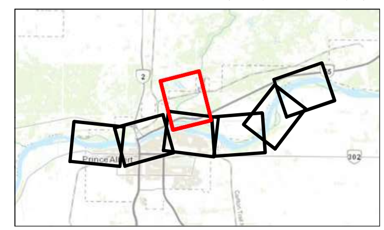

Project Location
Prince Albert, SK

Prepared by MA on 2019-12-6
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Client/Project
City of Prince Albert
Flood Plain Mapping
Report

Figure No.

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Title
Flood Plain Model - Inundation Results
Floodway / Flood Fringe

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