Carrot Creek Regional Drainage Master Plan – Final Report

November 4, 2022

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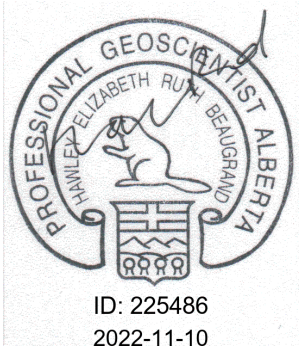
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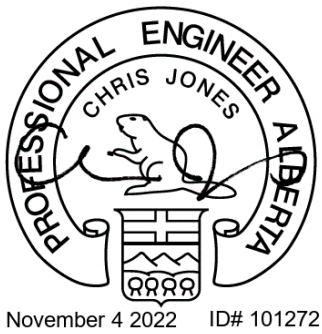
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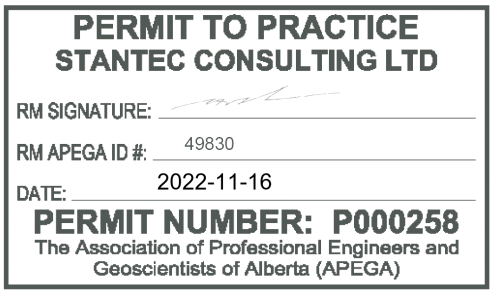


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APEGA Permit to Practice

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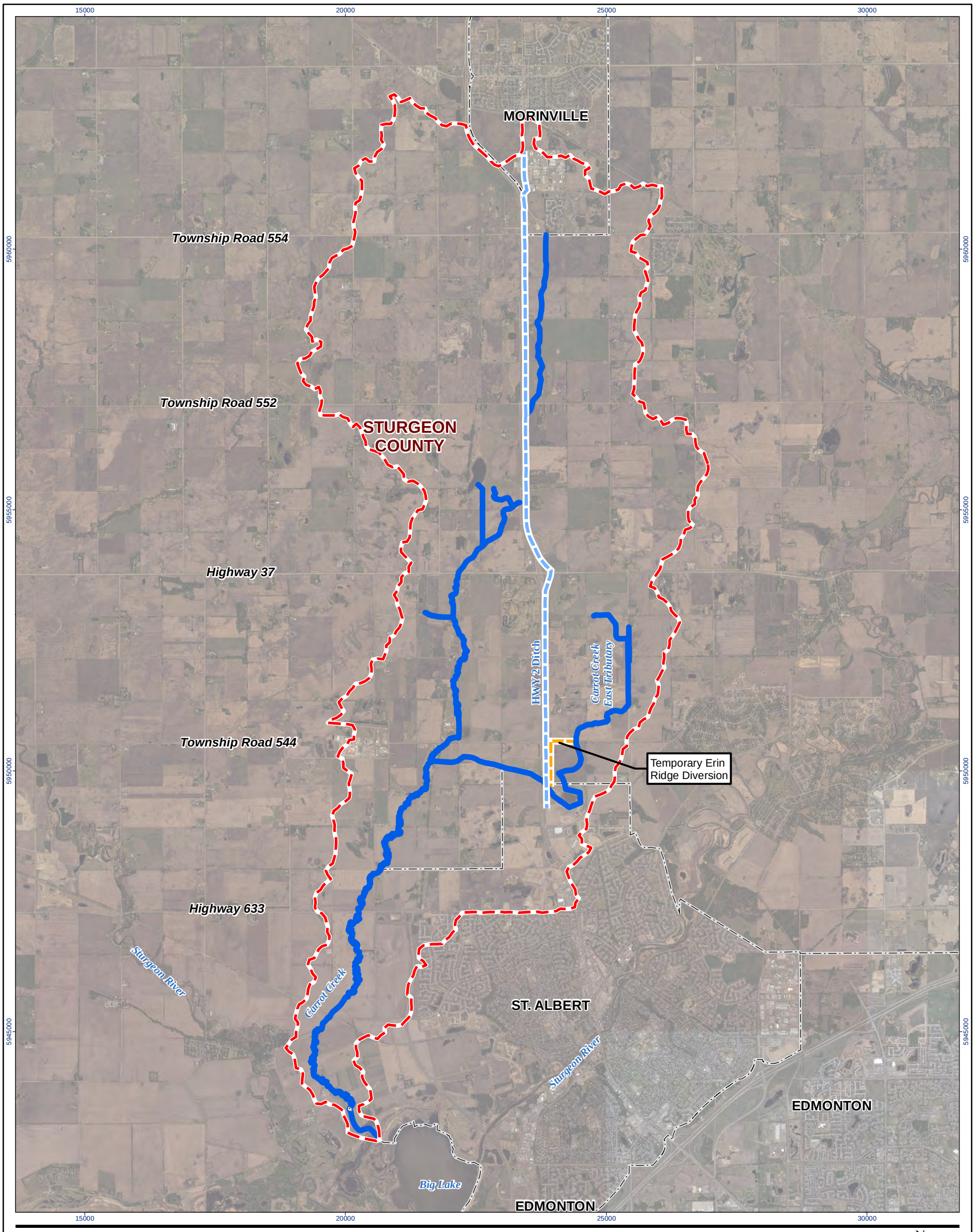
Executive Summary

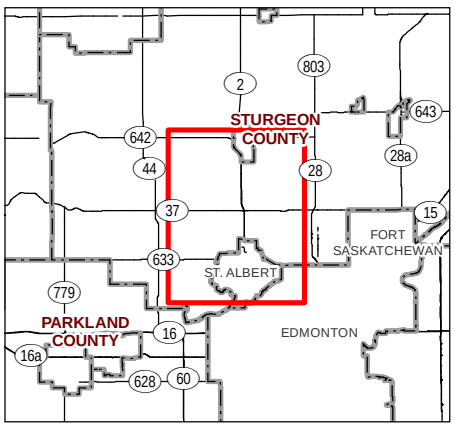
The Carrot Creek watershed (shown on **Figure ES-1**) is part of the Sturgeon River basin, and ultimately the North Saskatchewan River basin. The basin is approximately 87.9 km^2 (85.9 km^2 considering the portion of North Erin Ridge that is being removed from the Carrot Creek Basin due to the ongoing development) and extends from its headwaters near Morinville, Alberta in the north to its outlet to Big Lake just southwest of St. Albert, Alberta. The Town of Morinville, Sturgeon County and the City of St. Albert all have lands within the Carrot Creek watershed, which consists primarily of agricultural land. The watershed also includes portions of the Highway 2, Highway 37 and Secondary Highway 633 right of ways which are owned and operated by Alberta Transportation. The main tributary of the creek flows in a roughly north to south direction, west of Highway 2, and is well defined in its downstream reach south of Township Road 544 towards its outlet to Big Lake. Flow from an eastern tributary (east of Highway 2) and a drainage ditch along Highway 2 join with the main tributary, via a constructed drainage channel, just south of Township Road 544. The northern (upstream) reaches of the creek are typically poorly defined and the surrounding topography can be classified as flat with numerous natural depression storage areas.

Stantec Consulting Ltd. (Stantec) was retained by the City of St. Albert (City) to provide a regional drainage master plan (RDMP) study. The Carrot Creek RDMP (CCRDMP) study provides the City of St. Albert, Town of Morinville, and Sturgeon County with guidance on how to accommodate future development within the Carrot Creek watershed. The CCRDMP was developed in a consultative manner with the affected municipalities such that it would be acceptable to Alberta Environment and Parks (AEP). The overall objective was to recommend policies and design criteria that would achieve consensus among member municipalities (City of St. Albert, Sturgeon County and Town of Morinville) and key stakeholders (Alberta Environment and Park and Alberta Transportation) on a maximum discharge rate and general recommendations for future stormwater management in the Carrot Creek watershed. The intent of those policies and design criteria are to protect the watershed from an environmental perspective without hindering future development plans within each of the three member municipalities. If adopted by AEP, the CCRDMP will expedite drainage planning and approvals in the watershed provided that future stormwater plans abide by the policies and guidelines, including maximum unit area stormwater runoff discharge rate, that are outlined in this document.

The specific objectives of this document are to:

- Present an assessment of Carrot Creek in terms of erosion and hydraulic capacity.
- Determine proactive measures to protect Carrot Creek, and the associated opinions of probable cost, to accommodate stormwater servicing requirements in future growth area.
- Identify stormwater servicing options within the watershed and determine opinions of probable cost.
- Incorporate sustainable development features and Best Management Practices (BMPs) to enhance stormwater management within the watershed and long-term environmental protection.





- Municipal Boundary
- Predevelopment Watershed Boundary
- Carrot Creek Centerline
- HWY 2 Ditch
- Temporary Erin Ridge Diversion

0 1,500 3,000 metres

(At original document size of 11x17)
1:75,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location
Sturgeon County,
Alberta

Prepared by EH on 9/29/2022
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IR Review by FK on 9/29/2022

Client/Project
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City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
ES-1

Title
Existing Carrot Creek Watershed

Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
3. Background: 2015 Aerials from Sturgeon County
4. See associated Carrot Creek Master Drainage Plan Report body for infrastructure sizing information for each servicing option.

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This study included the following key activities:

- Delineation of wetlands in the Carrot Creek watershed.
- Geotechnical desktop study of the watershed.
- Geomorphic assessment of Carrot Creek to characterize the existing condition of the creek reaches and identify areas prone to erosion. This task included field work and desktop work.
- Hydraulic modeling of Carrot Creek to estimate flooding extents in a 1:100 year flow event and to assess creek flow characteristics throughout a range of flow events.
- Develop stormwater management strategies that will protect the creek from erosion damage while not hindering residential and non-residential development in the watershed.
- Based on the results of the geomorphic assessment, hydraulic modeling and assessment of stormwater management strategies, develop recommendations for future stormwater management and erosion protection in Carrot Creek watershed.

Managing creek flows from the East Tributary and Highway 2 drainage ditch was the key issue in developing drainage strategies for the watershed. This is because the large depression storage located in the North Erin Ridge area of north St. Albert (currently under development east of Highway 2) was removed to make room for the development, and the East Tributary was diverted around the development through a temporary drainage ditch west along Township Road 544 and south along Highway 2. In place of the removed storage, a second depression storage (south of Township Road 544) is being used temporarily, but this temporary storage may also be removed as development proceeds north. Previous stormwater management reports related to the North Erin Ridge development identify this as an issue that must be rectified to accommodate ultimate development, and an option to divert the East Tributary to the Sturgeon River was identified. However, prior to this study, no permanent solution has been finalized for managing flows from the East Tributary.

Four configurations for managing East Tributary flows were considered:

- Option 1: Divert the East Tributary to the Sturgeon River through a new storm trunk.
- Option 2: Divert the East Tributary and Highway 2 drainage ditch to the Sturgeon River through a new storm trunk.
- Option 3: Make the existing drainage ditch that diverts the East Tributary west along Township Road 544 and south along Highway 2 permanent such that East Tributary remains connected to Carrot Creek. The large storage area east of Highway 2 and south of Township Road 544 is assumed removed in this option but this is somewhat offset by the diversion of the North Erin Ridge lands away from the Carrot Creek Basin via the City's Northeast Storm Trunk to the Sturgeon River that is currently under design and construction in 2022.
- Option 4: Similar to Option 3, except a new permanent storage facility is constructed east of Highway 2 and south of Township Road 544 such that peak flows from the East Tributary are attenuated as in the condition that existed before the recent development in North Erin Ridge.



Within each configuration, 1:100 year unit area release rates (UARR) for new development of 1.8 L/s/ha and 2.5 L/s/ha (which matches the existing condition according to the hydrologic assessment conducted in this study) were considered (denoted as Options a and b, respectively). In addition, a UARR of 5.0 L/s/ha was considered for new developments in Options 1 to 3. Each option was modeled using PCSWMM to estimate stormwater management facility sizes for future growth in the Carrot Creek basin, which were in turn used to estimate the cost of stormwater management for each option. **Table ES-1** summarizes the options considered. Costs provided in **Table ES-1** are for the intermediate UARR of 2.5 L/s/ha only for ease of comparing the relative costs of each option.

Table ES-1 Stormwater and East Tributary Management Options

Option	Description	Summary of Findings
Option 1 a: 1.8 L/s/ha b: 2.5 L/s/ha c: 5.0 L/s/ha	Divert East Tributary to Sturgeon River. Build stormwater management facilities in new development areas to attenuate flow to the desired UARR (options a, b or c)	Stormwater Servicing Cost (2.5 L/s/ha): $189 Million • Previously suggested in City of St. Albert Northeast Area Storm Sturgeon River Outfall Predesign Report (Associated Engineering, 2020). • Storm trunk currently under construction ("NEST Trunk") to service North Erin Ridge was not sized to accommodate East Tributary flows. • Requires a 3.24 km long, 1.8mx1.2m box storm trunk (or equivalent size) from Township Road 544 to Sturgeon River. • Removes 1,003 ha (10.03 km^2 or 11.4% of the total basin) of the Carrot Creek basin which will reduce flows in the main reach of Carrot Creek.
Option 2 a: 1.8 L/s/ha b: 2.5 L/s/ha c: 5.0 L/s/ha	Divert East Tributary and Highway 2 ditch to Sturgeon River. Build stormwater management facilities in new development areas to attenuate flow to the desired UARR (options a, b or c)	Stormwater Servicing Cost (2.5 L/s/ha): $206 Million • Storm trunk currently under construction ("NEST Trunk") to service North Erin Ridge was not sized to accommodate East Tributary flows. • Requires a 3.82 km long, 2.4mx1.8m box storm trunk (or equivalent size) from Highway 2 to Sturgeon River. • Removes 3,599 ha (35.99 km^2, or 40.9% of the total basin) of the Carrot Creek basin which significantly reduces flows in the main reach of Carrot Creek. • Not recommended due to high cost and large diversion of Carrot Creek basin.
Option 3 a: 1.8 L/s/ha b: 2.5 L/s/ha c: 5.0 L/s/ha	Maintain East Tributary Connection to Carrot Creek via drainage ditch west along Township Road 544 and south along Highway 2. The large storage facility in North Erin Ridge is removed. Build stormwater management facilities in new development areas to attenuate flow to the desired UARR (options a, b or c)	Stormwater Servicing Cost (2.5 L/s/ha): $165 Million • Requires the recently constructed drainage ditch along Township Road 544 and Hwy 2, that diverts the East Tributary around North Erin Ridge and was intended to be temporary, to become permanent (or an alternative means of conveying the East Tributary through or around the North Erin Ridge development). • Loss of attenuation of East Tributary flows near Highway 2 results in higher peak flows entering the main reach of Carrot Creek during infrequent high flow events. • During more frequent and lower flow events, the flow rates are similar to Option 4 and not expected to significantly exceed the existing condition. • Not recommended due the permanent loss of the large storage area east of Highway 2 which provides peak flow attenuation to the East Tributary.

Option	Description	Summary of Findings
Option 4 a: 1.8 L/s/ha b: 2.5 L/s/ha	Maintain East Tributary Connection to Carrot Creek via drainage ditch west along Township Road 544 and south along Highway 2. The large storage facility in North Erin Ridge that was previously removed is replaced with a new storage area south of Township Road 544 and east of Highway 2 to attenuate peak flows from the East Tributary. Build stormwater management facilities in new development areas to attenuate flow to the desired UARR (options a or b)	Stormwater Servicing Cost (2.5 L/s/ha): $166 Million • Requires the recently constructed drainage ditch along Township Road 544 and Hwy 2, that diverts the East Tributary around North Erin Ridge and was intended to be temporary, to become permanent (or an alternative means of conveying the East Tributary through or around the North Erin Ridge development). • Slightly less developable land in North Erin Ridge due to the permanent drainage ditch and a new storage facility (approximately 60,500 m^3 of active storage required, not including freeboard). • Option to construct two discharge locations from the storage: Some flows may be released to Carrot Creek and some flows may be released to the City storm system if there is capacity (i.e. "NEST" system to the Sturgeon River). • Provides peak flow attenuation of East Tributary flows during high flow events but during more frequent and lower flow events, the flow rates are similar to Option 3.

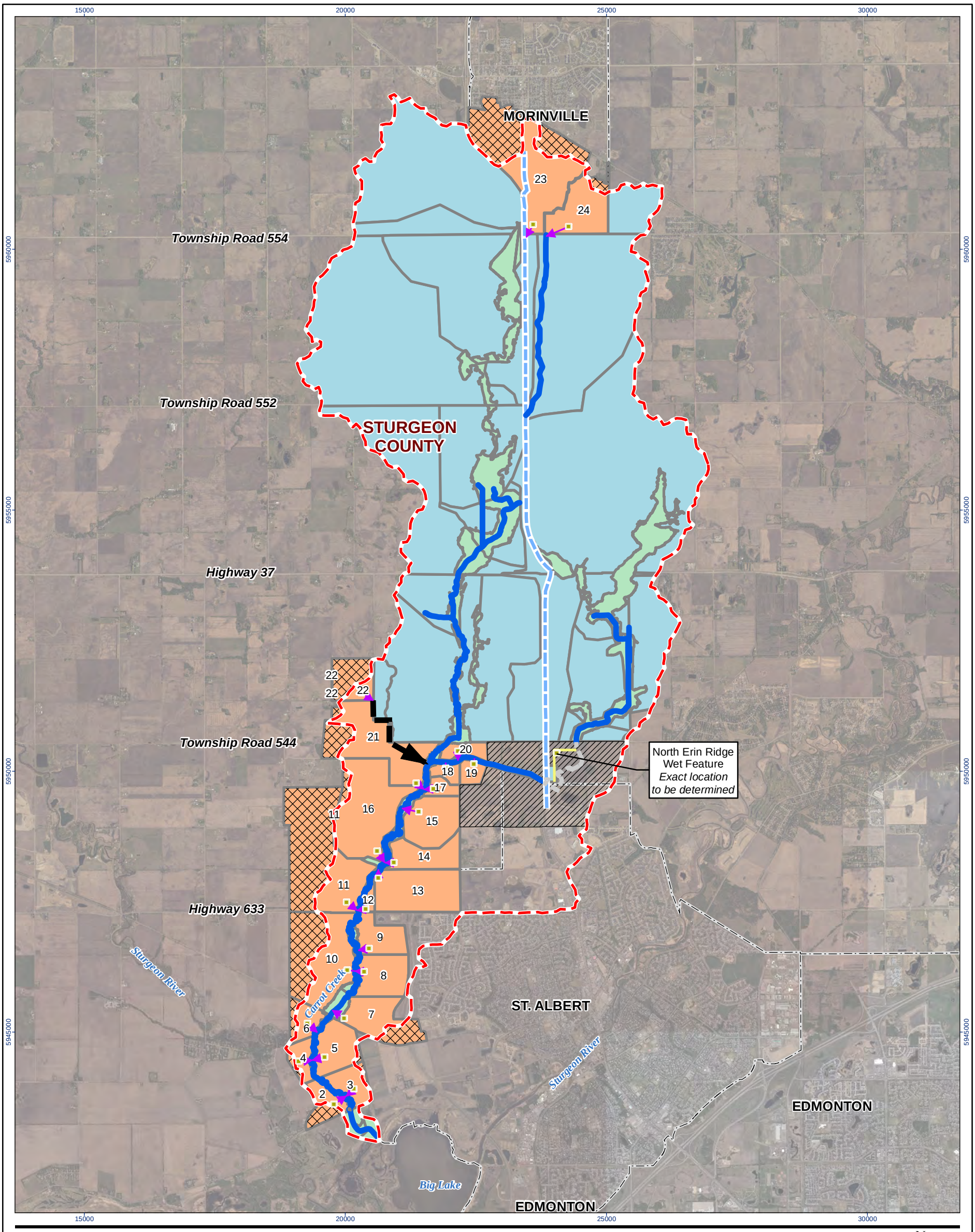
A UARR of 5.0 L/s/ha was ruled out because it is higher than the current UARR and there are concerns that higher peak flows in Carrot Creek may exacerbate erosion. Stakeholders (City of St. Albert, Sturgeon County, Town of Morinville and Alberta Environment and Parks) were consulted and the consensus was that 2.5 L/s/ha is appropriate as it matches the existing condition and will result in slightly smaller stormwater management facilities compared to a UARR of 1.8 L/s/ha.

Options 1 and 2 are not recommended as they are the highest cost options (due to the long diversion trunk to the Sturgeon River) and there are concerns with diverting a large area away from the basin. Options 3 and 4 were considered further. Both Options 3 and 4 maintain the connectivity of the East Tributary to Carrot Creek, but Option 4 includes construction of a stormwater management facility south of Township Road 544 that would attenuate peak flow from the East Tributary, in a manner similar to the previously removed storage area in North Erin Ridge. Both options have similar cost, with a slightly higher cost of storage in Option 4 while an additional allowance for erosion protection was considered for Option 3 as a contingency because the peak flows during high and infrequent flow events are expected to be higher without the East Tributary storage.

Ultimately, Option 3 was ruled out because it is undesirable to allow the East Tributary to discharge higher peak flows to Carrot Creek during significant rainfall or snowmelt events (which would be the case with the removal of the large storage area east of Highway 2).

Option 4b is the recommended option. Option 4 includes construction of a stormwater management facility south of Township Road 544 that would replace the large depression storage located in the North Erin Ridge area of north St. Albert (currently under development east of Highway 2) that was removed to make room for the development. The estimated volume of the new stormwater management facility is 60,500 m^3 (not including freeboard) and it is required to attenuate peak flows from the East Tributary before they cross Highway 2 and enter the main reach of Carrot Creek. **Figure ES-2** shows the preferred option. As mentioned above, the recommended UARR is 2.5 L/s/ha for all new development areas that will contribute stormwater to Carrot Creek and its tributaries.





Stantec

City of St. Albert Planning and Engineering

Project Location	Prepared by EH on 10/3/2022
Sturgeon County, Alberta	TR by BS on 10/3/2022
	IR Review by FK on 10/3/2022
Client/Project	110149416 - 7-5 REV A

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.

ES-2

Title

Preferred Option for Managing East Tributary Flows

Notes

1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
3. Background: 2015 Aerials from Sturgeon County
4. See associated Carrot Creek Master Drainage Plan Report body for infrastructure sizing information for each servicing option.

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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Controlling stormwater peak flow rate to Carrot Creek using stormwater management facilities in new development areas will eliminate the need for a large diameter storm trunk that is parallel to Carrot Creek, as was previously proposed for servicing future northwest and west St. Albert developments.

Implementation of erosion control at key locations that are prone to erosion, and to protect infrastructure such as bridges over Carrot Creek, are recommended per **Table ES-2** below. Further, annual erosion monitoring at key locations is recommended in order to verify that erosion and bank stability are not negatively impacted by ongoing development. Monitoring interval should be designed to capture potential changes resulting from watershed development (e.g., annual to 5-year interval depending on development activity) and should continue until such time that creek morphology has achieved equilibrium with the development scenario.

Table ES-2 Preliminary Creek Erosion Protection and Culvert Recommendations

Location	Recommended Improvements
CN Rail Crossing	Add or upsize and replace culverts. Install riprap/bioengineering upstream (30 m) and downstream (130 m) of crossing.
Meadowview Drive Bridge	Install riprap/bioengineering for ~160 m downstream of the bridge.
RR 260 North of Villeneuve Road	Install rip rap/bioengineering for ~50 m downstream of crossing.
Highway 2 Crossing	Extend existing riprap additional 30 m upstream of culvert (pending future monitoring)
Old McKenney Avenue	Install rip rap for ~ 40 m downstream of crossing.
Carrot Creek Erosion Monitoring Program	Erosion monitoring Program at areas of concern from the geomorphic assessment (Section 5.2.2.1)

Abbreviations

AEP	Alberta Environment and Parks
BEHI	Bank Erosion Hazard Index
CCRDMP	Carrot Creek Regional Drainage Master Plan
DEM	Digital Elevation Model
ET	Eastern Tributary (of Carrot Creek)
Hwy	Highway
KP	Kilometer Post
LiDAR	Light Detection and Ranging
RDMP	Regional Drainage Master Plan
ROW	Right-of-way
RR	Range Road
TR	Township Road

Glossary

Anabranch	Section of a river or stream that diverts from the main channel of the watercourse and then rejoins it again downstream.
Bank Erosion	Lateral bank retreat due to erosional processes including fluvial entrainment, tractive force action, freeze-thaw, dry ravel, ice scour, and other processes.
Bank Failure	When erosion at the toe of a streambank increases the height and angle of the bank to the point where gravitational forces exceed the shear strength of the bank material and the bank fails (Simon, Curini, Darby, & Langendoen, 2000). Bank failures are considered herein to be local in nature. Stream erosion that causes instability that extends upslope beyond the usual influence of the stream are classified as a separate type of landslide
Bifurcate	Division into two branches.
DEM	A digital model of terrain surfaces using point elevation and location data provided by LiDAR.
Dune-ripple	Field morphology where the bed of the watercourse is mobile at most stages and dune-forms are present.
Landslide	Downslope movement of sediment, rock, organics, and debris, under the influence of gravity.
LiDAR	Technology used to capture a three-dimensional point cloud of a target. For our purposes, the instrument is typically mounted on an airborne platform, scanning the Earth's surface. A laser pulse is emitted from the instrument and the system calculates the time it takes for the pulse to hit an object or surface and return to the scanner. When the pulse hits a weak or non-reflective surface (e.g., water) there is typically a weak or absent return.
Nadir	Point on a sphere directly below the observer.
Riffle-pool	Field morphology where the watercourse contains sediment bars, deeper, less turbulent pools, and shallower, more turbulent riffles.
Run	Field morphology where the cross section of the watercourse has a trapezoidal shape, the bed is featureless (no pools or riffles), the depth to width ratio is high, and the thalweg is weak.



Scour	Concentrated erosive action, particularly by a stream. General scour refers to the movement depth of the mobile streambed over the entire channel cross section. It may affect one side or reach more than another. Local scour is scour occurring over a limited extent due to local flow conditions generated from interactions with an instream feature (USDA, 2007).
Strahler Stream Order	The Strahler stream order is a method of classifying watercourses based on the number of tributaries a watercourse has. Watercourses with no tributaries are assigned a stream order of 1. The order increases in a downstream manner when two watercourses of the same order merge. If two watercourses of different orders merge, then the watercourse downstream of the confluence maintains the higher of the two stream orders.
Thalweg	The deepest location in a channel cross-section. The thalweg often corresponds to the location of minimum depth of cover.

1 INTRODUCTION

The City of St. Albert (City) is mandated by its Municipal Development Plan to preserve and protect the Sturgeon River Valley and Carrot Creek corridors while accommodating future growth within the City. With respect to Carrot Creek, the City is concerned that, in the absence of long-term planning, inflowing surface drainage under future growth scenarios would cause continued bank erosion and would require substantial rehabilitation. In addition, the City seeks understanding of Carrot Creek to facilitate informed decision-making related to development permitting within the watershed.

Stantec Consulting Ltd. (Stantec) was retained by the City to provide a regional drainage master plan (RDMP) study. The Carrot Creek RDMP (CCRDMP) study will provide the City of St. Albert, Town of Morinville, and Sturgeon County with guidance on how to accommodate future development within the Carrot Creek watershed. The CCRDMP was developed in a consultative manner with the affected municipalities such that it would be acceptable to Alberta Environment and Parks (AEP). The overall objective was to recommend policies and design criteria that would achieve consensus among member municipalities (City of St. Albert, Sturgeon County and Town of Morinville) and key stakeholders (Alberta Environment and Park and Alberta Transportation) on a maximum discharge rate and general recommendations for future stormwater management in the Carrot Creek watershed. The intent of those policies and design criteria are to protect the watershed from an environmental perspective without hindering future development plans within each of the three municipalities. If adopted by AEP, the CCRDMP will expedite drainage planning and approvals in the watershed provided that future stormwater plans abide by the policies and guidelines, including maximum discharge rate, that are outlined in this document.

The specific objectives of this document are to:

- Present an assessment of Carrot Creek in terms of existing erosion and hydraulic capacity.
- Determine proactive measures to protect Carrot Creek, and the associated opinions of probable cost, to accommodate stormwater servicing requirements in future growth areas.
- Identify stormwater servicing options within the watershed and determine opinions of probable cost.
- Incorporate sustainable development features and Best Management Practices (BMPs) to enhance stormwater management within the watershed and long-term environmental protection.

1.1 STUDY AREA

The study area is defined as the Carrot Creek watershed (Figure 1-1). Field work was conducted as shown within the area bounded by the red line in Figure 1-2 from Big Lake north to Township Road 544 and from the confluence with the East Tributary (ET) east to Highway 2. The Carrot Creek basin includes portions of the City of St. Albert, Sturgeon County and Town of Morinville.

Within the study area, Carrot Creek was subdivided into reference points spaced approximately one kilometer apart for both the main trunk of Carrot Creek and the ET of Carrot Creek. These reference points are referred to as Kilometer Posts (KP) and are numbered from downstream to upstream (Figure 1-3 and Figure 1-4).

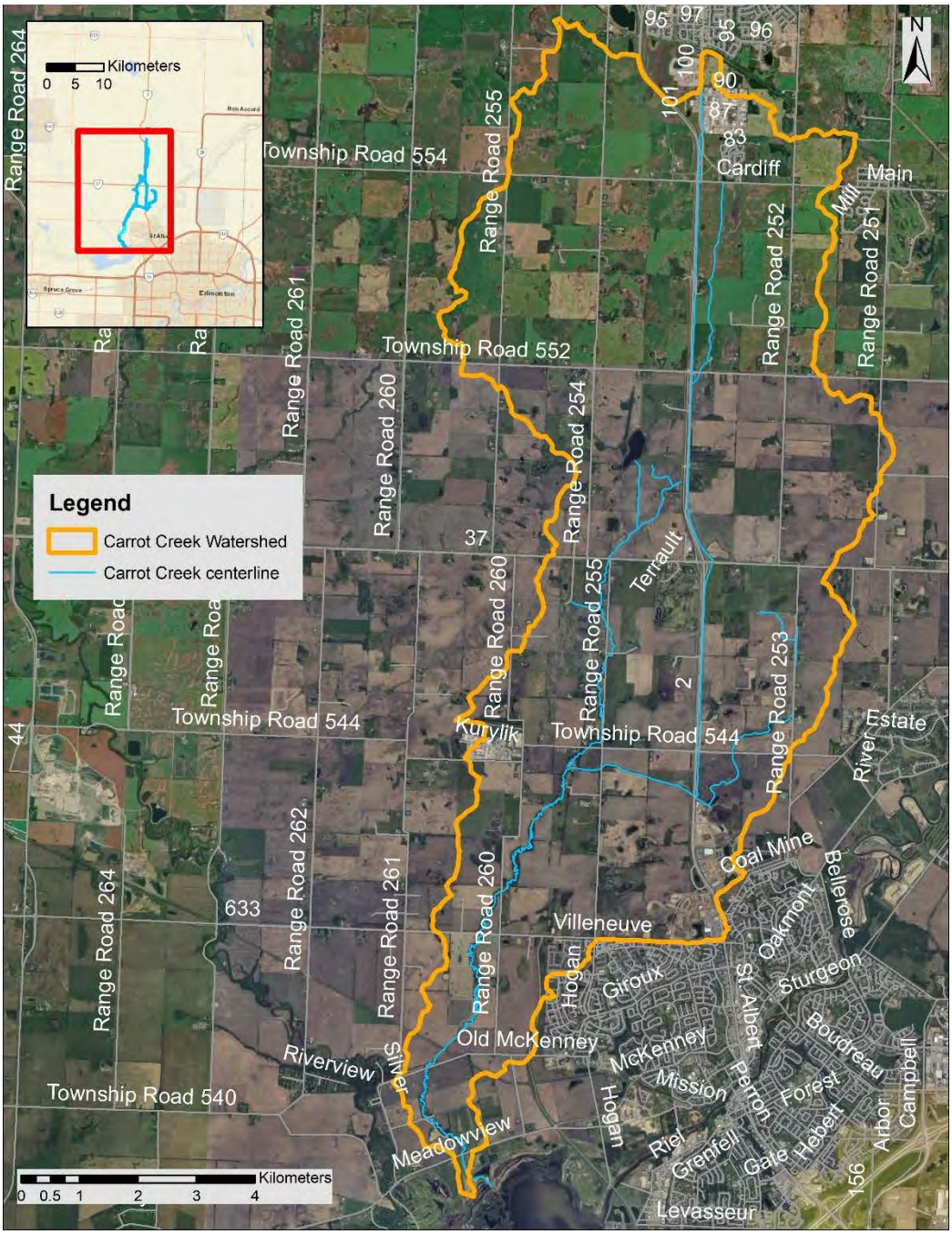


Figure 1-1 Carrot Creek study area showing the Carrot Creek watershed and creek centerline with roads and ESRI ArcGIS background imagery for reference

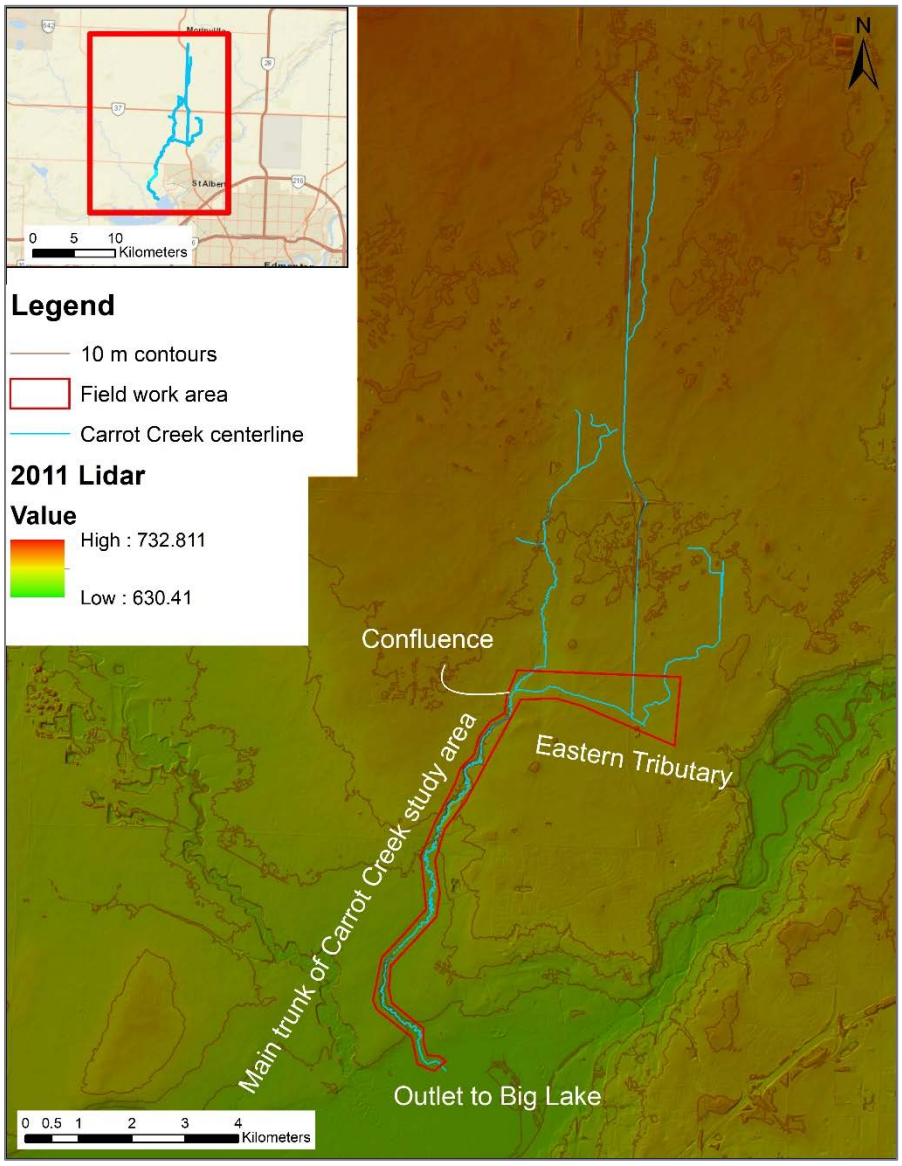


Figure 1-2 Carrot Creek alignment with the 2011 LiDAR hillshade as the background. Higher elevations are red (732.811 m, maximum) and lower elevations fade towards green (630.410 m, minimum).

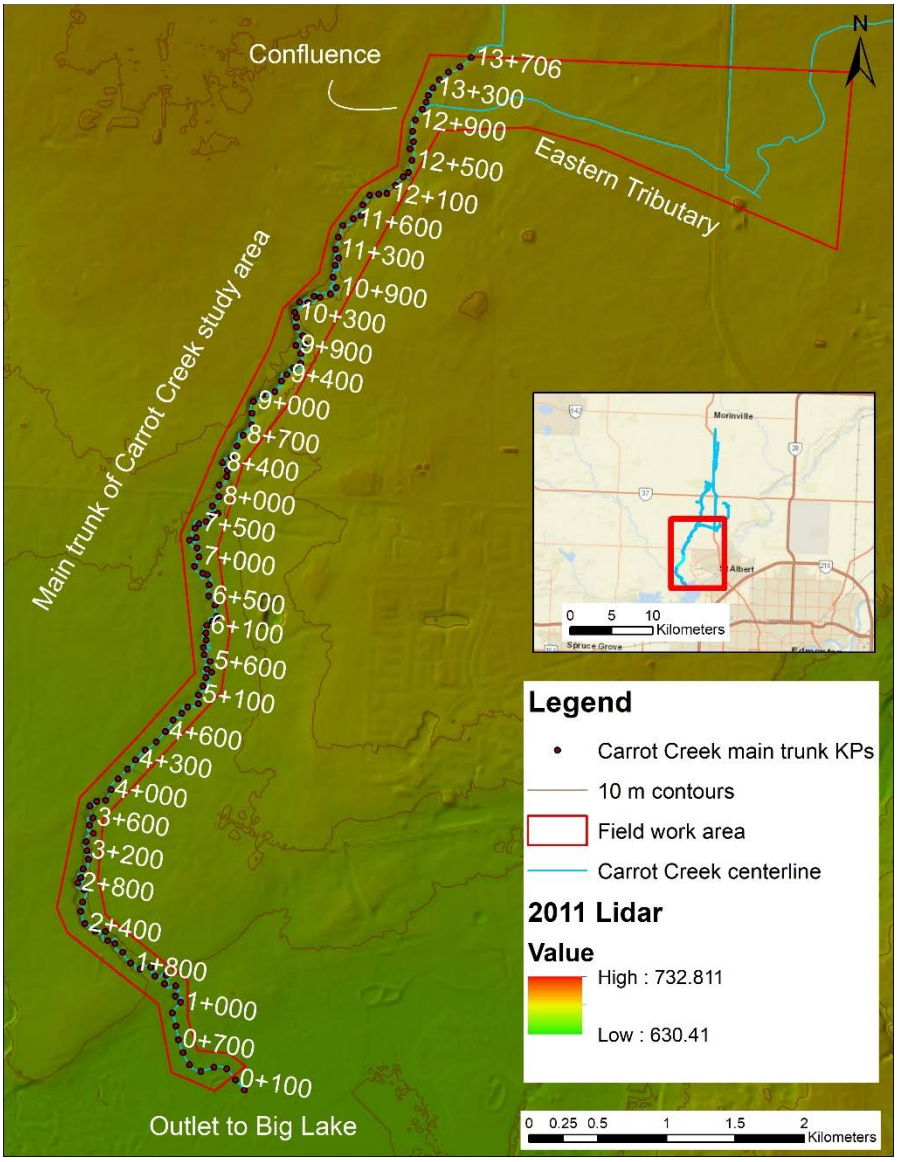


Figure 1-3 Main trunk of Carrot Creek study area with KPs from 0+000 (at the outlet to Big Lake) to 13+706 (where the main trunk intersects with Township Road 544). The 2011 LiDAR hillshade is the background; higher elevations (red) fade to lower elevations (green).

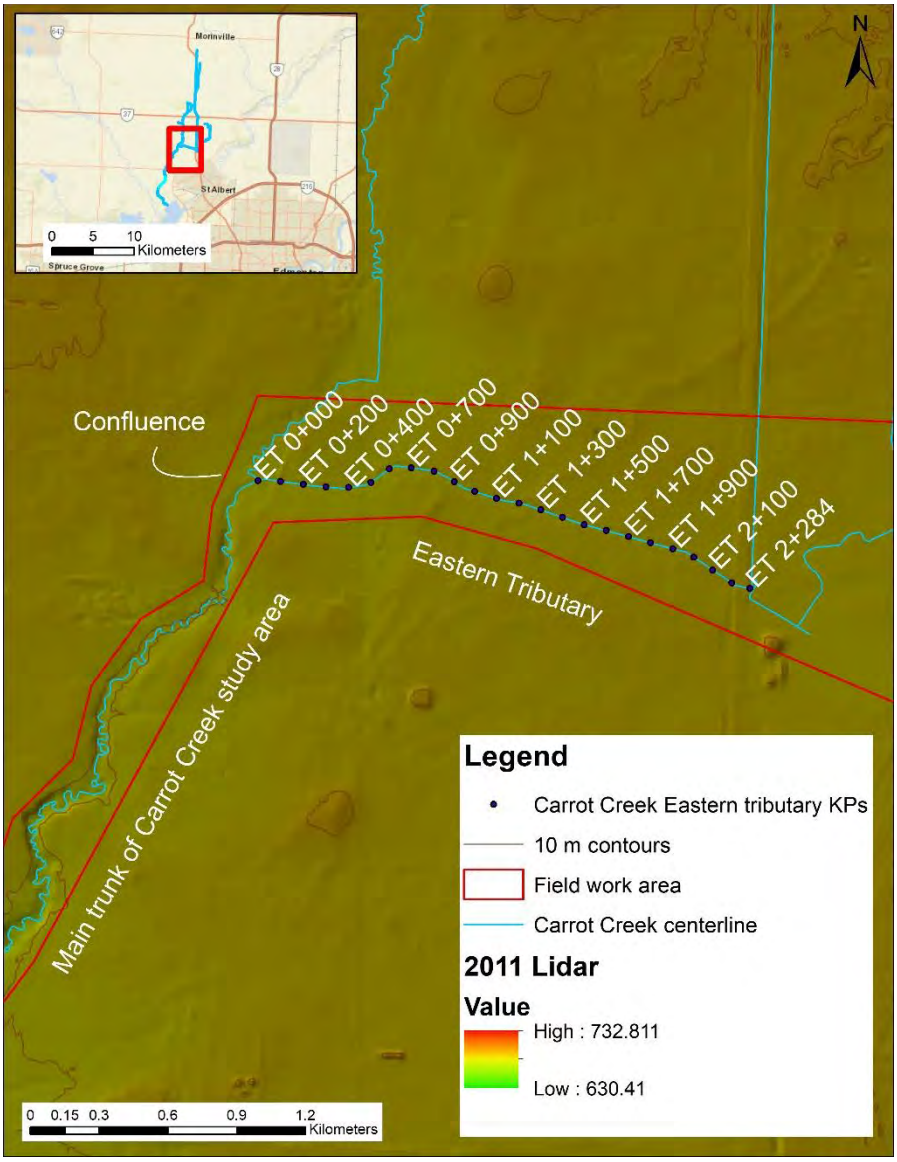


Figure 1-4 Eastern Tributary of Carrot Creek study area with KPs from ET 0+000 (at the confluence) to ET 2+284 (where the eastern tributary intersects with Highway 2). The 2011 LiDAR hillshade is the background; higher elevations (red) fade to lower elevations (green).

2 BASIS OF REPORT

Stantec's geomorphic and hydrotechnical assessments and subsequent erosion mitigation recommendations are based on the following information and assumptions:

- Site survey and field reconnaissance of Carrot Creek and its tributaries south of Township Road 544 completed June 22 to 26, 2020.
- Additional site survey of culverts north of Township Road 544 completed on July 29, 2020.
- LiDAR data provided by Sturgeon County. The data are from 2011, provided at 15 m resolution, and projected in UTM Zone 12 (NAD83).
- LiDAR data provided by Airborne Imaging. The data were collected in April 2015 and May 2018, have a resolution of 1 m, and are projected in UTM zone 12 (NAD83). Data coverage is approximately 150 to 250 m on either side of Carrot Creek and its tributaries, for a total area of 5.5 km^2.
- 5 and 10 cm (1:100 and 1:200 scale) resolution aerial imagery from April 2020 flown and provided by Z-Air Inc.
- 10 m resolution (1:20,000 scale) aerial imagery from the Government of Alberta's Air Photo Library, purchased and georeferenced by IGI Consulting Inc. Images are from 1976, 1992/1993, and 2008.
- Discharge data, elevation data and rating curve published by Environment Canada for the Water Survey of Canada (WSC) hydrometric Station Number 05EA011, Carrot Creek Near the Mouth.
- City of Calgary's Design Guidelines for Erosion and Flood Control (2014): Streambanks and Riparian were used as the basis for analyzing shear stress results in Carrot Creek, and
- Due to the transient nature of beaver dams: their presence, location, and extents; they are excluded from the hydraulic analysis. The potential effects of a beaver dam breach are discussed throughout the geomorphic assessment in Section 5.

This report should be read in conjunction with the Statement of General Conditions, which are included in **Appendix A**.

2.1 REGULATORY FRAMEWORK

For this project, regulatory approvals are not required as there are no construction works that need to be completed. However, regulatory review and coordination with Environmental Protection and Enhancement Act and Water Act staff for adaptation of the study recommendations has been accommodated during the stakeholder engagement process.

Statutory documents that preside over this study and future works include, but are not necessarily limited to:

- Fisheries Act (Federal)
- Canadian Navigable Waters Act (Federal)
- Environmental Protection and Enhancement Act (Provincial)
- Public Lands Act (Provincial)
- Water Act (Provincial)
- Morinville Municipal Development Plan (Municipal)
- St. Albert Municipal Development Plan (Municipal)
- Sturgeon County and St. Albert Intermunicipal Development Plan (Regional / Municipal)
- Stormwater Management Guidelines for the Province of Alberta (latest version, January 1999)
- Alberta Wetland Policy

In addition to compliance with the CCRDMP, future development plans may require:

- Provincial and Federal permitting for related in-river or in-stream projects in watercourses and water bodies in the surrounding area (e.g. Code of Practice for Outfall Structures on Water Bodies)
- Provincial Water Act approval for removal or potential impact to natural drainage areas, water courses, and wetlands in the development limits
- Provincial Public Lands Act for any works within the bed and shore of Carrot Creek (e.g. outfalls, erosion protection). Note that applications for Public Land Acts approvals (e.g. Department License of Occupation) should be completed well in advance of construction as approval can take 12 months or more
- Supporting Biophysical Impact Assessments, Historical Resources Impact Assessments, and/or Wetland Impact Assessment Reports
- Legal land surveys and dedication of utility, road, and/or public right-of-ways for future servicing strategies, as agreed to by applicable landowners

3 REGIONAL CONTEXT

3.1 REGIONAL CLIMATE AND HYDROLOGY

This project lies within the Parkland Natural Region and Central Parkland Natural Subregion. The Central Parkland Natural Subregion is intensively cultivated, is the most densely populated subregion in Alberta, and includes all or parts of Alberta's three largest cities: Calgary, Edmonton, and Red Deer. Topography primarily ranges from undulating to hummocky till plains and uplands. The subregion is a transition zone between the cooler, moister boreal forests, and warmer, dry southern grasslands. Numerous small waterbodies occur throughout the subregion, covering about 2% of the area, and wetlands cover another 10% (Alberta Parks, 2015).

One third of annual precipitation occurs during the winter as snow and its distribution is highly variable due to wind redistribution and sublimation (Fang, et al., 2007). Most precipitation occurs during spring and early summer from large frontal systems and the most intense rainfall occurs in summer from convective storms over localized areas. July brings the highest amount of precipitation, but significant amounts fall in June and August as well (Alberta Parks, 2015).

Regional topography is typified by undulating to gently rolling terrain. This topography results in a fill-and-spill type hydrology where flow is not established until full storage is achieved within depressions and water spills out of the basin and flows to downgradient depressions. When the drainage pathways connect through fill-and-spill mechanisms, this rapidly increases the contributing watershed area during runoff events. However, outside of larger events, much of the prairie landscape is non-contributing to streamflow. In the prairies, the effective watershed area, or the area actively contributing to runoff generation, is often much smaller than the gross watershed area. This fill-and-spill hydrology with disconnected drainages dominates the headwaters of Carrot Creek from Township Road 544 to the north and east.

Carrot Creek and its tributaries are part of the Sturgeon River basin, and ultimately, the North Saskatchewan River basin. The eastern tributary of Carrot Creek has a Strahler stream order of 2 before the confluence with the main stem where it is promoted to a stream order of 3. Water Survey of Canada (WSC) operates the seasonal Carrot Creek near the Mouth (station ID 05EA011) hydrometric station. Breakup in the channel typically begins in March. Peak flow typically occurs in April (average 0.6 m^3/s) because of snowmelt, after which the hydrograph continually recedes, with the exception of July, until the end of October, where monthly flows are at their lowest, with an average flow of 0.003 m^3/s. A secondary peak in the hydrograph occurs in July. This secondary peak is attributed to the high amount of precipitation that typically occurs, as July is the wettest month of the year in this area (see above). Figure 3-1 Shows the average creek discharge at the downstream end of Carrot Creek based on the hydrometric station.

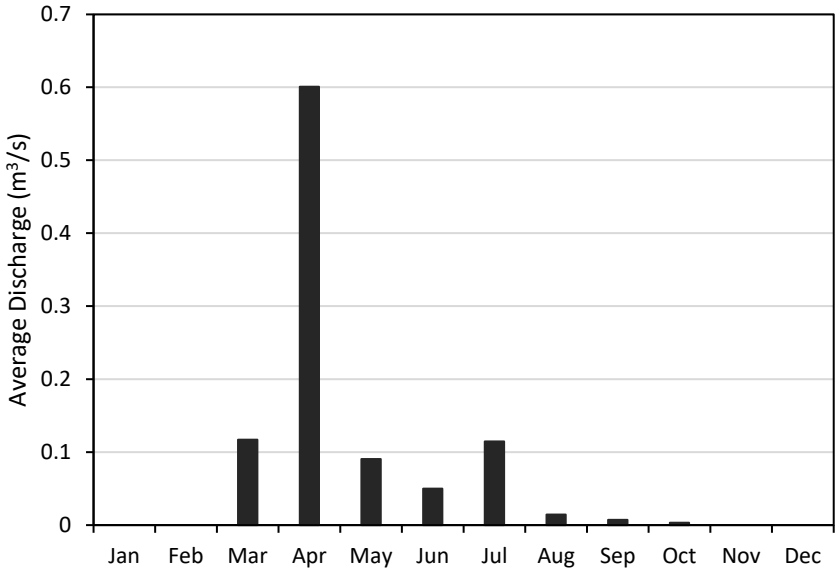


Figure 3-1 Water Survey of Canada Station Carrot Creek near the Mouth (05EA011) - Average Monthly Discharge for the Period of 2005 to 2018.

3.2 REGIONAL SURFICIAL AND BEDROCK GEOLOGY

Carrot Creek is, in geologic terms, a relatively young creek. At the end of the last glaciation about 10,000 years ago, after the pre-glacial valleys in the region were buried by glacial sediment, the Laurentide (Keewatin) ice sheet was retreating to the northeast (Bayrock & Hughes, 1962). At the time, natural drainage of the area flowed in the same direction as the glacial retreat, causing water to dam up against the glacier to form glacial lake Edmonton (Bayrock & Hughes, 1962). Glaciolacustrine sediments from glacial lake Edmonton were deposited on till and formed the youngest Pleistocene deposits from the last glaciation in this area, the Glacial Lake Edmonton unit (Andriashek, 1988).

Carrot Creek is located within the Lake Edmonton Plain District of the Eastern Alberta Plains Region, characterized by undulating glaciolacustrine deposits from Glacial Lake Edmonton with infrequent occurrences of glaciofluvial deposits, till, and bedrock (Pettapiece, 1986; Bayrock, 2005). From Big Lake to Villeneuve Road, Carrot Creek intersects a blanket (2-15 m thick) of glaciolacustrine deposits overlying stratified clay, silt, sand, and gravel of the Empress formation, thought to be pre-glacial fluvial deposits re-worked by glacial meltwaters (Andriashek, 1988). North of Villeneuve Road, Carrot Creek intersects a veneer (<1 m) to thin blanket (<2 m) of glaciolacustrine deposits that lie overtop of 5-10 m thick, undulating to gently rolling till. Because the glaciolacustrine deposits are so thin north of Villeneuve Road, the underlying till largely controls the topography in this area. The till is part of the widespread sandy clayey Cooking Lake Till unit around Edmonton (Andriashek, 1988). The Cooking Lake Till and Empress formation generally lie directly on bedrock (Bayrock, 2005). Though not exposed in the study area, the bedrock is part of the Horseshoe Canyon Formation and consists of Upper Cretaceous marginal marine to nonmarine sandstone, siltstone, and mudstone (Prior, et al., 2013).

3.3 GEOMORPHIC SETTING

The morphology of Carrot Creek varies from an undefined channel in poorly drained fill and spill topography, to manmade channel and ditch segments, to a low gradient (0.2% slope), meandering watercourse confined by valley walls that are two- to five-meters tall. Beavers have a significant presence in many reaches.

Beaver dams alter hydrologic processes, raise the local water table, increase inundated area, locally lower stream gradient and velocity, increase flood attenuation and residence time of water, and potentially reduce peak flood magnitudes (Welsh, 2012). When breached they can result in outburst floods, head cut erosion migrating from the breach location upstream into pond deposits, and lateral bank erosion and bank failure and/or landslides downstream of the dam (Welsh, 2012). A partial breach may result in localized bed scour and bank erosion immediately downstream of or adjacent to the dam (Demmer & Beschta, 2008). In addition, a beaver dam breach may lead to bank failures or landslides immediately upstream of the dam due to rapid drawdown.

4 WETLAND DELINEATION

4.1 METHODS

Waterbodies identified from current and historical aerial photography were mapped and a preliminary classification was assigned based on image texture, color and water permanence following the Alberta Wetland Identification and Delineation Directive (GOA 2015a). Historical aerial photographs were reviewed for the presence of standing water, and areas lacking standing water but with evidence of past standing water (i.e., bare ground, presence of salt or carbonates, patchy vegetation). The extent of these potential waterbodies were then mapped in an orthorectified geographic information system using a minimum polygon size of 0.1 ha, at a scale of 1:500 where resolution allowed. Wetland and waterbody type were assigned using the *Alberta Wetland Classification System* (AWCS) (GOA 2015b). The overall type was determined by the vegetation zone representing the deepest and most permanent water, occupying greater than 25% of the total wetland or waterbody area.

At this time, no field verification of wetland boundaries or classifications were completed for the purposes of this drainage master plan. Wetlands will need to be identified, classified and delineated at the field level for any applications to Alberta Environment and Parks according to the province's Wetland Policy. There may be additional wetlands on the landscape that are not identified in the wetland map provided in this drainage master plan, and the boundary of wetlands will need to be delineated on the ground as per the requirements of the Wetland Policy.

4.2 RESULTS

Within the study area, a total of 891 ha of wetlands, 30 ha of dugouts, 123 ha of stormwater management facilities and 42 ha of ephemeral waterbodies were identified. Table 4-1 outlines the desktop results and further classifies all wetlands according to the AWCS (GOA 2015b). These identified waterbodies are also presented in **Appendix B.**

Table 4-1 Desktop Delineation Results

Waterbody Classification	Total Area (ha)	Number of Individual Features
Stormwater Management Facility	123	76
Dugout	30	65
Ephemeral Waterbody	42	215
Temporary Graminoid Marsh	109	254
Seasonal Graminoid Marsh	174	143
Semi-Permanent Graminoid Marsh	172	39
Temporary Shrubby Swamp	15	22
Seasonal Shrubby Swamp	51	24
Wooded Deciduous Swamp	33	15
Permanent Shallow Open Water	337	75
Total	**1086**	**928**

5 GEOMORPHIC ASSESSMENT

5.1 METHODS

5.1.1 Desktop Review

To supplement the field assessment, specifically in areas north of Township Road 544, Stantec carried out a desktop review of Carrot Creek using available data. This included a review of:

- Google Earth™ and Bing imagery of the sites
- 2011, 2015, and 2018 LiDAR of Carrot Creek and the surrounding area (see Section 1)
- Historical aerial photographs (see **Appendix C**.)
- Relevant and available reports about the area including the St. Albert Natural Areas Assessment-2015 Update (Spencer Environmental Management Services Ltd., 2015), Stantec's Geotechnical Desktop Review (**Appendix D**), and Stantec's City of St. Albert 2013 Utility Master Plan Update report (Stantec Consulting Ltd., 2014)
- Regional bedrock and surficial geology maps of Alberta (Fenton, Waters, Atkinson, Utting, & Mckay, 2013; Andriashek, 1988; Bayrock, 2005; Prior, et al., 2013)

The Carrot Creek centerline and reaches were delineated in ArcGIS using a 1:5,000 scale or better from LiDAR and aerial photographs.

5.1.1.1 Historical Aerial Photograph Analysis

Stantec reviewed historical aerial photographs of Carrot Creek obtained from the Government of Alberta's Air Photo Library (1976, 1992/1993, 2008) and from an April 2020 flyover. Images from each year were assessed to characterize the geomorphology of Carrot Creek and compared to evaluate geomorphic and channel centerline changes between years. The approximate channel centerline was mapped for each aerial photograph using a scale of 1:2000, or better, as photograph quality permitted. Aerial photographs for each year are shown in **Appendix C**.

Table 5-1 Inventory of aerial photographs used in analysis.

Source	Date	Nominal Scale
Alberta Air Photo Library	September 1976	1:20,000
Alberta Air Photo Library	July 27 & August 13, 1992 and July 9, 1993 (combined images)	1:20,000
Alberta Air Photo Library	October 2, 2008	1:20,000
Z-Air Inc.	April 23, 2020	1:100 and 1:200

Limitations of aerial photograph interpretation include:

- The scale and resolution of available aerial photographs
- Residual error in georeferencing
- Differences in aerial photograph geometry (e.g., imagery collected obliquely versus at nadir)
- Potential fluctuation in water levels shown on imagery where change in water level may be interpreted as geomorphological change or high-water levels may limit the ability to interpret channel geomorphology by concealing features below the water surface
- Poor image contrast
- Concealment of features shown in imagery due to shadow, cloud cover, or vegetation cover

5.1.2 Field Assessment

A geomorphic field assessment of Carrot Creek and its adjacent lands was conducted for the study area south of Township Road 544. Where possible, the channel was viewed at some road crossings north of this location. Portions of the study area north of Township Road 544 and east of Highway 2 were assessed at a desktop level through review of aerial photographs and LiDAR.

Channel characteristics for each reach assessed in the field were recorded in the field using a standardized Stantec Fluvial Geomorphology form. The abbreviated version of this form is provided in Figure 5-1. The form was used to summarize key observations made for each reach (e.g., sediment pattern, channel form, channel stability, observed geohazards, etc.). Commonly observed hazards for each reach (e.g., landslides, bank failures, undercut banks/bank erosion, avulsion, flooding, etc.) were recorded. Bed and bank material sizes were classified in the field through hand texturing using a USDA classification scheme (Garcia-Gaines & Frankenstein, 2015). Several reaches were flooded at the time of the survey and some reach attributes could not be characterized.

A Rosgen Bank Erosion Hazard Index (BEHI) form (worksheet 5-16, **Appendix E**) was filled out for all reaches assessed during field work. The BEHI assessment was based on a typical bank for each specific channel reach. BEHI was not estimated for reaches assessed at a desktop level. The Rosen BEHI allows for a systematic evaluation of the susceptibility of each reach to the combined erosive effects of surface erosion, fluvial entrainment, and mass erosion (Rosgen, 2006; Rosgen, 2008a; Rosgen, 2008b). The method uses seven variables to calculate the total BEHI score: bank height, bankfull height, root depth, root density, bank angle, surface protection, and bank material and stratification adjustments (Rosgen, 2006; Rosgen, 2008a; Rosgen, 2008b) (refer to **Appendix E**). This score then translates to an adjective (relative) rating of bank susceptibility to erosion: very low, low, moderate, high, very high or extreme (Rosgen, 2006; Rosgen, 2008a; Rosgen, 2008b).

A summary of the geomorphologic characteristics, BEHI score and adjective rating, observed hazards, and the methods used for assessment (i.e., field or desktop) is provided in tabular format for each reach (Table 5-2). The summary table is included at the beginning of every reach section to concisely describe the characteristics of each one. Where the reach was defined at the desktop level, some characteristics may have been indiscernible, including left and right bank materials, grain size (D_{50} and D_{90}), vertical channel stability, sediment pattern, and field morphology.

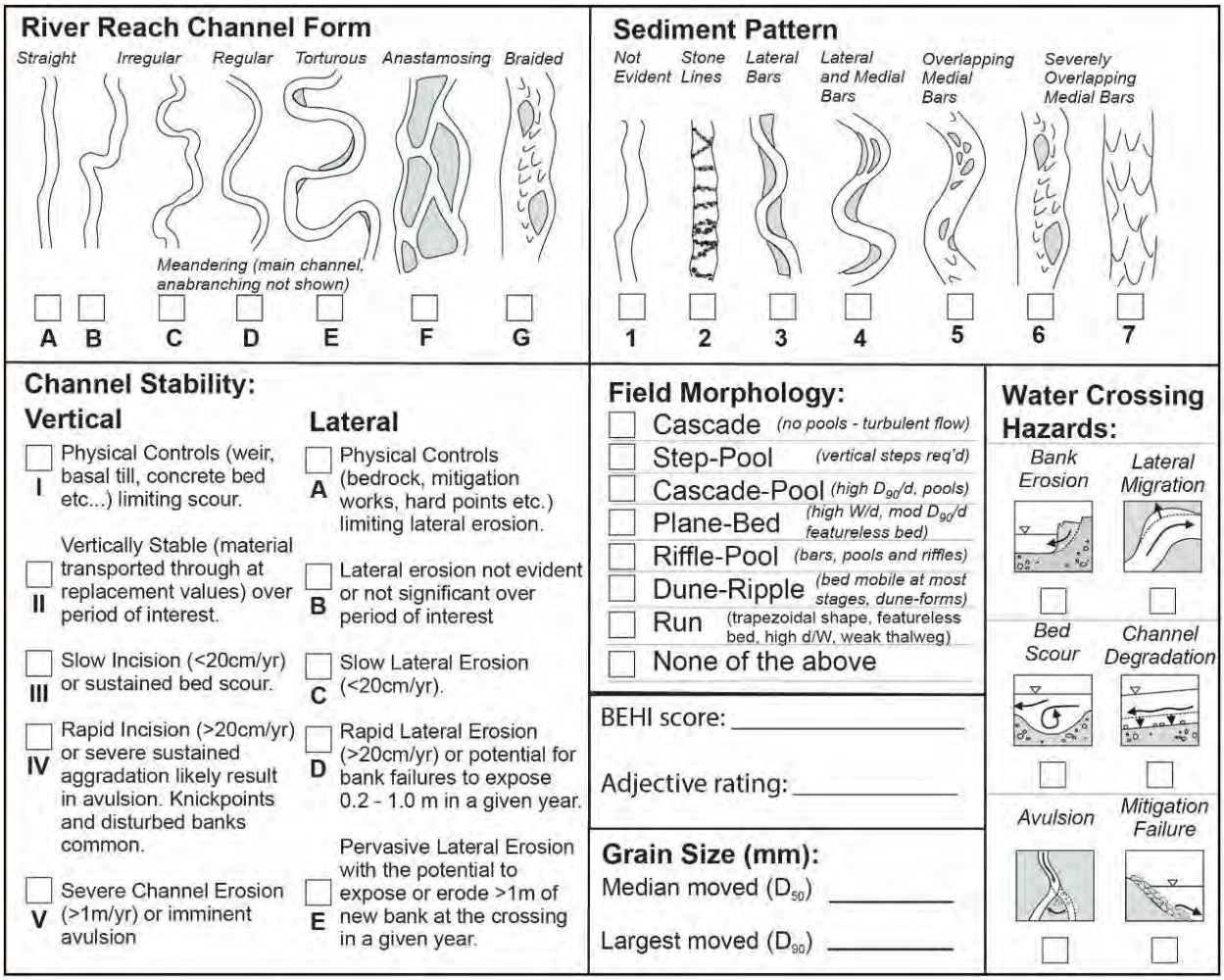


Figure 5-1 Abbreviated (blank) Stantec Fluvial Geomorphology form including the BEHI score.

Table 5-2 Summary Table for Reach Characteristics

Reach Characteristics Summary			
Reach number	1, 2, 3, etc.	**Location/extent**	e.g. KP__ to KP __
Assessment type	Field or desktop		
Channel Form	Straight, irregular, torturous, etc.	**Field morphology**	Cascade, step-pool, riffle pool, etc.
Sediment pattern	Stone lines, lateral bars, not evident, etc.	**Floodplain width (m)**	e.g., 40-60 m
Left bank material	e.g., Clay, silt, sand, sandy gravel, etc.	**Right bank material**	e.g., Clay, silt, sand, sandy gravel, etc.

Reach Characteristics Summary			
Median grain size (D_{50}, mm)	e.g., Clay, silt, sand, sandy gravel, etc.	**Largest grain size (D_{90}, mm)**	e.g., Clay, silt, sand, sandy gravel, etc.
Vertical channel stability	e.g., Slow incision (<20 cm/yr).	**Lateral channel stability**	e.g., Lateral erosion not evident or significant over period of interest.
River left[1] valley confinement	Confined or unconfined	**River right valley confinement**	Confined or unconfined
River left valley height (m)	e.g., 0 (if unconfined) or e.g., 2-5 (if confined)	**River right valley height (m)**	e.g., 0 (if unconfined) or e.g., 2-5 (if confined)
Left bank vegetation	Trees, shrubs or grass, or not vegetated	**Right bank vegetation**	Trees, shrubs or grass, or not vegetated
Large woody debris	Controlling channel, functioning but not dominant, present but not functioning, or none	**BEHI score/ adjective rating**	e.g., 8/Very low
Hazards observed	Landslides, bank failures, undercut banks/bank erosion, avulsion, flooding, lateral migration, channel degradation, presence of beaver dams and possibility of beaver dam failure or outburst floods, etc.		

5.1.3 Reach Delineation

Carrot Creek was broken up into reaches. Dividing a watercourse into reaches is a common method used to classify a watercourse and to understand and/or anticipate the unique ways in which each segment is affected by natural and anthropogenic change (Buffington & Montgomery, 2013). A reach is defined as a roughly homogeneous, geographically unique, channel section based on factors such as channel pattern, stream gradient, sediment supply, riparian vegetation, bed and bank material, channel stability, and channel confinement (Buffington & Montgomery, 2013). The project team used these factors and additional characteristics, such as valley confinement and height, floodplain width, and presence of large woody debris, to delineate reaches for Carrot Creek. Division of Carrot Creek into reaches allows for understanding of the potential impacts of a change in flow on a reach-by-reach basis.

5.2 RESULTS

5.2.1 Channel Reaches

The Carrot Creek watershed has low regional relief and, in many areas, has altered drainage pathways from cultivation, ranching, and development. The single mainstem of Carrot Creek diverges at the confluence and, in the upper reaches of the Carrot Creek watershed north of Highway 37, the channel becomes difficult to discern. Where the channel becomes intermittent and difficult to define at the desktop level, delineation of the channel centerline was terminated.

[1] River left and river right are relative to the downstream flow direction.

A total of seventeen reaches were delineated for Carrot Creek (Figure 5-2).

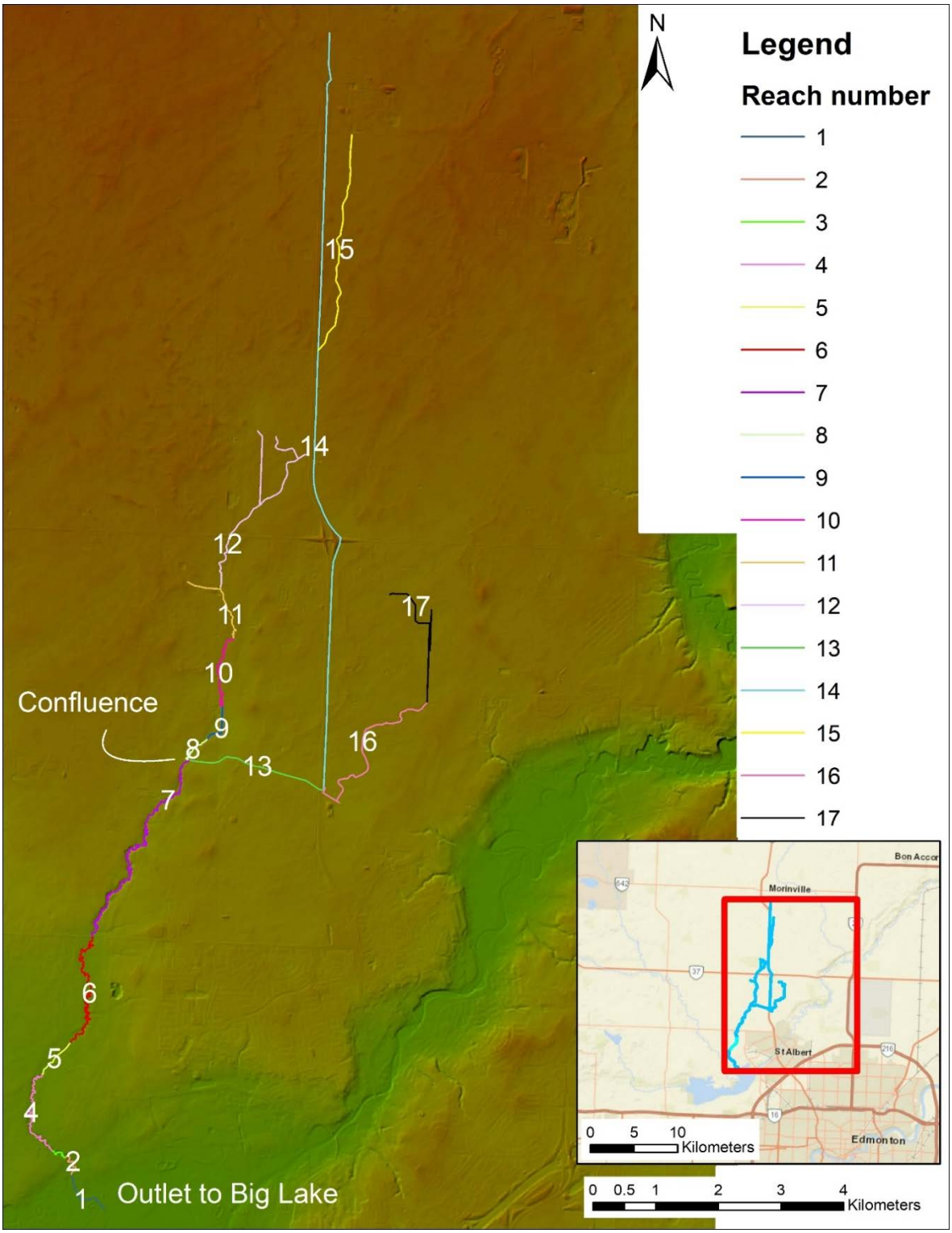


Figure 5-2 Reaches of Carrot Creek

5.2.1.1 Reach One

Table 5-3 Reach One Summary Table

Reach One Summary			
Reach number	1	**Location/extent**	KP 0+000 to KP 0+900
Assessment type	Field		
Channel form	Irregular (semi-straight)	**Field morphology**	Riffle-pool
Sediment pattern	Lateral bars	**Floodplain width (m)**	6-13
Left bank material	Black clayey organics	**Right bank material**	Black clayey organics
Median grain size (D_{50}, mm)	Clay and silt	**Largest grain size (D_{90}, mm)**	Coarse sand
Vertical channel stability	Vertically stable, except at KP 0+900 where slow incision (<20 cm/yr) is occurring	**Lateral channel stability**	Slow lateral erosion (<20 cm/yr)
River left valley confinement	Confined	**River right valley confinement**	Confined
River left valley height (m)	1.5-3	**River right valley height (m)**	1.5-3
Left bank vegetation	Shrubs or grass	**Right bank vegetation**	Shrubs or grass
Large woody debris	Functioning, not dominant	**BEHI score/ adjective rating**	20/Moderate
Hazards observed	Bank failure, broad floodplain prone to flooding, undercut banks/bank erosion, local scour at KP 0+900 bridge, four beaver dams		

Reach one runs from Big Lake at KP 0+000 north to Meadowview Drive at KP 0+900 (Figure 5-2). Stantec interprets this reach as manmade. Valley walls are 1.5 m to 3 m tall, the floodplain is narrow (6 m to 13 m wide) and the channel planform is generally irregular (semi-straight) to straight.

The floodplain and surrounding land are poorly drained and are vegetated by tall grass and hydrophilic vegetation (Figure 5-3). The banks are vegetated and soft. Generally, this low gradient (0.08%) reach is interpreted to be vertically stable, and downstream gradient is controlled by the lake. The exception to this is at KP 0+900, immediately downstream of the Meadowview Drive bridge, where the bridge causes local scour (Figure 5-4). Four failing or abandoned/relict beaver dams are present in this reach (Figure 5-5). During the field inspection in June 2020, a large portion of the reach was flooded (see Figure 5-3). Areas of extensive flooding in reach one during the April 2020 flood event are shown in Figure 5-6. The surrounding area is agricultural land.

Lateral migration of the main channel within the anthropogenically constructed valley is contributing to ongoing bank erosion and bank failure, specifically in the upper portions of the reach (Figure 5-7). One small, shallow, bank failure was present at KP 0+600 at the left bank (Figure 5-8). The failure was 11 m wide by 6 m long with a 0.45-1.0 m tall head scarp. Undercut banks were observed throughout the reach.

Historical aerial photograph analysis reveals that the channel centerline in reach one has not experienced substantial changes from 1976 to 2020. The surrounding wetlands, however, appear to have expanded up to 500 m northward from Big Lake into the surrounding farmlands.



Figure 5-3 Photograph of the manmade channel (foreground) near KP 0+100 with the marshland in the background.



Figure 5-4 Scour hole immediately downstream of the Meadowview Drive Bridge at KP 0+900, with the field crew for scale.



Figure 5-5 Failed beaver dam close to KP 0+300 with surveyor for scale.

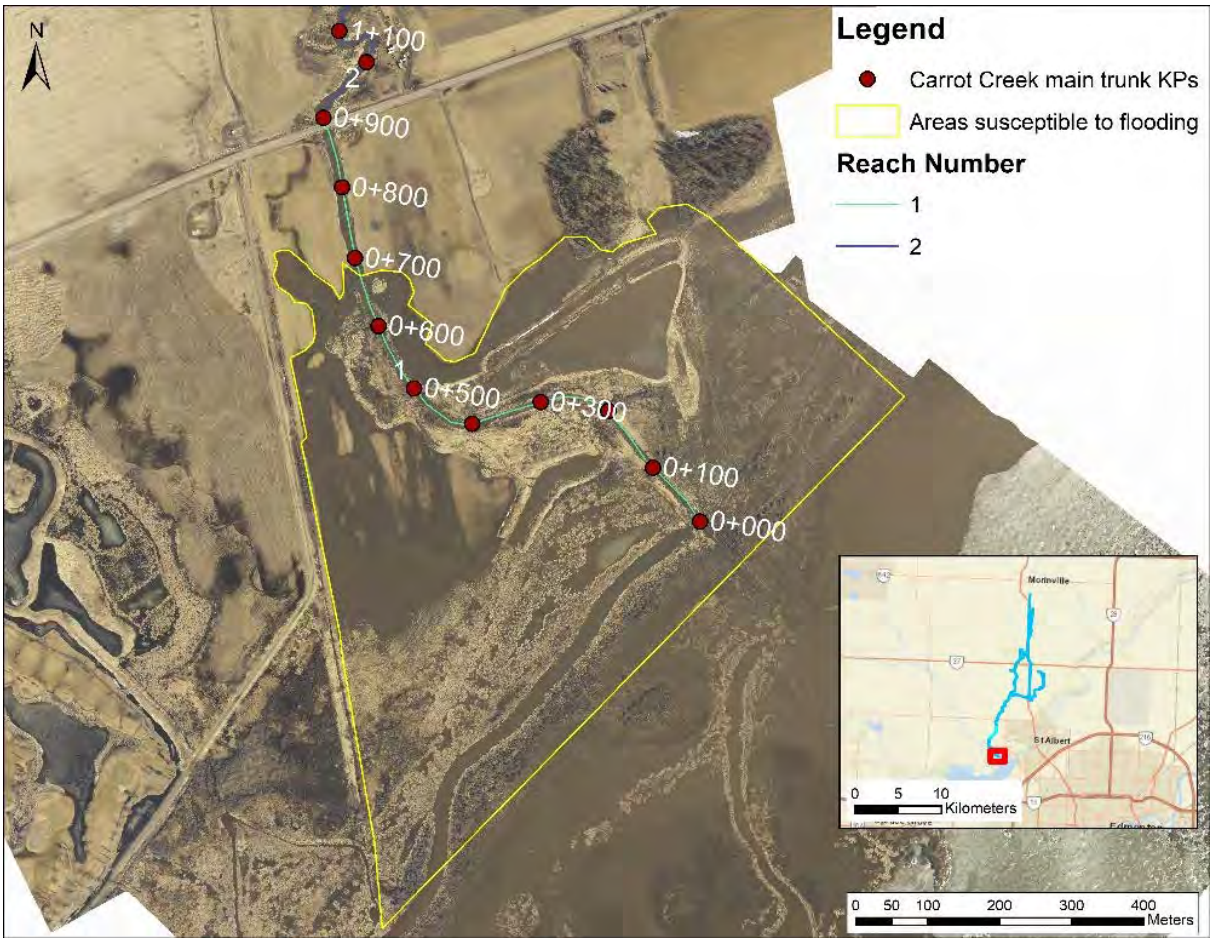


Figure 5-6 Areas of extensive flooding in reach one during the April 2020 flood event.

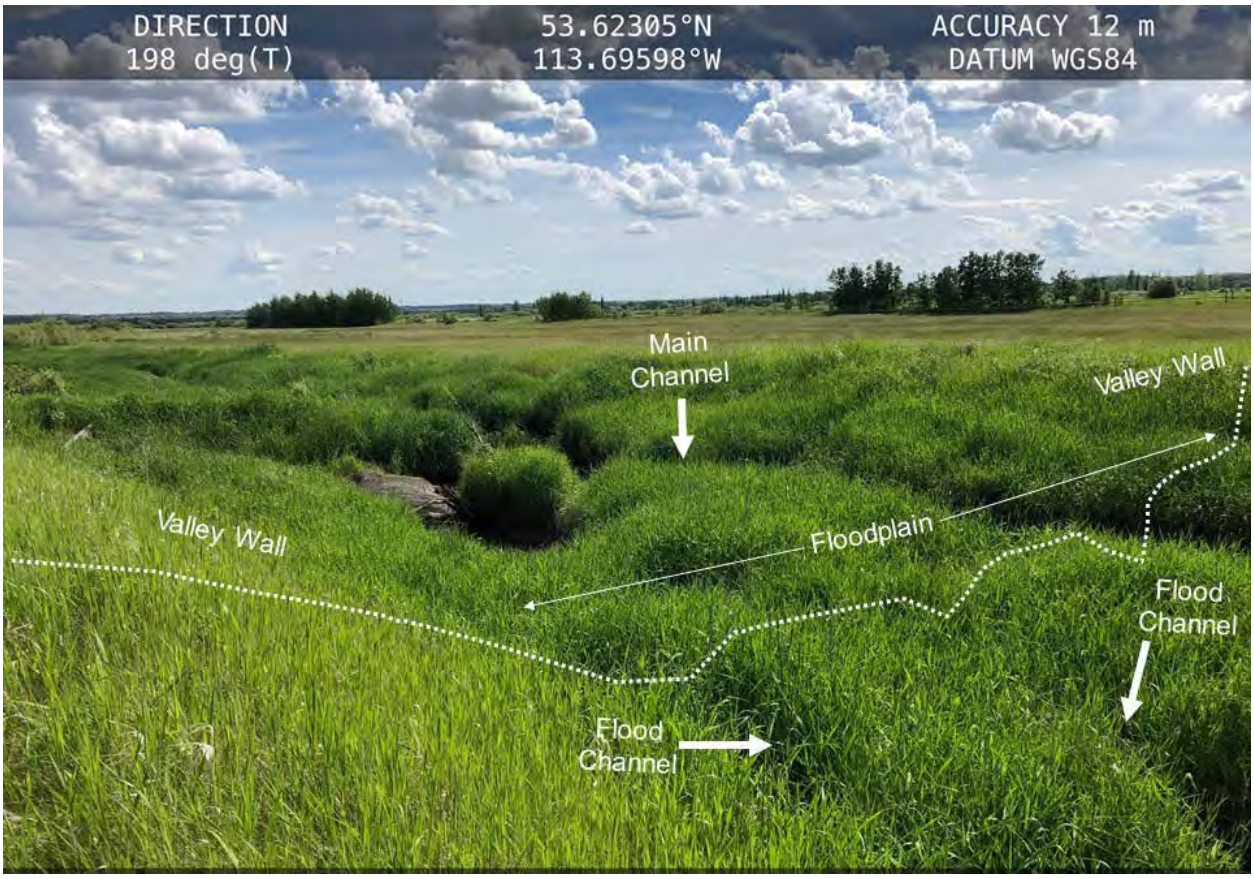


Figure 5-7 Annotated site photograph of reach one looking downstream near KP 0+700 showing the 8 m wide floodplain, main channel, and flood channels within the manmade channel.



Figure 5-8 Photograph looking upstream showing the outline of the shallow bank failure on the left bank close to KP 0+600. The white arrow shows the direction of bank failure movement.

5.2.1.2 Reach Two

Table 5-4 Reach Two Summary Table

Reach Two Summary			
Reach number	2	**Location/extent**	KP 0+900 to KP 1+475
Assessment type	Field		
Channel form	Irregularly meandering	**Field morphology**	Dune-Ripple
Sediment pattern	Lateral and medial bars	**Floodplain width (m)**	55-80 m
Left bank material	Light brown to dark brown clayey sand	**Right bank material**	Light brown to dark brown clayey sand
Median grain size (D_{50}, mm)	Fine sand	**Largest grain size (D_{90}, mm)**	Medium gravel
Vertical Channel Stability	Slow incision (<20 cm/yr)	**Lateral Channel Stability**	Slow to rapid lateral erosion (<20 cm/yr to 100 cm/yr)
River left valley confinement	Confined	**River right valley confinement**	Confined
River left valley height (m)	2-4	**River right valley height (m)**	2-4
Left bank vegetation	Not vegetated for 1-3 m from thalweg. Shrubs or grass beyond that	**Right bank vegetation**	Not vegetated for 1-3 m from thalweg. Shrubs or grass beyond that
Large woody debris	Present, not functioning	**BEHI score/ adjective rating**	35.5/High
Hazards observed	Bank failure, undercut banks/bank erosion, lateral migration, beaver dams		

Reach two runs from KP 0+900 to KP 1+475 (Figure 5-2). The bed and banks in this reach are clayey sand and are susceptible to erosion (both scour and lateral migration). The banks were unvegetated up to 3 m from the bank edge (Figure 5-9).

Undercut banks and bank failures (less than 20 m^2) were common (Figure 5-10). The river left valley wall at KP 1+425 is locally steep and may be prone to small landslides (Figure 5-11).

One failed beaver dam was observed within the reach (Figure 5-12). The floodplain narrows from 80 m to 55 m and the height of the valley wall increases from 2 m to 4 m tall from the downstream to upstream extent of the reach.

Historical aerial photographs reveal that the channel centerline in reach two has experienced minor changes from 1976 to 2020. Most variance in the mapped channel centerline is attributed to limitations of aerial photograph analysis (see Section 5.1.1.1). Between 1992/1993 and 2008, vegetation density on both the banks and valley walls appears to have decreased from KP 1+100 to KP 1+475. During this same time period, channel widening occurred over a length of channel at KP 1+150 where bankfull width increased from 6 m to 25 m (Figure 5-13).





Figure 5-9 Looking upstream (north) of the Meadowview bridge at KP 1+000 at exposed soils and woody debris on the floodplain.



Figure 5-10 Site photograph near 1+000 showing a bank failure on the right bank approximately 5 m wide and 1.5 m deep with field crew for scale.

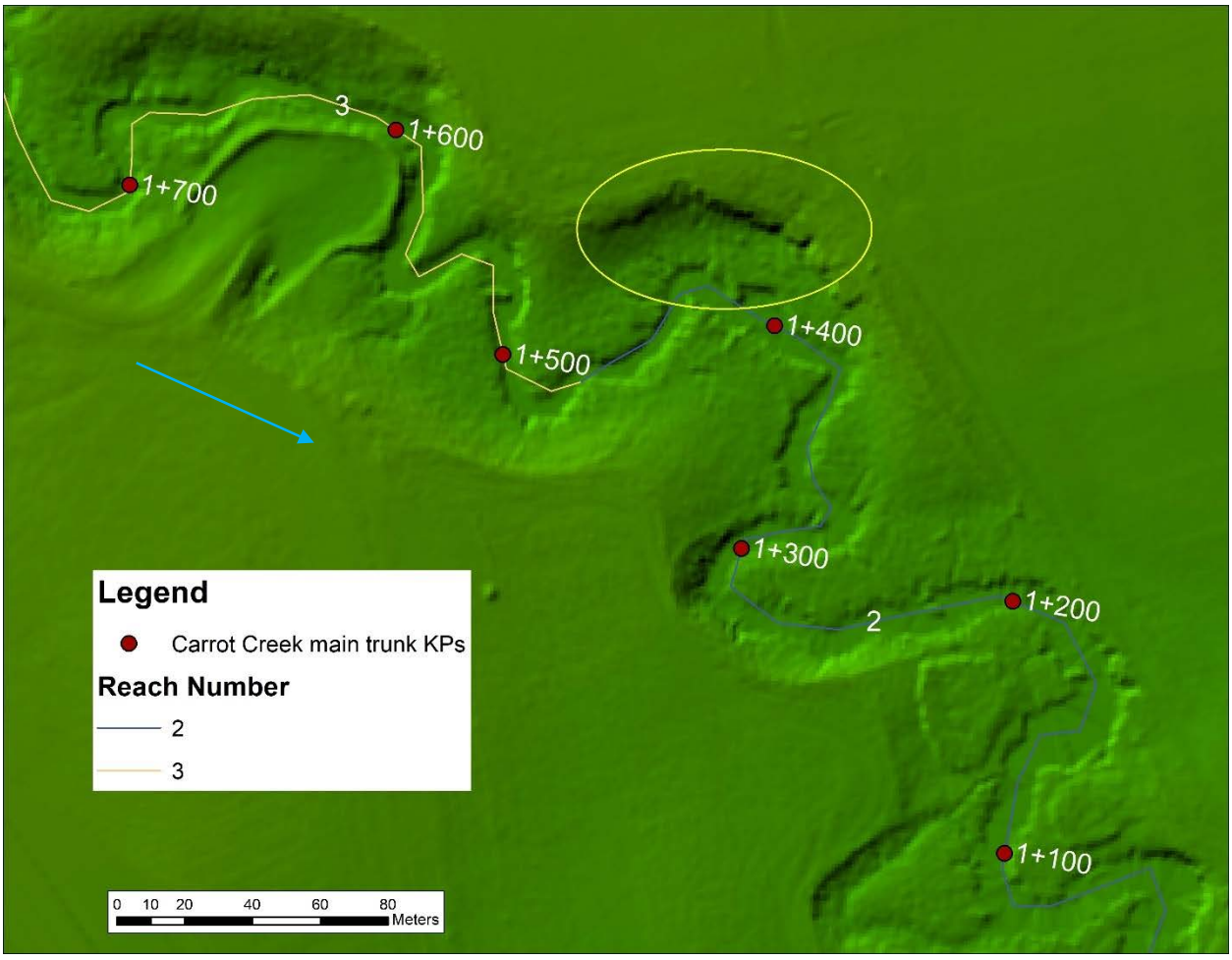


Figure 5-11 River left valley wall at KP 1+425 (circled) is locally steep and may be prone to small landslides or erosion. The background is a 2018 LiDAR hillshade. Flow direction is indicated by the blue arrow.



Figure 5-12 Looking northeast (upstream) near KP 1+300 at the remains of a beaver dam. Note the short valley walls.

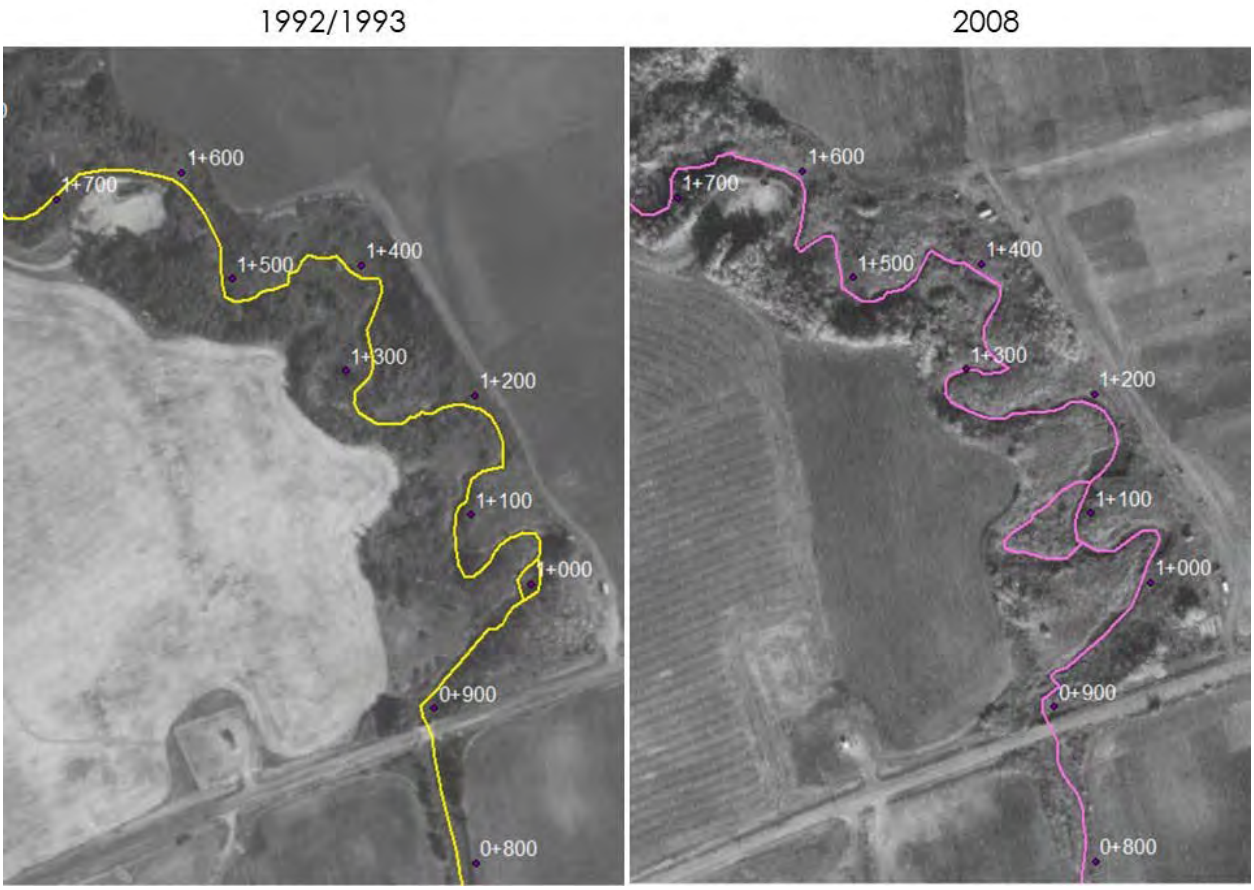


Figure 5-13 Comparison of 1992/1993 imagery and 2008 imagery in reach two.

5.2.1.3 Reach Three

Table 5-5 Reach Three Summary Table

Reach Three Summary			
Reach Number	3	**Location/extent**	KP 1+475 to KP 1+800
Assessment Type	Field		
Channel Form	Irregularly meandering	**Field morphology**	Dune-Ripple
Sediment pattern	Lateral bars	**Floodplain width (m)**	35-55 m
Left bank material	Light brown sand	**Right bank material**	Light brown sand
Median Grain Size (D_{50}, mm):	Fine sand	**Largest Grain Size (D_{90}, mm):**	Medium gravel
Vertical Channel Stability	Slow incision (<20 cm/yr)	**Lateral Channel Stability**	Slow lateral erosion (<20 cm/yr)
River left valley confinement	Confined	**River right valley confinement**	Confined
River left valley height (m)	5	**River right valley height (m)**	5
Left bank vegetation	Trees and shrubs or grass	**Right bank vegetation**	Trees and shrubs or grass
Large woody debris	Functioning, not dominant	**BEHI Score/ Adjective rating**	27/Moderate
Hazards observed:	Undercut banks/bank erosion, lateral migration		

Reach three runs from KP 1+475 to KP 1+800 (Figure 5-2). The banks in this reach are sandier than those in reach two and are supported by extensive root systems (Figure 5-14). The banks are typically undercut where root density decreases (Figure 5-15). However, few bank failures were observed within the reach. The channel bed is made of gravelly sand and is incised within the narrow 35-55 m wide floodplain and 5 m tall valley walls. An old plywood bridge is present at KP 1+800 at the north end of the reach (Figure 5-16).

Historical aerial photographs reveal that the channel centerline in reach two has experienced minor changes from 1976 to 2020. Most variance in the mapped channel centerline is attributed to limitations of aerial photograph analysis (see Section 5.1.1.1).



Figure 5-14 Looking downstream along reach three at KP 1+800, showing heavily vegetated 1-2 m tall banks.



Figure 5-15 Undercutting at right bank near KP 1+800.



Figure 5-16 Looking northeast at the plywood bridge crossing Carrot Creek at KP 1+800, with surveyors for scale.

5.2.1.4 Reach Four

Table 5-6 Reach Four Summary Table

Reach Four Summary			
Reach number	4	**Location/extent**	KP 1+800 to KP 3+950
Assessment type	Field		
Channel Form	Irregularly meandering	**Field morphology**	Riffle-pool
Sediment pattern	Lateral bars	**Floodplain width (m)**	40-70
Left bank material	Light to dark brown sandy clay	**Right bank material**	Light to dark brown sandy clay
Median grain size (D_{50}, mm)	Fine sand	**Largest grain size (D_{90}, mm)**	Coarse gravel
Vertical channel stability	Slow incision (<20 cm/yr)	**Lateral channel stability**	Slow lateral erosion (<20 cm/yr)
River left valley confinement	Confined to unconfined	**River right valley confinement**	Confined to unconfined
River left valley height (m)	0-5	**River right valley height (m)**	0-5
Left bank vegetation	Trees and shrubs or grass	**Right bank vegetation**	Trees and shrubs or grass
Large woody debris	Controlling channel	**BEHI score/ adjective rating**	20.5/Moderate
Hazards observed	Undercut banks/bank erosion, bank failure, local scour at bridges and beaver dam outflow, beaver dams, flooding observed in April 2020 between KP 3+600 and KP 3+950		

Reach four runs from the bridge at KP 1+800 to KP 3+950 (Figure 5-2). Channel confinement gradually decreases in a northward direction within the reach. The channel is confined within 2 m to 5 m high valley walls at the southern extent of the reach and is unconfined at the northern extent of the reach (Figure 5-17). Areas adjacent to the unconfined portions of the reach may be more vulnerable to flooding (Figure 5-18). Where confined, the valley walls have gentle slopes (4-15°). One bank failure, interpreted to be recent due to exposed soils, was observed along the outer meander bend at KP 3+450 (Figure 5-18, Figure 5-19).

Beaver damming is extensive in this reach (see Figure 5-17). Both active/stable and inactive/failing dams were observed. Contemporary beaver damming increases in a northward direction within the reach until KP 3+400. Locally, some erosion was observed immediately downstream of beaver dams related to dam outflow (see Figure 5-17, bottom right image). Three bridges were observed in this reach: at KP 2+400, at KP 3+650 where Township Road 540A/Old McKenney Ave crosses Carrot Creek, and a footbridge at KP 3+900 (Figure 5-20). Local scour was observed at all bridges. Downstream of the KP 3+650 bridge, a flood channel was observed on the left floodplain (see location in Figure 5-18, Figure 5-21).

Reviewing historical aerial photographs, it appears the channel bifurcates between KP 3+000 and 3+100 between 1992/1993 and 2008. Most variance in the channel centerline from 1976 to 2008 is attributed to limitations of aerial photograph analysis (see Section 5.1.1.1). Recent construction of a pipeline right-of-way (ROW) crossing on Carrot Creek near KP 2+650 is evident in the 1976 aerial photograph. While signage observed in the field indicated pipeline water crossings exist elsewhere within this reach, the timeline for construction of these crossings is not evident in the aerial photograph record reviewed.



Figure 5-17 Top left: At KP 2+500, looking upstream at the 4 m tall river right valley wall, with surveyors for scale. The foreground is a beaver pond. Top right: At KP 2+850 on the outer edge of a meander bend looking downstream, showcasing the wide floodplain and flooded channel due to beaver dams. Bottom left: Looking downstream from the bridge at KP 2+400 bridge. Note the six pipeline signs (red circle) in the upper right corner of the photograph. Bottom right: Looking upstream towards a 2 m tall, 8 m long, damaged beaver dam near KP 1+900.

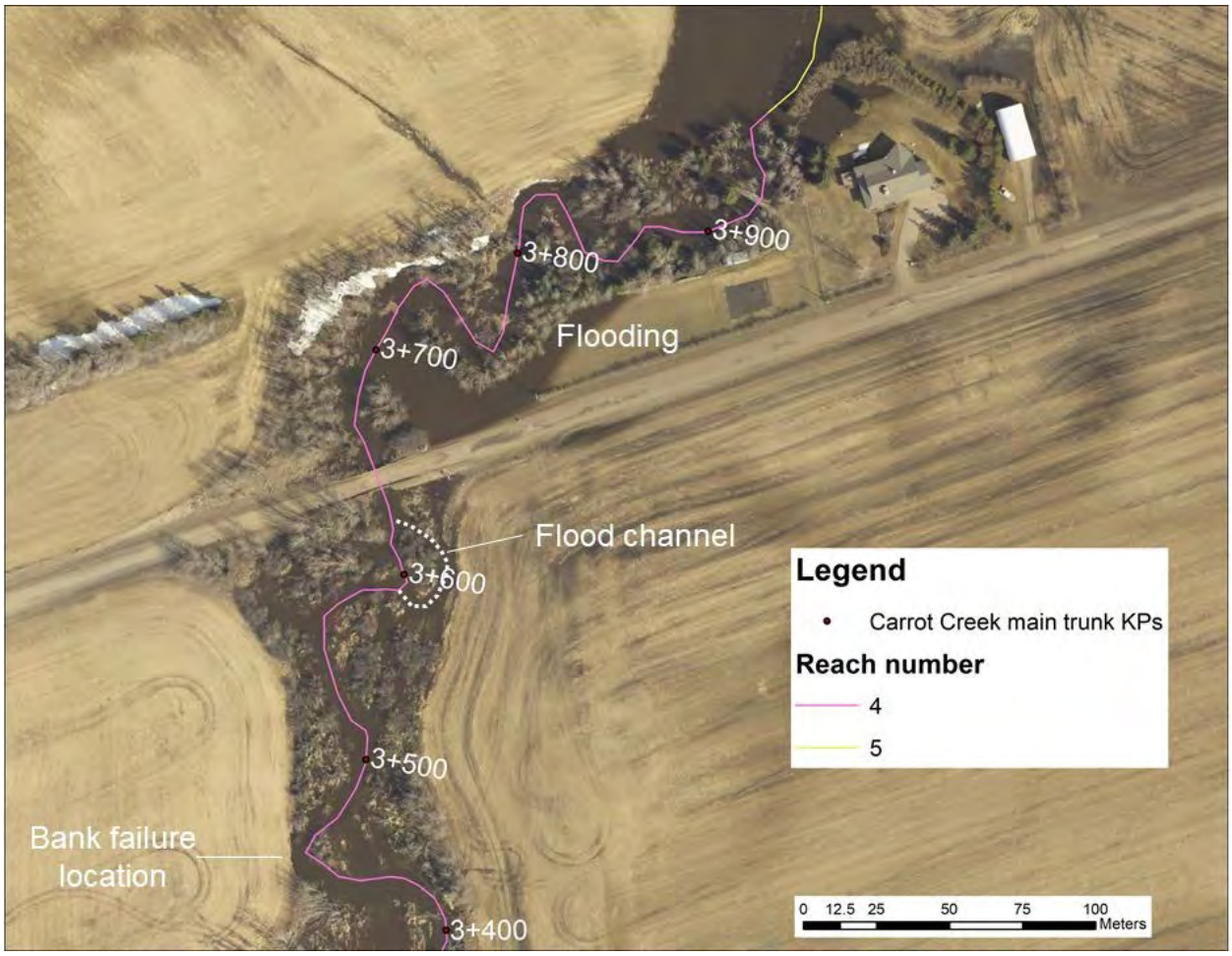


Figure 5-18 Aerial photograph taken during flood stages in 2020. Annotations indicate the location of the observed flood channel at KP 3+600 (dotted white line) and bank failure at KP 3+450.



Figure 5-19 Looking northwest (upstream) at a local bank failure at KP 3+450 south of the intersection of Carrot Creek and Township Road 540A/ Old McKenney Ave.

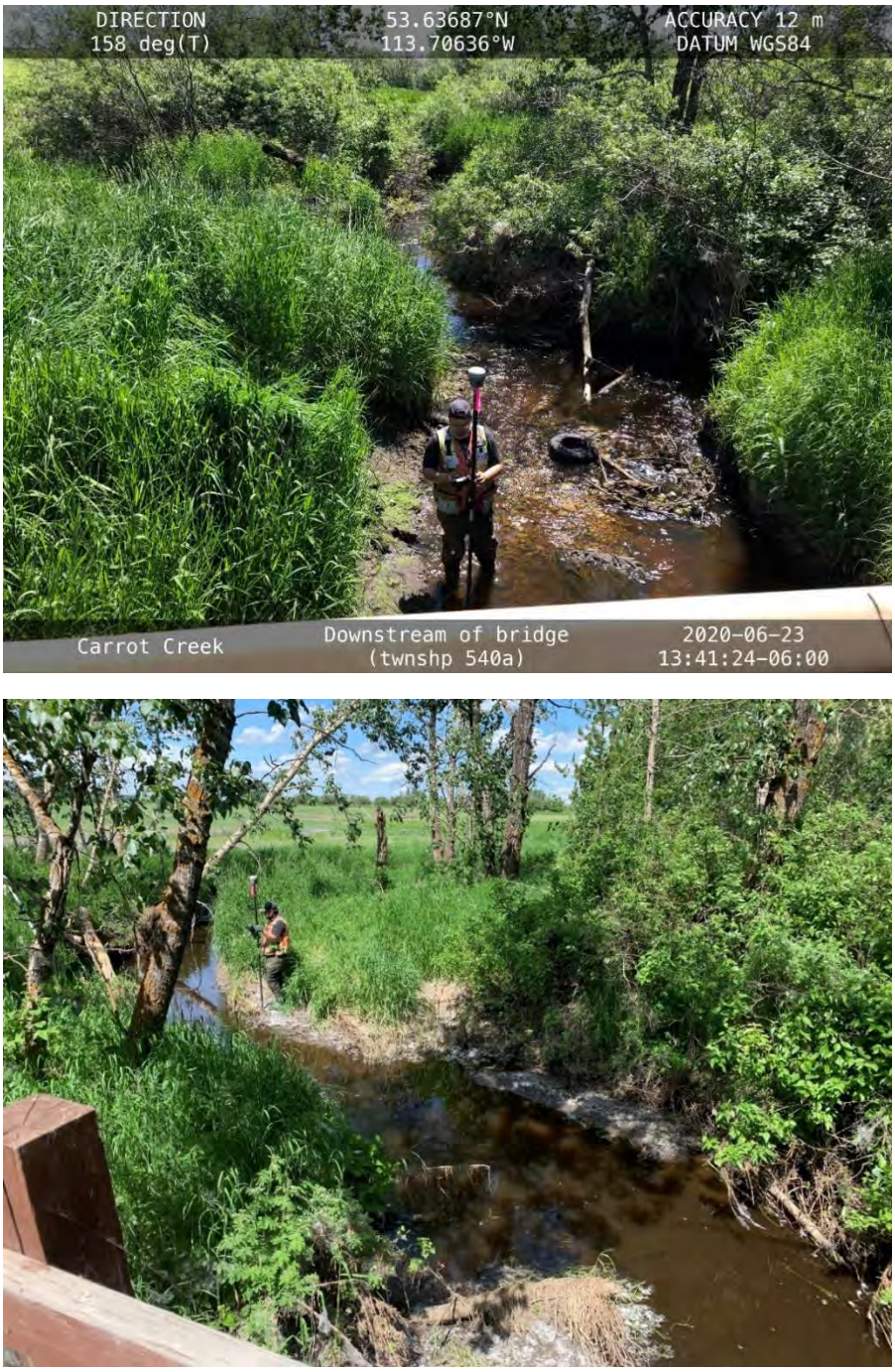


Figure 5-20 Top: Looking downstream from the bridge at KP 3+650 at the locally scoured channel with undercut banks with a surveyor for scale. Bottom: Carrot Creek at KP 3+900 looking upstream at the upstream extent of reach five where the channel becomes unconfined. The edge of the foot bridge is in the foreground.



Figure 5-21 Top image: Looking upstream at the flood channel just south of the bridge at KP 3+650. Bottom image: Looking downstream at an incised portion of the flood channel.

5.2.1.5 Reach Five

Table 5-7 Reach Five Summary Table

Reach Five Summary			
Reach number	5	**Location/extent**	KP 3+950 to KP 4+650
Assessment type	Field		
Channel form	Straight	**Field morphology**	Run
Sediment pattern	Lateral bars	**Floodplain width (m)**	70 - >250
Left bank material	Light to dark brown sandy clay	**Right bank material**	Light to dark brown sandy clay
Median grain size (D_{50}, mm)	Clay and silt	**Largest grain size (D_{90}, mm)**	Coarse sand
Vertical channel stability	Slow incision (<20 cm/yr)	**Lateral channel stability**	Slow lateral erosion (<20 cm/yr)
River left valley confinement	Unconfined	**River right valley confinement**	Unconfined
River left valley height (m)	0	**River right valley height (m)**	0
Left bank vegetation	Shrubs or grass	**Right bank vegetation**	Shrubs or grass
Large woody debris	None	**BEHI score/ adjective rating**	30/High
Hazards observed	Upstream of railroad culverts at KP 4+200: Local scour and bank erosion around culverts, flooding observed in April 2020 Downstream of railroad culverts at KP 4+200: Undercut banks/bank erosion, extensive bank failures, local scour around culverts, channel degradation, flooding observed in April 2020		

Reach five runs from KP 3+950 to KP 4+650 (Figure 5-2) and is crossed by a railroad at KP 4+200. The channel in this reach is inferred to have been anthropogenically straightened prior to 1976 (Figure 5-22, Figure 5-25). Two one-meter diameter culverts are in place beneath the railway (Figure 5-22). Extensive bank failures, bank erosion, and scour is occurring immediately upstream and downstream of the culverts (Figure 5-23, Figure 5-24). This reach was extensively flooded in the April 2020 flood event (Figure 5-25).

Historical aerial photographs reveal that the channel centerline in reach five has not experienced any notable change from 1976 to 2020.



Figure 5-22 Looking upstream from the top of the railroad at KP 4+200 at the anthropogenically straightened channel of Carrot Creek. Note the two culverts below the surveyor.



Figure 5-23 Photographs showing scouring and bank erosion around the upstream end of the culverts (left photograph) and the scour hole and bank failures around the downstream end of the culverts (right photograph).



Figure 5-24 Looking upstream at bank failures on both banks. Photograph taken at KP 4+100, approximately 100 m downstream of the railroad crossing.

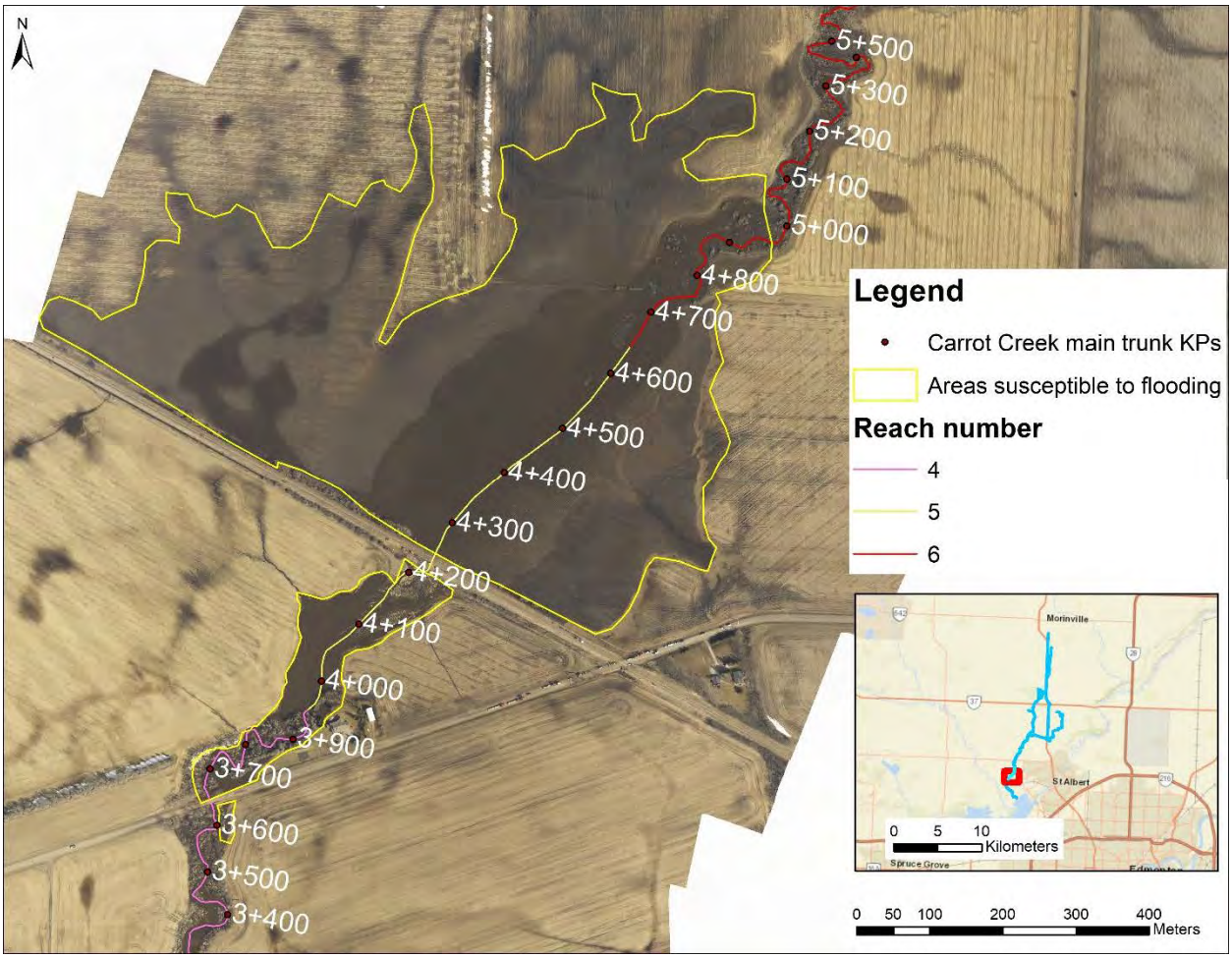


Figure 5-25 Areas of extensive flooding during the April 2020 event.

5.2.1.6 Reach Six

Table 5-8 Reach Six Summary Table

Reach Six Summary			
Reach number	6	**Location/extent**	KP 4+650 to KP 8+000
Assessment type	Field		
Channel form	Irregularly meandering to tortuous	**Field morphology**	Not evident (due to flooding from beaver dams)
Sediment pattern	Lateral bars	**Floodplain width (m)**	60-100
Left bank material	Brown, black, red clay	**Right bank material**	Brown, black, red clay
Median grain size (D_{50}, mm)	Clay and silt	**Largest grain size (D_{90}, mm)**	Fine sand
Vertical channel stability	Slow incision (<20 cm/yr)	**Lateral channel stability**	Slow lateral erosion (<20 cm/yr)
River left valley confinement	Unconfined to confined	**River right valley confinement**	Unconfined to confined
River left valley height (m)	0-3	**River right valley height (m)**	0-3
Left bank vegetation	Shrubs or grass, few trees	**Right bank vegetation**	Shrubs or grass, few trees
Large woody debris	Controlling channel	**BEHI score/ adjective rating**	21.5/ Moderate
Hazards observed	Undercut banks/bank erosion, lateral migration, flooding observed in April 2020 from KP 4+650 to KP 5+100, beaver dams, scour		

Reach six runs from KP 4+650 to KP 8+000 at Villeneuve Road (Figure 5-2). The bed and banks are made of clay and are vegetated by tall grass and shrubs (Figure 5-26, bottom right). Trees are more common in the upstream extents of the reach. Areas of this reach were extensively flooded in the April 2020 flood event (see Figure 5-25). Carrot Creek is unconfined in downstream portions of this reach and valley confinement increases in the upstream direction. Flood channels were observed within the floodplain between KP 4+800 and 5+000 (Figure 5-26) along the river right side of the channel/valley. Beaver dams are present and more common in the upstream extents of the reach (Figure 5-26, Figure 5-27). Local scour, undercut banks, and small bank failures were commonly observed downstream of beaver dams (Figure 5-26).

Historical aerial photographs reveal that the channel centerline in reach six has experienced change between KP 4+700 and 5+000 and change is interpreted to be related to beaver damming. In addition, a road crossing at KP 6+500 is evident in the 1976 aerial photographs (Figure 5-28). It is unclear where Carrot Creek flows were directed in 1976 at KP 6+500. However, by 1992/1993 it appears a channel formed at the eastern extent of the valley. During 2020 fieldwork, beaver dams were found blocking the channel.



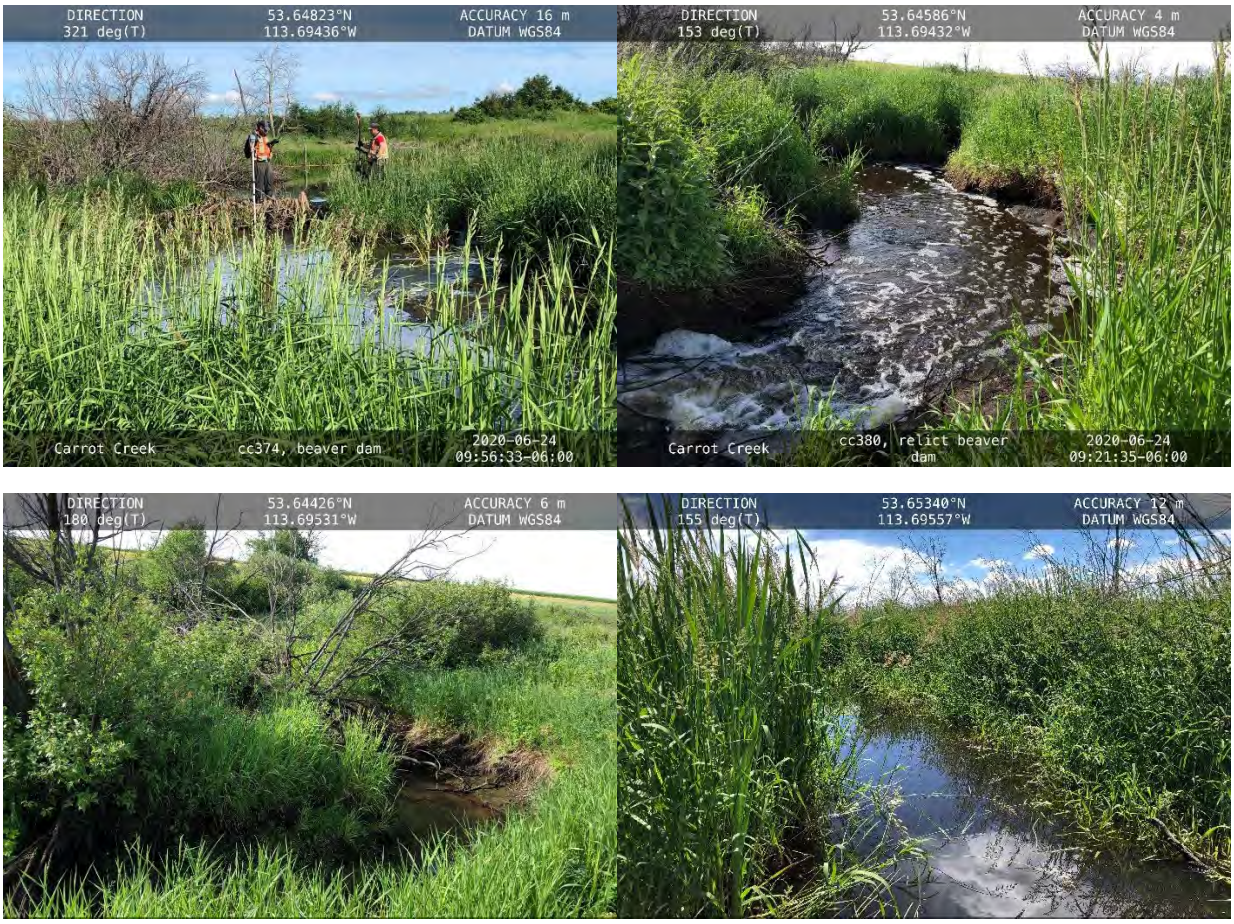


Figure 5-26 Top left: Looking upstream at a failing beaver dam at KP 5+875. Top right: Looking downstream below a failed beaver dam at KP 5+300. Bottom left: Flood channel located near KP 5+000. Bottom right: Main channel at KP 6+950.



Figure 5-27 Site photographs showing beaver dams south of Villeneuve Road. The blue arrows indicate the flow direction. The white dashed line (on the bottom) shows the higher stand of a relict beaver dam.

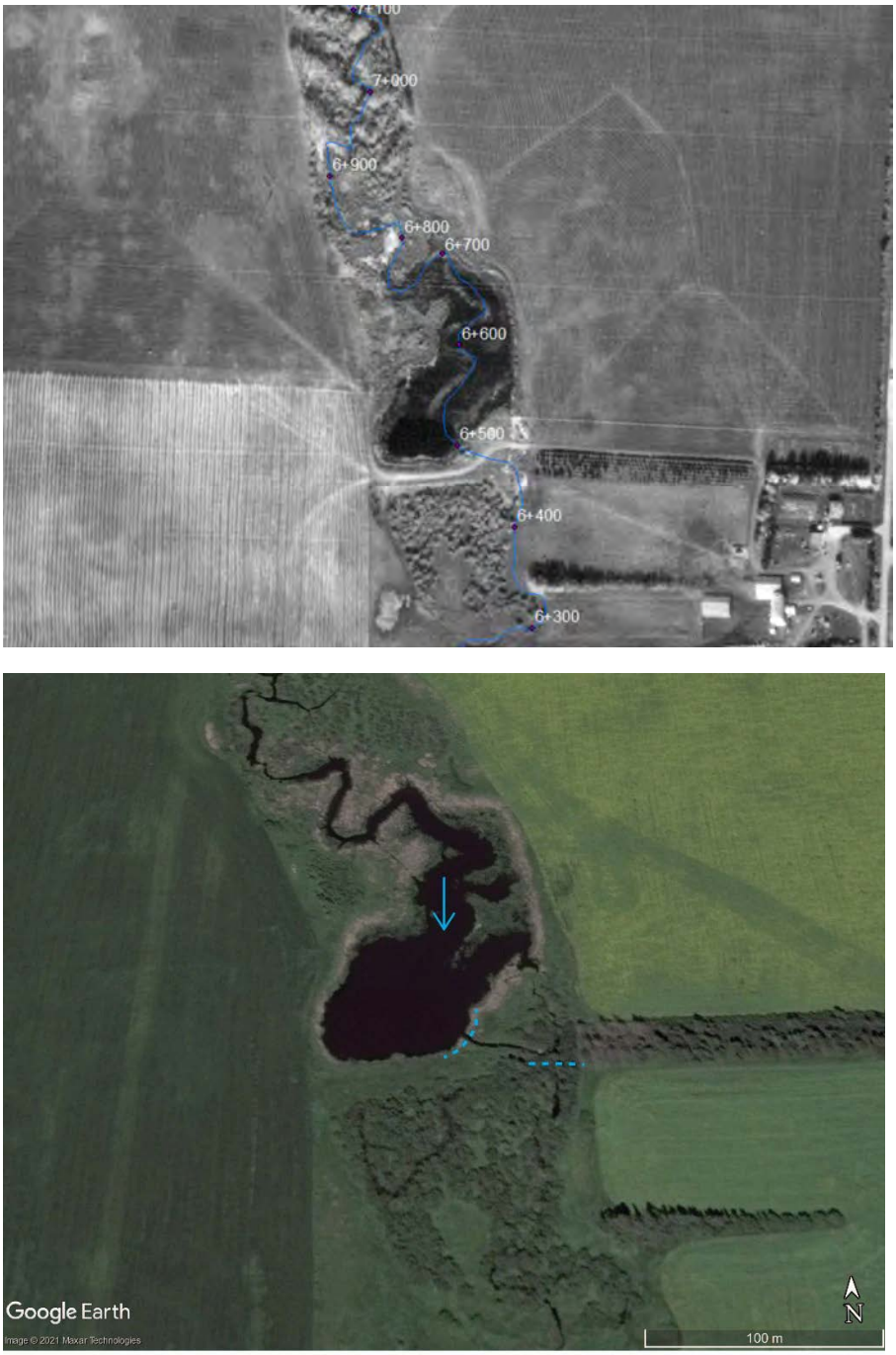


Figure 5-28 Top: 1976 aerial photograph showing the road across Carrot Creek at KP 6+500. Bottom: July 2014 aerial image from Google Earth™ of the same location showing the outlet channel. Blue dashed lines show beaver dams present during the 2020 field inspection. The blue arrow shows the flow direction.

5.2.1.7 Reach Seven

Table 5-9 Reach Seven Summary Table

Reach Seven Summary			
Reach number	7	**Location/extent**	KP 8+000 to KP 13+050
Assessment type	Field		
Channel form	Irregularly meandering	**Field morphology**	Not evident (due to flooding from beaver dams)
Sediment pattern	Lateral and medial bars	**Floodplain width (m)**	40-60, typically, but can be as wide as 100 in a few locations
Left bank material	Brown and black clay with organics	**Right bank material**	Brown and black clay with organics
Median grain size (D_{50}, mm)	Clay and silt	**Largest grain size (D_{90}, mm)**	Coarse gravel
Vertical channel stability	Vertically stable	**Lateral channel stability**	Slow lateral erosion (<20cm/yr)
River left valley confinement	Unconfined to confined	**River right valley confinement**	Confined
River left valley height (m)	0-7	**River right valley height (m)**	1-8
Left bank vegetation	Shrubs or grass, trees	**Right bank vegetation**	Shrubs or grass, trees
Large woody debris	Controlling channel	**BEHI score/ adjective rating**	16.5/Low
Hazards observed	Landslides, bank failures, beaver dams, local scour around culverts and beaver dams, undercut banks/bank erosion downstream of beaver dams		

Reach seven runs from KP 8+000 at Villeneuve Road to KP 13+050 at the confluence (Figure 5-2). This low gradient reach typically has tall valley walls (5 m to 8 m, Figure 5-29) a relatively narrow floodplain (40-60 m width), and an irregularly meandering channel form. For some short sections, the channel adopts an anastomosing form (KP 8+00 to KP 9+000 and KP 11+200 to KP 11+400). Channel confinement gradually decreases at the upstream extent of the reach near the confluence. The valley becomes unconfined at the left bank upstream of KP 12+900. The right bank appears to be confined by a levee beginning at KP 12+900 and the levee continues upstream along the eastern tributary (Figure 5-30). A notch in the levee at KP 13+050 allows for outflow from the main trunk at the confluence.

One three-meter diameter culvert is present at KP 9+100 at the intersection of Carrot Creek and Range Road 260 (Figure 5-31) and a bridge is present at KP 12+450, approximately 600 m south of the confluence. The bridge was present prior to 1976.

The reach is extensively beaver dammed (Figure 5-32). At the time of the field inspection, little flow was observed due to beaver damming (see Figure 5-32). Flooding due to beaver damming at the confluence (KP 12+800 and 13+050) has occurred historically (Figure 5-33, Figure 5-34). The main channel is generally considered vertically stable due to beaver damming. However, local scour and bank erosion were observed downstream of culverts and beaver dams (Figure 5-35).

One active landslide (Figure 5-36) and one bank failure (Figure 5-37) were observed during the field assessment at KP 9+100. Several suspected landslides were identified on LiDAR along the valley walls (Figure 5-61).

Apparent changes in the channel centerline over the period of record of aerial photographs analyzed appear to be largely due to beaver dam construction and failure. Other variance in the mapped channel centerline is attributed to limitations of aerial photograph analysis (Section 5.1.1.1). An increase in beaver dams was observed from 1976 to 2020. A pipeline ROW at KP 9+275 was observed first in the 1992/1993 aerial photograph.



Figure 5-29 Beaver ponds confined by five- to eight-meter-tall valley walls.

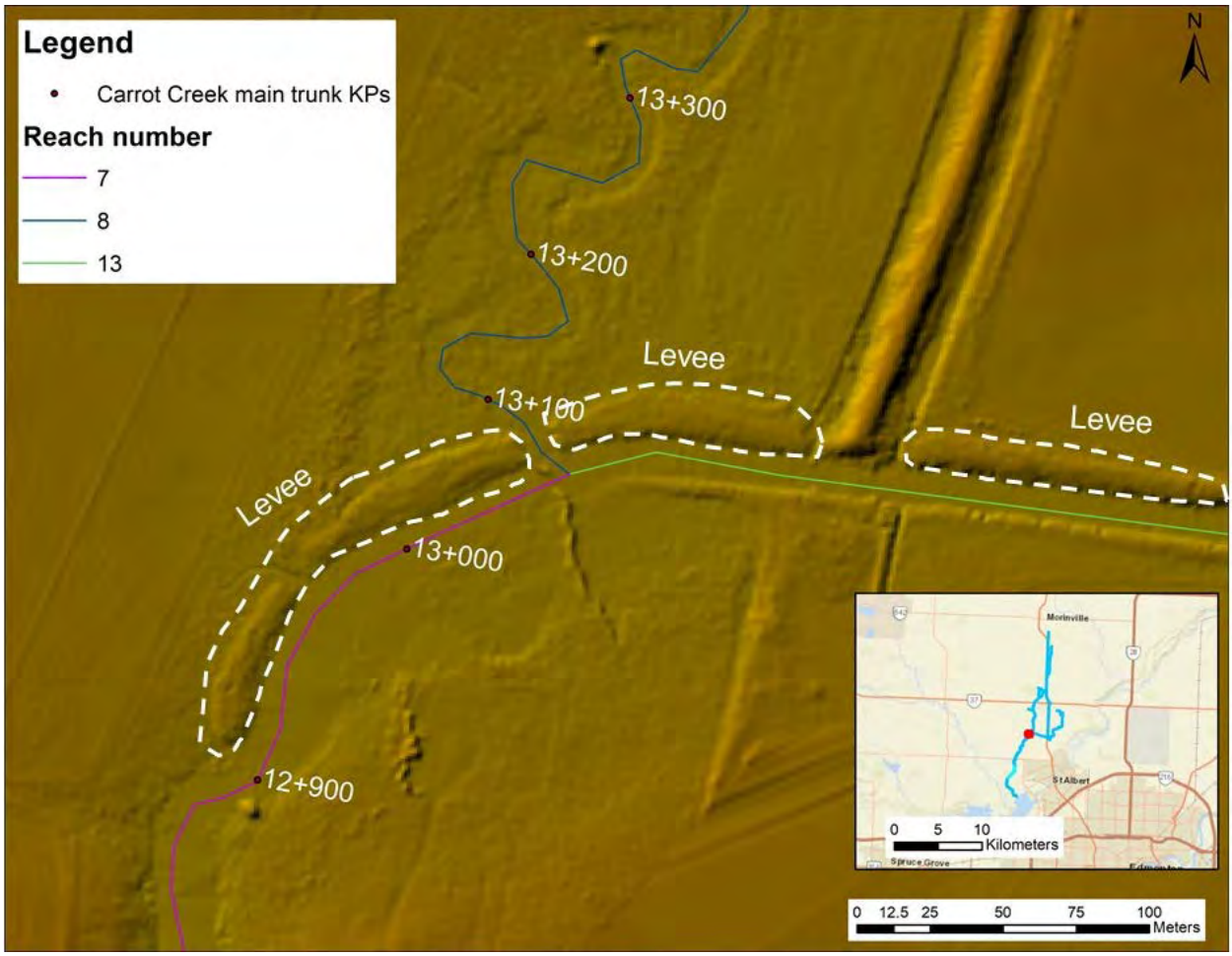


Figure 5-30 Annotated LiDAR image showing the levee on the right bank of Carrot Creek around the confluence.



Figure 5-31 Photograph of the three-meter diameter culvert at KP 9+100 on the downstream side of the intersection of Carrot Creek and Range Road 260.

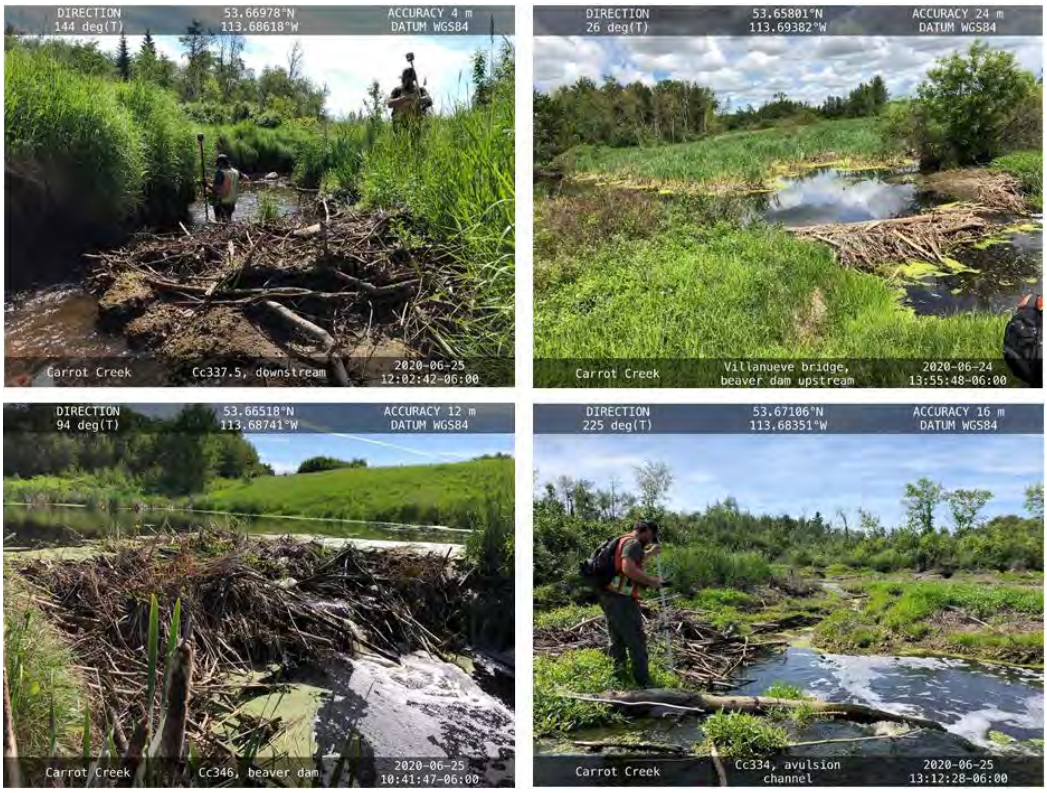


Figure 5-32 Examples of beaver dams encountered in reach seven.



Figure 5-33 October 2017 Google Earth™ image of flooding due to beaver dams and unconfined valley walls around the confluence.



Figure 5-34 Photograph of the confluence at KP 13+050. The blue arrow shows the flow direction of the main trunk of Carrot Creek through the notch in the levee. The orange arrow shows the flow direction of the eastern tributary. The white dashed lines delineate the location of a relict beaver dam.



Figure 5-35 Looking upstream around KP 10+250 at a failing beaver dam and downstream scour and bank erosion.



Figure 5-36 Outline of landslide observed at KP 9+100, with the field crew for scale. White arrows show movement direction of the landslide. Blue arrow shows direction of flow.



Figure 5-37 Bank failure immediately downstream of the beaver dam at KP 9+275 with surveyor standing at the edge of the scour hole, for scale.

5.2.1.8 Reach Eight

Table 5-10 Reach Eight Summary Table

Reach Eight Summary			
Reach number	8	**Location/extent**	KP 13+050 to KP 13+706
Assessment type	Field		
Channel form	Regular	**Field morphology**	Run
Sediment pattern	Not evident	**Floodplain width (m)**	130-170
Left bank material	Black clay with organics	**Right bank material**	Black clay with organics
Median grain size (D_{50}, mm)	Clay and silt	**Largest grain size (D_{90}, mm)**	Very fine sand
Vertical channel stability	Vertically stable	**Lateral channel stability**	Slow lateral erosion (<20 cm/yr)
River left valley confinement	Confined	**River right valley confinement**	Unconfined to confined
River left valley height (m)	2.5-3	**River right valley height (m)**	0-1
Left bank vegetation	Shrubs or grass, trees	**Right bank vegetation**	Shrubs or grass, trees
Large woody debris	Controlling channel	**BEHI score/ adjective rating**	9.5/Very low
Hazards observed	Undercut banks/bank erosion, bank failures, local scour		

Reach eight runs from the confluence at KP 13+050 to KP 13+706 (Figure 5-2). The channel width and depth rapidly decrease from 2-3 m wide and 1 m deep at the confluence (Figure 5-38), to 1-1.5 m wide and 0.5 m deep moving away from the confluence. The banks are undercut in places, and small, shallow bank failures (<1 m^2) were observed. The eastern side of the floodplain is built up and may be part of the levee system or previous roadway (see Figure 5-30). A notch in the levee/roadway allows for conveyance of Carrot Creek from east to west. This reach was flooded from KP 13+400 to KP 13+706 at the time of assessment (Figure 5-39). Some degree of flooding due to beaver damming at the confluence (in reach seven) is evident in this reach since 2004 (Google Earth™ imagery) and floodplain vegetation has correspondingly decreased since 1992/1993 imagery (Figure 5-40). Carrot Creek flows through two culverts beneath Township Road 544 at the upstream extent of the reach. One culvert is back sloped.

Between 2008 and 2011 a pond was excavated within the left floodplain at KP 13+550. Most variance in the mapped channel centerline is attributed to limitations of aerial photograph analysis (Section 5.1.1.1).



Figure 5-38 Looking upstream from the confluence at the channel and floodplain of reach eight.



Figure 5-39 Looking downstream (south) at KP 13+706, with surveyor for scale.

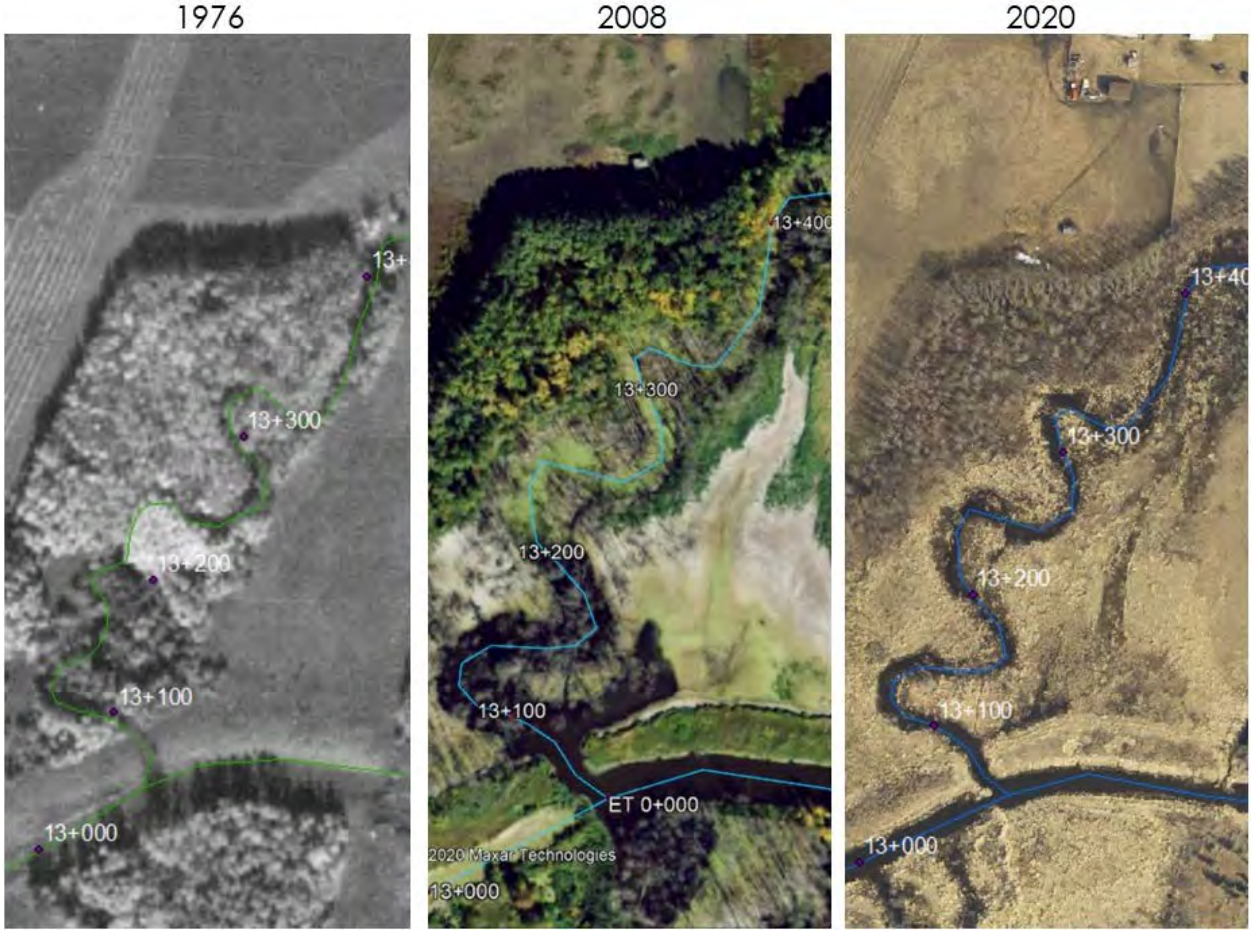


Figure 5-40 Historical aerial photographs and Google Earth™ images of reach eight showing the relatively densely forested floodplain in 1976 (left image), the flooded, sparsely-forested floodplain in 2008 (middle image) and the unforested floodplain in 2020 (right image).

5.2.1.9 Reach Nine

Table 5-11 Reach Nine Summary Table

Reach Nine Summary			
Reach number	9	**Location/extent**	North of TOWNSHIP ROAD 544, see Figure 5-41
Assessment type	Desktop and limited field[2]		
Channel form	Irregular (semi-straight)	**Field morphology**	Run
Sediment pattern	Not assessed	**Floodplain width (m)**	-
Left bank material	Not assessed	**Right bank material**	Not assessed
Median grain size (D_{50}, mm)	Not assessed	**Largest grain size (D_{90}, mm)**	Not assessed
Vertical channel stability	Not assessed	**Lateral channel stability**	Not assessed
River left valley confinement	Not assessed	**River right valley confinement**	Unconfined
River left valley height (m)	0	**River right valley height (m)**	0
Left bank vegetation	Shrubs or grass	**Right bank vegetation**	Shrubs or grass
Large woody debris	Not assessed	**BEHI score/ adjective rating**	-
Hazards observed	Flooding		

Flow through this reach is mainly conveyed by drainage ditches along the western edge of Township Road 255. Some surface flow is observed at higher stages in topographic lows west of the drainage ditch (Figure 5-42). In the downstream extent of the reach the Carrot Creek passes through poorly drained ranchland (Figure 5-43) before flowing beneath Township Road 255 via two culverts. One culvert is back sloped. Areas of extensive flooding in this reach were observed in the 2020 imagery, which was captured during the April flood event (Figure 5-44).

See Figure 5-41 for the location/extent of the reach.

[2] Extensive field work was not conducted.



Figure 5-41 Reaches north of Township Road 544 and west of Highway 2.



Figure 5-42 May 2020 Google Earth™ image of flow through both the road drainage ditch and the abandoned channel to the west (outlined).



Figure 5-43 Carrot Creek channel in poorly to imperfectly drained ranchland just north of Township Road 544.

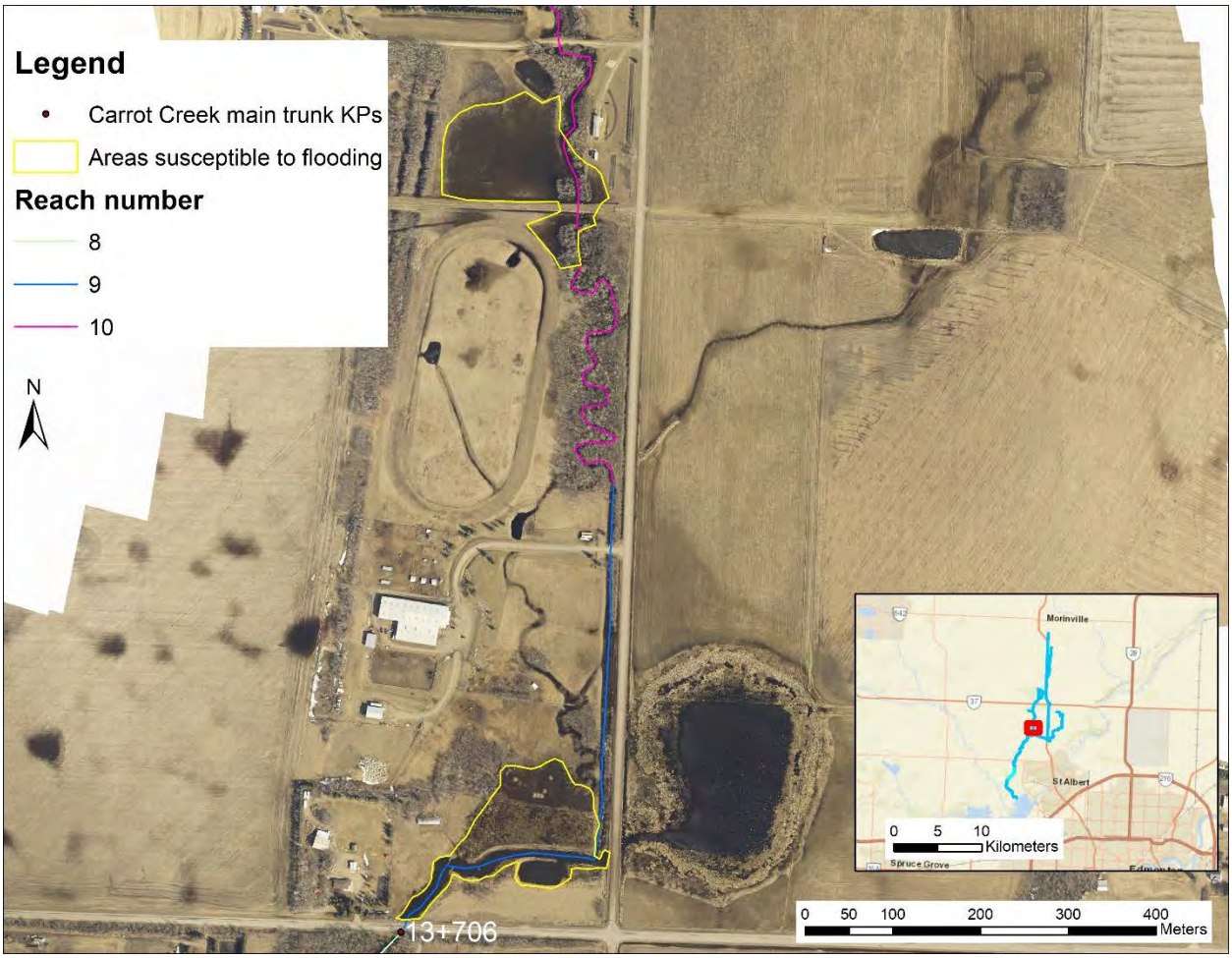


Figure 5-44 Areas of extensive flooding in reaches nine and ten during the April 2020 flood event.

5.2.1.10 Reach Ten

Table 5-12 Reach Ten Summary Table

Reach Ten Summary			
Reach number	10	**Location/extent**	See Figure 5-41
Assessment type	Desktop[3]		
Channel form	Irregularly meandering	**Field morphology**	Run
Sediment pattern	Not assessed	**Floodplain width (m)**	-
Left bank material	Not assessed	**Right bank material**	Not assessed
Median grain size (D_{50}, mm)	Not assessed	**Largest grain size (D_{90}, mm)**	Not assessed
Vertical channel stability	Not assessed	**Lateral channel stability**	Not assessed
River left valley confinement	Confined	**River right valley confinement**	Confined
River left valley height (m)	0.5-1	**River right valley height (m)**	0.5-1
Left bank vegetation	Shrubs, grass or trees	**Right bank vegetation**	Shrubs, grass, or trees
Large woody debris	Not assessed	**BEHI score/ adjective rating**	-
Hazards observed	Flooding		

This reach is semi-confined and irregularly meandering. Due to concealment by vegetation, the centerline was delineated using 2015 LiDAR (Figure 5-45). Areas of extensive flooding in this reach were observed in the 2020 imagery, captured during the April flood event (Figure 5-44).

See Figure 5-41 for the location/extent of the reach.

[3] Field work was not conducted for this reach.

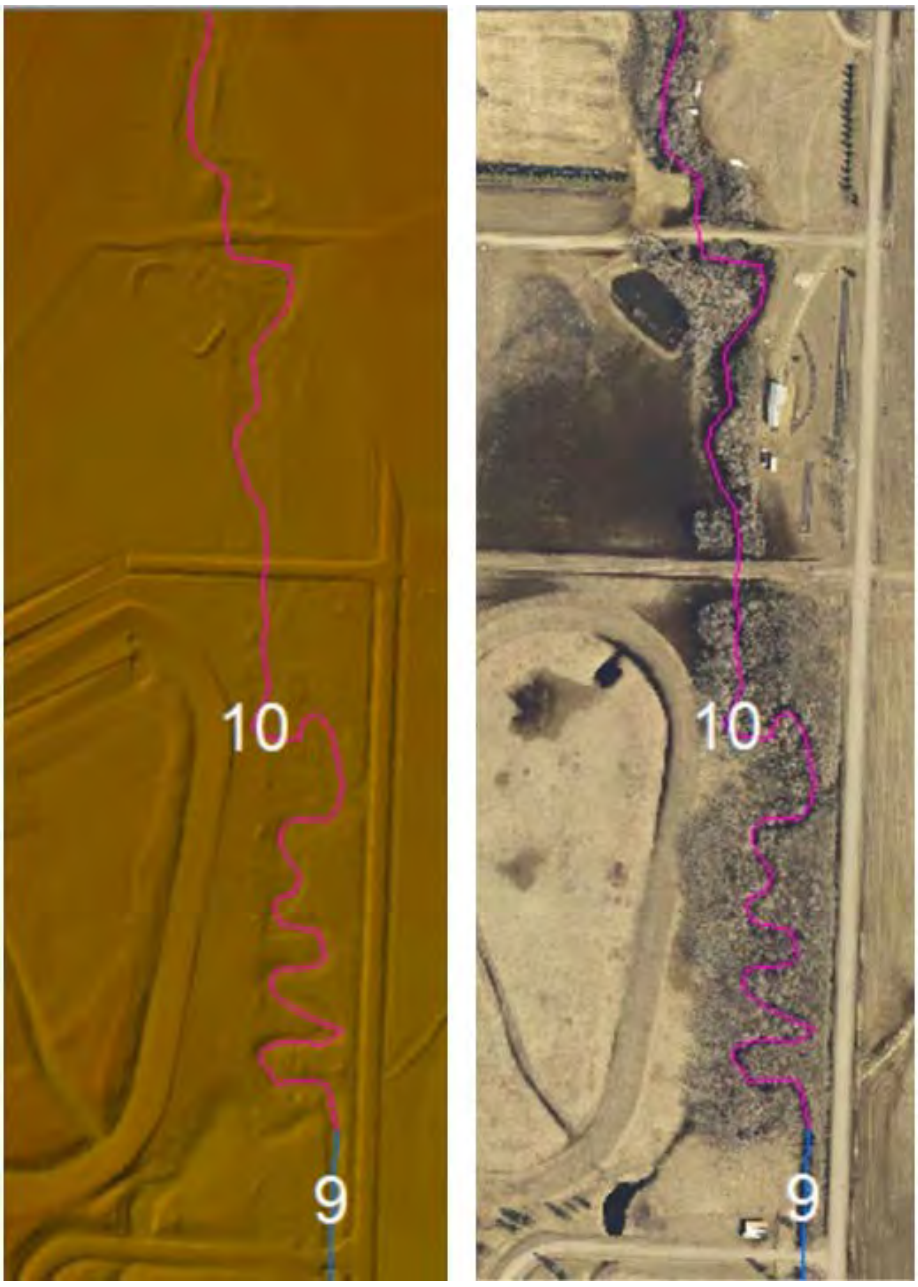


Figure 5-45 Left: 2015 LiDAR Hillshade showing a portion of the confined, meandering channel of reach ten. Right: April 2020 aerial photograph of the reach.

5.2.1.11 Reach Eleven

Table 5-13 Reach Eleven Summary Table

Reach Eleven Summary			
Reach number	11	**Location/extent**	See Figure 5-41
Assessment type	Desktop		
Channel form	Irregular (semi-straight) to straight	**Field morphology**	Run
Sediment pattern	Not assessed	**Floodplain width (m)**	-
Left bank material	Not assessed	**Right bank material**	Not assessed
Median grain size (D_{50}, mm)	Not assessed	**Largest grain size (D_{90}, mm)**	Not assessed
Vertical channel stability	Not assessed	**Lateral channel stability**	Not assessed
River left valley confinement	Confined	**River right valley confinement**	Confined
River left valley height (m)	0.5-1	**River right valley height (m)**	0.5-1
Left bank vegetation	Shrub or grass	**Right bank vegetation**	Shrub or grass
Large woody debris	Not assessed	**BEHI score/ adjective rating**	-
Hazards observed			

The Carrot Creek channel in reach eleven is confined by short valley walls and is irregular (semi-straight) to ditched (straight). The reach is connected at the upstream extent of the reach to manmade ponds (Figure 5-46). In much of the reach cultivation extends to the channel banks.

See Figure 5-41 for the location/extent of the reach.

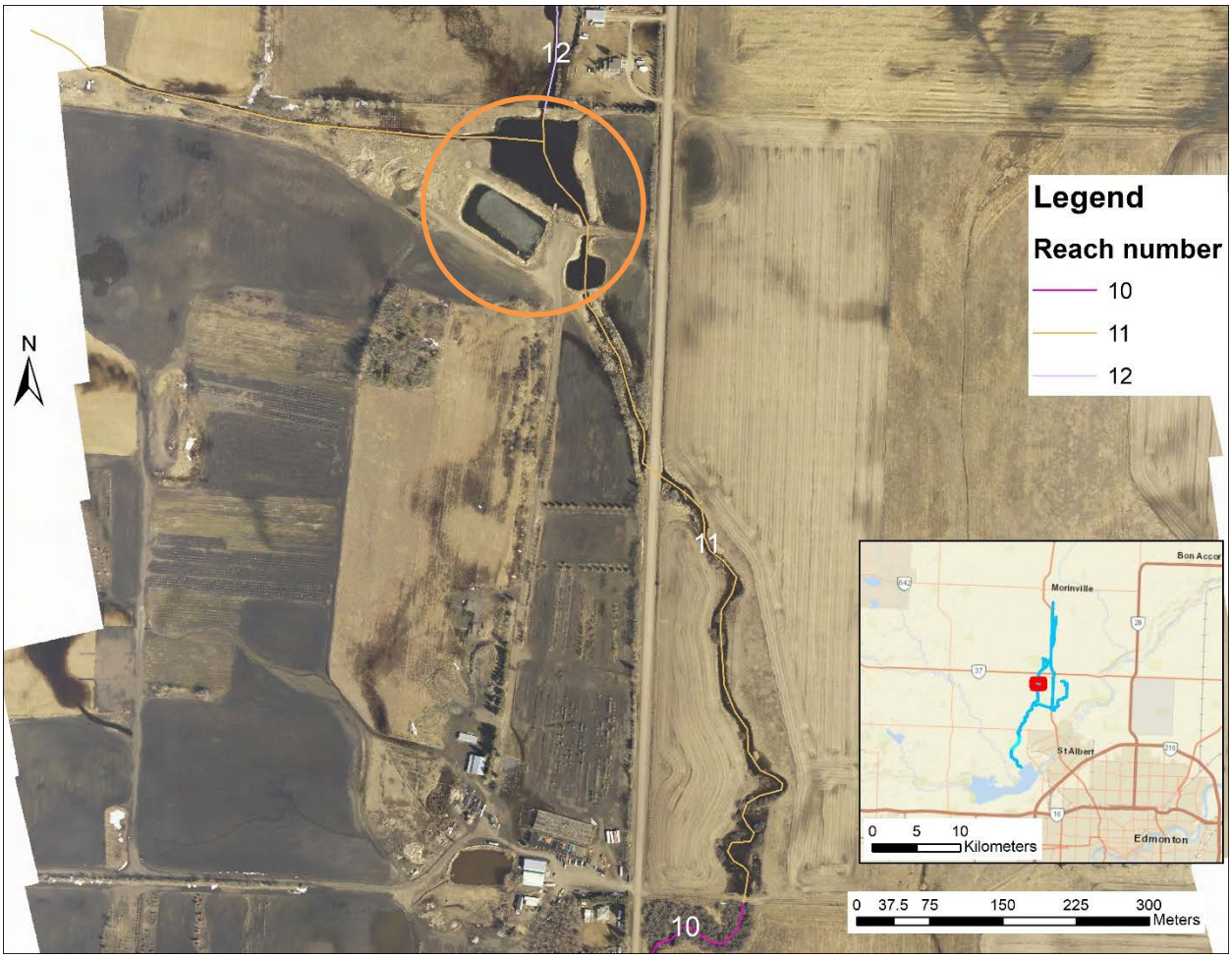


Figure 5-46 April 2020 aerial image showing the extent of reach eleven. The manmade ponds at the upstream extent are circled.

5.2.1.12 Reach Twelve

Table 5-14 Reach Twelve Summary Table

Reach Twelve Summary			
Reach number	12	**Location/extent**	See Figure 5-41
Assessment type	Desktop		
Channel form	Irregularly meandering to straight	**Field morphology**	Run
Sediment pattern	Not assessed	**Floodplain width (m)**	-
Left bank material	Not assessed	**Right bank material**	Not assessed
Median grain size (D_{50}, mm)	Not assessed	**Largest grain size (D_{90}, mm):**	Not assessed
Vertical channel stability	Not assessed	**Lateral channel stability**	Not assessed
River left valley confinement	Unconfined	**River right valley confinement**	Unconfined
River left valley height (m)	0	**River right valley height (m)**	0
Left bank vegetation	Shrub or grass	**Right bank vegetation**	Shrub or grass
Large woody debris	Not assessed	**BEHI score/ adjective rating**	-
Hazards observed:	Flooding		

The channel in reach twelve is unconfined and is irregularly meandering to ditched (straight). In some of the reach cultivation extends to the channel banks. Between 1976 and 1992/1993, a small pond was excavated 25 m west of the residence at 53.70979°, 113.66505°W (Figure 5-47). The creek was re-routed through this pond. Areas of extensive flooding in this reach were observed in the 2020 imagery, captured during the April flood event (Figure 5-48).

See Figure 5-41 for the location/extent of the reach.



Figure 5-47 2020 Google Earth™ image showing the pond (circled) excavated between 1976 and 1992/1993.

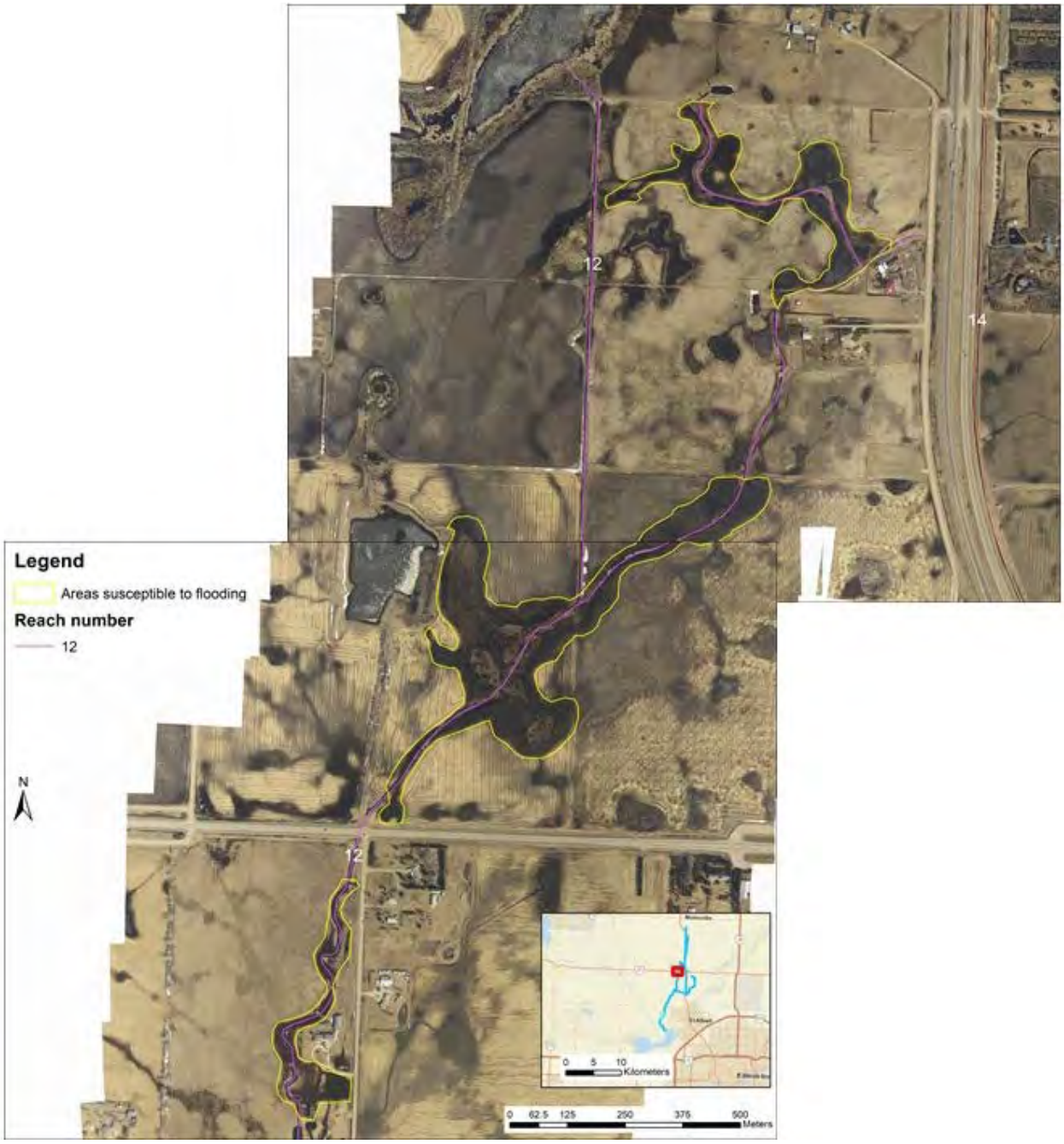


Figure 5-48 Areas of extensive flooding in reach twelve during the April 2020 flood event.

5.2.1.13 Reach Thirteen

Table 5-15 Reach Thirteen Summary Table

Reach Thirteen Summary			
Reach number	13	**Location/extent**	KP ET 0+000 to KP ET 2+284
Assessment type	Field		
Channel form	Straight	**Field morphology**	Run
Sediment pattern	Lateral bars	**Floodplain width (m)**	5-10
Left bank material	Light to dark brown clay	**Right bank material**	Light to dark brown clay
Median grain size (D_{50}, mm)	Clay and silt	**Largest grain size (D_{90}, mm):**	Coarse sand
Vertical channel stability	Slow incision (<20 cm/yr)	**Lateral channel stability**	Lateral erosion not evident
River left valley confinement	Confined	**River right valley confinement**	Confined
River left valley height (m)	0.5-3	**River right valley height (m)**	1-3
Left bank vegetation	Shrubs or grass, few trees	**Right bank vegetation**	Shrubs or grass, few trees
Large woody debris	Present, not functioning	**BEHI score/ adjective rating**	7.5/ Very low
Hazards observed	Local scour around bridges and culverts		

Reach thirteen runs from KP ET 0+000 at the confluence, also known as KP 13+050, to KP ET 2+284. Carrot Creek is generally straight in this reach and appears to be confined by levees (Figure 5-49). Local scour was observed around culverts and bridges. The reach is crossed by four bridges at: KP ET 0+500; KP ET 0+800; KP ET 2+100; and KP ET 2+200. A weir is present at KP ET 0+700 and was constructed prior to 1976. Carrot Creek is conveyed through a culvert beneath Highway 2 (Figure 5-50).

A pipeline crossing at KP ET 0+350 is distinct in the 1992/1993 aerial photograph. Between 1976 and 1993, Highway 2 underwent construction to widen it into a double divided Highway, but construction did not considerably change the planform of Carrot Creek.



Figure 5-49 Annotated site photograph of reach thirteen showing the leveed channel.



Figure 5-50 Looking upstream at the culvert below Highway 2.

5.2.1.14 Reach Fourteen

Table 5-16 Reach Fourteen Summary Table

Reach Fourteen Summary			
Reach number	14	**Location/extent**	East of Highway 2, see Figure 5-41 and Figure 5-52
Assessment type	Desktop and limited field		
Channel form	Straight	**Field morphology**	Run
Sediment pattern	Not assessed	**Floodplain width (m)**	-
Left bank material	Not assessed	**Right bank material**	Not assessed
Median grain size (D_{50}, mm)	Not assessed	**Largest grain size (D_{90}, mm)**	Not assessed
Vertical channel stability	Not assessed	**Lateral channel stability**	Not assessed
River left valley confinement	Not assessed	**River right valley confinement**	Unconfined
River left valley height (m)	0	**River right valley height (m)**	0
Left bank vegetation	Shrub or grass	**Right bank vegetation**	Shrub or grass
Large woody debris	None	**BEHI score/ adjective rating**	Not applicable
Hazards observed	Local scour around culverts, flooding		

Carrot Creek in reach fourteen is conveyed through manmade ditches adjacent to Highway 2 and 100 Street in Morinville. Areas of extensive flooding in this reach were observed at the northeast corner of the intersection of Highways 2 and 37 in the 2020 imagery, which was captured during the April flood event (Figure 5-51).

The historic aerial photograph review reveals no change to the channel centerline from 1976 to 2020. Between 1976 and 1993, Highway 2 underwent construction to widen it into a double divided Highway; this construction did not change the course of reach fourteen.



Figure 5-51 April 2020 aerial photograph showing flooding at the intersection of Highway 2 and Highway 37.

5.2.1.15 Reach Fifteen

Table 5-17 Reach Fifteen Summary Table

Reach Fifteen Summary			
Reach number	15	**Location/extent**	See Figure 5-52
Assessment type	Desktop		
Channel form	Irregular (semi-straight)	**Field morphology**	Run
Sediment pattern	Not assessed	**Floodplain width (m)**	-
Left bank material	Not assessed	**Right bank material**	Not assessed
Median grain size (D_{50}, mm)	Not assessed	**Largest grain size (D_{90}, mm)**	Not assessed
Vertical channel stability	Not assessed	**Lateral channel stability**	Not assessed
River left valley confinement	Unconfined	**River right valley confinement**	Unconfined
River left valley height (m)	0	**River right valley height (m)**	0
Left bank vegetation	Shrub or grass	**Right bank vegetation**	Shrub or grass
Large woody debris	Not assessed	**BEHI score/ adjective rating**	-
Hazards observed			

The channel planform in reach fifteen is irregular (semi-straight) and appears to be manmade or modified. It appears that in much of the reach cultivation extends to the channel banks. Aerial photograph analysis revealed that the channel alignment was straightened over an approximate 200 m length between 1976 and 1992/1993 (Figure 5-53).

See Figure 5-52 for the location/extent of the reach.

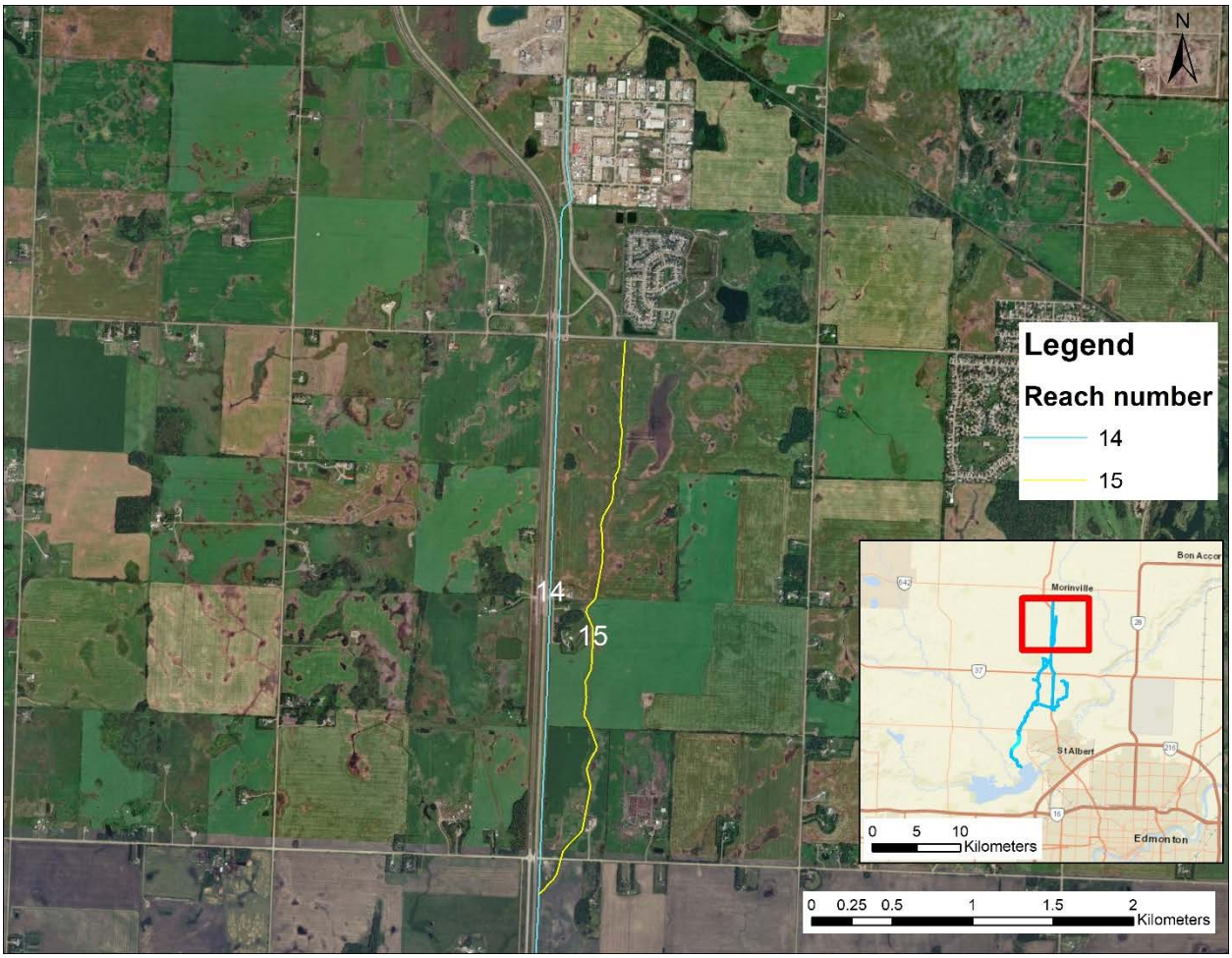


Figure 5-52 Figure showing the northern extent of reach 14 and all of reach 15.



Figure 5-53 Comparison of 1976 and 1992/1993 aerial photographs showing where the reach was straightened.

5.2.1.16 Reach Sixteen

Table 5-18 Reach Sixteen Summary Table

Reach Sixteen Summary			
Reach number	16	**Location/extent**	See Figure 5-54
Assessment type	Field and desktop		
Channel form	Irregular (semi-straight) to straight	**Field morphology**	Run
Sediment pattern	Not evident	**Floodplain width (m)**	Not applicable
Left bank material	Brown clay	**Right bank material**	Brown clay
Median grain size (D_{50}, mm)	Clay and silt	**Largest grain size (D_{90}, mm)**	Clay and silt
Vertical channel stability	Slow incision (<20 cm/yr)	**Lateral channel stability**	Slow lateral erosion (<20 cm/yr)
River left valley confinement	Unconfined	**River right valley confinement**	Unconfined
River left valley height (m)	0	**River right valley height (m)**	0
Left bank vegetation	Shrub or grass	**Right bank vegetation**	Shrub or grass
Large woody debris	None	**BEHI score/ adjective rating**	-
Hazards observed	Bank failures, undercut banks, flooding		

The channel in reach sixteen is unconfined and is irregularly meandering to ditched (straight). Undercut banks and bank failures were observed in the downstream most extent of the reach over a 110 m length of channel. The two culverts in the lower extent of the reach (at 53.679459°, -113.637765° and 53.679811°, -113.638946°) did not appear to be effectively conveying flow and may be partially blocked. In some of the reach, cultivation extends to the channel banks (Figure 5-55). Areas of extensive flooding in this reach were observed in the 2020 imagery, captured during the April flood event (Figure 5-56) and in the field (Figure 5-57).

The historic aerial photograph review reveals no considerable change to the channel centerline from 1976 to 2020. Most variance in the mapped channel centerline is attributed to limitations of aerial photograph analysis (see Section 5.1.1.1). However, development of the North Erin Ridge area in St. Albert since the spring 2020 field work has significantly altered the creek in reach sixteen. The creek has been diverted west along a new ditch south of Township Road 544 and then south along a new ditch east of Highway 2. The large depression storage area near the downstream end of the reach has been eliminated, and the developer has established a “temporary” storage area in a natural depression north of the eliminated storage feature.

See Figure 5-54 for the location/extent of the reach.

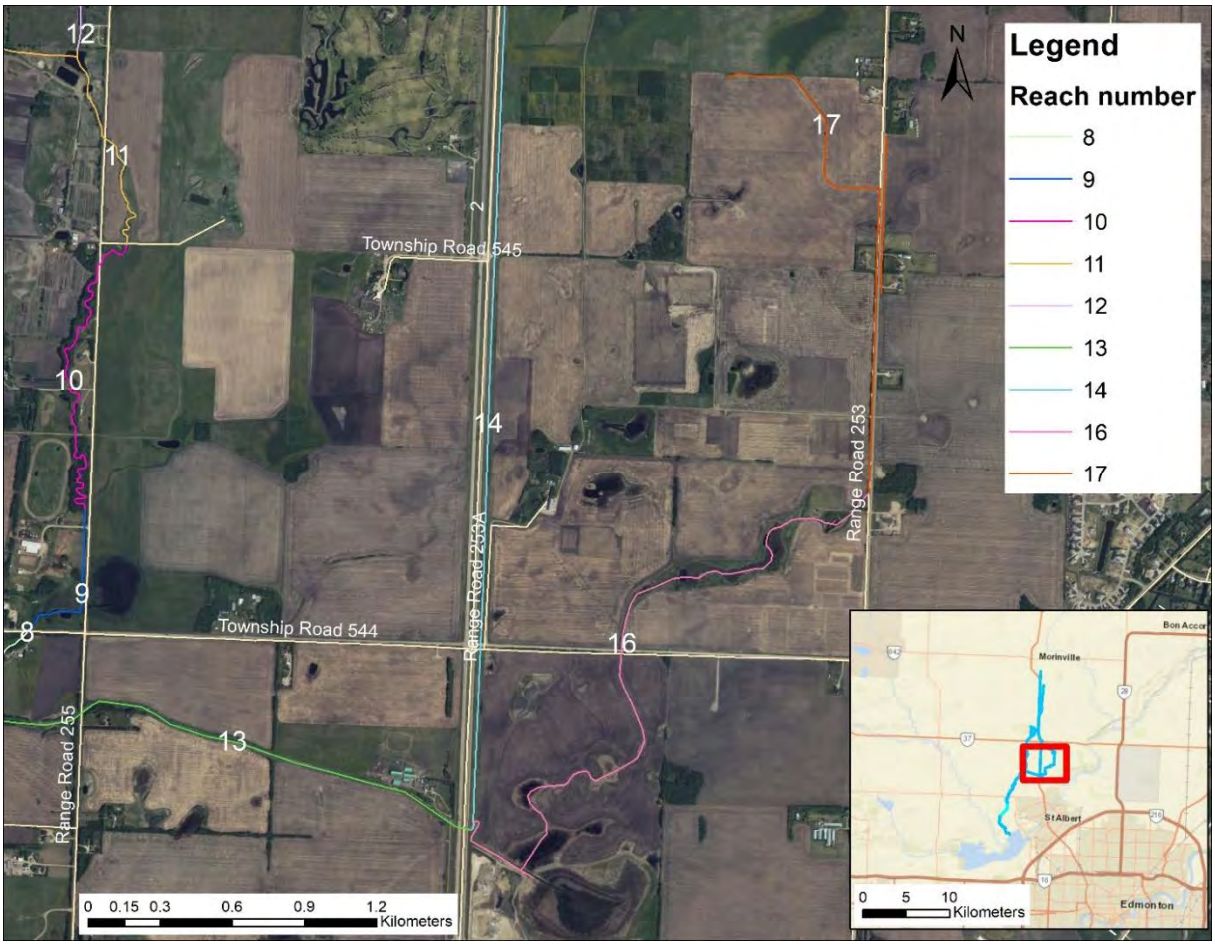


Figure 5-54 Reaches east of Highway 2.



Figure 5-55 Areas of reach sixteen where cultivation extends to the channel bank position.

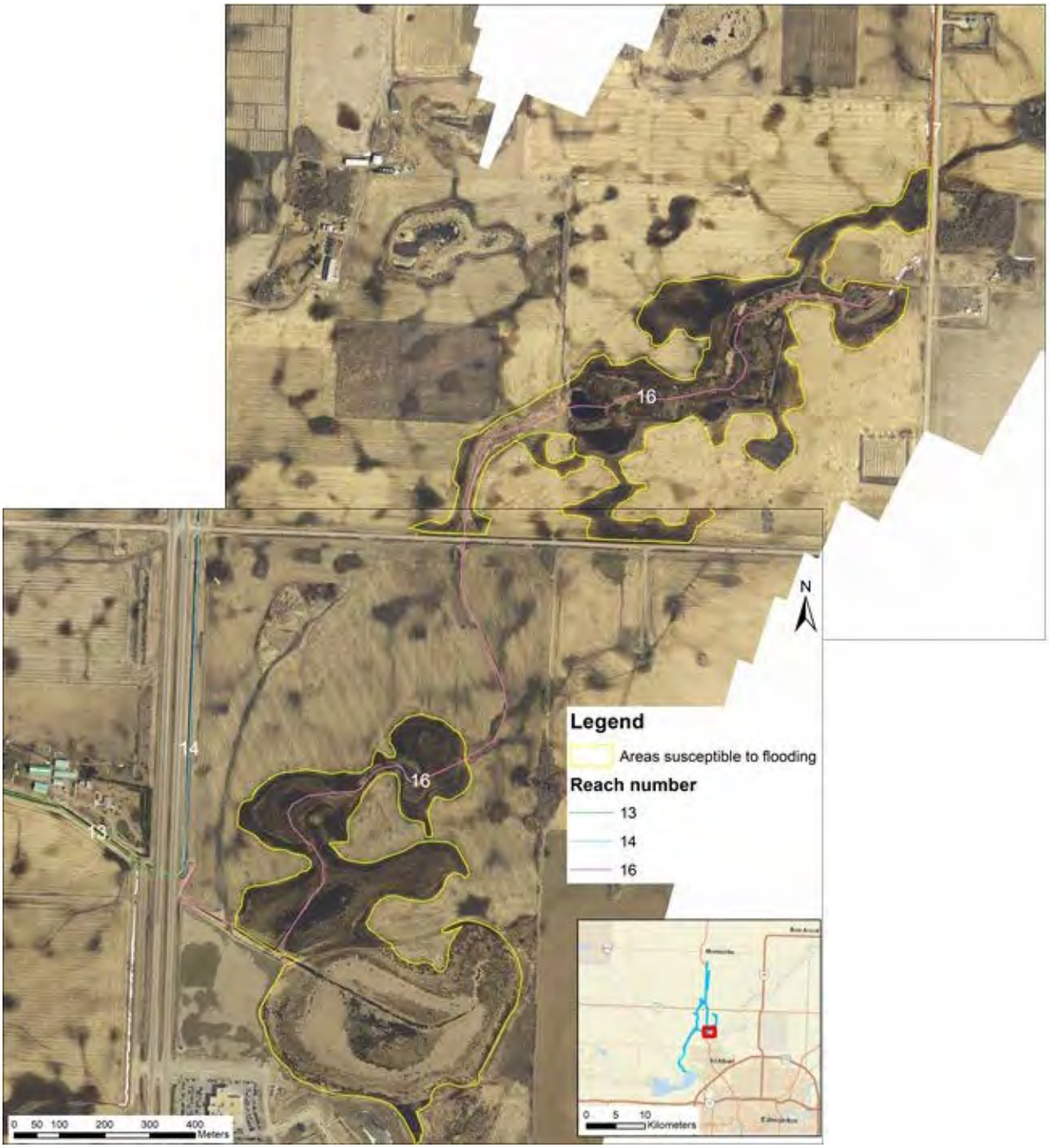


Figure 5-56 Areas of extensive flooding in reach sixteen during the April 2020 flood event.



Figure 5-57 Looking north towards the extensive flooding in reach sixteen.

5.2.1.17 Reach Seventeen

Table 5-19 Reach Seventeen Summary Table

Reach Seventeen Summary			
Reach number	17	**Location/extent**	See Figure 5-54
Assessment type	Field and desktop		
Channel form	Straight	**Field morphology**	Run
Sediment pattern	Not evident	**Floodplain width (m)**	-
Left bank material	Brown to black clay with organics	**Right bank material**	Brown to black clay with organics
Median grain size (D_{50}, mm):	Clay and silt	**Largest Grain Size (D_{90}, mm):**	Clay and silt
Vertical Channel Stability	Vertically stable	**Lateral Channel Stability**	Lateral erosion not evident
River left valley confinement	Unconfined	**River right valley confinement**	Unconfined
River left valley height (m)	0	**River right valley height (m)**	0
Left bank vegetation	Trees and shrubs or grass	**Right bank vegetation**	Trees and shrubs or grass
Large woody debris	Present, not functioning	**BEHI Score/ Adjective rating**	-
Hazards observed:	Flooding		

Flow through this reach is mainly conveyed by drainage ditches or modified channels. Some culverts in the reach were damaged, may be partially blocked by sediment, and did not appear to be effectively conveying flow (Figure 5-58). Areas of extensive flooding in this reach were observed in the 2020 imagery, captured during the April flood event (Figure 5-59, Figure 5-60).

The historic aerial photograph review reveals no considerable change to the channel centerline from 1976 to 2020.

See Figure 5-54 for the location/extent of the reach.



Figure 5-58 Damaged culvert within a drainage ditch in reach seventeen.

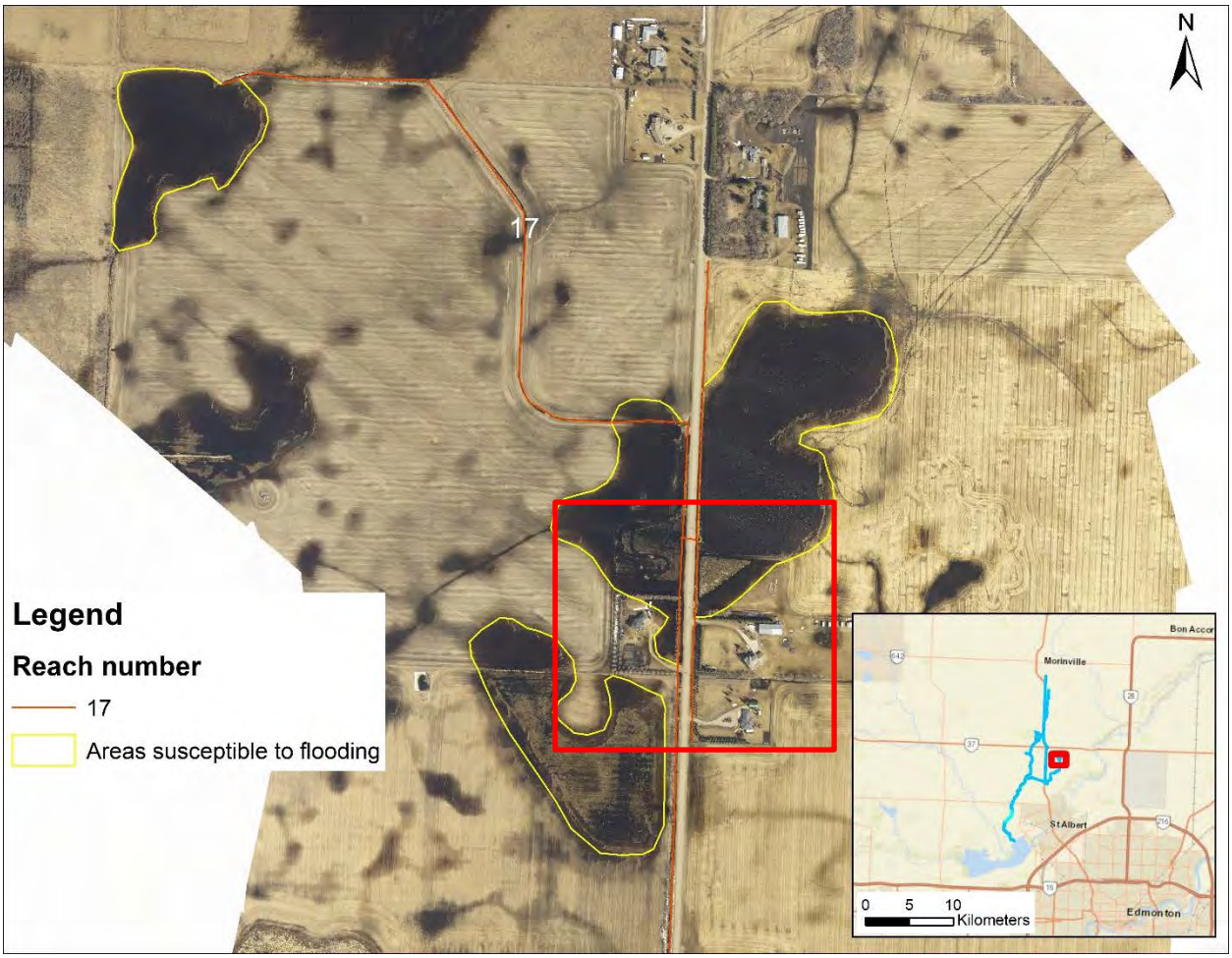


Figure 5-59 Areas of extensive flooding in reach seventeen during the April 2020 flood event. The flooded area delineated by the red square is shown in greater detail in Figure 5-60.

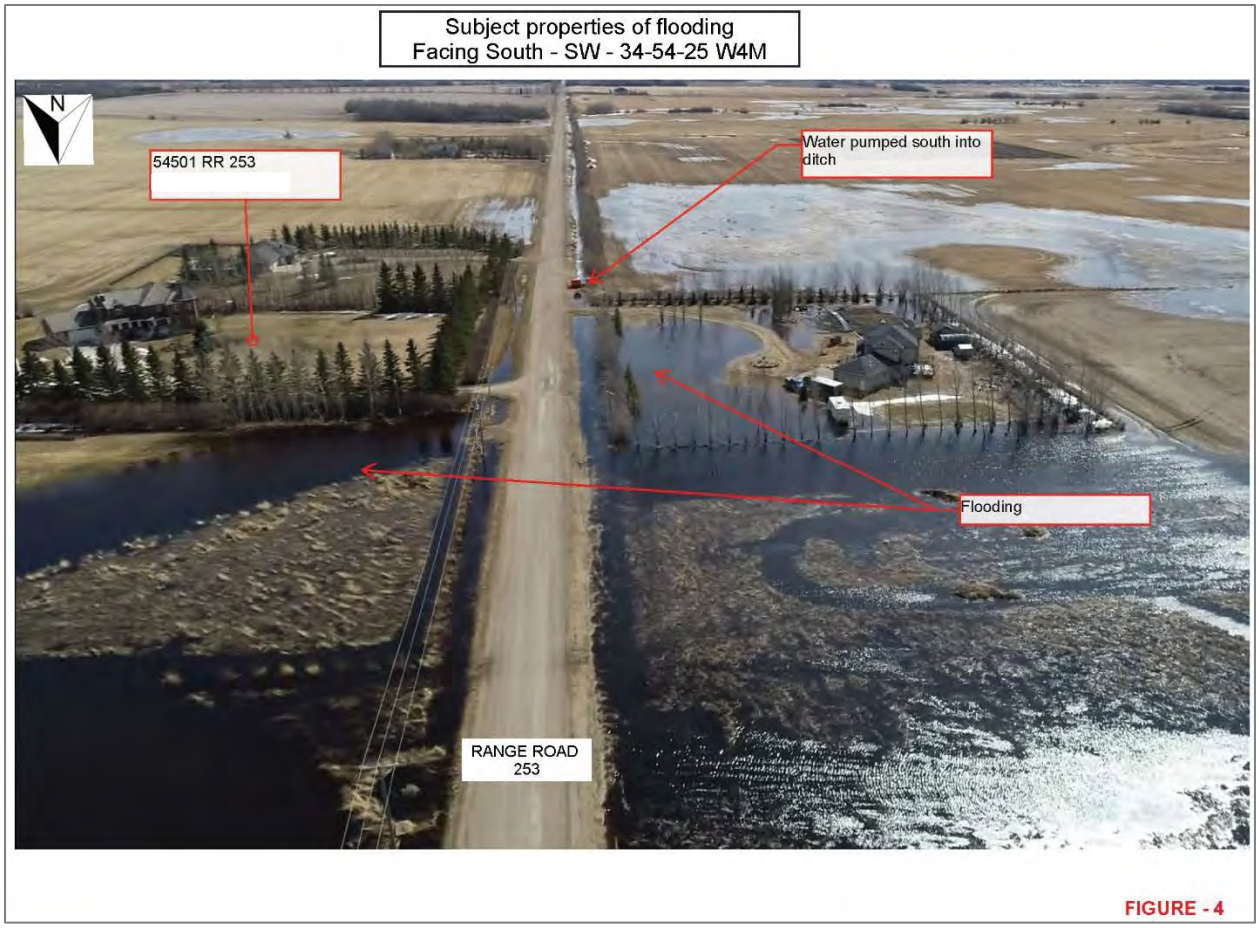


Figure 5-60 Figure 4 from BEAR Land Services report (2020) showing extensive flooding along reach seventeen in early 2020.

5.2.2 Landslides, Bank Failures, and Bank Erosion Along Carrot Creek

This section summarizes the reaches in which landslides, bank failures, and bank erosion were most common. Landslides, bank failures and bank erosion are differentiated as follows: Landslides are relatively larger features characterized by the downslope movement of sediment, rock, organics, and/or debris. The landslide's movement propagates upslope away from the influence of the channel. Bank failures occur when erosion at the toe of a streambank increases the height and angle of the bank to the point where gravitational forces exceed the shear strength of the bank material and the bank fails. Bank failures are more local in nature. Bank erosion is the lateral retreat of banks due to erosional processes including, but not limited to, fluvial entrainment, tractive force action, freeze-thaw, dry ravel, and ice scour.

In general, the valley walls confining Carrot Creek have gentle (4-15°) to moderate (16-26°) slopes and appear to be relatively stable. Landslides were observed on LiDAR and in the field in reach seven (Figure 5-61).

In general, bank failures were more common in downstream reaches (reaches 1-5) and were considered pervasive in reach five. Bank failures were typically observed downstream of beaver dams, bridges, and along cut banks.

The reaches that appeared especially prone to bank erosion were reaches two, three, four, and five (Figure 5-62). The erosion is hypothesized to be due to less cohesive (sandy) bank material in these reaches. Bank erosion was commonly observed upstream and downstream of bridges and culverts, downstream of beaver dams, and along cut banks.

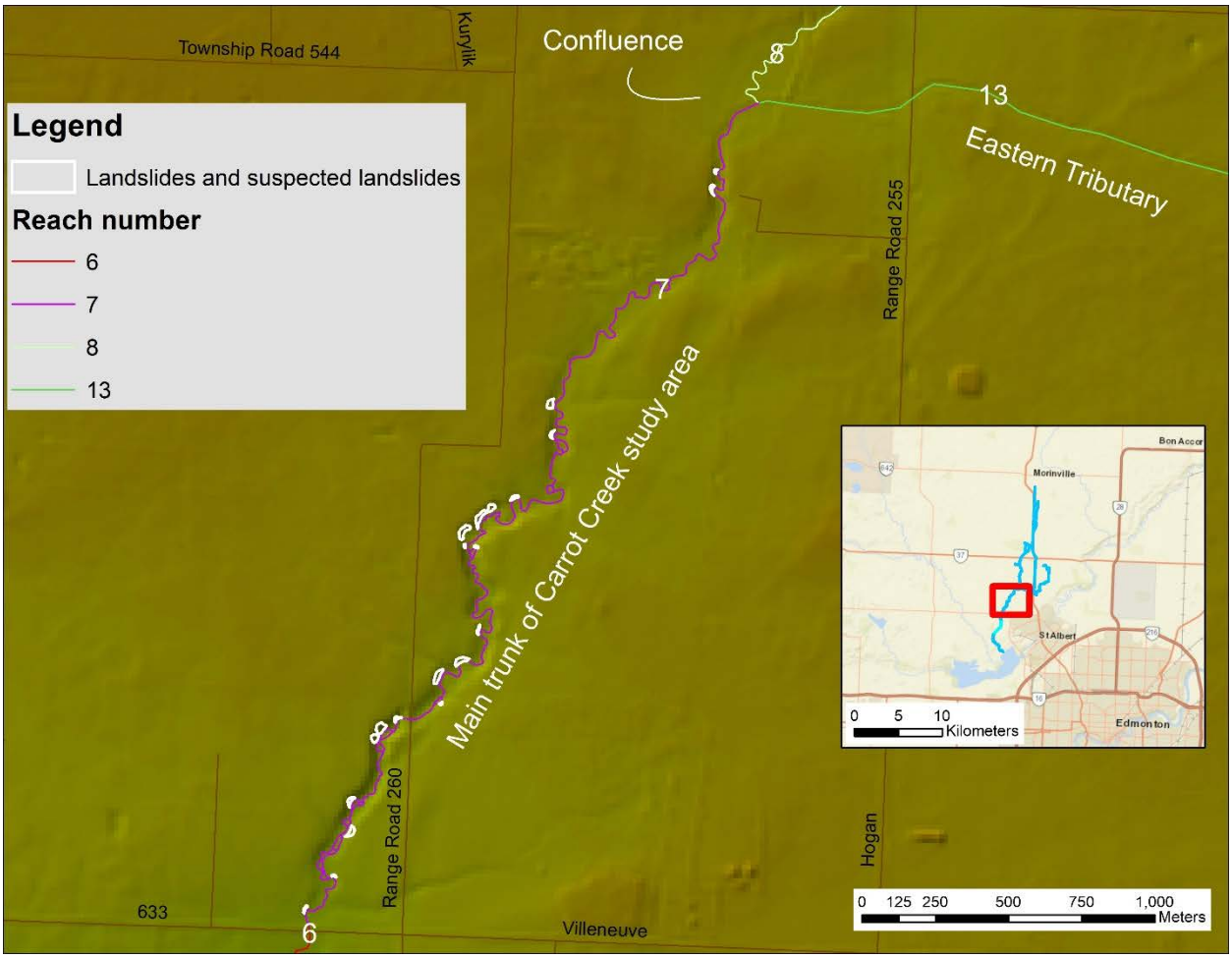


Figure 5-61 Landslides and suspected landslides, with the 2011 LiDAR hillshade as the background image.

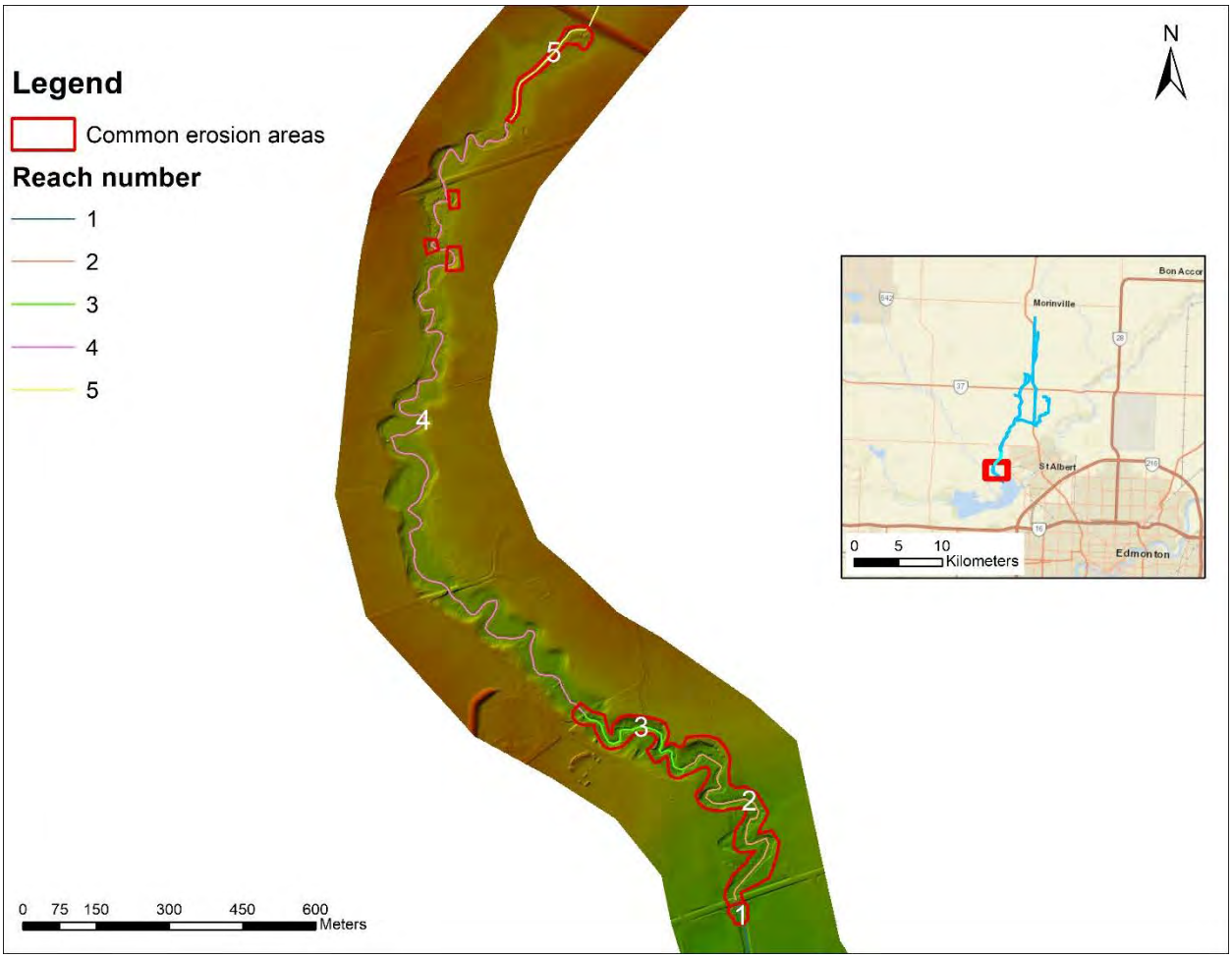


Figure 5-62 Areas of Carrot Creek where erosion was relatively common.

5.2.2.1 Geomorphic areas of concern

The following are the primary areas of concern based on Stantec's geomorphic assessment:

- Flooding observed or identified in reach one, four (between KP 3+600 and KP 3+950), five, six (between KP 4+650 to KP 5+100), nine, ten, twelve, fourteen, sixteen, and seventeen
- Observed erosion downstream of the bridge at Meadowview Drive (reach one) and Old McKenney Ave (reach four)
- Observed erosion in reaches two and three
- Observed erosion upstream and downstream of the Canadian National Railway Company (CN Rail) culverts in reach five
- Observed erosion downstream of the culvert at Range Road 260 (reach seven)
- Landslides in reach seven

6 HYDROTECHNICAL ASSESSMENT

6.1 HYDROLOGIC ANALYSIS

A regional hydrology assessment was conducted to estimate Carrot Creek station flows (gauged and ungauged) for a separate HEC-RAS analysis and to estimate the unit area release rate to Carrot Creek under the 100-year return period. This hydrological assessment is intended to support the development of the proposed post-development unit area release rate under 100-year level of service conditions.

6.1.1 Study Context & Methodology

The delineated watershed of Carrot Creek is shown in Figure 6-1. Based on aerial photograph and LiDAR surface, a well-defined creek only exists south of Township Road 544. East of Highway 2, a ditch system parallel to Highway 2 exists that collects and conveys runoff to Carrot Creek's East Tributary (ET).

A confluence exists south of Township Road 544 where Highway 2 ditch system drains to Carrot Creek. Separate sub-watersheds were delineated at this confluence point and upstream of the confluence as shown in Figure 6-1.

To estimate the creek flows under various return period events, the following methodology was utilized:

1. Reviewed existing regional analysis for the Big Lake Watershed (Associated Engineering, 2004) and determined flow estimates for the Carrot Creek sub-watershed stations using the regional regression equations identified. Confirmed the proposed post-development unit area release rate determined for development in the Carrot Creek watershed.
2. Gathered Carrot Creek hydrometric station flow data and conducted a frequency analysis. Confirmed estimated flows for various return period events. Compared the 100-year frequency analysis result to the regional analysis estimate. Confirmed or proposed modified post-development unit area release rate.
3. Estimated ungauged station flow rates using the "Transposition of Frequency Data" method (equation below) from the USBR Flood Hydrology Manual (1989).

$$Q = Q_{HydrometricStation} * (A/A_{HydrometricStation})^{x}$$

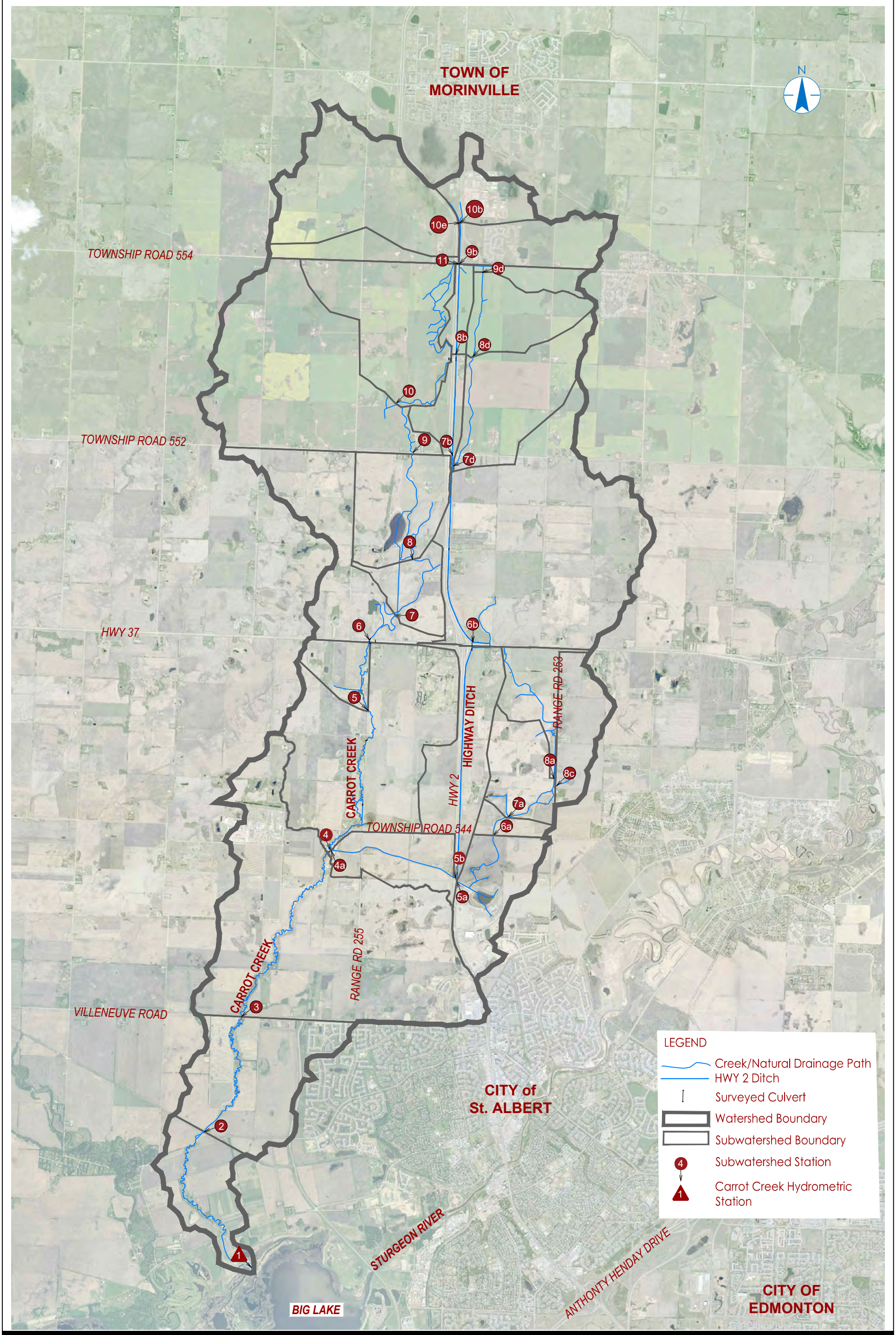
   a. Estimated effective drainage areas for Carrot Creek sub-watersheds up to 2-year return period events using GIS storage polygon and watershed delineation tools. Ineffective areas were estimated based on contributing drainage areas for large depression storages in the study area that contain sufficient capacity to limit runoff during frequent return period storm events. Assumed gross drainage area applies to all other return periods (i.e., event runoffs exceed depression storage capacity).

   b. Estimated area transposition exponent based on 2-year and 100-year regional analysis calculated flows for each ungauged drainage area.

c. Chose area transposition exponent (valid between 0.5-0.8 according to USBR Flood Hydrology Manual).

d. Calculated and tabulated estimated ungauged station flows for erosion study analysis.

The drainage areas, gross and effective, delineated in Figure 6-1 are shown in Table 6-1 for the purpose of providing sub-watershed estimated flows for the erosion study.



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Stantec

Stantec Consulting Ltd.
10220 103 Avenue
Edmonton AB T5J OK4
Tel: (780) 917-7000
www.stantec.com

Notes:
Computed flowrates are for a 100 year flood event

Scale
1:60,000
0 480 1440 2400m

Client/Project
City of St. Albert Planning and Engineering
CARROT CREEK REGIONAL MASTER DRAINAGE PLAN

Project No.
110149416

Title
CARROT CREEK WATERSHED
Existing Drainage Areas

Revision
0

Date
2021.03.15

Reference Sheet

Figure No.
6-1

Table 6-1 Carrot Creek Existing Drainage Areas

Station ID	Gross Drainage Area (km^2)	2-year Effective Drainage Area (km^2)
1 (Carrot Creek Hydrometric Station)	87.9	46.9[4]
2	85.5	44.5
3	81.1	40.1
4	29.4	13.3
5	22.1	5.9
6	21.1	4.9
7	17.2	2.8
8	15.9	1.5
9	13.1	1.0
10	5.2	0.1
11	1.0	0.1
4a	38.8	14.5
5a	7.6	2.6
6a	5.3	2.0
7a	4.9	2.0
8a	1.4	0.0
5b	29.4	10.1
6b	26.4	7.4
7b	9.7	5.1
8b	8.8	5.1
9b	8.3	5.1
10b	1.3	0.4
8c	1.7	1.2
7d	5.9	0.3
8d	2.6	0.1
9d	0.6	0.0
10e	4.9	4.1

[4] Current study assessment estimate. AEP hydrometric station data provides an effective drainage area of 39.2 ha.

6.1.2 Existing Regional Analysis

Associated Engineering (AE) carried out a comprehensive regional flood frequency analysis for the Big Lake watershed (Big Lake Stormwater Management Plan, 2004) and recommended a release rate of 2.5 L/s/ha for both urban development and agricultural drainage for this watershed. **Appendix F** contains the 1:2 year and 1:100 year flood versus effective drainage area figures from the 2004 AE study. AE developed the following equations from the regional regression analysis:

- 1:2 Year Flood Discharge, $m^3/s = 0.1336 * (\text{Effective Drainage Area, } km^2)^{0.6834}$
- 1:100 Year Flood Discharge, $m^3/s = 1.0478 * (\text{Effective Drainage Area, } km^2)^{0.6491}$

The Big Lake Stormwater Management Plan (2004) report also recommended to install a new hydrometric station at the mouth of Carrot Creek. A hydrometric station was later installed (Station ID 05EA011) and monitored flow data at Carrot Creek is available on and after 2005. These data can be downloaded from Water Survey of Canada's website at: https://wateroffice.ec.gc.ca/search/historical_e.html using the Station ID 05EA011.

6.1.3 Carrot Creek at Big Lake Hydrometric Station Frequency Analysis

A frequency analysis was carried out for the newly available WSC hydrometric station (05EA011) data using Log Pearson Type 3 distribution. This distribution is the most common for flood frequency analysis of riverine systems and provided 22 m^3/s flowrate for the 1:100-year flood event. When divided by the estimated gross drainage area of 87.9 km^2, the unit release rate obtained for the existing condition, which for the purposes of this study is considered the "predevelopment condition", is 2.55 L/s/ha. Since this is very close to the 2.5 L/s/ha estimated predevelopment release rate reported previously by AE (2014) for the Carrot Creek drainage basin, this unit release rate remains appropriate for the Carrot Creek RDMP. The frequency analysis is provided in **Appendix G**. Table 6-2 shows the results.

Table 6-2 Carrot Creek Hydrometric Station Frequency Data

Return Period, T (years)	Discharge (m^3/s) Log Pearson III Distribution
2	1.7
5	6.8
10	11.2
25	16.4
50	19.7
100	22.4
200	24.5

6.1.4 Upstream Ungauged Station Hydrology Results

The effective and gross drainage area for each identified station in the Carrot Creek watershed for the erosion study are identified in Table 6-1.

As per the described methodology, the Transposition of Frequency Data exponent was estimated using the calculated flow rates for each drainage area using the equations identified in Section 6.1.1. The average exponent was determined to be 0.70 and 0.73 for the 2-year and 100-year calculations. Therefore, the average exponent of 0.71 was chosen for the final ungauged station flow estimates. Generally, exponents between 0.5 and 0.8 are accepted (USBR, 1989).

The estimated ungauged station flow rates are presented in Table 6-3. The 2-year and 100-year estimated flow rates are compared to the estimated flows from the existing Big Lake Regional Analysis (Associated Engineering, 2004) in Figure 6-2 and Figure 6-3, respectively.

There is a close correlation of the results for the 2-year and 100-year flow estimates between the Regional Analysis regression curves (AE, 2004) and the Transposition of Frequency Data method (USBR, 1989). The results for the chosen calculations (USBR method) are generally lower for effective drainage areas less than 10 km^2 for both the 2-year and 100-year return period results compared to the regional analysis (AE, 2004) estimates. The inverse is generally applicable for effective drainage areas larger than 10 km^2.

Carrot Creek hydrometric station was not available for use in the regional analysis for Big Lake. Therefore, the predetermined regional regression equations (AE, 2004) do not consider specific watershed characteristics from Carrot Creek. The transposition of frequency data using the USBR methodology is an industry accepted practice, particularly valid for use within the same watershed, so the results identified in Table 6-3 were selected as the final flows to be used in the hydraulic model of Carrot Creek.

Table 6-3 Estimated Gauged and Ungauged Carrot Creek Station Flow Rates

Return Period, T, Years	1, Hydrometric Station Frequency Analysis Results	2	3	4	5	6	7	8	9	10	11	4a	5a	6a	7a	8a	5b	6b	7b	8b	9b	10b	8c	7d	8d	9d	10e
	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
2	1.7	1.66	1.54	0.70	0.40	0.35	0.23	0.15	0.11	0.02	0.02	0.75	0.22	0.18	0.18	0.01	0.58	0.46	0.35	0.35	0.35	0.06	0.13	0.04	0.02	0.01	0.31
5	6.8	6.7	6.4	3.1	2.6	2.5	2.1	2.0	1.8	0.9	0.3	3.8	1.2	0.9	0.9	0.4	3.1	2.9	1.4	1.3	1.3	0.3	0.4	1.0	0.6	0.2	0.9
10	11.2	10.9	10.5	5.1	4.2	4.1	3.5	3.3	2.9	1.5	0.5	6.2	2.0	1.5	1.4	0.6	5.1	4.7	2.3	2.2	2.1	0.6	0.7	1.6	0.9	0.3	1.4
25	16.4	16.1	15.5	7.5	6.2	6.0	5.1	4.9	4.2	2.2	0.7	9.2	2.9	2.2	2.1	0.9	7.5	7.0	3.4	3.2	3.1	0.8	1.0	2.4	1.3	0.5	2.1
50	19.7	19.3	18.6	9.1	7.4	7.2	6.2	5.9	5.1	2.7	0.8	11.0	3.5	2.7	2.5	1.0	9.1	8.4	4.1	3.9	3.7	1.0	1.2	2.9	1.6	0.6	2.6
100	22.4	22.0	21.2	10.3	8.4	8.1	7.0	6.7	5.8	3.0	0.9	12.6	4.0	3.1	2.9	1.2	10.3	9.5	4.7	4.4	4.2	1.1	1.4	3.3	1.8	0.7	2.9
200	24.5	24.1	23.2	11.3	9.2	8.9	7.7	7.3	6.3	3.3	1.0	13.7	4.3	3.4	3.1	1.3	11.3	10.4	5.1	4.8	4.6	1.2	1.5	3.6	2.0	0.7	3.2

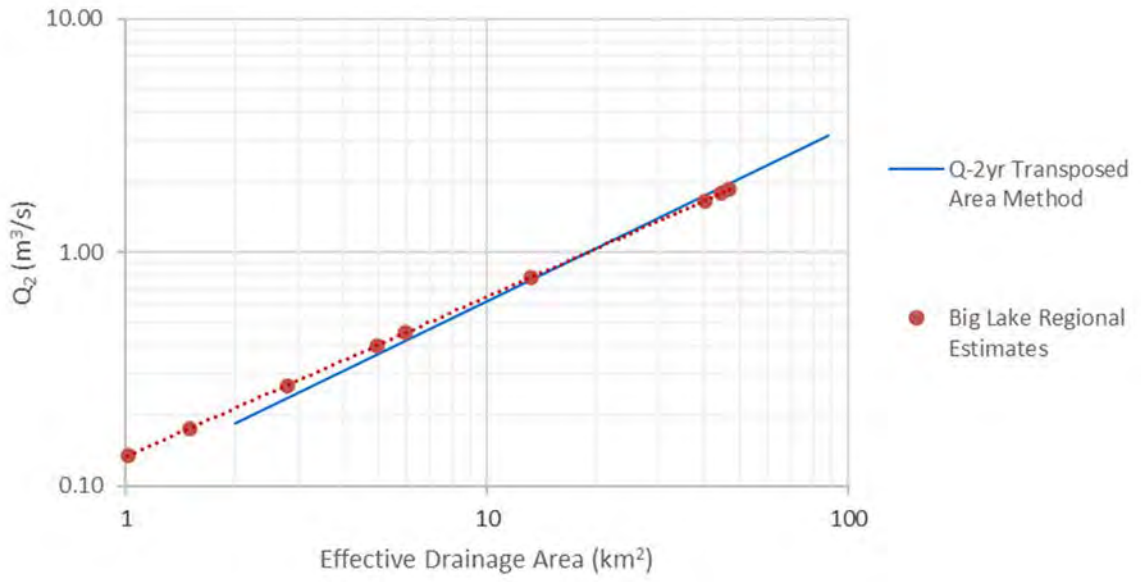


Figure 6-2 Estimate 2-Year Return Period Flow Rates

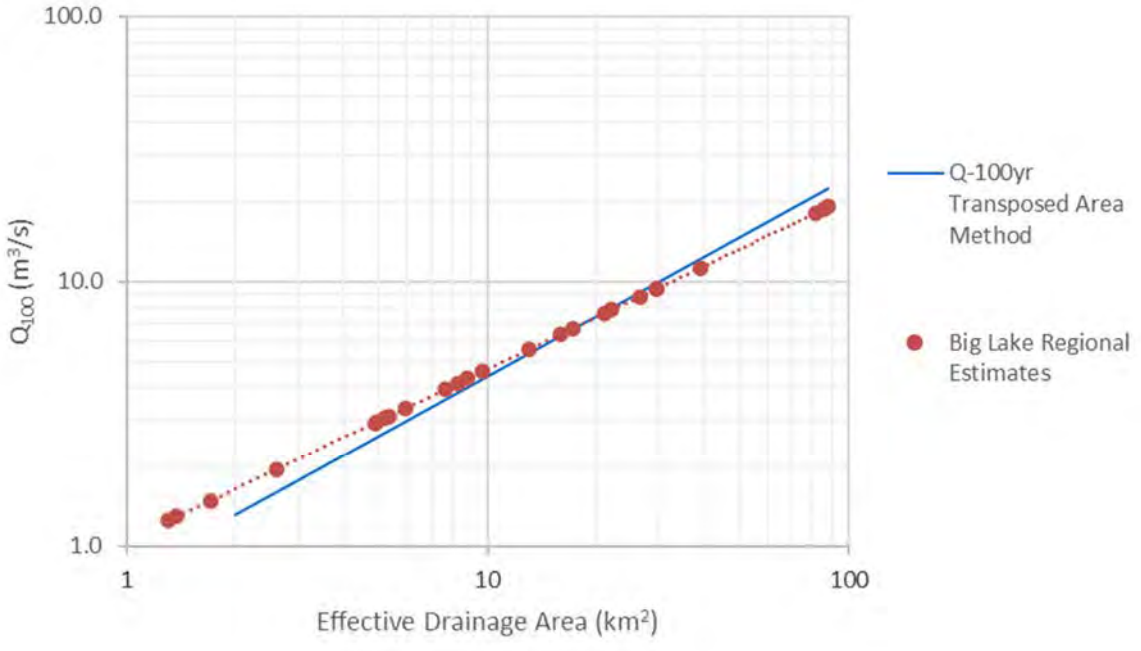


Figure 6-3 Estimate 100-year Return Period Flow Rates

6.2 HYDRAULIC MODELING

6.2.1 Objective

This section describes the hydraulic assessment that was conducted for Carrot Creek. The objective of the hydraulic modeling task was to delineate the 1:100-year flood risk boundary for Carrot Creek, assess the capacity of the creek to convey flows and to compliment the geomorphic assessment in identifying areas prone to erosion.

The hydraulic analysis was completed for the 1:5, 1:25 and 1:100-year flood events for the existing drainage conditions. The modeling did not consider the recently altered drainage path south of Township Road 544 and east of Highway 2, where the East Tributary of Carrot Creek has been diverted around the ongoing development in a constructed drainage ditch.

The 1:5, 1:25 and 1:100-year flood depths for Carrot Creek are provided within the study area at key locations from Cardiff Road south of Morinville to Big Lake. The flood depths were computed for all three return period events using US Army Corps of Engineers HEC-RAS two-dimensional (2D) hydraulic model (Version 5.0.7). The extents of the 1:100-year flood event are delineated and shown on maps in **Appendix H**.

As of 2021, Alberta Environment and Parks has not yet completed a flood hazard study for Carrot Creek. Any future flood hazard analysis by AEP may supersede the modeling completed for this study.

6.2.2 Approach

Stantec used the following steps for the hydraulic analysis:

- A HEC-RAS 2D model was used to simulate the return period flood events in Carrot Creek upstream of Villeneuve Road due to the lack of defined channel. The precipitation option of the model was selected as the upstream boundary condition.
- A HEC-RAS 1D model was used to simulate the return period flood events in Carrot Creek downstream of Villeneuve Road due to the hydraulic structures and their impacts on flood routing. The water surface elevation at Big Lake was selected as the downstream boundary condition.
- The LiDAR data and land survey data were merged to generate the terrain which constitutes the geometry for the model.
- The model was calibrated based on the flow discharges estimated for the flood events at the WSC Carrot Creek station (05EA011) in Section 6.1, at the downstream end of the model.
- The model results for different return periods were exported at critical locations identified in the geomorphic assessment (i.e. road intersections such as bridges and culverts). The results are summarized in tables, charts and figures in this report.
- General erosion protection recommendations were provided based on the flow velocity and shear stress at the critical locations.

6.2.1 Modeling Inputs

6.2.1.1 Terrain

The terrain consists of the LiDAR data sets as well as site survey of Carrot Creek south of Township Road 544 where the creek channel is defined, as noted in Section 2.0. These data sets were merged to incorporate survey into the LIDAR, where available, to create the geometry used in the model.

6.2.1.2 Flow Area

The 2D flow area for the model was created based on the model terrain. The survey data used in the model consists of 8 culverts, 5 bridges and 1 weir.

The 2D flow area mesh was generated in the model using the following cell spacing, to improve the quality of the results in the areas of interest:

- 5 m cell spacing along the channel and overbanks; and
- 50 m cell spacing in the floodplain.

The total number of cells in the 2D flow area was 783,000 cells. The calculation time with a computer equipped with a 3.70 GHz processor was approximately 96 hours.

6.2.1.1 Manning's Roughness

The Manning's roughness coefficients (Manning's *n*) were estimated based on site observations in the surveyed regions, Google Earth imagery in the un-surveyed regions and supporting literature (Chow, 1959). The Manning's *n* used in the HEC-RAS model include the following land use types for each section provided in Table 6-4.

Table 6-4 Manning's Roughness' used in the HEC-RAS Model

Section	Manning's Roughness, *n*
Channel	0.04
Immediate Overbank	0.06
Floodplain	0.06
Treed Areas	0.08

The geometry of Carrot Creek varies significantly throughout its entire reach. The following widths were estimated along different sections of Carrot Creek based on Google Earth imagery to account for the variation in Manning's roughness between the channel, overbanks, treed area. All remaining areas were considered to be the floodplain. These widths are provided in Table 6-5.

Table 6-5 Section Widths used in the HEC-RAS Model

Section	Channel Width (m)	Immediate Overbank Width – Total (m)	Treed Area Width – Total (m)
Big Lake to TWP 544	7	40	120
TWP 544 to Highway 37 – West Reach	4	8	30
TWP 544 to Highway 37 – East Reach	4	15	0
Highway 2 Ditch	4	10	0
Highway 37 to TWP 552 – West Reach, East Reach	4	15	0
TWP 552 to North End – East Reach	4	13	0
TWP 552 to North End – West Reach	3	5	0

6.2.1.1 Boundary Conditions

The boundary condition selected in the HEC-RAS 2D model was the unsteady state precipitation option. The Atmospheric Environmental Science (AES) storm distribution for precipitation was selected to distribute the rainfall over a 24-hour period to the entire catchment area. This option was selected because there was no defined channel at the north section of the watershed. The precipitation values were manually adjusted for the three return periods to match with the corresponding estimated discharge at the WSC hydrometric station provided in Section 6.1.3. The precipitation values were used to generate the return period discharges that are provided in Table 6-6.

Table 6-6 Boundary Conditions (Precipitation) used in the HEC-RAS Model

Return Period (Year)	Estimated Discharge at the Carrot Creek Hydrometric Station (m^3/s) [1]	24-Hour Precipitation (mm)
5	6.8	25
25	16.4	42
100	22.4	51

[1] Estimated return period discharge based on the values provided in Section 6.1.3.

The downstream boundary condition was selected based on the St. Albert Flood Hazard Study. The 1:5- year, 1:20-year and 1:100-year open water surface elevation at Big Lake were 651.6 m, 652.3 m and 653.2 m respectively (Matrix-Solutions Inc. 2020). The model is highly sensitive to this downstream boundary condition, and the impact of it propagates upstream to Meadowview Drive bridge, Old McKenney Avenue Bridge, CN Rail crossing and Villeneuve Road.

6.2.1.1 Modelled Structures

Stantec surveyed the structures listed in Table 6-7, Table 6-8 and Table 6-9. The survey data was used to set up the HEC-RAS model for culverts, weirs and bridges that were defined as critical locations. Where the survey and LIDAR had discrepancies in elevation, the LIDAR data was used in the HEC-RAS model surface to allow the model to run without continuity errors.

Table 6-7 Culvert Data used for the Model

Culvert	Location Coordinates (NAD 83 UTM Zone 12N)	Diameter (mm)	Length (m)	Upstream Invert (m)	Downstream Invert (m)	Type
TWP 544 East of Highway 2 Culvert 1	N 5951928 E 326311	600	14	686.681	686.589	CSP
TWP 544 East of Highway 2 Culvert 2	N 5951928 E 326311	600	14	686.695	686.602	CSP
Highway 2 Culvert	N 5951192 E 325684	3380 x 2150	70	685.369	685.393	CSP
Immediately West of Highway 2 Culvert	N 5951226 E 325599	3380 x 2150	22	684.402	683.808	CSP
RR 260 North of Highway 633	N 5949557 E 322329	3000	35	674.920	673.600	CSP
CN Rail Culvert 1	N 5946872 E 321338	1200	35	659.682	659.622	CSP
CN Rail Culvert 2	N 5946872 E 321338	1200	35	659.742	659.637	CSP

Table 6-8 Weir data used for the Model

Weir Location	Location Coordinates (NAD 83 UTM Zone 12N)	Length (m)	Width (m)	Weir Crest Elevation (m)
SE of TWP 544 and TWP 255	N 5951715 E 324232	10	6	682.241

Table 6-9 Bridge data used for the Model

Bridge Location	Location Coordinates (NAD 83 UTM Zone 12N)	Distance (m)	Width (m)	Low Chord Elevation (m)	High Chord Elevation (m)
TWP 544 West of RR 255	N 5952004 E 323841	5	10	684.3	685.3
Highway 633 West of RR 260 (Villeneuve Road)	N 5948842 E 322008	5	25	669.3	670.5
Old McKenney Ave	N 5946529 E 321074	5	8	660.5	661.1
Meadowview Drive	N 5945058 E 321676	6	8	654.9	655.4

6.2.2 Assumptions

The following assumptions were made for this hydraulic analysis:

- Water ponds generated by the model with a depth less than 0.1 m which are disconnected from the main Carrot Creek channel would eventually infiltrate into the ground and can be removed from the flood map. Water ponds with a depth between 0.1 m to 0.2 m disconnected from the main channel are considered as potential ponding areas and were denoted as a separate layer (**Appendix H**).
- Culverts, weirs and bridges were modelled to function and convey the flow during the flood event. It was assumed that they will not be blocked by debris, beaver dams or fail by overtopping.
- Hydraulic performance under ice jam scenarios was not included in the scope of this project.
- Climate change has not been considered in the hydrologic or hydraulic modeling tasks; it is recommended that climate change be considered during detailed design of any of the proposed infrastructure and improvements recommended in this study.
- The recently constructed North Erin Ridge ditch, culvert and storage (WSP, 2021) were not included in the HEC-RAS model.

6.2.3 Calibration

The model was calibrated using the aerial photography taken over Carrot Creek on April 23, 2020 at a preliminary estimated discharge of 9.96 m^3/s (Environment Canada 2021). Based on Stantec's hydrologic assessment (Section 6.1.3), this recorded discharge is approximately a 1:10 year flood event.

Since the computation time of the 2D model was long and a 1D model can more accurately model bridges, a HEC-RAS 1D model south of Villeneuve Road was calibrated to the flood event in April 2020. Then the 1D model was used to estimate the inundation extents for a 1:100-year event and calibrate the 2D model. The 1D model results were also used as the downstream boundary condition for the 2D model.

6.2.4 Results

The HEC-RAS model was setup for the three flood events (5-year, 25-year and 100-year) and the results were analyzed for the following: maximum depth, velocity and shear stresses.

The creek channel is not well-defined in the north of Township Road 544 and in the East Tributary of Carrot Creek upstream (east) of Highway 2. Thus, the inundation maps show a large area with shallow flows, less than 0.1 m depth in the floodplain.

In the southern reach of Carrot Creek, south of the confluence (south of Township Road 544), Carrot Creek is well defined. There are several key areas of concern noted in the model and in the geomorphic assessment in Section 5.2.2.1. These locations were overlayed onto the hydraulic modeling results and in many cases they were consistent with higher levels of depths, velocities and shear stresses. In addition to velocity, shear stresses in the channel are a function of both slope and flow depth. These output results are provided in Table 6-10 to Table 6-12 below.



Table 6-10 Hydraulic Parameters Estimated for 1:100-year Event (22.4 m^3/s) at the Critical Locations

Location	Maximum Flow Depth (m)	Maximum Flow Velocity (m/s)	Shear Stress (N/m^2)
TWP 544 East of Highway 2	0.8	1.5	65.0
Highway 2	1.5	1.2	3.4
RR 260 North of Villeneuve Road	4.9	7.7	106
Villeneuve Road	1.4	1.9	60.1
CN Rail Culvert	5.7	1.1	17.3
Old McKenney Avenue	2.3	2.2	141.5
Meadowview Drive	2.8	1.3	24.5

Table 6-11 Hydraulic Parameters Estimated for 1:25-year Event (16.4 m^3/s) at the Critical Locations

Location	Maximum Flow Depth (m)	Maximum Flow Velocity (m/s)	Shear Stress (N/m^2)
TWP 544 East of Highway 2	0.8	1.3	46.5
Highway 2	1.3	0.5	3.0
RR 260 North of Villeneuve Road	4.7	6.8	39.2
Villeneuve Road	1.2	1.8	56.7
CN Rail Culvert	5.2	0.9	12.3
Old McKenney Avenue	2.0	2.8	133.4
Meadowview Drive	2.6	1.2	21.9

Table 6-12 Hydraulic Parameters Estimated for 1:5-year Event (6.8 m^3/s) at the Critical Locations

Location	Maximum Flow Depth (m)	Maximum Flow Velocity (m/s)	Shear Stress (N/m^2)
TWP 544 East of Highway 2	0.7	1.2	31.0
Highway 2	1.0	0.2	2.9
RR 260 North of Villeneuve Road	4.5	2.1	22.0
Villeneuve Road	0.7	1.5	43.6
CN Rail Culvert	2.9	0.5	4.4
Old McKenney Avenue	1.3	2.2	101.5
Meadowview Drive	2.0	0.8	10.5



The results of the flood events found consistency in flow velocity and shear stress with the areas of concern noted in the geomorphic assessment in Section 5.2.2.1. In the 1:100-year event, the maximum flow depth is 5.7 m, the maximum velocity is 7.7 m/s and the maximum shear stress is 142 N/m^2, as shown in Table 6-10. Based on the hydraulic model results and field observations, preliminary erosion protection recommendations are provided in Table 6-13.

6.3 CREEK REMEDIATION RECOMMENDATIONS

The results of both the geomorphic assessment and hydraulic modeling were used to establish recommendations for potential erosion protection and culvert capacity increases along Carrot Creek. The locations outlined in Table 6-13 and identified on Figure 6-4 and Figure 6-5 were found to have capacity issues or erosion potential in the hydraulic modeling task and/or issues were observed during the field work conducted for the geomorphic study.

Some additional areas of erosion potential were identified in the hydraulic modeling task. However, if erosion issues were not observed during the field work, no improvements were recommended. It is likely the thick vegetation covering the banks of Carrot Creek has prevented erosion in some locations and no improvements are recommended at this time.

The improvements noted in Table 6-13 should be implemented by the municipalities within the Carrot Creek watershed (City of St. Albert, Town of Morinville and Sturgeon County) in order to proactively protect Carrot Creek from additional erosion caused by future development. Although peak flows will be controlled, the additional development will increase the volume of runoff (see Section 7) and erosion risk may increase in the future if these proactive measures are ignored. Some of the recommendations outlined in Table 6-13 are related to culvert sizing or where flooding is a concern from culvert blockages. The municipalities should include budget in future years to accommodate these recommendations, the timing of which will depend on the timing of proposed development. Note that any improvements to culverts or bridge crossings of Alberta Transportation roadways will need to follow Alberta Transportation's Bridge Conceptual Design Guidelines for bridges and bridge-sized culverts.

One of the key recommendations is for the three municipalities with jurisdiction in Carrot Creek (City of St. Albert, Town of Morinville and Sturgeon County) to agree to conduct erosion monitoring of the creek. Further discussion about the proposed erosion monitoring is found in Section 7.7.7.

Table 6-13 Preliminary Creek Erosion Protection and Culvert Recommendations

Location	Justification	Recommended Improvements	OPC ($ CAD) – includes 50% contingency and engineering
CN Rail Crossing	Modeling indicated backup of flow upstream of crossing and elevated erosion risk. Observed erosion and backwater. Flooding in April 2020 may be caused due to beaver dam blockage.	Add or upsize and replace culverts. The model was checked and the change made no significant difference in the output. Install riprap/bioengineering upstream (30 m) and downstream (130 m) of crossing.	$1,440,000
Meadowview Drive Bridge	Observed erosion and model indicated elevated erosion risk	Install riprap/bioengineering for ~160 m downstream of the bridge.	$1,200,000
RR 260 North of Villeneuve Road	Based on field observations of erosion.	Install riprap/bioengineering for ~50 m downstream of crossing.	$375,000
Highway 2 Crossing	Based on modeling results.	Possible need to extend existing riprap additional 30 m upstream of culvert. Erosion at this location can be monitored in the future to confirm if additional erosion protection is required or not (and may be impacted by the final configuration of the stormwater management of the East Tributary).	$225,000
Old McKenney Ave	Observed erosion and model indicated elevated erosion risk.	Install rip rap for ~ 40 m downstream of crossing.	$300,000
Carrot Creek Erosion Monitoring Program	Required to monitor creek erosion as development proceeds in the watershed.	Erosion monitoring Program at areas of concern from the geomorphic assessment (Section 5.2.2.1)	$25,000 / year

TOWNSHIP ROAD 544

HIGHWAY 2:
POSSIBLE NEED TO EXTEND RIP RAP ADDITIONAL 30m UPSTREAM OF CULVERT CROSSING (IF EROSION IS OBSERVED TO INCREASE)

2

TOWNSHIP ROAD 543

RANGE ROAD 255

RANGE ROAD 254

RANGE ROAD 260 CROSSING:
RIP RAP OR BIOENGINEERING FOR 50m DOWNSTREAM OF CROSSING

633

Carrot Creek

RANGE ROAD 260

NORTHRIDGE DRIVE

HOGAN ROAD

GIROUX ROAD

RAY GIBBON DRIVE



Landslides
Observed Erosion Areas
Municipal Boundary
Carrot Creek Centerline
HWY 2 Ditch
Major Road
Minor Road

0 300 600 metres

(At original document size of 11x17)
1:17,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location
Sturgeon County, Alberta

Prepared by AL on 10/27/2022
TR by CJ on 10/27/2022

Client/Project
110149416 - REVA

City of St. Albert
Carrot Creek Regional Master Drainage Plan Report

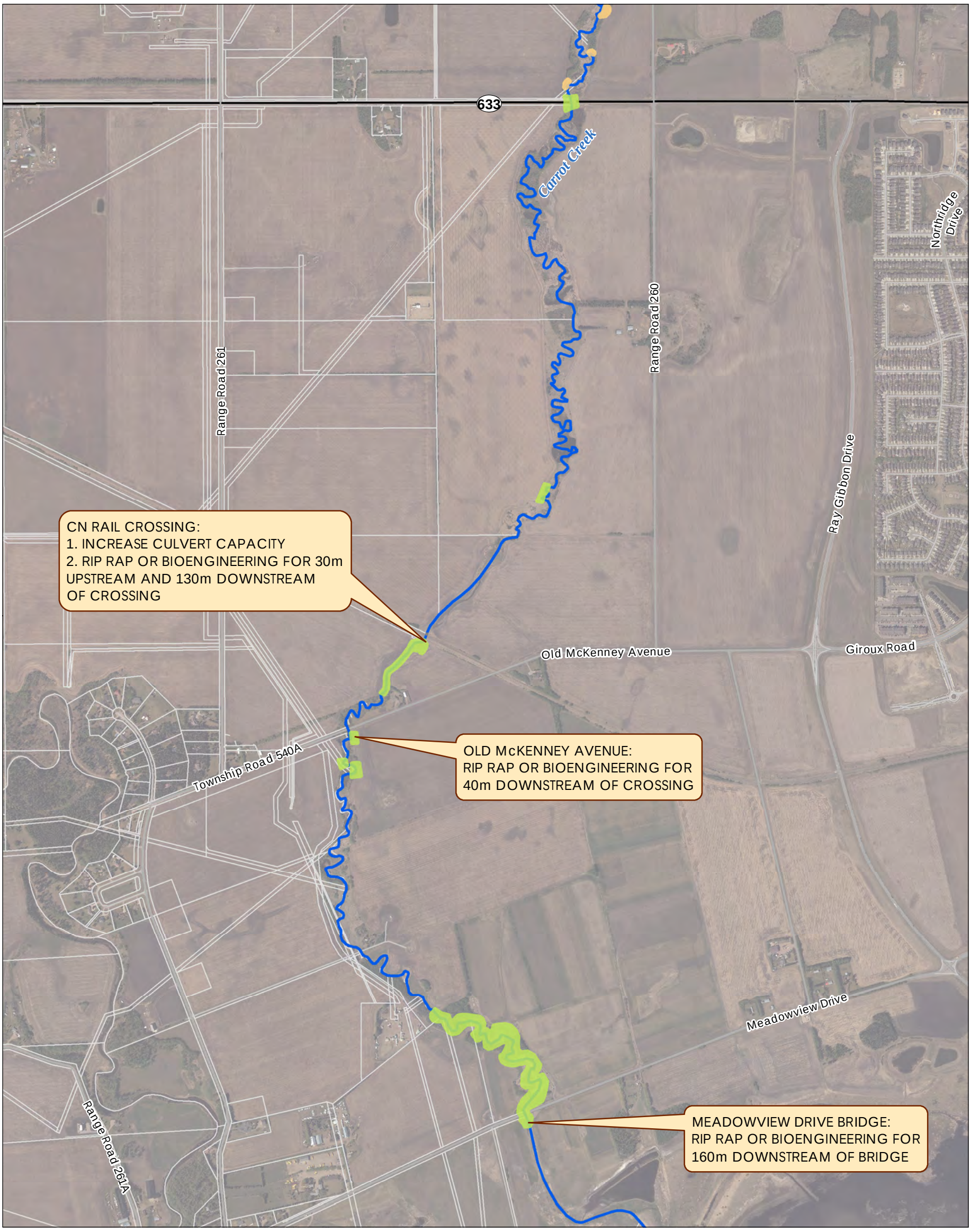
Figure No.
6-4

Title
Carrot Creek Restoration & Stabilization Project Areas (North)

Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
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), (c) OpenStreetMap contributors, and the GIS User Community 2015 Aerials from Sturgeon County

\\Cd1001-c200\workgroup\1101\active\110149416\drafting\figures\gis\90% Report\110149416_6-4_p_restoration_stabilization.mxd Revised: 2022-10-27 By: alelee

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Landslides
Observed Erosion Areas
Municipal Boundary
Carrot Creek Centerline
HWY 2 Ditch
Major Road
Minor Road

0 250 500 metres

(At original document size of 11x17)
1:15,000

N

Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
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), (c) OpenStreetMap contributors, and the GIS User Community 2015 Aerials from Sturgeon County

Stantec

City of St. Albert Planning and Engineering

Project Location
Sturgeon County, Alberta

Prepared by AL on 10/27/2022
TR by CJ on 10/27/2022

Client/Project
110149416 - REVA

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
6-5

Title
Carrot Creek Restoration & Stabilization Project Areas (South)

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7 STORMWATER MANAGEMENT ALTERNATIVE SERVICING PLAN ANALYSIS

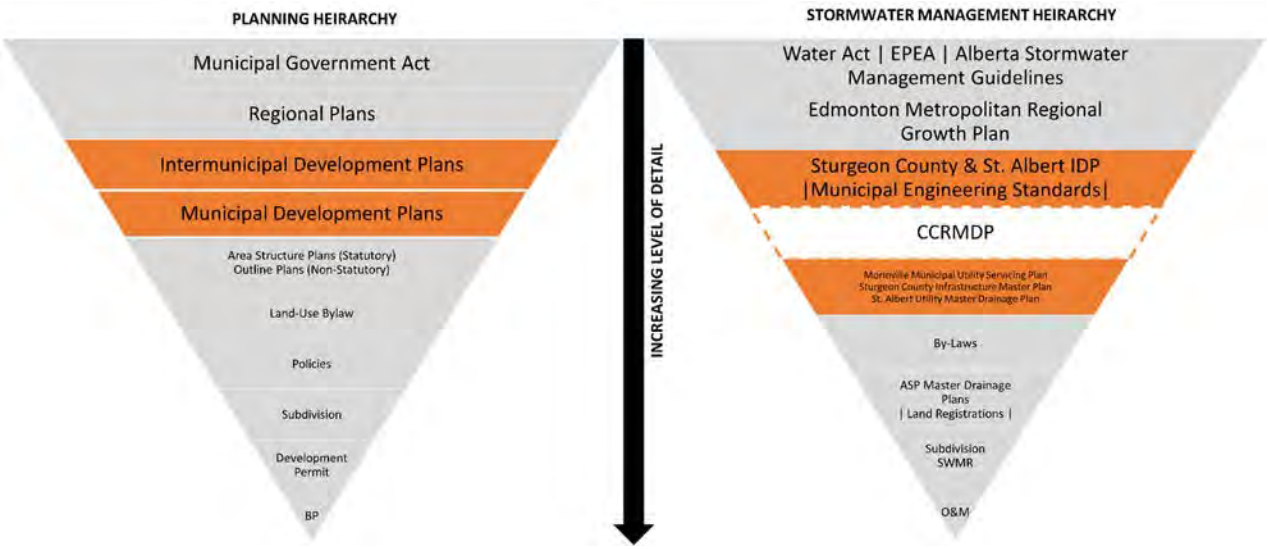
7.1 CONTEXT

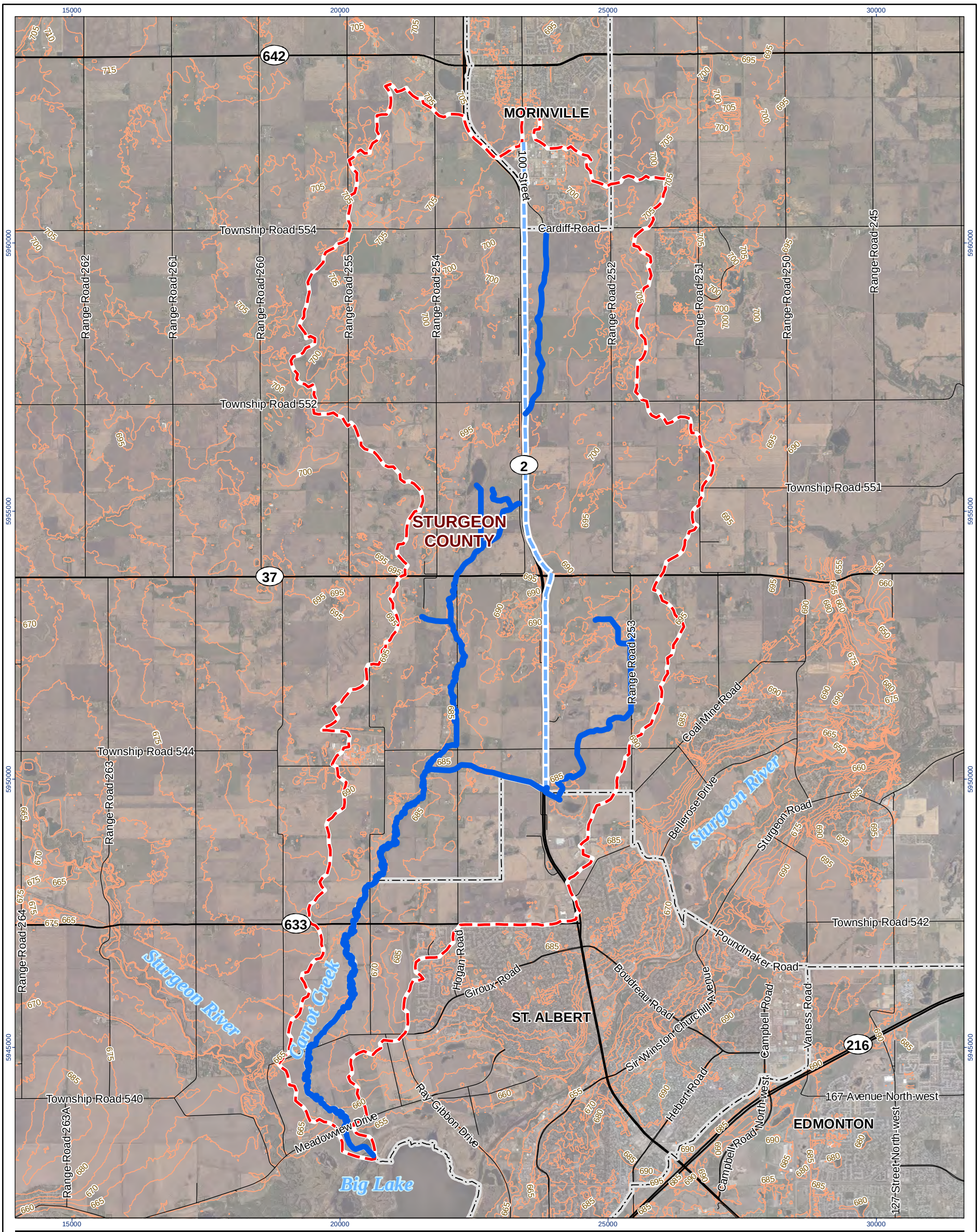
The stormwater management alternative servicing plans herein summarize the findings from previous studies in the Carrot Creek watershed boundary and results from hydrological analysis of future development scenarios in the basin. A series of stormwater servicing options were developed to address existing and future development impacts anticipated in the watershed. Costs shown are planning-level (budgetary) and include both costs that will likely be borne by the municipalities (e.g. proactive upgrades to Carrot Creek so that the creek can accommodate higher runoff volumes from future development) and by developers (e.g. stormwater management facilities). Stormwater servicing options should strike a balance between facilitating future growth and development in the Carrot Creek basin while also protecting the natural environment of Carrot Creek from adverse impacts such as elevated erosion.

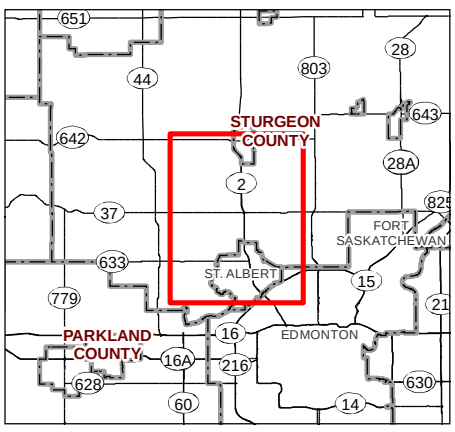
Stormwater management servicing options were assessed in the context of the Carrot Creek watershed boundary, existing topography information based on available LiDAR and survey data, existing available development plans on the fringe or overlapping with the Carrot Creek watershed boundary, and land-use and growth area GIS layers provided by the City of St. Albert, Sturgeon County, and the Town of Morinville. Figure 7-1 shows the study area considered for the stormwater management options, while Figure 7-2 shows the existing topography in the study area and Figure 7-3 summarizes the land use plan based on future projections provided by the City of St. Albert, Sturgeon County and Town of Morinville.

7.2 DOCUMENT HEIRARCHY

A visual representation of the hierarchy of planning and stormwater management documents at the municipal level is provided in an infographic below:







Municipal Boundary
Carrot Creek Centerline
HWY 2 Ditch
Major Road
Minor Road
5m Contours
Watershed Boundary

0 1,400 2,800 metres

(At original document size of 11x17)
1:73,222

N

Notes

1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
3. Background: 2015 Aerials from Sturgeon County

Stantec

City of St. Albert Planning and Engineering

Project Location	Prepared by AL on 4/20/2021
Sturgeon County, Alberta	TR by BS on 4/20/2021
	IR Review by FK on 4/20/2021
Client/Project	110149416-7-2 REV A

City of St. Albert
Carrot Creek Regional Master Drainage Plan
Report

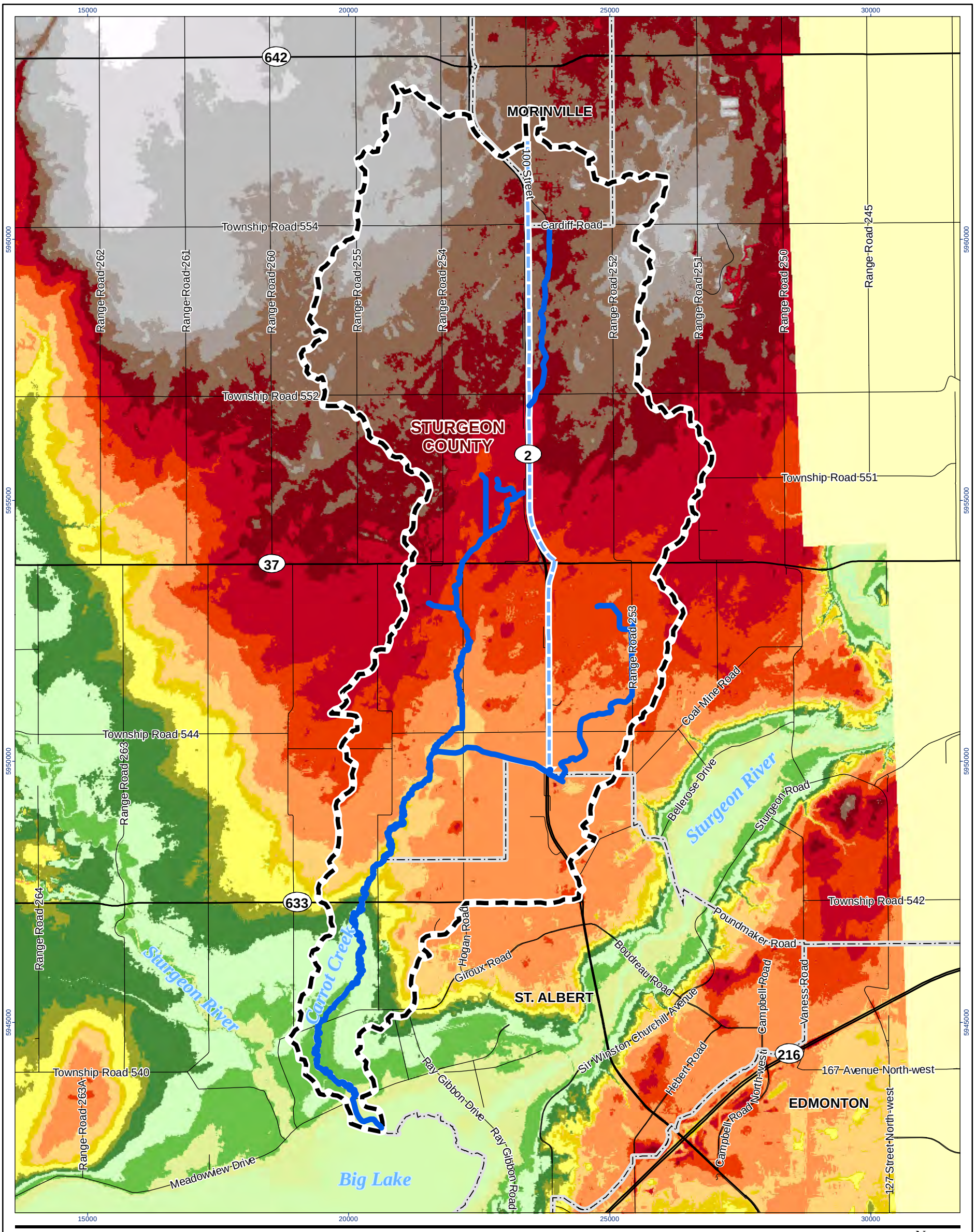
Figure No.
7-1

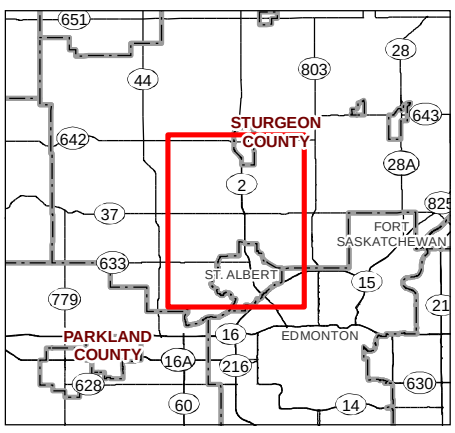
Title
Study Area

Revised: 2021-04-20 By: alelee

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Watershed Boundary
Municipal Boundary
Carrot Creek Centerline
HWY 2 Ditch
Major Road
Minor Road

Elevation Gradient (m)

- 648 - 649
- 650 - 652
- 653 - 658
- 659 - 664
- 665 - 670
- 671 - 672
- 673 - 675
- 676 - 678
- 679 - 681
- 682 - 684
- 685 - 690
- 691 - 693
- 694 - 695
- 696 - 698
- 699 - 701
- 702 - 704
- 705 - 710
- 711 - 716
- 717 - 721
- No Data

0 1,400 2,800 metres

(At original document size of 11x17)
1:75,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location	Prepared by AL on 4/20/2021
Sturgeon County, Alberta	TR by BS on 4/20/2021
	IR Review by FK on 4/20/2021
Client/Project	110149416 - 7-2 REVA

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
7-2

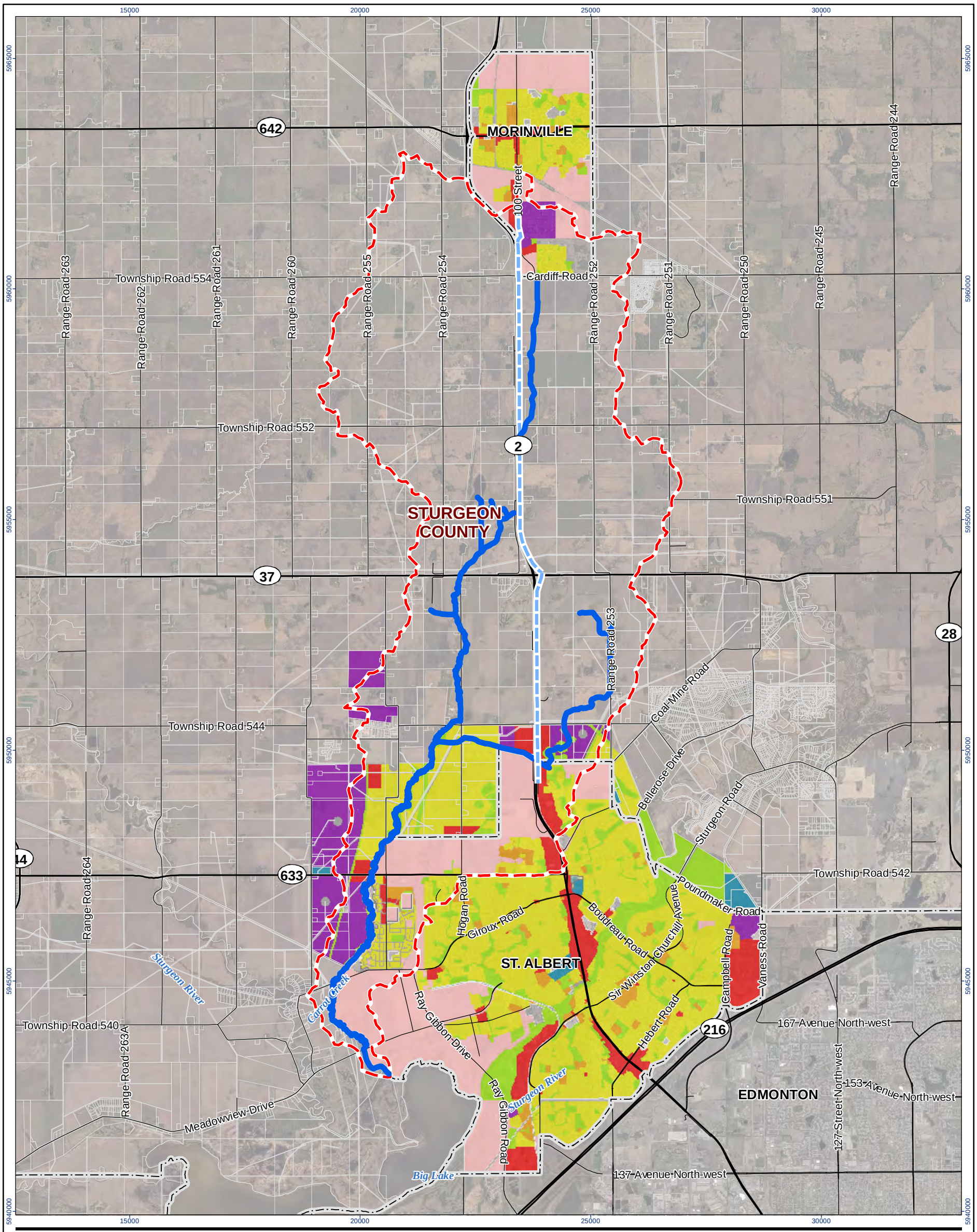
Title
Topography

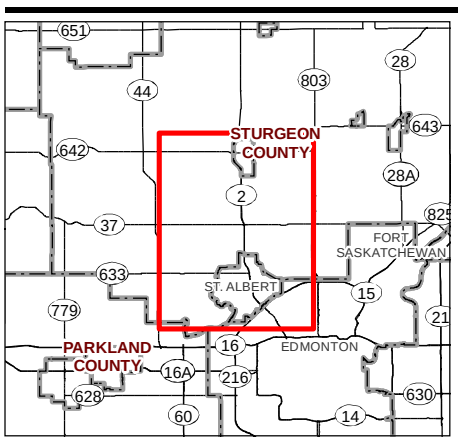
Notes
1. Coordinate System: NAD 1983 3TM 114
2. Elevations classified by Natural Breaks.
3. Data Sources: St. Albert, Morinville, AEP, Stantec
4. Background:

Revised: 2021-04-20 By: alelee

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Municipal Boundary
Watershed Boundary
Cadastral
Carrot Creek Centerline
HWY 2 Ditch
Major Road
Minor Road

Zoning

Land Use Type
Residential
Commercial
Industrial
Institutional

Public Utilities
Parks and Open Spaces
Future Development Area
Private
Urban Reserve
Direct Control

0 1,600 3,200 metres

(At original document size of 11x17)
1:85,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location	Prepared by AL on 5/9/2021
Sturgeon County, Alberta	TR by BS on 5/9/2021
	IR Review by FK on 5/9/2021
Client/Project	110149416 - 7-3 REV A

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
7-3

Title
Land Use Plan

Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: St. Albert (Land-use shapefiles, October 2020), Morinville (Land-use shapefiles, January 2021)
3. Background: 2015 Aerials from Sturgeon County
4. Areas where land-use information was not provided but there is overlap with developed sub-catchment areas in Figure 7-5, 7-6, or 7-7 were assumed Urban Reserve

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The servicing concepts presented in the CCRDMP provide the context for which future area structure plans (or neighborhood plans), future stormwater management plans, and future stormwater infrastructure construction plans must comply in the Carrot Creek basin area.

7.3 DESIGN BASIS

The stormwater management alternatives in Carrot Creek should have the following attributes:

- Facilitate future development to proceed in a cost-effective manner from a stormwater management perspective
- Protect Carrot Creek from excessive human-caused erosion
- Address the identified areas of concern along Carrot Creek including areas of higher erosion potential and culvert capacity limitations as identified in the geomorphic assessment and hydraulic modeling tasks

The stormwater management servicing concepts are developed based on the following guidance documents:

- Alberta Environment; Stormwater Management Guidelines for the Province of Alberta; January 1999
- City of St. Albert; Municipal Engineering Standards; updated June 2015
- EPCOR (City of Edmonton) Design and Construction Standards: Volume 3 Drainage; August 2020 (used design rainfall events from EPCOR Standards as City of St. Albert standards do not contain any)
- Sturgeon County; General Municipal Servicing Standards; May 2002 [amended May 2009]
- Town of Morinville Municipal Engineering Standards; December 2003 [amended March 2005]
- The background studies review and understanding of existing works occurring in the basin.

7.3.1 Major & Minor System Design Criteria

The recommended minimum design criteria to apply to stormwater major systems (conveyance and storage) are based on the City of St. Albert Municipal Engineering Standards (2015) since they are currently the most descriptive and readily available standards in the Carrot Creek basin:

- The major system shall be designed to accommodate runoff generated by a 1:100-year rainfall event.
- The maximum depth of peak flows and ponding shall not exceed 150 mm on arterial roadways.
- The design must include an analysis of the capacity and characteristics of the downstream receiving drainage course and identification of any measures to be completed to prevent downstream flooding and/or for erosion and sediment control.

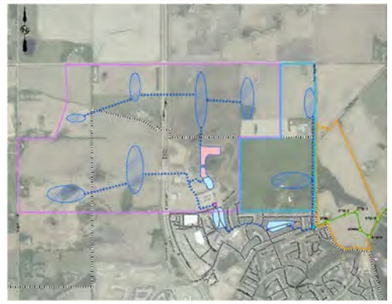
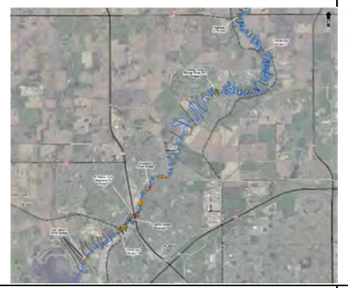
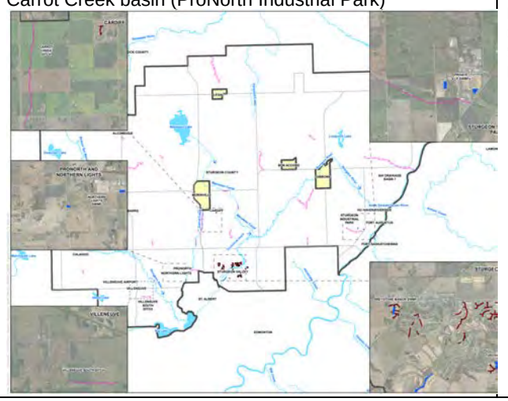
- Major system conveyance components must provide continuous overland flow routes to a designated receiving watercourse.
- Overland flow routes shall accommodate design flows plus anticipated overflows from stormwater management facilities.
- The depth of peak flows and ponding for major system conveyance components (i.e. roadways, channels, etc.) shall be limited to prevent significant hazard to the public, property damage, and erosion to the permissible depth versus velocity (AEP, 1999) and to the extent of minimum freeboard (AEP, 1999).

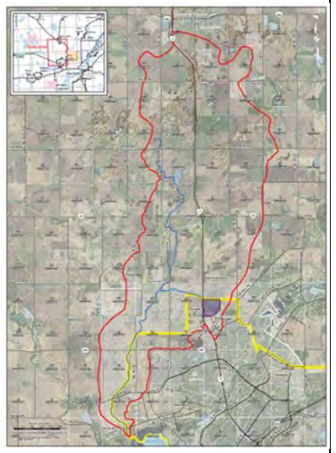
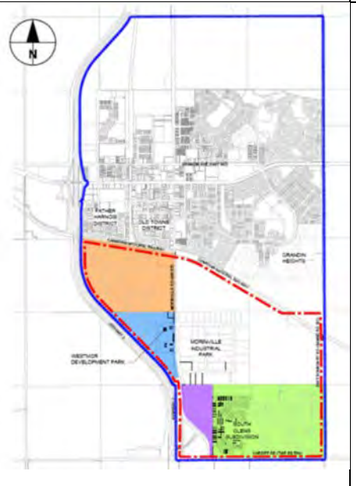
Proposed diversion storm trunks that are required for some of the stormwater servicing options in the Carrot Creek basin are conceptual only. Major system components (e.g. storm ponds) were designed for the 100-year 24 hour rainfall event and were modeled with consideration for additional capacity for emergency conditions. Further analysis is required during subsequent design stages.

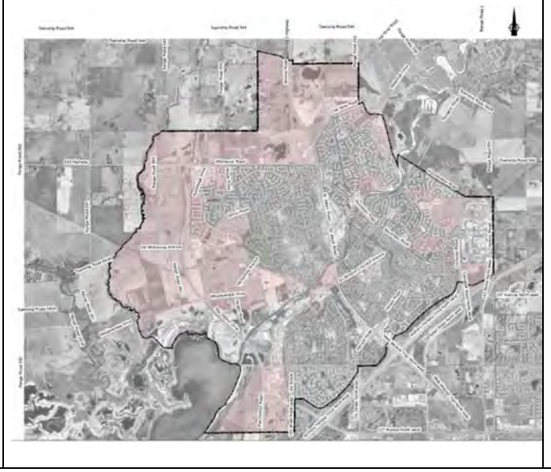
7.4 BACKGROUND STUDIES

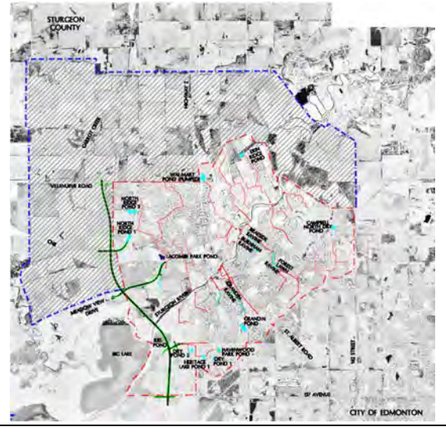
A review and brief summary of relevant previous stormwater studies in the Carrot Creek watershed to support the design basis and development of future stormwater servicing strategies is provided in Table 7-1.

Table 7-1 Supporting Stormwater Studies Review Highlights

Index	Study Title	Project Description	Study Area	Watershed / Outfall	Recommended 100yr Release Rate(s)	Notable Development Constraints	Additional Highlight(s)
1	City of St. Albert Northeast Area Storm Sturgeon River Outfall Predesign Report (Associated Engineering, 2020)	— Preliminary design of a stormwater storm trunk that supports future development north and northeast of Erin Ridge North community due to existing capacity constraints in the existing stormwater minor system. — Storm trunk accommodates future development and provides some relief to the existing stormwater minor system by capturing discharge from existing Edgewater Pond.	 — 7.5 quarter sections north of the existing Erin Ridge North community in St. Albert — "The Key Cross" development area (~65ha) to the northeast of Erin Ridge North	Sturgeon River	2.5 L/s/ha (1.98 m^3/s to new stormwater trunk and outfall)	— Private property impacts. — Land acquisitions and utility ROWs — Existing utilities (crossings) — Regulatory review timelines — Depth/grades of proposed trunk	— No accommodation for existing ~30 km^2 undeveloped contributing drainage area from Sturgeon County (east of Hwy 2) to the north of the study extents. Assumed diverted east to Sturgeon River (separately) based on consultant's discussions with St. Albert and review of WSP Carrot Creek MDP.
2	St. Albert Flood Hazard Study Sturgeon River (Matrix Solutions Inc., 2020)	— Government of Alberta Flood Hazard study to update Sturgeon River flood mapping through St. Albert including portions of Sturgeon County	— Study extends from Big Lake to the Highway 37 bridge along the Sturgeon River — Approx. 2680 km^2 drainage basin including Carrot Creek, Atim Creek, & Big Lake 	Sturgeon River	90 m^3/s (total river flow)	— Flood mapping indicates development constraints within St. Albert and portions of Sturgeon County, however recommended benchmark unchanged (100-year)	— Big Lake provides significant flood peak attenuation to St. Albert based on recorded extreme event hydrometric station data.
3	Sturgeon County Infrastructure Master Plan (ISL Engineering, 2019)	— Infrastructure Master Plan for Sturgeon County accommodating growth area projects in various locations across the County	— Spread across Sturgeon County, with one area in the Carrot Creek basin (ProNorth Industrial Park) 	Sturgeon River, Atim Creek, Big Lake, Carrot Creek, North Saskatchewan River	2.5 L/s/ha for Carrot Creek; various (1-7 L/s/ha) for other watersheds and rivers in the study boundary	— Availability of downstream infrastructure (i.e. missing or extensive connections to downstream watercourses or ponds) — Existing flooding and undersized existing drainage ditches/culverts/ponds — Non-residential growth (increased employment) projected in ProNorth Industrial Park (Carrot Creek drainage basin)	— Additional SWMF proposed in existing development areas to meet release rate restrictions — Cardiff growth area proposed to release to evaporation pond with emergency spill to a park area (southeast of Morinville)

Index	Study Title	Project Description	Study Area	Watershed / Outfall	Recommended 100yr Release Rate(s)	Notable Development Constraints	Additional Highlight(s)
4	Carrot Creek Drainage master plan (WSP, 2018)	— City of St. Albert and Sturgeon County wanted a Drainage master plan for Carrot Creek which identified current hydrologic and hydraulic status of Carrot Creek, assessed Carrot Creek's capacity for receiving water without causing adverse flooding or erosion, and recommendations on water management strategies that could be implemented to mitigate impacts of urbanization.	— Carrot Creek basin extends from Morinville through Sturgeon County and portions of north and northwest St. Albert with the final confluence at Big Lake. — Study is broken into 3 main basins: 1. Lower Basin (1630 ha) 2. West Branch Basin (2434 ha) Just North of St. Albert to Morinville following the west side of Highway 2 3. East Branch Basin (4622 ha) Just North of St. Albert to Morinville following the EAST side of Highway 2 	Carrot Creek	Big Lake release rate: 2.5 L/s/ha	— Various drainage works exist in the basin: the most significant of which is the Highway 2 ditch to convey runoff from the south portion of Morinville directly to the upstream end of Carrot Creek; there is a culvert at Highway 2; a weir west of Erin Ridge North Wetland; a culvert at the CN Railway crossing; and a culvert at Range Road 260. — Creek flows and flooding impacts private property — Runoff from post development must either be diverted, further attenuated, or a combination. — The proposed changes to Erin Ridge North would remove the current wetland which has an approximate storage capacity of 124,700 m^3 during a 1:100 year, 24 hour event	— Consider a flow monitoring program — Recommends the parallel storm trunk proposed in the 2013 UMP and the Highway 2 drainage diversion measure as the most feasible. — Potential neighborhood development in Erin Ridge North area (North point of St. Albert) — Pre- and post-development floodplain limits in relation to Erin Ridge North area were similar and determined not to exacerbate the hydraulic conditions in Carrot Creek. — The parallel storm trunk would divert flow from Carrot Creek providing an indirect benefit to erosion control and protection. The overall volume introduced to Big Lake would not be changed/modified.
5	Municipal Utility Servicing Plan Stormwater Management Plan Update (Revision 1) (AECOM, 2016)	— Town of Morinville stormwater management plan performance review, flood mitigation strategies, and development of a Stormwater Management Plan based on future development.	— Town of Morinville development boundary and contibuting drainage areas south of the CN rail line. Majority of areas north of the CN rail line contribute to the Manwan Canal. 	Tributaries of Carrot Creek (Highway 2 ditch and other tributary south of Township Road 554)	Provides design options based on 2.5 L/s/ha, 1.9 L/s/ha, and 1.65 L/s/ha discharge rates for development flexibility.	— Stormwater management facilities have to be pumped to the downstream receiving waterbodies.	— Existing capacity constraints of the downstream receiving water bodies was not conducted

Index	Study Title	Project Description	Study Area	Watershed / Outfall	Recommended 100yr Release Rate(s)	Notable Development Constraints	Additional Highlight(s)
6	Alberta Transportation Final Report #R-1192 Highway 2 Network Review (ISL Engineering and Land Services, 2015)	— Highway 2 network review — Transportation network review of suitable alignment of a free-flow connection from Highway 2 at Morinville to St. Albert (Ray Gibbon Drive). As part of the network review, alignment and network options for local road was carried out in the study area. — Included geotechnical study	— The study area incorporates a 6.0 mile (~9.7 km) wide area from Morinville to the north of St. Albert (Highway 633) with the existing Highway 2 running north-south in the middle of the study area. 	Carrot Creek	None recommended. Descriptive report only. Future realigned Highway drainage would be managed through ditches, culverts, and a storm pond prior to release to Carrot Creek. Anticipated pond and discharge point in the lower reach of Carrot Creek near the future Highway 633 interchange (Villeneuve Road).	— Existing Highway 2 drainage follows the existing roadside ditches immediately south of Morinville in the southerly direction. Past Highway 544, ditch drainage from the north portion of the Highway joins a water course / ditch draining east-west (a tributary of Carrot Creek). — A secondary drainage ditch originates east of the Highway 2 ditch south of Morinville and eventually crossing Highway 2 approximately 1 quarter section south of Highway 544. — Future realigned Highway grading / profile to generally follow existing grades, except where major interchanges / overpasses are proposed at major road crossings.	— Topography is relatively flat.
7	City of St. Albert 2013 Utility Master Plan Update (Stantec, 2014)	— Update to the 2008 UMP — Water, Wastewater, and Stormwater utilities system improvements and future system servicing strategies to inform the City of St. Albert's long term infrastructure requirements, offsite levies programs, and long-term capital planning to service new development areas	— All areas within the City of St. Albert City Boundary (Inter-municipal Development Plan areas in Sturgeon County were remove for final report) 	Sturgeon River, Carrot Creek, Big Lake	1.9 L/s/ha, 2.5 L/s/ha, 10 L/s/ha depending on servicing scenario. — Direct inflow of 1.9 L/s/ha (to Carrot Creek) and 2.5 L/s/ha (to Big Lake / Sturgeon River) — Northwest areas east of Carrot Creek recommended release rate of 10 L/s/ha when discharging to new storm trunk. All other areas 2.5 L/s/ha	— 1937, 1978, and 100-year 24 synthetic design storm used to size storm ponds — Predevelopment hydrology assessment for flow frequencies of Carrot Creek based on gauged station data available was 1.9 L/s/ha for the 100-year — Future growth scenarios for 2017, 2022, 2032, & 2042 evaluated using Traffic District Zoning projections — Some of the Northwest catchment in the Carrot Creek basin is diverted south through the existing Deer Ridge Storm Sewer — East Growth areas and IDP north catchments diverted to Sturgeon River through new outfall.	— Much of the infrastructure required for growth is developer funded. Offsite infrastructure is funded by the municipality. — LID recommended to be integrated with improvement projects and new growth infrastructure to enhance water quality. — To meet sediment removal obligations under AEP standards, wet ponds or wetlands are recommended for the future SWMFs. — Oil and grit separators are also recommended to reduce TSS loading. — Erosion and conveyance limitations of Carrot Creek the main reason to discourage future development discharges to the Creek.

Index	Study Title	Project Description	Study Area	Watershed / Outfall	Recommended 100yr Release Rate(s)	Notable Development Constraints	Additional Highlight(s)
8	Sturgeon County Sturgeon Valley Stormwater Update Final Report (Sameng Inc., 2013)	— Identify and analyze the existing stormwater infrastructure, including culverts, outfalls and drainage channels for the entire Sturgeon Country Study Area — Develop a stormwater management plan for the undeveloped land along the Valley, adjacent to the City of St. Albert, and on the north side of the City of Edmonton. — Recommend a stormwater levy and identify phasing options and potential conflicts with future road plans.	— Sturgeon valley is located on the south-central region of Sturgeon County. The area borders the City of Edmonton to the south and the City of St. Albert to the west. Sturgeon Valley currently has a mix of country residential and agricultural land uses. 	Sturgeon River	2.5 L/s/ha Recommended stormwater release rate for the Big Lake Basin (Associated Engineering, 2004).	— Existing infrastructure consists of storm sewers, ditches, stormwater management facilities, natural channels, and culvert crossings. — Most of the culvert crossings inspected in this study had an estimated capacity more than the 2.5 L/s/ha of the post development control target. There are no reported flooding problems resulting from small culverts.	— SWM Ponds required in new development sub-basins. — Recommends building 4,300 m of pipe and 1,100 m of ditch in the West Study Area as there is more flexibility in construction, provides better service to a larger area, and has more opportunity for water quality improvements. — Install oil/grit separators at storm sewer outfalls to reduce sediment discharge to the river.
9	Big Lake Stormwater Management Plan (Associated Engineering, 2004)	— Big Lake Basin drainage review for problems and recommended stormwater management guidelines for development	— Big Lake Basin, which encompasses 3,500 km^2 east of St. Albert and is composed of 8 municipalities. Land uses include a mix of agricultural, urban, country residential, and recreational development — Carrot Creek basin (contributing) indicated as 87 km^2 (8,700 ha)	Big Lake / Sturgeon River	2.5 L/s/ha	— Floodplain should contain 100-year design event + 0.5 m factor of safety and should be protected and preserved. — Big Lake Design Flood level of 654.18m — Development scenarios with growth projections and discharge rates up to 5 L/s/ha statistically do not indicate adverse impact to 100-year Big Lake water level	— Older areas without stormwater management should be upgraded. — Impact of improved agricultural practices should be monitored.
10	City of St. Albert Stormwater Management Master Plan (Associated Engineering, 2004)	— Assess the capacity of the storm drainage system for present and future needs of the city and recommend practices and policies for stormwater management, floodplain management, and sediment management within the Sturgeon River.	— Study area includes a mix of agricultural, urban, country residential, and recreational development. 	Sturgeon River & Big Lake	2.5 L/s/ha (proposed for all new basins as recommended in the Big Lake Basin Drainage Study)	— The pilot trunk sewer inspection program (6,000 m) revealed that the storm trunk drainage system is in reasonably good structural condition, but some portions require repairs due to cracked pipes and other deficiencies before they lead to more serious problems. — One pilot oil-and-grit separator has been constructed and has been highly effective. Construction of 23 more oi-and-grit separators scheduled over next 10 years (starting in 2004). — Recommended minimum design flood elevation on Big Lake is 654.18m	— Installation of an inflatable weir in the Sturgeon River, downstream of St. Albert, could be a feasible means of maintaining a minimum depth of water in the Sturgeon River and in Big Lake.

7.5 METHODOLOGY

The stormwater servicing options were developed using the following general approach:

1. Gather and process background data for use in GIS (including but not limited to cadastral, orthophoto, LiDAR, topographical survey data, reports and available existing infrastructure design data, land-use and growth areas, etc.)

2. Process information obtained from data files and reports, create digital elevation model, and run GIS tools to develop:

    a. overland flow paths

    b. sub-catchment boundaries

    c. existing natural depressions storage areas
    (*based on specific depth and inundation area parameters using GIS tools and does not necessarily correspond to the wetlands mapped in Section 4 of this study*).

    d. stormwater model input parameters (hydrology and hydraulic layers)

3. Develop stormwater servicing options in accordance with planned development and growth within the Carrot Creek basins. Document characteristics of stormwater servicing options for assessment and comparison. The unit area release rate (UARR) of stormwater runoff from developed areas is one of the components to be considered in the stormwater servicing options.

4. Create stormwater model to simulate the stormwater servicing options based on specific development characteristics.

5. Tabulate results and compare estimated flows in Carrot Creek at the mouth of Big Lake to existing condition 100-year frequency analysis result estimated in the hydrology review (see Section 6.1).

6. Generate concept-level opinion of probable costs for the stormwater servicing options for the purpose of comparing different options.

7. Based on the model results, opinions of probable cost and consultation with the City of St. Albert, Sturgeon County and Town of Morinville, determine the preferred stormwater servicing strategy for the Carrot Creek basin.

7.6 MODEL INPUT PARAMETERS

PCSWMM Professional (Version 7.4.3220) is a rainfall-runoff model that uses the computational engine of US EPA SWMM5. It is used to simulate stormwater flows under specific rainfall events in model elements created by the user. This is a *discrete* model that can analyze dual drainage systems (major and minor networks). The user's manual (CHI, 2013) provides a detailed description of the US EPA SWMM5 model.



Under proposed future development conditions, stormwater flows were simulated using PCSWMM for specific reaches of Carrot Creek including the East Tributary, for proposed stormwater management facilities and their controlled discharges, and stormwater trunks created to divert flows under specific servicing options.

7.6.1 Design Storms

Both single event design storms and continuous simulations (using several decades of rainfall data) were simulated. The single event design storms used for the assessment of stormwater servicing options and the development of concept-level stormwater management facility sizing are based on the following storm events:

- City of Edmonton (EPCOR) 100-year 24-hour Huff Distribution design storm
- City of Edmonton 1978 design storm

The sizing of storm ponds in this study is based on the 100-year single event. The 1978 design storm was found to be a more severe design storm, resulting in larger storage volumes. As such, the 1978 event was simulated to confirm containment in the freeboard of the proposed stormwater facilities.

Continuous simulation modeling was used to compare flow regimes in Carrot Creek for various stormwater servicing options, and to compare simulated flows to existing hydrometric station (05EA011) frequency analysis results. Continuous simulation is useful for evaluating how the frequent day-to-day flows in Carrot Creek vary from one stormwater servicing option to another (whereas the single event design storms only consider infrequent and high flow events). The continuous simulation modeling uses available climate data and assumptions. The following data were utilized for the continuous simulations:

- City of Edmonton 1961-2018 hourly precipitation rainfall intensity (Edmonton International Airport Weather Stations 3012205 & 3012206)
- City of Edmonton 1961-2018 hourly temperature data (Edmonton International Airport Weather Stations 3012205 & 3012206)
- City of Edmonton Shallow Lake Evaporation monthly estimates (Alberta Environment and Sustainable Resource Development, 2013)
- City of Edmonton average monthly wind speeds (Edmonton International Airport Weather Stations 3012205) Surface Runoff

7.6.2 Land-Use & Imperviousness

The following planning documents and layers were considered in the development of land-use and imperviousness assumptions for future growth areas within the Carrot Creek basin:

- Future land use and development plans in St. Albert: GIS land-use polygon layers were provided within the St. Albert municipal boundary and growth areas in the Intermunicipal Development Plan (IDP) areas along the border with Sturgeon County. These include planned growth in the north and west areas of St. Albert that are within the existing Carrot Creek basin.



- Future land use and development plans in the Town of Morinville: GIS land-use polygon layers were provided by the Town in October 2020 for areas within the municipal boundary. It was assumed that the south end of Morinville, which contributes stormwater to Carrot Creek, was fully developed according to current zoning. Additional growth area projections outside of the existing town boundary were discussed, but it was deemed too early, at the time of this study, to anticipate potential annexation.

- Future land use and development plans in Sturgeon County: The County's Infrastructure Master Plan (ISL, 2019), including growth areas in the Pro North Industrial Area which is in the Carrot Creek basin, were considered. At this time, no additional growth and development is anticipated in the Sturgeon County portion of the Carrot Creek basin (other than the Pro North Industrial Area).

- Edmonton Metropolitan Regional Growth Plan, developed by the Edmonton Metropolitan Region Board (EMRB) effective October 2017, indicated the Carrot Creek basin overlaps with the Metropolitan Area and Rural Area policy tiers. The 2044 growth horizon (Schedule 2) shows no anticipated development expansion in the Sturgeon County portion of the basin, except for the Pro North Industrial area. The Sturgeon County portion of the Carrot Creek basin is mostly in the rural policy tier area[5].

Land-use planning layers (Figure 7-3) were used as a basis for imperviousness in existing and future development areas. Table 7-2 indicates the baseline parameters used for determining weighted imperviousness for sub-catchment boundaries based on land-use type.

Table 7-2 Land-use Imperviousness Matrix

Land Use Type	Imperviousness (%)
Single Family (SF) Residential	60
Multi-Family (MF) Residential	85
General Residential (average of SF and MF)	72.5
Commercial	90
Industrial	90
Institutional	90
PUL (permanent waterbodies)	100

In general, undeveloped agricultural and country residential areas in Sturgeon County were assigned a 5% weighted imperviousness. Riparian areas subject to flooding were assigned a 25% weighted imperviousness.

[5]One of the policy objectives determined through the EMRB Growth Plan is to "*identify and conserve an adequate supply of prime agricultural lands to provide a secure local food source for future generations.*" Prime agricultural lands are slated to be identified through a Regional Agricultural Master Plan (RAMP), which is ongoing. In alignment with Schedule 2, these areas are considered undeveloped (remain in predevelopment condition) under future stormwater servicing scenarios.

7.6.3 Infiltration and Depression Storage

Abstraction losses are accounted for in PCSWMM as soil infiltration using the Horton Infiltration Model and depression storage. For this study the following blended parameters were used:

- Maximum infiltration rate, F_0 = 40.0 mm/hr
- Minimum infiltration rate, F_c = 7.2 mm/hr
- Rate of Decay, k = 4.14 hr^{-1}

The study area contains urbanized, rural, and undeveloped agricultural land uses. The Horton parameters chosen are consistent with the medium size catchment blended parameters for maximum and minimum infiltration rates utilized in the City of St. Albert Utility Master Plan (Stantec, 2008). The blended parameters chosen for this planning-level study are not intended to supersede or replace typical Horton parameters utilized for urban catchments in the plan boundary. Infiltration parameters and models utilized for detailed studies in the Carrot Creek basin should be reviewed on an individual project basis, supported by site-specific geotechnical studies, and should align with the applicable development approval stormwater management guidance documents.

Depression storage are accounted for in PCSWMM using the following generally applied parameters:

- Undeveloped, agricultural and country residential developments:
    - Impervious areas = 3.2 mm
    - Pervious areas = 10 mm
- Developed or future growth areas:
    - Impervious areas = 3.2 mm
    - Pervious areas = 6.4 mm

For sub-catchments that contained significant surface depression storage features, captured by a GIS storage polygon delineation tool, additional depression storage was assigned to the sub-catchment to account for the depression volume.

7.6.4 Culverts & Weir

The culverts in Table 7-3 were included in the PCSWMM model using conduits and junctions along the Carrot Creek flow path.

Table 7-3 PCSWMM modeled Culvert Crossings

Culvert	Diameter (mm)	Length (m)	Upstream Invert (m)	Downstream Invert (m)	Type	Manning's roughness
Highway 37 on Carrot Creek Culvert 1*	1,600	53.1	689.84	689.62	CSP	0.024
Highway 37 on Carrot Creek Culvert 2*	600	23.6	691.1	691.14	CSP	0.024

Culvert	Diameter (mm)	Length (m)	Upstream Invert (m)	Downstream Invert (m)	Type	Manning's roughness
Highway 37 at Highway 2 Culvert*	3,200	92.3	687.039	686.828	CSP	0.024
Additional crossings along Highway 2 (5 Culverts, includes service roads, a township road and access roads**)** *	Box Culvert: 2,400 x 2,400 (span x width)	*Varies, based on GIS length*	*Varies, based on LiDAR elevation of Creek centeline upstream*	*Varies, based on LiDAR elevation of Creek centreline downstream*	CONC	0.013
TWP 544 west Highway 2 on Carrot Creek Culvert 1*	900	22.0	682.270	682.420	CSP	0.024
TWP 544 west of Highway 2 on Carrot Creek Culvert 2*	1,500	20.8	682.188	682.032	CSP	0.024
Highway 2 Culvert	3,380 x 2,150 *horizontal ellipse*	70	683.37	683.29	CSP	0.024
Immediately West of Highway 2 Culvert*	3,380 x 2,150	22	683.23	683.18	CSP	0.024
CN Rail Culvert 1	1,200	35	659.682	659.622	CSP	0.024
CN Rail Culvert 2	1,200	35	659.742	659.637	CSP	0.024

Note: *Different culverts and/or additional culverts compared to crossings used in the creek hydraulic assessment (HEC RAS). Based on survey data. Some crossing details were slightly modified to reduce routing errors in the model (to allow continuous positive drainage).

A bridge crossing at Highway 633 and Carrot Creek was modeled using a rectangular triangle in PCSWMM with a maximum depth of 6 m, top width of 20 m and triangle height of 0.3 m to represent the creek (similar to characteristics in Table 6-9).

Additionally, the weir on the East Tributary of Carrot Creek (west of Highway 2) was modeled with a conduit link in PCSWMM with the width, length, and invert details as indicated in Table 6-8, a Manning's n of 0.013, and entry loss coefficient of 3.33 using a trapezoidal weir transect and a cross section cut through the DEM to estimate side slopes.

Weir links can sometimes become unstable in PCSWMM. However, a weir link was used as a sensitivity check in a separate model using appropriate parameters to confirm the acceptability of the results using the conduit link. The peak results were similar, without the flow rate instability, and therefore the conduit link was used in the final model.



7.6.5 Storage Facilities

Storage nodes in PCSWMM represent future stormwater ponds in growth areas. Storm ponds were included in the model to store surface runoff on future development sites prior to discharge at an allowable release rate to Carrot Creek. The functional storage curves are calculated using the following equation:

$$Area = A * Depth^B + C$$

A, unitless coefficient
B, unitless exponent
C, constant area in m^2
Depth, in meters
Area, in m^2

Baseline assumptions for storage facility geometry:

- C-value (constant area) is treated as the bottom area of a dry pond or the normal water level of a wet pond.
- The maximum active storage depth is 2 m.
- The ponds are idealized as rectangles with a 2:1 length to width ratio.
- Side slopes are assumed uniform at 5:1 (H:V) from the bottom of the pond (or normal water level) to the freeboard.
- The minimum freeboard is 0.5 m.

Using these baseline assumptions, the A and B coefficients are estimated for each pond assuming the coefficients must match for the resulting equations at a depth of 1 m and 2 m.

For this regional study, the exact number of stormwater facilities, potential grading limitations that might lead to pumped versus gravity discharge scenarios, and downstream hydraulic grade line impacts are not included. Subsequent drainage studies that support area structure plans and detailed neighborhood design plans are required to confirm further details.

7.6.6 Storage Outlet Control

Orifice links in PCSWMM connect storage nodes to the downstream receiving watercourse (represented with junctions and conduits). The flow restriction through an orifice is calculated using the following equation and coefficient:

$$Q = CA\sqrt{(2g\Delta h)}$$

Q, restricted discharge rate in m^3/s
C, unitless discharge coefficient = 0.65
A, Area of orifice = πr^2 in m (r, radius of circular orifice opening in m)
g, acceleration due to gravity in m/s^2
Δh, head of water acting on the centroid of the orifice opening in m

The restricted discharge rate is determined based on the maximum allowable release rate for each servicing option.

7.6.7 Erin Ridge North Ditch, Culvert, & Storage

After engagement with St. Albert and other stakeholders at the 90% project stage, it was determined that a stormwater servicing option including a new storage area south of Township Road 544 and east of Highway 2 along the East Tributary should be considered (Option 4 in Section 7.7). There is currently a "temporary" depression storage in this area as depicted in the as-built information for the Erin Ridge North Berm, Ditch, and Culvert Construction (WSP, 2021), which is summarized in Table 7-4. This storage area is existing and was constructed north of the previously removed wet feature on the East Tributary east of Highway 2.

Table 7-4: Estimated Stage-Area and Stage-Volume Curve for Existing (2022) Temporary Erin Ridge Storage Area

Depth (m)	Area (m^2)*	Volume (m^3)
0	0	0
0.26	3,587	466
0.59	60,357	11,017
0.99	163,383	55,765
1.01	186,252	59,262

Note: *Estimated from available as-built (WSP, 2021) contours (PDF)

The as-built culvert and ditch was maintained in the assessment of this additional servicing option, but for the purposes of modeling, a functional curve was used to represent the theoretical storage (as several potential storage volumes were considered in Option 4). The functional conceptualized potential storage curve is calculated using the following equation:

$$Area = A * Depth^B + C$$

A, unitless coefficient
B, unitless exponent
C, constant area in m^2
Depth, in meters
Area, in m^2

The potential storage was conceptualized as a rectangular prism with the following parameters:

- A-value of 1
- B-value of 0
- C-value, treated as the bottom area of the storage facility, of 55,000 m^2.
- The maximum active storage depth is 1.5 m.

7.6.8 Surface Roughness and Other Considerations

Other model parameters required for the PCSWMM model are representative of the physical characteristics of each sub-catchment (i.e., the sub-catchment slopes were extracted from the DEM and flow paths were estimated based on the estimated longest flow path in each sub-catchment).

The following Manning roughness values were used for future growth areas (future development):

- *n* = 0.015 for impervious areas
- *n* = 0.18 for pervious areas

The following Manning's roughness values were used for existing rural areas (remaining undeveloped) in Sturgeon County:

- *n* = 0.015 for impervious areas
- *n* = 0.25 for pervious areas

7.6.9 Overland Flow Paths

A topographical review in GIS was conducted to delineate major overland flow path alignments in the Carrot Creek basin. Results are shown along with the Carrot Creek centerline in Figure 7-4.

The Carrot Creek drainage corridor and portions of the Highway 2 drainage ditch were included in the models for the various stormwater servicing options. In the PCSWMM model, overland flow path transects were created by cutting cross sections in the DEM for selected overland flow conduits perpendicular to their alignment.

Figure 7-4 depicts additional potential overland routes (major overland flow routes) that were not included in the model. However, these overland paths should be protected or accounted for (e.g. re-alignment of flow path) during future development reviews to minimize impacts to private property under post-development conditions.

Manning's roughness values for the channel and overbanks are based on Table 6-4.

642

Presumed Road Ditch
Drainage Direction

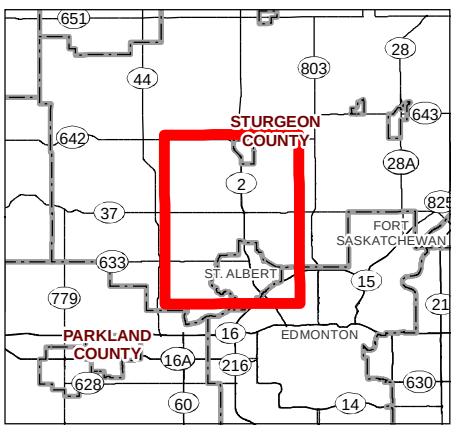
2

37

633

Presumed Road Ditch
Drainage Direction

216



Notes

1. Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec,
Natural Resources Canada CDED 1:50,000 scale elevation grid data (https://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/3A537B2D-7058-FCED-8D0B-76452EC9D01F.html)
3. Background: 2015 Aerials from Sturgeon County
4. Flow Paths data derived using ESRI Hydrology Tools in ArcGIS to generate flow path, direction and asccumuation grids

- Overland Flow Path
- Stantec Surveyed Culvert
- Carrot Creek Centerline
- HWY 2 Ditch
- Presumed Ditch Direction
- Watershed Boundary
- Major Road

0 2,400 4,800 metres

(At original document size of 11x17)
1:125,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location	Prepared by AL on 4/20/2021
Sturgeon County, Alberta	TR by BS on 4/20/2021
	IR Review by FK on 4/20/2021
Client/Project	110149416 - 7-4 REVA

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
7-4

Title
Overland Flow Paths

Revised: 2021-04-20 By: alelee

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7.7 STORMWATER SERVICING OPTIONS

7.7.1 General Characteristics

The storm servicing option concept plans presented in this study consider previously prepared drainage plans, including the Utility Master Plan (Stantec Consulting Ltd., 2014) and the North Erin Ridge development area diversion to Sturgeon River (Associated Engineering, 2020). These previous reports consider drainage areas on the fringe of the existing developed area in St. Albert, where stormwater would be directed to the City's storm drainage network which effectively removes them from the Carrot Creek basin. Therefore, under all proposed future storm servicing options, there is less contributing drainage area to Carrot Creek compared to the existing condition (8,790 ha). Refer to Sections 7.7.2 through Section 7.7.5 for additional description on the drainage plan characteristics of each storm servicing option. Storm servicing options were organized by:

- Concept plan (configuration of stormwater management). The main differences between Options 1, 2, 3, and 4 presented below is how the East Tributary of Carrot Creek (east of Highway 2) and the Highway 2 ditch drainage is managed. Concept plans consider the ongoing North Erin Ridge development diversion to the Sturgeon River (Associated Engineering, 2020) and the potential to maintain or remove a wet feature on the East Tributary east of Highway 2 and south of Township Road 544.
- Unit area release rate to Carrot Creek for a 1:100 year event (options of 1.8 L/s/ha, 2.5 L/s/ha and 5 L/s/ha were considered).
    - The 1.8 L/s/ha release rate was included to reflect current approvals in the basin, specifically Range Road 260 Area Structure Plan approved by City of St. Albert Council which targets the 1.8 L/s/ha UARR. This is close to the 1.9 L/s/ha release rate recommended in both the St. Albert Utility Master Plan (Stantec, 2014) and the Town of Morinville Municipal Utility Servicing Plan Update (AECOM, 2016).
    - The 2.5 L/s/ha developable area UARR matches the existing 1:100 year runoff release rate estimated in the hydrological analysis summarized in Section 6.1.
    - The 5.0 L/s/ha developable area UARR is proposed because the contributing drainage areas will decrease under proposed post-development conditions (especially for Options 1 and 2). A 5.0 L/s/ha UARR will reduce the required size of storage in future development areas.

General characteristics that applied to all servicing options are:

- Predevelopment release rates are maintained to Carrot Creek for undeveloped (existing) and riparian areas.
- Developable areas in the Carrot Creek watershed become fully developed as per the current growth projections indicated in the land-use plan (Figure 7-3). Undeveloped and riparian areas shown in Figure 7-3 remain undeveloped.

  - St. Albert and IDP growth areas become fully developed in accordance with the land-use information provided by the City of St. Albert's planning department at the time of this study. The growth cells are generally consistent with the St. Albert Utility Master Plan (2014).
  - Pro North Industrial area in Sturgeon County is developed as projected (ISL, 2019).
  - Morinville catchments are developed as per the Stormwater Servicing Concept Figure 5.1 from the Municipal Servicing Plan Update – Stormwater Management Plan Update (AECOM, 2016). This accounts for future growth within the current town limits.
- Stormwater in new developments in northeast St. Albert (east and west of Highway 2), including the ongoing North Erin Ridge development, is diverted through a new storm trunk to the Sturgeon River. This trunk is currently proceeding through the design stage as per the Northeast Area Storm Sturgeon River Outfall (AE, 2020) report.

General assumptions that apply to all proposed stormwater servicing concept plans are:

- Existing flow paths are protected in undeveloped areas within the Carrot Creek basin.
- No capital funded storm ponds are required. Proposed facilities are assumed to be developer funded.
- Storm outfall trunks in the St. Albert annexation areas are to avoid disturbance in areas of landslide and erosion concern.
- Existing roadside ditch conveyance capacity is assumed to be adequate for both existing and future drainage considerations.

General considerations for future development include:

- Lumped sub-catchments do not take into consideration conflicts with regards to land ownership, which could lead to additional storm pond requirements and extensive storm trunk networks to capture and discharge design flows in the basin to the stormwater outfalls. There is no existing storm pipe network that discharges storm flows to Carrot Creek to support future development in the basin.
- Grading constraints for the North Erin Ridge development in areas where development is bounded by the existing Carrot Creek tributaries and Highway 2 could impact proposed development water, sanitary and stormwater servicing strategy, and overall dirt balances

7.7.2 Option 1A, 1B, & 1C Servicing Concept

Figure 7-5 captures the Stormwater Servicing Option #1 concept plan, which has the following unique characteristics:

- East Tributary flows north of Township Road 544 are diverted to the Sturgeon River through a storm trunk around the ongoing and future North Erin Ridge development. One challenge of this option is obtaining landowner consent for a new sewer right-of-way; placing the storm trunk inside existing road allowances where possible will reduce this risk.
    - Although not confirmed, AEP has indicated that historically the East Tributary may have drained directly to the Sturgeon River until the manmade channel (with weir) south of Township Road 544 intercepted it and diverted it west to Carrot Creek.
- Highway 2 ditch drainage is maintained to Carrot Creek through the existing manmade Carrot Creek tributary west of Highway 2 and south of Township Road 544.
- Erin Ridge North existing natural storage area and diversion ditch are removed.

Option 1 was divided into three sub-options with the same stormwater servicing geometry but different unit area release rates to Carrot Creek:

- Option 1a: The permissible release rate for developed areas is **1.8 L/s/ha**.
- Option 1b: The permissible release rate for developed areas is **2.5 L/s/ha**.
- Option 1c: The permissible release rate for developed areas is **5.0 L/s/ha**.

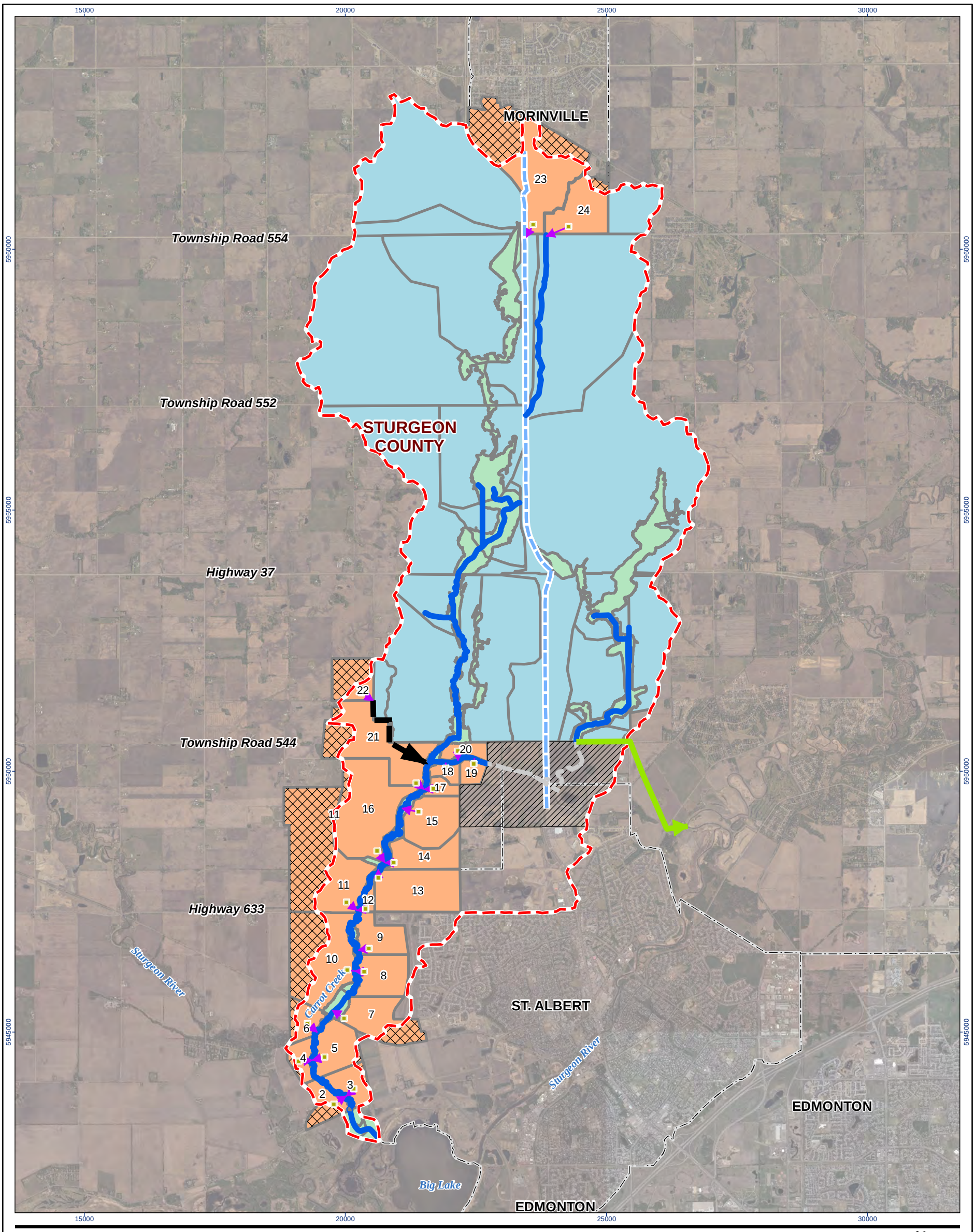
7.7.3 Option 2A, 2B, & 2C Servicing Concept

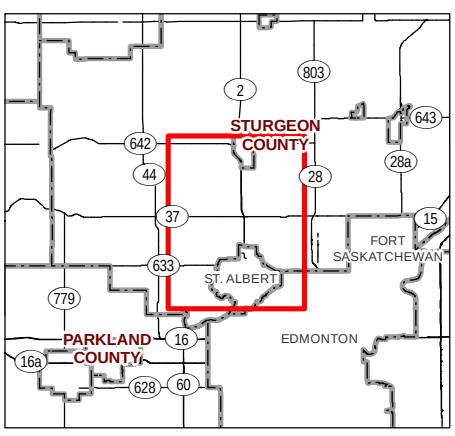
Figure 7-6 captures the Stormwater Servicing Option #2 concept plan, which has the following unique characteristics:

- East Tributary flows and Highway 2 ditch flows north of Township Road 544 are diverted to the Sturgeon River through a storm trunk around the ongoing and future North Erin Ridge development. One challenge of this option is obtaining landowner consent for a new sewer right-of-way; placing the storm trunk inside existing road allowances where possible will reduce this risk.
- Highway 2 drainage within the North Erin Ridge development boundary is captured by North Erin Ridge Storm Trunk to Sturgeon River.
- Erin Ridge North existing natural storage area and diversion ditch are removed.

Option 2 was divided into three sub-options with the same stormwater servicing geometry but different unit area release rates to Carrot Creek:

- Option 2a: The permissible release rate for developed areas is **1.8 L/s/ha**.
- Option 2b: The permissible release rate for developed areas is **2.5 L/s/ha**.
- Option 2c: The permissible release rate for developed areas is **5.0 L/s/ha**.





- Municipal Boundary
- Predevelopment Watershed Boundary
- Carrot Creek Centerline
- HWY 2 Ditch
- Removed Ditch and Creek
- Existing Overland Drainage Route
- Major Road
- Minor Road
- North Erin Ridge Diversion Areas
- Storage Areas
- Proposed Diversion Pipe
- Outfall to Creek/Ditch

Subcatchments

- Developed
- Riparian
- Undeveloped
- Area Proposed to be Added to Carrot Creek Watershed

0 1,500 3,000 metres

(At original document size of 11x17)
1:75,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location
Sturgeon County,
Alberta

Prepared by EH on 9/26/2022
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110149416 - 7-5 REV A

City of St. Albert
Carrot Creek Regional Master Drainage Plan

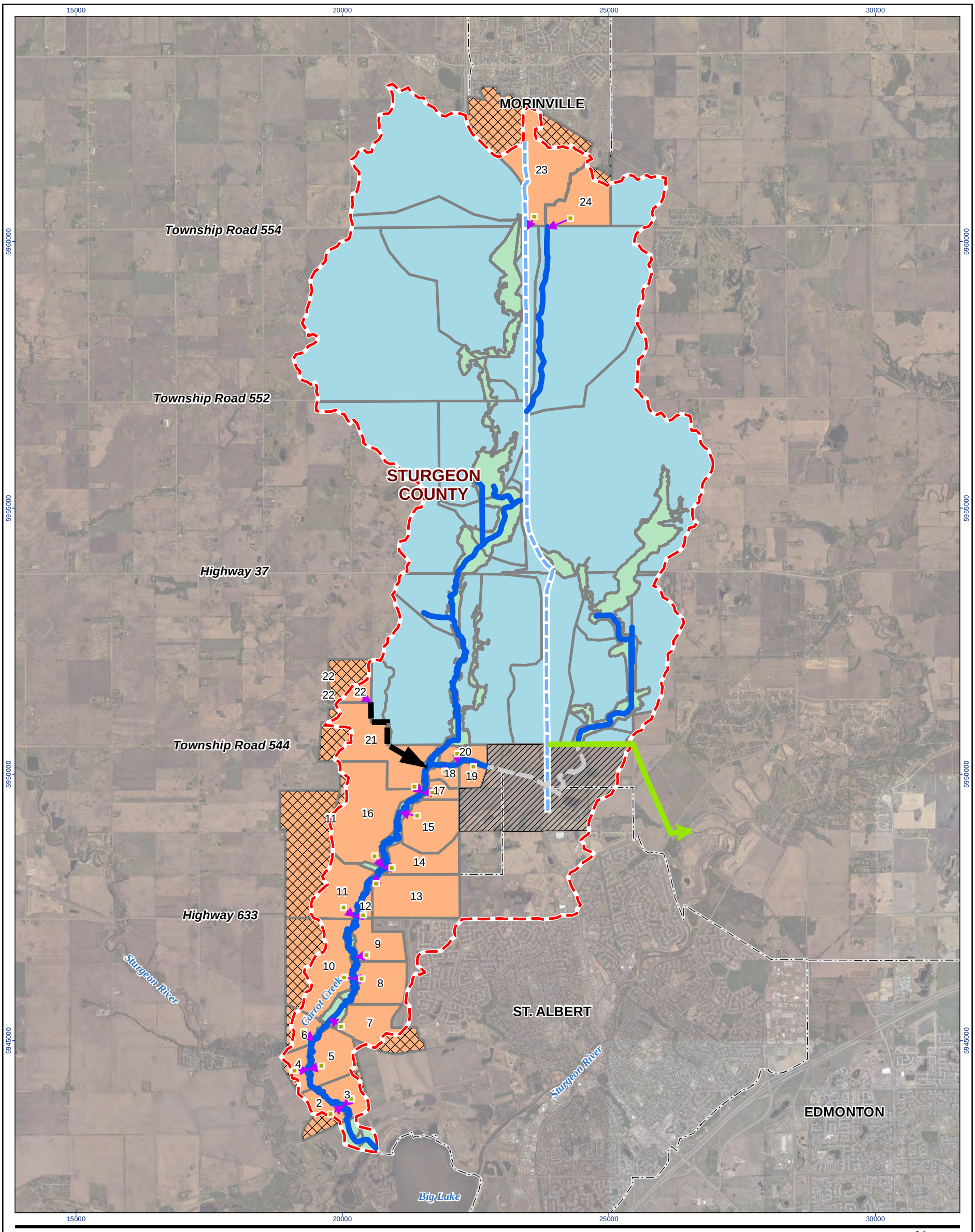
Figure No.
7-5

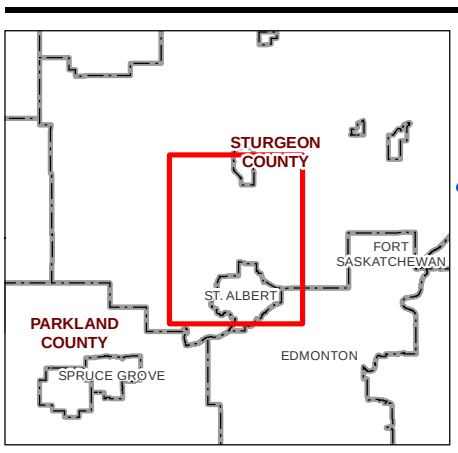
Title
Storm Servicing Options 1a, 1b, and 1c Plan View

Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
3. Background: 2015 Aerials from Sturgeon County
4. See associated Carrot Creek Master Drainage Plan Report body for infrastructure sizing information for each servicing option.

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- Municipal Boundary
- Predevelopment Watershed Boundary
- Removed Ditch and Creek
- Existing Overland Drainage Route
- Carrot Creek Centerline
- HWY 2 Ditch
- Major Road
- Minor Road
- North Erin Ridge Diversion Areas
- Storage Areas
- Proposed Diversion Pipe
- Outfall to Creek/Ditch

Subcatchments

- Developed
- Riparian
- Undeveloped
- Area Proposed to be Added to Carrot Creek Watershed

0 1,400 2,800 metres

(At original document size of 11x17)
1:73,488

N

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City of St. Albert Planning and Engineering

Project Location	Prepared by EH on 10/3/2022
Sturgeon County, Alberta	TR by BS on 10/3/2022
	IR Review by CJ on 10/3/2022
Client/Project	110149416 - 7-6 REV A

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
7-6

Title
Storm Servicing Options 2a, 2b, and 2c Plan View

Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
3. Background: 2015 Aerials from Sturgeon County
4. See associated Carrot Creek Master Drainage Plan Report body for infrastructure sizing information fro each servicing option.

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7.7.5 Options 3A, 3B, & 3C Servicing Concept

Figure 7-7 captures the Stormwater Servicing Option #3 concept plan, which has the following unique characteristics:

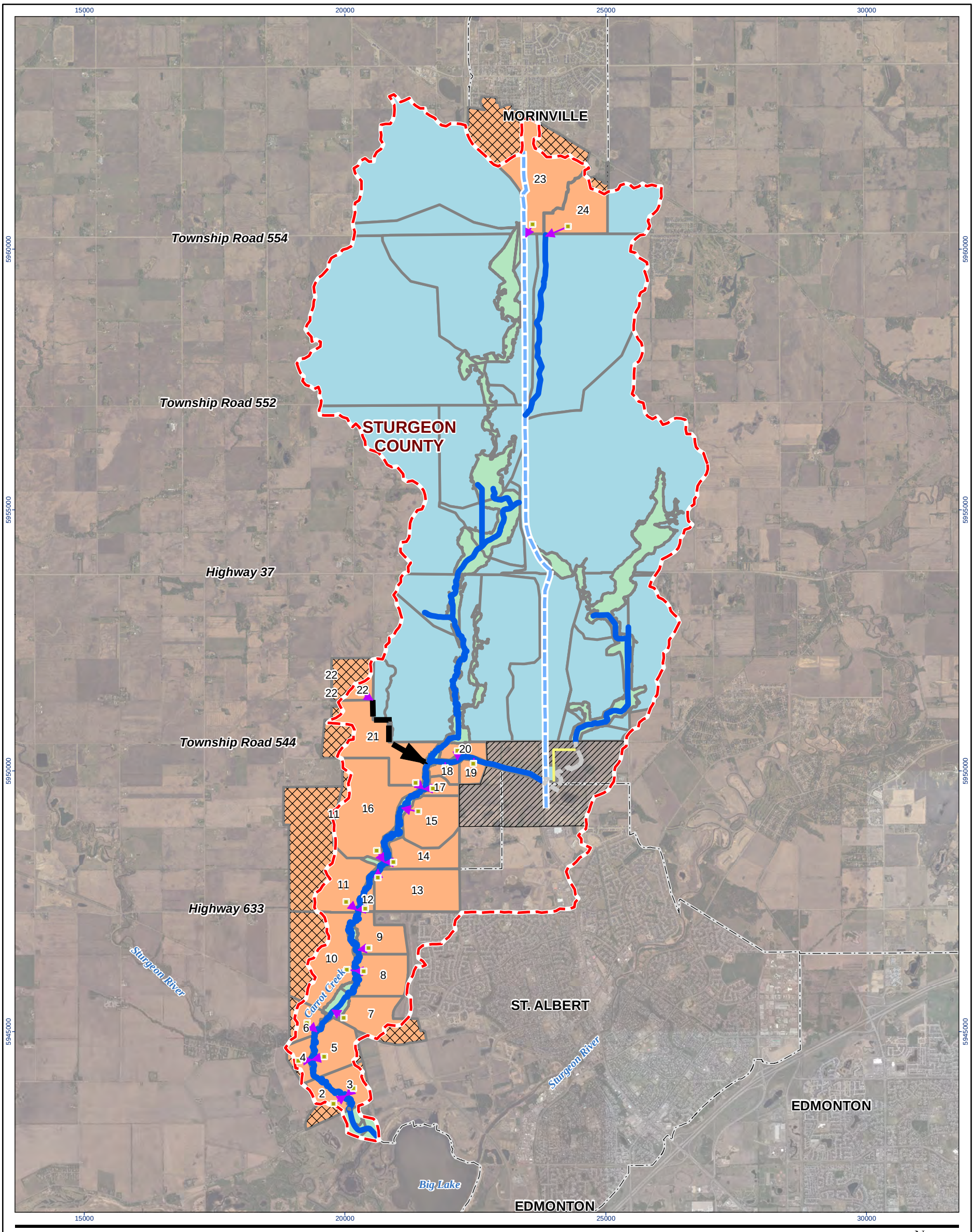
- The East Tributary drainage and Highway 2 ditch drainage are maintained to Carrot Creek and are not diverted to the Sturgeon River (i.e. similar to existing condition).
- Runoff from within the North Erin Ridge development area is collected in a storm trunk to the Sturgeon River and does not discharge to the East Tributary drainage system or Highway 2 ditch network.
- The recently constructed ditch running around the North Erin Ridge development that connects the East Tributary to the Highway 2 crossing and Carrot Creek, which was previously proposed as a temporary ditch (WSP, 2018), is maintained as a permanent conveyance feature. Alternatively, the temporary ditch can be removed and an alternative method for conveying East Tributary flows around the development, to the Highway 2 crossing, can be developed.
- Highway 2 ditch drainage is maintained to Carrot Creek through the existing manmade Carrot Creek tributary west of Highway 2 and south of Township Road 544.

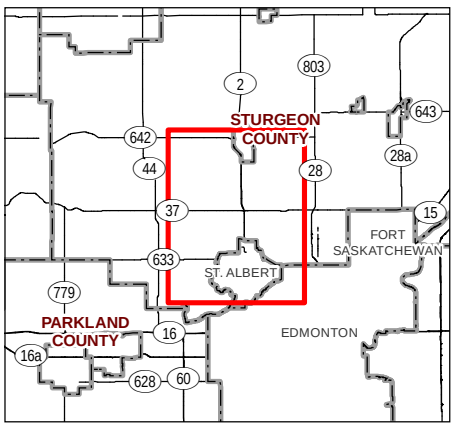
Option 3 was divided into three sub-options with the same stormwater servicing geometry but different unit area release rates to Carrot Creek:

- Option 3a: The permissible release rate for developed areas is **1.8 L/s/ha**.
- Option 3b: The permissible release rate for developed areas is **2.5 L/s/ha**.
- Option 3c: The permissible release rate for developed areas is **5.0 L/s/ha**.

In Option 3, it was assumed that the utility right-of-way for the existing East Tributary diversion ditch through the North Erin Ridge development area adjacent to Township Road 544 and Highway 2 could be maintained as a permanent feature under a future development scenario. It is also assumed that the large wetland previously located in Erin Ridge North, as well as the temporary storage area being used as of 2022, are permanently removed.

Option 3 carries additional risk due to the open drainage ditch through a developed area and with no storage area to attenuate peak flows from the East Tributary (i.e. offsite flows passing through the North Erin Ridge area). If this scenario is carried forward, detailed modeling to assess the water elevations in the ditch and the available freeboard, with respect to the adjacent developed area, should be conducted. The hydraulic modeling for the CCRDMP herein (see Section 6.2) did not include detailed 2D flooding analysis of the proposed East Tributary connection ditch along Township Road 544 and Highway 2. Further, the capacity of the existing Highway 2 ditch to convey East Tributary Flows between Township Road 544 and the Highway 2 culvert crossing was not assessed in this study.





- Municipal Boundary
- Predevelopment Watershed Boundary
- Carrot Creek Centerline
- HWY 2 Ditch
- Removed Ditch and Creek
- Existing Overland Drainage Route
- Major Road
- Minor Road
- North Erin Ridge Diversion Areas
- Storage Areas
- Existing Diversion Channel
- Outfall to Creek/Ditch

Subcatchments

- Developed
- Riparian
- Undeveloped
- Area Proposed to be Added to Carrot Creek Watershed

0 1,500 3,000 metres

(At original document size of 11x17)
1:75,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location
Sturgeon County,
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Prepared by EH on 9/29/2022
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Client/Project
110149416 - 7-5 REV A

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
7-7

Title
Storm Servicing Options 3a, 3b and 3c Plan View

Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
3. Background: 2015 Aerials from Sturgeon County
4. See associated Carrot Creek Master Drainage Plan Report body for infrastructure sizing information for each servicing option.

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7.7.7 Options 4A & 4B Servicing Concept

Figure 7-8 captures the Stormwater Servicing Option #4 concept plan. Option #4 is similar to the Option #3 (Figure 7-7) concept plan, but has the following unique characteristics:

- The storage feature east of Highway 2, which was recently removed as part of the North Erin Ridge development, is partially re-established north of the existing (2022) development boundary (east of Highway 2 and south of Township Road 544). This wet feature will attenuate East Tributary peak flows that backup east of Highway 2 using an appropriately sized culvert. Contours of the existing wet feature were extracted from the as-built PDFs (WSP, April 2021) to estimate the storage volume (WSP, 2021).
- The infrastructure or modification of existing infrastructure required to divert peak flows to or attenuate peak flows in the new storage facility (i.e. weir, orifice, control structure) will need to be determined in the detailed design phase should this storage facility become the preferred option to address the loss of the previous wet feature in North Erin Ridge.
- It should be clarified that the new storage facility proposed in North Erin Ridge is not required to store runoff from the North Erin Ridge development boundary, which is already proposed to be diverted through the new storm trunk to the Sturgeon River. Instead, the storage facility is for peak attenuation of East Tributary flows originating north of Township Road 544 (i.e. offsite flows to the North Erin Ridge Development). That said, the developer may elect to combine the onsite and offsite storage at the same location in which case the volume may need to be larger than shown in this report.

Option 4 was included in the servicing concepts after engagement with stakeholders during the 90% project stage. Option 4 was divided into two sub-options with the same stormwater servicing geometry but different unit area release rates to Carrot Creek:

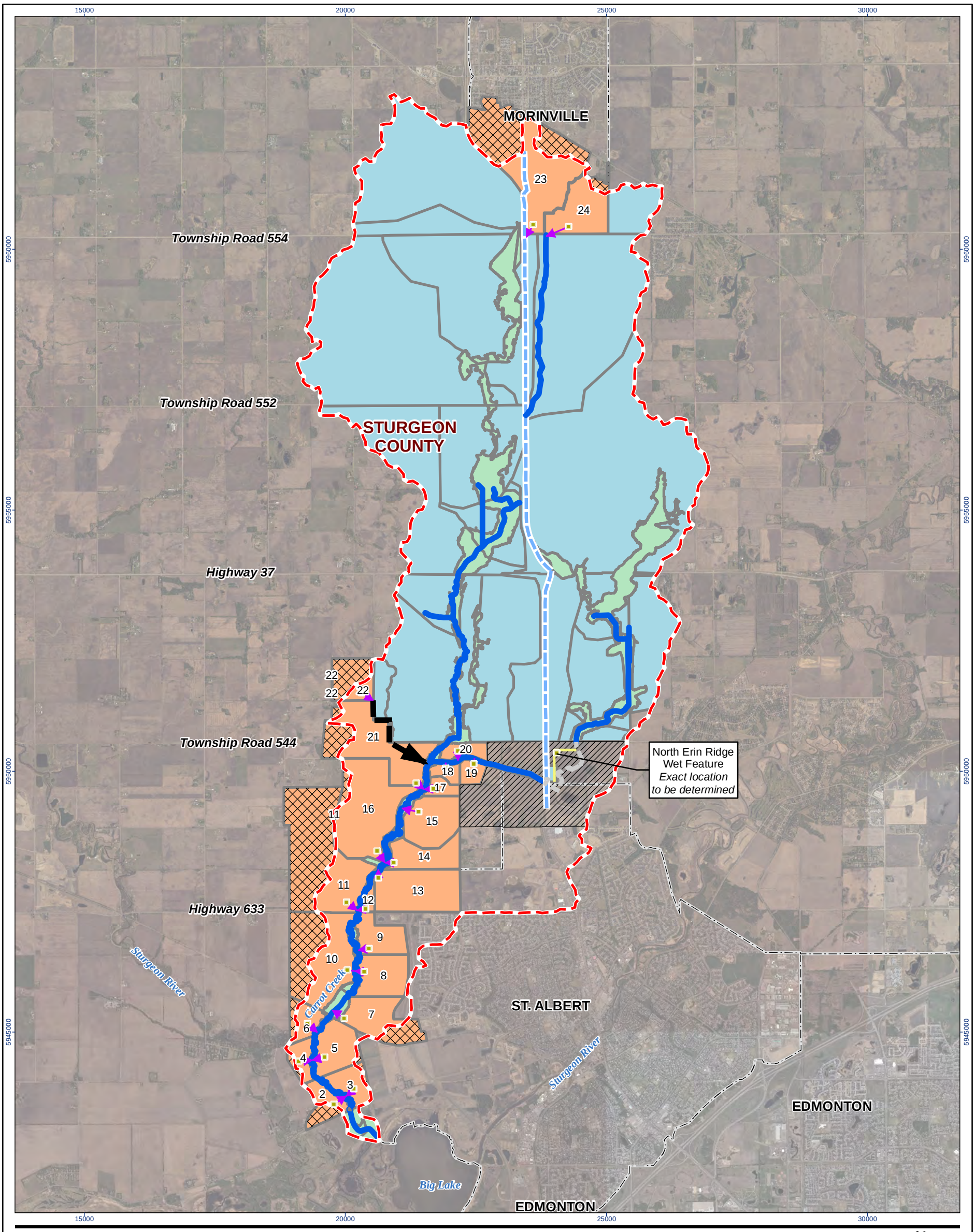
- Option 4a: The permissible release rate for developed areas is **1.8 L/s/ha**.
- Option 4b: The permissible release rate for developed areas is **2.5 L/s/ha**

The release rate of 5.0 L/s/ha was not included in the sub-options. Engagement with stakeholders at the 90% design stage indicated this was not a desirable release rate and could be ignored for Option 4.

The depth and corresponding storage volume required in the single event and the continuous simulation events were compared to determine the design HWL in Table 7-5.

Table 7-5 Depth and Storage Volumes for Option 4

	100-Year 24-Hour Huff	Estimated 100-Year Frequency Analysis	Recommended Design HWL
Depth (m)	1.06	1.72	1.10
Volume Result (m^3)	58,200	94,600	60,500



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Project Location	Prepared by EH on 10/3/2022
Sturgeon County,	TR by BS on 10/3/2022
Alberta	IR Review by FK on 10/3/2022
Client/Project	110149416 - 7-5 REV A

City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
7-8

Title
Storm Servicing Options 4a and 4b
Plan View

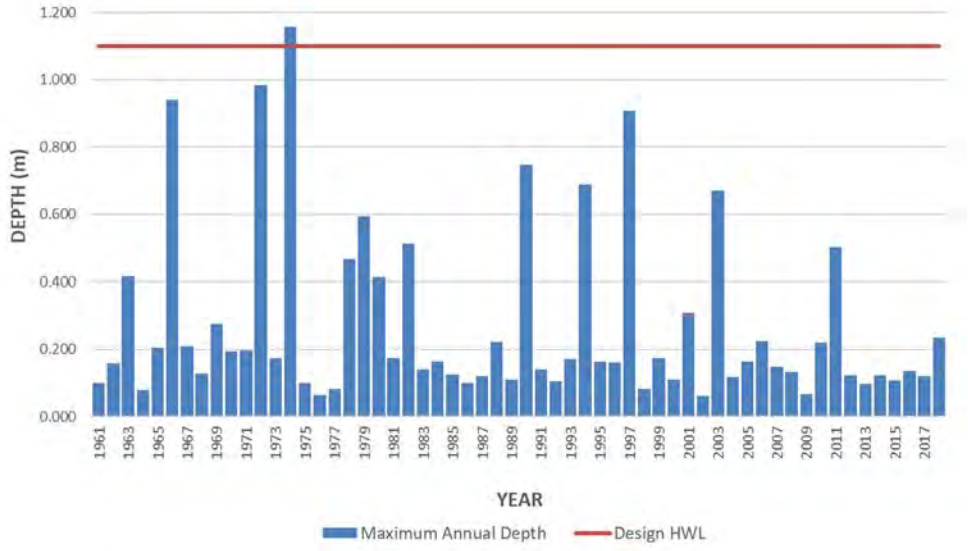
Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Sturgeon County, St. Albert, Morinville, Alberta Environment and Parks, Stantec
3. Background: 2015 Aerials from Sturgeon County
4. See associated Carrot Creek Master Drainage Plan Report body for infrastructure sizing information for each servicing option.

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The background study review in Section 7.4 indicated that the previous (recently removed) wet feature in North Erin Ridge had a 100-year storage volume of 124,700 m^3 (WSP, 2018). The previous capacity is greater than the results shown in Table 7-5. The 60,500 m^3 recommended in this study is similar to the 53,000 m^3 (1:100 year volume) that was proposed for the relocated temporary storage according to the Erin Ridge North Berm, Ditch and Culvert Construction as-built drawings (WSP, 2021). A scenario with approximately 100,000 m^3 of storage (close to the original storage area that has been removed) was also considered but modeling results indicated that it would not provide significant benefit in terms of peak flow rates in the downstream reaches of Carrot Creek (see Table 7-8). The smaller storage area being recommended for Option 4 in this study (60,500 m^3) compared to the removed storage (124,700 m^3) can be justified by the fact that a significant portion of the East Tributary (North Erin Ridge development) is being diverted to the Sturgeon River and the larger storage is unlikely to provide significant reduction of erosion risk downstream. Further, the modeling completed for Option 4 assumed that only flows from the East Tributary are attenuated while the previous larger wet feature attenuated flows from the confluence of the East Tributary and the Highway 2 ditch.

The 100-year frequency analysis, while resulting in a higher storage volume compared to the single 100-year event, is not a required design approach for the wet feature (AEP, 1999). From a risk management perspective, it has been included in Table 7-5 to demonstrate that it may be appropriate to provide a significant freeboard (>0.5m) to protect critical infrastructure and private property. A review of the Highway 2 culvert conveyance capacity and upgrades to accommodate emergency spill capacity may be required during future design and development stages. Based on the depth versus time graph in the continuous simulation shown in Figure 7-9, potential storage overflow events would be anticipated to be infrequent over the long term. The overflow events estimated using historical climate data would be 1 event over a period of 58 years. The maximum depths plotted against the design HWL of 1.10 m is presented in Figure 7-9.



An emergency spillway was not included in the continuous model analysis. Inclusion of a spillway in future assessment is required.

Figure 7-9 Annual Maximum Depth at Proposed North Erin Ridge Storage

The following are considerations for the proposed storage facility east of Highway 2 in Option 4a and 4b:

- Consideration for a control structure and bypass system for ease of maintenance & operations, as required by the utility owner & operations team.
- Surface treatments to enhance the environmental value, aesthetic appeal in the context of the surrounding development(s), and to prevent erosion should be considered at the detailed design stage.
- The estimated design volume (active storage) of 60,500 m^3 is to be refined at the detailed design stage with the following minimum considerations: revised stage-storage curves accounting for AEP side slope requirements and freeboard requirements, inclusion of an emergency spillway in the model and design at or above the design HWL, updated infiltration parameterization based on site geotechnical studies.
- The configuration and geometry of the storage, including the inlet/outlet configuration, are to be confirmed at the detailed design stage. There are likely several options for providing the required East Tributary attenuation storage.
- Analysis and design of an emergency overland escape route may be required.
- Upgrades to Highway 2 East Tributary culvert crossings to accommodate emergency overflows.
- Updated model runs for the continuous simulation and frequency analysis results are recommended at the detailed design stage to confirm recommended storage volume.

7.7.8 Option Characteristics Summary

A summary of the developable, undeveloped, and riparian areas for each storm servicing option is shown in Table 7-6 on the following page.

Table 7-6 Storm Servicing Options Characteristics Summary

Option ID	Carrot Creek Contributing Drainage Area[1] (ha)	Diversion Contributing Drainage Area[2] (ha)	Future Developed Area (ha)	Weighted Developed Area IMP[3] (%)	Undeveloped & Riparian Area (ha)	Weighted Undeveloped Area IMP (%)	Developed Area UARR[4] (L/s/ha)
1a	7,526	1,003	2,200	77.5%	5,326	6.7%	1.8
1b	7,526	1,003	2,200	77.5%	5,326	6.7%	2.5
1c	7,526	1,003	2,200	77.5%	5,326	6.7%	5.0
2a	4,907	3,599	2,200	77.5%	2,707	6.7%	1.8
2b	4,907	3,599	2,200	77.5%	2,707	6.7%	2.5
2c	4,907	3,599	2,200	77.5%	2,707	6.7%	5.0
3a	8,528	0	2,200	77.5%	6,329	6.7%	1.8
3b	8,528	0	2,200	77.5%	6,329	6.7%	2.5
3c	8,528	0	2,200	77.5%	6,329	6.7%	5.0
4a[5]	8,538	0	2,200	77.5%	6,338	6.7%	1.8
4b	8,538	0	2,200	77.5%	6,338	6.7%	2.5

Notes:

1. Existing contributing Carrot Creek Basin drainage area is approximately 8790 ha. IDP areas proposed to contribute to St. Albert drainage network and North Erin Ridge development are removed from the Carrot Creek contributing drainage area in all servicing options considered.
2. Diversion area refers to area diverted to Sturgeon River (removed from Carrot Creek basin) and does not include North Erin Ridge development area and other parts of Northeast St. Albert (east and west of Highway 2) that will drain to the Sturgeon River though the Northeast Storm Trunk currently under design and construction).
3. IMP = Imperviousness. Weighted IMP for future developed area only.
4. UARR = Unit Area Release Rate (permissible or allowable unit flow rate from the development).
5. Options 3 & 4 essentially have the same contributing drainage area, except for the addition of a small drainage area added for the proposed storage area on the East Tributary in Option 4.

7.7.9 Storm Servicing Option Performance

The technical performance of each storm servicing option was assessed using:

- 100-year peak discharge rates modeled for Carrot Creek at the mouth of Big Lake
- Stormwater management facility footprint and maximum storage volume in developed areas
- Stormwater management facility drawdown times from developed areas
- East Tributary storage feature footprint and maximum storage volume
- Forecasted flow regime changes in Carrot Creek assessed using simulated flow-duration curves. The flow duration curves vary from option to option based on the UARR from developed areas and changes to the Carrot Creek basin boundary caused by proposed stormwater diversions to the Sturgeon River in some options.



7.7.9.1 Carrot Creek Peak Flow Results

A list of the model runs conducted is shown below for ease of reference.

Table 7-7 Model Simulations

Option ID	Single Event 100-year 24hr Event Model	1978 Storm Model	1961-2018 Continuous Simulation Model
1a	☒	☒	☒
1b	☒	☒	☒
1c	☒	☒	☒
2a	☒	see Note[1]	☒
2b	☒	see Note[2]	☐
2c	☒	see Note[3]	☒
3a	☒	see Note[1]	☒
3b	☒	see Note[2]	☒
3c	☒	see Note[3]	☒
4a	☒	see Note[1]	☒
4b	☒	see Note[2]	☒

Notes:
[1]Development area SWMF results unchanged from Option 1a 1978 Storm Model results. 1978 models used to check freeboard only.
[2]Development area SWMF results unchanged from Option 1b 1978 Storm Model results. 1978 models used to check freeboard only.
[3]Development area SWMF results unchanged from Option 1c 1978 Storm Model results. 1978 models used to check freeboard only.

The storm model was used to simulate the peak flows at the mouth of Carrot Creek for each proposed stormwater servicing option, and the peak flows were compared to the existing 100-year flows.

Table 7-8 Summary of Peak Flow Results

Event ID	Development Unit Area Release Rate (L/s/ha)	Modeled Carrot Creek Maximum Peak Flow Rate		
		100-year 24hr Single Event (m^3/s)	Continuous Simulation Maximum (m^3/s)	100-year Frequency Analysis[1] (m^3/s)
Existing Condition (05EA001)	N/A	-	-	22.4
Option 1a	1.8	12.3	15.2	16.3
Option 1b	2.5	14.2	16.2	17.0
Option 1c	5	20.0	19.0	18.6
Option 2a	1.8	8.3	11.5	12.4
Option 2b	2.5	11.3	12.7	12.8
Option 2c	5	18.0	15.8	14.4
Option 3a	1.8	17.0	18.5	20.6
Option 3b	2.5	18.6	19.5	21.0
Option 3c	5	23.6	22.3	23.7

Event ID	Development Unit Area Release Rate (L/s/ha)	Modeled Carrot Creek Maximum Peak Flow Rate		
		100-year 24hr Single Event (m^3/s)	Continuous Simulation Maximum (m^3/s)	100-year Frequency Analysis[1] (m^3/s)
Option 4a	1.8	13.2 (100,000 m^3 storage) 14.5 (60,500 m^3 Storage)	15.8	17.3
Option 4b	2.5	14.8 (100,000 m^3 storage) 16.1 (60,500 m^3 Storage)	16.6	17.9

Notes:
[1]Based on Log Pearson III probability distribution

Model results indicated that most peak flows generated in Carrot Creek at the mouth of Big Lake are less than the estimated existing 100-year peak flow of 22.4 m^3/s, particularly in Options 1 and 2 where larger parts of the existing Carrot Creek basin are diverted to the Sturgeon River. Option 3 and 4 flow rates are higher than Options 1 and 2 (for the same UARR) because the East Tributary and Highway 2 ditch remain connected to Carrot Creek and only stormwater from the North Erin Ridge development is diverted to the Sturgeon River. 100-year peak flow rate in Option 3c at the downstream end of Carrot Creek is expected to be slightly higher than the existing condition because most of the Carrot Creek basin is left intact (except North Erin Ridge) and the UARR from future developed land is higher at 5 L/s/ha (higher than existing condition). Option 4 flow rates are greater than Options 1 and 2 but less than Option 3 due to the proposed storage provided in North Erin Ridge. The 100-year peak flow results at the mouth of Big Lake in Options 3 & 4 simulations were not as close to the 22.4 m^3/s 100-year hydrometric station frequency analysis result as might be expected. This is because the 22.4 m^3/s flow estimated from the hydrometric station is based on 13 years of measured flow data, whereas the results shown in Table 7-8 are based on modeling with PCSWMM software using various events and continuous simulation. It is recommended that geotechnical investigations are conducted to support infiltration parametrization for subsequent drainage studies to support detailed designs. Further refinement and model calibration may be required at the detailed design phase before the pond volumes are finalized.

As this study neared its conclusion, it was decided with key stakeholders that Options 3 and 4 would be considered for the preferred option, whereas Options 1 and 2 could be ruled out due to the high cost and logistical challenge of constructing a new storm trunk to the Sturgeon River (as further described in Section 7.9). A discrepancy in the Highway 2 and Highway 2 service road culvert crossing sizes was also discovered at this stage. The previous model used circular culverts with diameters of 2,000 mm at each crossing, whereas the correct size of both culverts according to Alberta Transportation is a 2,150 mm rise and 3,380 mm horizontal ellipse. The project team re-ran Option 3 for the 1:100 year 24 hour single event scenario with the correct Highway 2 crossing culvert size and found that the culvert did not make a significant difference in the simulated flows:

- Option 3a: 17.0 m^3/s with 2,000 mm culverts and 16.6 m^3/s with ellipse culverts
- Option 3b: 18.6 m^3/s with 2,000 mm culverts and 18.3 m^3/s with ellipse culverts
- Option 3c: 23.6 m^3/s with 2,000 mm culverts and 23.7 m^3/s with ellipse culverts

It was concluded that the culvert size discrepancy did not have a significant impact on the overall modeling results. Nonetheless, the culvert size was corrected in the Option 4 model which ended up being the preferred option (Option 4b is preferred as described in Section 7.9). In Table 7-8, the 1:100-year single event for Option 4 with the 60,500 m^3 of storage was simulated using the correct elliptical culverts.

7.7.9.2 Creek Flow Frequency Results

An indicator of stream health and erosion hazard is stream flow regime characterized using flow duration curves. For the purposes of this study, a flow duration curve is defined as the graphical representation of the probability distribution of instantaneous peak flow rates at a specific location along a given stream network. The relationship between the probability of exceedance and return period is shown in Table 7-9, for reference. In this study, frequency analysis of annual maximum flow rates was used to develop the flow duration curves. For each storm servicing option, the annual maximum peak flows in Carrot Creek at the mouth of Big Lake were extracted from the continuous simulation model. The results are tabulated in Table 7-10 and plotted in Figure 7-10.

The tail end of the flow-duration curves indicates that under post-development conditions low flow events will increase in magnitude and duration over time compared to existing conditions in the Carrot Creek basin. The increase in imperviousness due to development increases the volume of runoff and the prolonged release of attenuated flows from proposed storm ponds in developed areas (i.e. protracted drawdown times) increases low flow events on the flow duration curve. Based on the simulation results, the lower the developable area UARR, the closer the convergence of the tail end of the curves under the post-development and existing condition.

Table 7-9 Probability of Exceedance and Return Period Relationship

Probability of Exceedance (%)	Return Period (Year)
99%	1.01
66.7%	1.5
50%	2
20%	5
10%	10
4%	25
2%	50
1%	100
0.5%	200

Table 7-10 Flow Frequency Analysis Comparison Table

Probability of Exceedance (%)	Existing Condition[1] Discharge (m^3/s)	Option 1a Discharge[3] (m^3/s)	Option 2a Discharge[3] (m^3/s)	Option 3a Discharge[3] (m^3/s)	Option 4a Discharge[3] (m^3/s)	Option 1b Discharge[4] (m^3/s)	Option 2b Discharge[4] (m^3/s)	Option 3b Discharge[4] (m^3/s)	Option 4b Discharge[4] (m^3/s)	Option 1c Discharge[5] (m^3/s)	Option 2c Discharge[5] (m^3/s)	Option 3c Discharge[5] (m^3/s)
99%	0.001	1.4	1.3	1.5	1.5	1.7	1.5	1.7	1.8	2.4	2.1	2.3
66.7%[2]	*1.1*	*2.6*	*2.3*	*2.7*	*2.7*	*3.0*	*2.7*	*3.1*	3.1	*4.2*	*3.9*	*4.4*
50%	1.7	3.2	2.8	3.4	3.4	3.7	3.3	3.9	3.8	5.2	4.7	5.5
20%	6.8	5.1	4.4	5.7	5.5	5.8	5.0	6.4	6.0	7.8	6.8	8.6
10%	11.2	7.0	5.7	7.9	7.4	7.6	6.4	8.7	8.0	9.8	8.4	11.2
4%	16.4	9.9	7.9	11.8	10.6	10.7	8.6	12.6	11.2	12.9	10.6	15.4
2%	19.7	12.8	10.0	15.7	13.6	13.5	10.6	16.3	14.3	15.6	12.4	19.2
1%	22.4	16.3	12.4	20.6	17.3	17.0	12.8	21.0	17.9	18.6	14.4	23.7
0.5%	24.5	20.6	15.3	26.9	21.9	21.1	15.5	26.7	22.3	22.0	16.5	28.9

Note:
[1]Based on hydrometric station (05EA011) monitored flow data. See **Section 6.1.3** for more detail.
[2]Values for the 66.7% probability of exceedance are interpolated from the flow duration curves.
[3]Options 1a, 2a, 3a & 4a have a development UARR of 1.8 L/s/ha. Sub-options organized by decreasing contributing drainage area are 4a-3a-1a-2a.;
[4]Options 1b, 2b, 3b, & 4b have a development UARR of 2.5 L/s/ha. Sub-options organized by decreasing contributing drainage area are 4b-3b-1b-2b.
[5]Options 1c, 2c, & 3c have a development UARR of 5.0 L/s/ha. Sub-options organized by decreasing contributing drainage area are 3c-1c-2c.

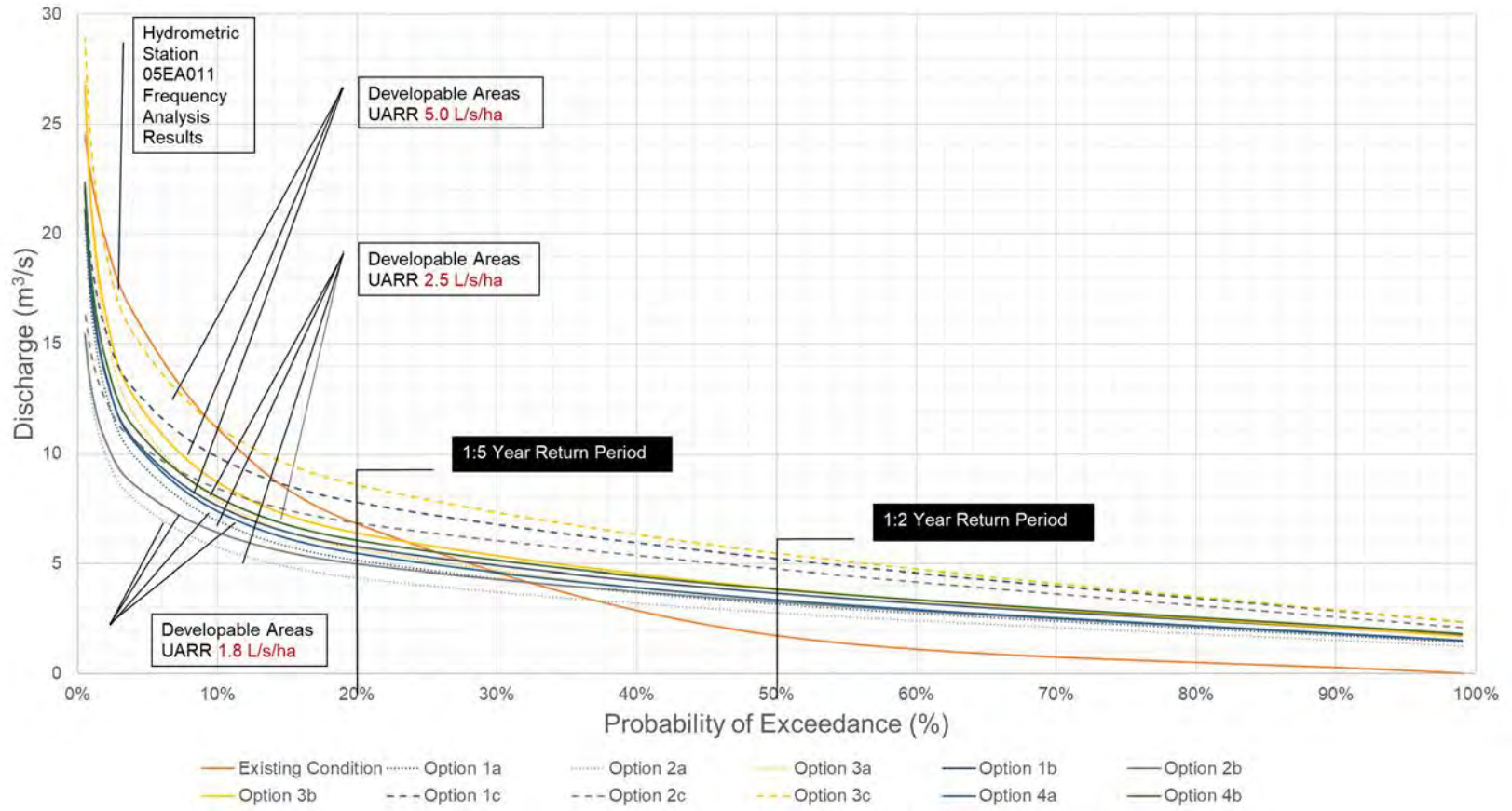


Figure 7-10 Flow Duration Curves

7.7.9.3 Stormwater Facilities Footprint and Maximum Volume Results

The stormwater management facility (SWMF) 100-year maximum storage results are shown in Table 7-11, Table 7-12, and Table 7-13. Options with lower UARR require higher storage volumes.

Table 7-11 Options 1a, 2a, 3a & 4a (UARR = 1.8 L/s/ha) Developed Area Storage Volumes

Area ID	SWMFID	NWL Area (m^2)	HWL Area (m^2)	Max. Active Storage Volume (1000 m^3)	Permissible Outflow (m^3/s)	Contributing Area (ha)
2	SU2	18,500	24,668	42.3	0.080	44.7
3	SU3	19,000	25,248	43.8	0.083	46.3
4	SU4	13,000	18,237	30.1	0.057	31.7
5	SU5	32,000	39,992	70.8	0.134	74.6
6	SU6	16,500	22,349	38.5	0.073	40.6
7	SU7	32,000	39,992	71.1	0.177	98.5
8	SU8	33,000	41,108	72.7	0.138	76.5
9	SU9	25,000	32,107	57.0	0.108	60.1
10	SU10	110,000	124,469	227.6	0.364	202.5
11	SU11	155,000	172,104	318.7	0.510	283.2
12	SU12	4,700	8,008	12.5	0.020	11.1
13	SU13	70,000	81,624	148.7	0.238	132.4
14	SU14	30,000	37,749	67.0	0.124	68.8
15	SU15	40,000	48,885	86.9	0.165	91.6
16	SU16	78,000	90,252	166.8	0.364	202.2
17	SU17	7,000	10,950	17.8	0.034	18.8
18	SU18	6,800	10,698	16.9	0.032	17.8
19	SU19	8,000	12,193	19.5	0.037	20.6
20	SU20	9,800	14,400	23.6	0.045	25.0
21	SU21	85,000	97,772	178.0	0.329	182.8
22	SU22	33,000	41,108	72.4	0.116	64.6
23	SU23	149,000	165,772	306.6	0.540	300.1
24	SU24	50,000	59,883	107.3	0.189	105.1
Totals:			**1,219,568**	**2,196.6**		

Table 7-12 Options 1b, 2b, 3b & 4b (UARR = 2.5 L/s/ha) Developed Area Storage Volumes

Area ID	SWMF ID	NWL Area (m^2)	HWL Area (m^2)	Max. Active Storage Volume (1000 m^3)	Permissible Outflow (m^3/s)	Contributing Area (ha)
2	SU2	17,500	23,513	40.2	0.112	44.7
3	SU3	18,000	24,091	41.7	0.116	46.3
4	SU4	12,000	17,047	28.6	0.079	31.7
5	SU5	30,500	38,308	67.4	0.187	74.6
6	SU6	16,000	21,766	36.6	0.102	40.6
7	SU7	30,800	38,645	67.3	0.246	98.5
8	SU8	31,000	38,869	69.1	0.191	76.5
9	SU9	24,500	31,542	54.3	0.150	60.1
10	SU10	103,000	117,019	217.5	0.506	202.5
11	SU11	148,000	164,718	305.5	0.708	283.2
12	SU12	4,500	7,747	11.9	0.028	11.1
13	SU13	67,500	78,918	142.4	0.331	132.4
14	SU14	28,500	36,064	63.7	0.172	68.8
15	SU15	37,000	45,559	82.5	0.229	91.6
16	SU16	75,000	87,016	158.4	0.505	202.2
17	SU17	6,850	10,763	16.9	0.047	18.8
18	SU18	6,300	10,069	16.0	0.045	17.8
19	SU19	7,400	11,450	18.5	0.051	20.6
20	SU20	9,100	13,547	22.5	0.063	25.0
21	SU21	81,000	93,471	169.8	0.457	182.8
22	SU22	31,000	38,869	69.2	0.161	64.6
23	SU23	140,000	156,276	292.4	0.750	300.1
24	SU24	48,000	57,696	102.4	0.263	105.1
Totals:			**1,162,963**	**1,952.4**		

Table 7-13 Options 1c, 2c, & 3c (UARR = 5.0 L/s/ha) Developed Area Storage Volumes

Area ID	SWMF ID	NWL Area (m^2)	HWL Area (m^2)	Max. Active Storage Volume (1000 m^3)	Permissible Outflow (m^3/s)	Contributing Area (ha)
2	SU2	15,000	20,598	34.8	0.224	44.7
3	SU3	15,500	21,183	36.0	0.232	46.3
4	SU4	10,200	14,884	24.7	0.159	31.7
5	SU5	25,500	32,675	58.2	0.373	74.6
6	SU6	13,500	18,829	31.6	0.203	40.6
7	SU7	26,500	33,806	58.8	0.493	98.5
8	SU8	26,800	34,147	59.9	0.383	76.5
9	SU9	21,000	27,545	47.0	0.300	60.1
10	SU10	88,000	100,982	188.8	1.012	202.5
11	SU11	125,000	140,402	264.9	1.416	283.2
12	SU12	3,700	6,680	10.2	0.056	11.1
13	SU13	56,500	66,986	123.2	0.662	132.4
14	SU14	25,000	32,107	55.3	0.344	68.8
15	SU15	32,000	39,992	71.5	0.458	91.6
16	SU16	64,700	75,892	137.9	1.011	202.2
17	SU17	5,600	9,174	14.5	0.094	18.8
18	SU18	5,400	8,917	13.8	0.089	17.8
19	SU19	6,200	9,939	15.9	0.103	20.6
20	SU20	8,000	12,193	19.5	0.125	25.0
21	SU21	68,000	79,461	146.8	0.914	182.8
22	SU22	26,500	33,806	59.8	0.323	64.6
23	SU23	120,000	135,093	253.6	1.500	300.1
24	SU24	40,000	48,887	88.3	0.525	105.1
Totals:			**1,004,178**	**1,815.0**		

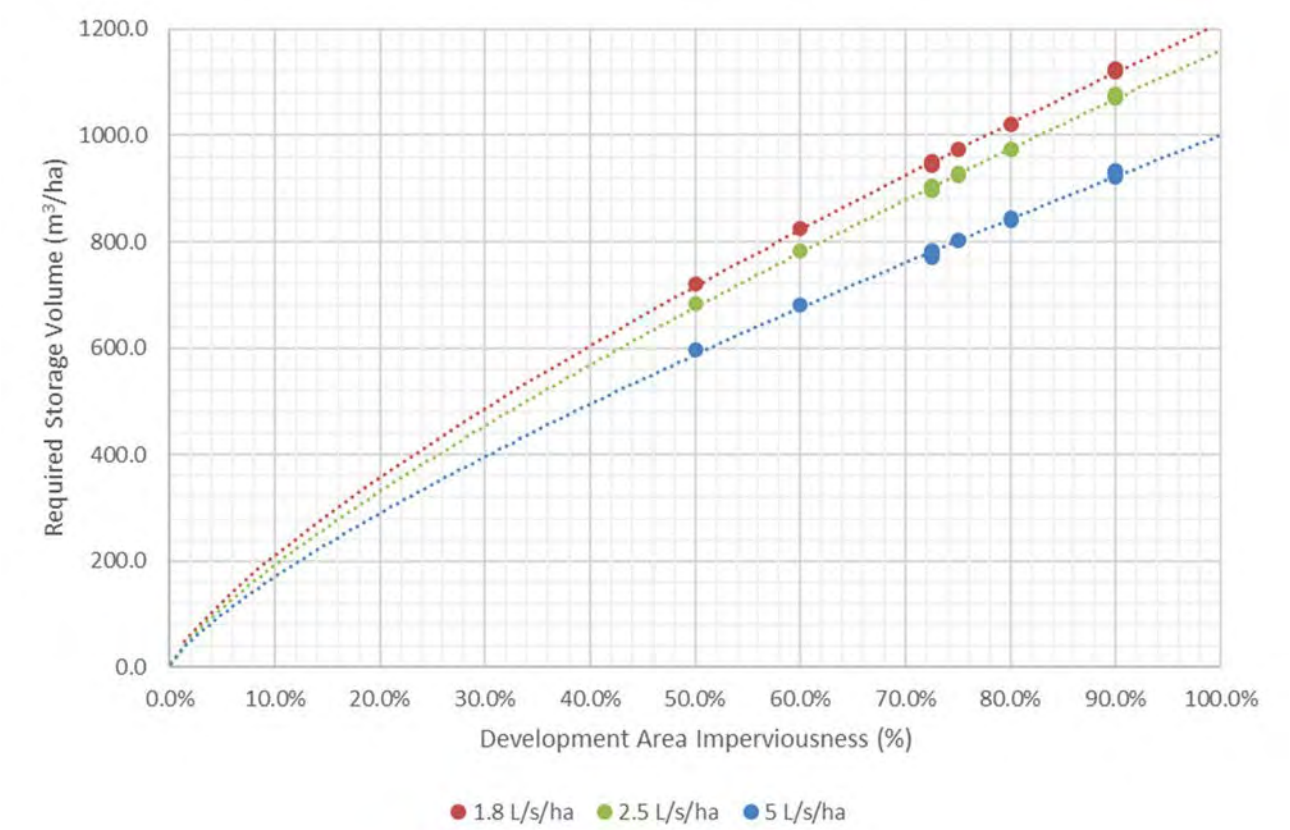


Figure 7-11 Required Storage Volume versus Development Area Imperviousness[6]

In Figure 7-11, the storage volume results shown in Table 7-11, Table 7-12, and Table 7-13 are converted to volume per hectare of contributing drainage area and plotted against the contributing drainage area imperviousness. The results are separated into three series, 1.8 L/s/ha, 2.5 L/s/ha and 5.0 L/s/ha permissible UARRs. The power trendlines (dotted lines) were chosen as a best fit to the data series. The trendlines indicate that storage volume requirements are generally lower for developments with higher UARRs and lower imperviousness and that there is a sharp decline in the storage volume requirement as imperviousness trends lower. These results are generalized at a basin scale, however, and do not consider the nuance of site-specific infiltration and drainage characteristics and their impact on site-specific runoff release rates prior to and after development. The overall basin predevelopment release rate and preferred development unit area release rate will apply as a blanket to all future developments in the basin boundary. Future developments are required to determine the appropriate stormwater management strategies and to provide site-specific analysis that demonstrates that the required UARR discharge is achieved.

[6] *Based on detention of the 24-hr 100-yr Design Storm*

7.7.9.4 Stormwater Management Facilities Drawdown Time Results

Drawdown times for the stormwater storage facilities are based on the single event 100-year design storm. Each pond was considered adequately drawn down when the storage volume reached 10% of the design high water level storage volume. The simulation period was extended beyond the design storm duration to ensure the drawdown time results could be captured in the model results. Some statistical results based on the permissible discharge rate are shown in Table 7-14. Figure 7-12 shows the drawdown times for each modeled storage facility and for each allowable UARR considered.

Table 7-14 Stormwater Management Facility General Results Statistics by UARR

Statistical Measurement	1.8 L/s/ha Permissible Discharge (Option 1a, 2a, 3a or 4a)	2.5 L/s/ha Permissible Discharge (Option 1b, 2b, 3b or 4b)	5.0 L/s/ha Permissible Discharge (Option 1c, 2c or 3c)
Drawdown Time, $\bar{x}$, days	9.1	6.5	3.1
Drawdown Time, x_{min}, days	6.8	4.9	2.3
Drawdown Time, x_{max}, days	12.1	9.0	4.4
Drawdown Time, σ, days	1.3	1.0	0.5

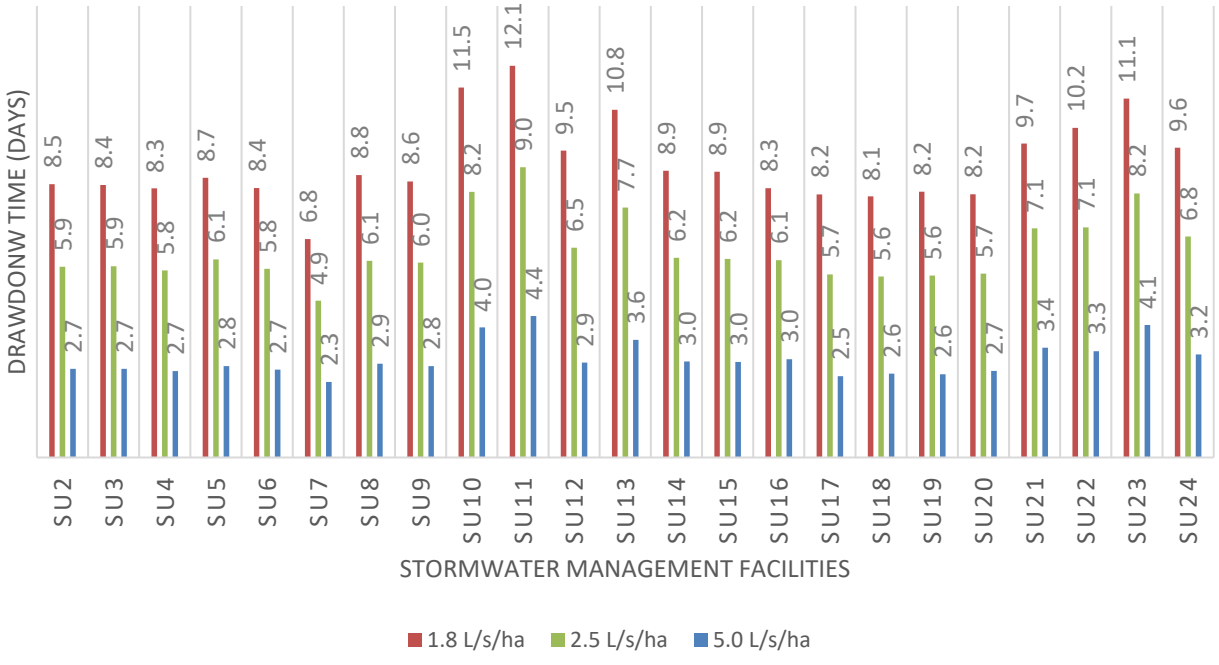


Figure 7-12 Estimated Stormwater Management Facility Drawdown Times

7.7.9.5 Diversion Storm Trunk Concept (Options 1 and 2 Only)

In this study, three diversion scenarios were considered:

(1) Diversion storm trunk to Sturgeon River capturing East Tributary flows upstream of Township Road 544, but not including Highway 2 drainage areas (Option 1; see Figure 7-5)

(2) Diversion storm trunk to Sturgeon River capturing Highway 2 ditch and East Tributary flows upstream of Township Road 544 (Option 2; see Figure 7-6)

(3) No diversion trunk. East Tributary connection to Carrot Creek is maintained (Options 3 and 4; see Figures 7-7 and 7-8).

A summary of the concept-level trunk sizing and other details (for Options 1 and 2) is shown in Table 7-15.

Table 7-15 Conceptualized Diversion Storm Trunk Summary

Applicable Servicing Options	1a, 1b, 1c	2a, 2b, 2c	3a, 3b, 3c, 4a, 4b
Contributing Drainage Area (ha)	1003	3599	N/A
100-year 24hr Single Event Maximum Simulated Pipe Flow Rate (m^3/s)	4.553	5.151	N/A
Inlet Maximum Depth @ East Tributary	0.54	0.86	N/A
Inlet Maximum Depth @ Highway 2	N/A	0.68	N/A
Estimated Trunk Length (km)	3.24	3.82	N/A
Material	Concrete	Concrete	N/A
Cross Section	Rectangular Box	Rectangular Box	N/A
Dimensions (Span x Depth)	1.8m X 1.2m	2.4m x 1.8m	N/A
Minimum Slope (%)	0.50	0.10	N/A
Manning's Full Flow Velocity (m/s)	2.75	1.23	N/A
Manning's Full Flow (m^3/s)	5.95	6.75	N/A
Design Flow/Capacity	0.77	0.76	N/A
Emergency Flow Capacity (m^3/s)	1.39	1.59	N/A

The conceptualized diversion storm trunks are sized and modeled to convey the anticipated 100-year 24 hour single event storm without overtopping the roadways or causing undue flooding to upstream lands. There is a utility right-of-way that exists on the south side of Township Road 544 (east of Highway 2). Therefore, it is reasonable to assume the future diversion storm trunk for Option 1 and 2 would also run along the south side of Township Road 544 east towards the Sturgeon River. Ditches and culverts near Township Road 544, east of Highway 2, would need to be modified to facilitate the diversion to the Sturgeon River proposed in Options 1 and 2.

The storm trunk diversion could turn south to run parallel to the future North Erin Ridge development boundaries. This strategy should allow land acquisitions and utility rights-of-ways to be assessed and requested in a logical fashion with respects to adjacent development approvals and development timelines.

7.7.10 Carrot Creek Flow Regime and Erosion Consideration

Development (urbanization) has been demonstrated to alter the character of rainfall-generated runoff related to (but not limited to) an increase in impervious surfaces and decrease in infiltration. The typical response of unmitigated post-development flows includes an increase in flood peaks and decrease in lag-times and event durations (i.e., flashiness). For Carrot Creek, these effects are mitigated by stormwater ponds and permissible release rates that regulate discharge and consequently influence event duration. In modeled stormwater servicing options (Options 1a – 3c, 4a, and 4b) the 100-year peak discharge rates for Carrot Creek at the mouth of Big Lake generally do not exceed the discharge rates for the existing condition 100-year event (only exceeded by Option 3c).

While controlling for flood peaks and flashiness, all future development, regardless of stormwater servicing option, are predicted to alter the magnitude of low flow events (Table 7-10, Figure 7-10)**.** Relative to existing conditions in the Carrot Creek basin, predicted discharge is greater for more frequent events, beginning for events with a 9 to 37% probability of exceedance (approximately 11-year to 2-year return interval, respectively). For example, for stormwater servicing Option 1b the predicted discharge for the 1-year event is equivalent to the discharge for the 2-year discharge for the existing condition. Changes in frequency and magnitude of lower flow events are geomorphically significant. While infrequent events are certainly important, channel form is broadly understood to be the result of more frequent flows occurring between 1 and 2 years on average (Wolman & Miller, 1960; Dunne and Leopold, 1978). The recurrence interval of bankfull flow is herein inferred to be 1.5 years or to have a 66.7% probability of exceedance. If unmitigated, in response to an increased magnitude of bankfull flows, it can be expected that Carrot Creek will experience morphological adjustments. Common morphological adjustments due to changes in the bankfull flow regime include channel widening and incision, adjustment in channel slope, bed coarsening, bank instability, and alteration of bed morphology. System response is dependent on several factors including geologic setting (Kang & Marston, 2006; Nelson, Smith, & Miller, 2006), vegetation (Millar, 2000), and mode of sediment transport (Rosburg, 2015). Beyond effects of changes in the flow regime, development may also modify sediment supply to a watercourse, where relative sediment supply typically increases during construction phases and decreases as construction concludes (Rosburg, 2015).

To better understand the ability of predicted flows to transport sediment under stormwater servicing scenarios, the flows for the 1.5-year return event (66.7% probability of exceedance) were input to the Carrot Creek HEC-RAS 1D model and estimated channel shear stress values were compared to critical shear stress values[7] for reach D_{50} and D_{90} sediments to evaluate if flows were likely to initiate sediment transport (i.e., competent to erode local materials). The extent of the assessment was limited to the bounds of the HEC-RAS 1D model (Villeneuve Road to Carrot Creek outlet at Big Lake; Carrot Creek Reaches 1 - 6). To enable this assessment, boundary conditions for the HEC-RAS 1D model were updated to normal depth using surveyed channel slope.

Channel shear stress values show that predicted flows will transport both D_{50} and D_{90} sediments in all reaches (not at all cross-sections) for both existing and stormwater servicing scenarios during the 1.5-year return flows except for Reach 1 under the existing condition (Table 7-16). Predicted 1.5-year flows in Reach 1 can potentially transport non-cohesive sediments up to the D_{90} size.

Due to the variability in natural vegetation communities, it becomes complex to quantitively define the extent and rate of bank erosion under stormwater servicing scenarios. Nevertheless, with a predicted two to four times increase of in magnitude of bankfull flows, a corresponding increase in the sediment transport capability of Carrot Creek is expected. Morphological adjustments may include channel widening, incision, adjustment in channel slope, bed coarsening, bank instability, and alteration of bed morphology.

7.7.10.1 Erosion Monitoring

River reaches will need time to adjust to their new regime and stakeholders should expect morphological changes during this adjustment period. Implementation of an erosion monitoring program is recommended for Carrot Creek. Monitoring interval should be designed to capture potential changes resulting from watershed development (e.g., annual to 5-year interval depending on development activity) and should continue until such time that creek morphology has achieved equilibrium with the ultimate development scenario. Erosion monitoring should focus on geomorphic areas of concern (see Section 5.2.2.1). In addition, the program should consider monitoring the location and condition of beaver dams over time. The geomorphological assessment provided herein can function as a baseline for future monitoring.

Sturgeon County staff have indicated that they possess survey and field observation data along some sections of Carrot Creek and this data could be considered when comparing erosion observations/survey measurements in the proposed erosion monitoring program to historical observations.

[7] Shear stress value required to initiate sediment transport. Published values are available for range of grain sizes (Fischenich C. , 2001).



Table 7-16 Reach materials and corresponding critical shear stress values versus modeled channel shear stress for 1.5-year return flows for existing condition and stormwater servicing options.

Reach	Channel Material						Range of Modeled Channel Shear Stress (N/m^2) for 1.5-year Return Flows*											
	D_{50}			D_{90}														
	Description	Size (Wentworth; mm)	Critical Shear Stress (N/m^2; Fischenich)	Description	Size (Wentworth; mm)	Critical Shear Stress (N/m^2; Fischenich)	Existing Condition (1.1 m^3/s)	Option 1a (2.6 m^3/s)	Option 1b (3.0 m^3/s)	Option 1c (4.2 m^3/s)	Option 2a (2.3 m^3/s)	Option 2b (2.7 m^3/s)	Option 2c (3.9 m^3/s)	Option 3a (2.7 m^3/s)	Option 3b (3.1 m^3/s)	Option 3c (4.4 m^3/s)	Option 4a (2.7 m^3/s)	Option 4b (3.1 m^3/s)
1	Clay and silt	0.062	12.449	Coarse sand	0.54 - 1	0.29	2.3 - 10.2	2.5 - 17.4	2.4 - 19.2	2.4 - 23.1	2.5 - 16.1	2.5 - 17.9	2.3 - 22.2	2.5 - 17.9	2.5 - 19.5	2.4 - 23.5	2.5 - 17.9	2.5 - 19.5
2	Fine sand	0.125 - 0.25	0.14	Medium gravel	8 - 16	5.7	5.8	7.1	7.3	7.7	6.9	7.2	7.4	7.2	7.4	7.9	7.2	7.4
3	Fine sand	0.125 - 0.25	0.14	Medium gravel	8 - 16	5.7	9.8 - 13.9	13.5 - 19.8	14.2 - 20.9	16.1 - 23.5	12.9 - 18.9	13.6 - 20.1	15.8 - 22.8	13.6 - 20.1	14.3 - 21.2	16.3 - 23.9	13.6 - 20.1	14.3 - 21.2
4	Fine sand	0.125 - 0.25	0.14	Coarse gravel	16 - 32	12	2.6 - 20.3	2.4 - 63.4	2.4 - 73.2	2.4 - 84.5	2.4 - 51.5	2.4 - 67.8	2.4 - 83.0	2.4 - 67.8	2.4 - 75.6	2.4 - 84.2	2.4 - 67.8	2.4 - 75.6
5	Clay and silt	0.062	12.449	Coarse sand	0.54 - 1	0.29	1.6 - 35.3	2.1 - 28.8	2.2 - 25.7	2.8 - 17.0	2.0 - 30.5	2.1 - 28.0	2.6 - 19.7	2.1 - 28.0	2.2 - 25.0	2.4 - 14.6	2.1 - 28.0	2.2 - 25.0
6	Clay and silt	0.062	12.449	Fine sand	0.125 - 0.25	0.14	2.6 - 15.7	3.5 - 31.0	3.7 - 36.7	3.9 - 64.5	3.4 - 27.1	3.5 - 32.0	3.9 - 57.5	3.5 - 32.0	3.7 - 39.0	4.0 - 69.8	3.5 - 32.0	3.7 - 39.0

* Does not consider outputs at model boundary (i.e., cross-section 1 and cross-section 26)

7.8 OPINION OF PROBABLE COSTS

Table 7-17 provides a summary of the opinions of probable cost for each stormwater servicing option analyzed. The following are the key findings from the cost analysis:

- The recommended erosion monitoring program, as outlined in Section 7.7.7.1, is not included in the costs in Table 7-17. A budget of $25,000 per year should be considered.
- The cost of stormwater servicing decreases as the allowable UARR to Carrot Creek increases due to the reduced pond sizing at higher UARR.
- Options 2a, 2b and 2c have the highest cost for stormwater trunks and the highest overall cost (for the same UARR) because the diversion of the Highway 2 ditch and the East Tributary to the Sturgeon River requires a longer and larger storm trunk compared to just diverting the East Tributary (Options 1a, 1b and 1c).
- No stormwater trunks are required for Options 3a, 3b, 3c, 4a and 4b. Therefore, stormwater servicing costs for these options are lower. However, it should be noted that these options require the conversion of the temporary drainage ditch along Township Road 544 and Highway 2 into a permanent drainage ditch (or alternatively another method of conveying the East Tributary through the development lands). In the case of Options 4a and 4b, a storage facility (for attenuation of peak flows from the East Tributary) is also proposed south of Township Road 544 and east of Highway 2 which may also reduce developable land. The reduction in developable land south of Township Road 544 and east of Highway 2 is not accounted for in the opinions of probable cost.
- Options 3a, 3b and 3c will maintain connectivity of the East Tributary to Carrot Creek, but without the storage area east of Highway 2 that was recently removed for development. Therefore, due to a risk of higher peak flows in Carrot Creek, there is also a risk of more erosion in high flow events. An allowance for more erosion protection has been included in the costs for Options 3a, 3b and 3c but there is some uncertainty regarding the cost.
- It is expected that developers will pay for the stormwater management facilities as development proceeds. The source of funding for the proposed storage facility east of Highway 2 and south of Township Road 544, to attenuate peak flows from the East Tributary, will need to be determined by the City of St. Albert.
- Municipalities (and perhaps Alberta Transportation) will likely need to provide funding for the creek erosion protection and monitoring.
- For options 1 and 2, part of the basin is to be diverted to the Sturgeon River. The funding source for this trunk, should one of these options be selected, will need to be determined.
    - The cost of the diversion trunk to the Sturgeon River in Options 1 and 2 could be reduced significantly if the flow can be diverted to the “NEST” Trunk which is proposed to service the developing lands in North Erin Ridge. The status of the “NEST” trunk design and schedule for construction should be investigated to confirm if this option is feasible.



Table 7-17 Stormwater Servicing Options Opinions of Probable Cost

Option	Stormwater Management Facility Cost	Storm Trunk Cost	Creek Erosion Protection / Culvert Upgrade Cost	Total Stormwater Servicing Cost
1a	$165 Million	$28 Million	$4 Million	$197 Million
1b	$157 Million	$28 Million	$4 Million	$189 Million
1c	$136 Million	$28 Million	$4 Million	$168 Million
2a	$165 Million	$45 Million	$4 Million	$214 Million
2b	$157 Million	$45 Million	$4 Million	$206 Million
2c	$136 Million	$45 Million	$4 Million	$185 Million
3a	$165 Million	$0	$8 Million	$173 Million
3b	$157 Million	$0	$8 Million	$165 Million
3c	$136 Million	$0	$8 Million	$144 Million
4a	$169 Million	$0	$4 Million	$173 Million
4b	$162 Million	$0	$4 Million	$166 Million

Notes:
1. Storm sewers/trunks (on-site servicing) required to service new development is not included in the costs for each option. Storm trunk from ProNorth Industrial Area to Carrot Creek is not included.
2. All costs include 50% contingency and are considered planning-level opinions of probable cost.
3. Land acquisition and/or right of way acquisition costs are not included.

7.9 PREFERRED SERVICING PLAN

A UARR of 5.0 L/s/ha (i.e. all of the “c” options) was ruled out because it is higher than the current UARR and there are concerns that higher peak flows in Carrot Creek will worsen erosion. Stakeholders (City of St. Albert, Sturgeon County, Town of Morinville and Alberta Environment and Parks) were consulted and the consensus was that 2.5 L/s/ha is appropriate as it matches the existing condition and will result in slightly smaller stormwater management facilities compared to a UARR of 1.8 L/s/ha.

Options 1 and 2 are not preferred because they are the highest cost options (due to the diversion trunk to the Sturgeon River) and there are concerns with diverting a large area (1,003 ha or 3,599 ha) away from the Carrot Creek basin. Options 3 and 4 were considered further.

Option 3 was eventually ruled out because allowing the East Tributary to discharge higher peak flows to Carrot Creek (which would be the case with the removal of the large storage area east of Highway 2) may lead to an increase in erosion. Permanent removal of the storage on the East Tributary between Township Road 544 and Highway 2 may also pose a flooding risk during high flow events because the topography in this area is relatively flat and the channel relatively indistinct compared to the main reach of Carrot Creek downstream of the confluence with the East Tributary.

Option 4b is the recommended option. Option 4 includes construction of a stormwater management facility south of Township Road 544 that would replace the large depression storage located in the North Erin Ridge area of north St. Albert (currently under development east of Highway 2) that was removed to make room for the development. Option 4 has a much lower cost than Options 1 and 2 because it does not require a lengthy diversion sewer to the Sturgeon River, and a similar cost to Option 3. The estimated



active storage volume of the new stormwater management facility is 60,500 m^3 (not including freeboard) and it is required to attenuate peak flows from the East Tributary before they go under Highway 2 and enter the main reach of Carrot Creek. The recommended UARR is 2.5 L/s/ha for all new development areas that will contribute stormwater to Carrot Creek and its tributaries.

Several considerations for the preferred Option 4b include:

- Storage volume (for East Tributary attenuation) may be refined during the detailed design phase, which could include more detailed modeling focused on the East Tributary.
- Detailed design should also include the design of the flow control facility that will force peak flows to be attenuated.
- The storage facility location between Township Road 544 and Highway 2 must be determined during the detailed design phase. The current “temporary storage” according to the 2021 as-built drawings (WSP, 2021) could be expanded to the appropriate volume or an alternative location further north towards Township 544 could be considered.
- The conveyance pathways (ditches, culverts and/or storm sewers) of the East Tributary through the North Erin Ridge development area need to be sized during the detailed design phase. It is uncertain if the capacities of the recently constructed temporary ditch along Township Road 544 and Highway 2, as well as the Highway 2 ditch, are adequate (with sufficient freeboard) for the East Tributary flows on a permanent basis.

The preferred option includes a series of stormwater management facilities in new development areas to control the UARR to 2.5 L/s/ha. Low impact development (LID) facilities such as bioretention facilities, soil cells and rain gardens (among others) may be considered in addition to the storm ponds. Controlling stormwater peak flow rate to Carrot Creek using stormwater management facilities in new development areas will eliminate the need for a large diameter storm trunk that is parallel to Carrot Creek, as was proposed for servicing future northwest and west St. Albert developments in previous studies including the 2013 Utility Master Plan Update.

8 RECOMMENDATIONS

The recommendations that result from this study include the following:

- All future developments in the Carrot Creek Basin, that discharge stormwater to Carrot Creek, shall contain stormwater management facilities that attenuate peak flow to a maximum unit area release rate (UARR) of 2.5 L/s/ha for a 1:100 year rainfall event. This is close to the existing 1:100 year UARR for Carrot Creek at the mouth of Big Lake (2.55 L/s/ha) based on the statistical analysis of existing hydrometric station data.
- UARR of 2.5 L/s/ha should be achieved through the use of traditional stormwater management facilities (wet ponds, engineered wetlands).
- Low impact development (LID) in new development areas are encouraged to help attenuate peak stormwater flows and may also reduce stormwater volumes from new development areas. Example of LID include rain gardens, bioretention facilities and soil cells, among others. LID features can also improve stormwater quality before it is released to the creek.
- Controlling stormwater peak flow rate to Carrot Creek using stormwater management facilities and other attenuation methods (e.g. LID) in new development areas will eliminate the need for a large diameter storm trunk that is parallel to Carrot Creek, as was previously proposed for servicing future northwest and west St. Albert developments.
- A new stormwater management facility to attenuate peak flows from the East Tributary should be constructed east of Highway 2 and south of Township Road 544. This facility, with an estimated 1:100 year 24 hour rainfall event high water level volume of 60,500 m^3 (not including freeboard), is required to replace the large depression storage previously located in the North Erin Ridge area of north St. Albert that was removed to make room for the development. Detailed design of the storage, which may include refinement of the total volume, should commence during the Area Structure Plan (ASP) stage. The detailed design of this stormwater management facility should consider the following:
    - The peak flows that are discharged from the East Tributary and Highway 2 ditch to the culvert under Highway 2, and subsequently into the main reach of Carrot Creek, should not exceed the “pre-development” peak flows through the Highway 2 culvert that occurred before the previous depression area storage in North Erin Ridge was removed.
    - The detailed modeling to confirm the size of the storage facility may also include a refinement of the hydrologic parameters. Infiltration parameters may need to be refined based on local geotechnical data.
    - The detailed design should include the inlet and outlet structures/controls that will allow base flows from the East Tributary to continue uninterrupted under Highway 2 towards the main reach of Carrot Creek, while peak flows should be attenuated in the facility. The existing weir in the built channel between Highway 2 and the main reach of Carrot Creek may not be sufficient on its own to trigger the storage of peak flows because the new stormwater management facility will be in a different location. An additional diversion

structure or inlet/outlet control structure will likely be required, to be designed during the detailed design phase.

- The attenuated peak flow from the East Tributary may be released back to Carrot Creek (via the East Tributary east of Highway 2) and/or it could be released to the City storm sewer system in North Erin Ridge that would eventually discharge to the Sturgeon River. The capacity of the storm sewers would need to be verified to confirm how much flow could be diverted from the East Tributary through the new stormwater trunk in North Erin Ridge, if any. This can be considered during the detailed design phase.
- In addition to the new stormwater management facility for attenuating the peak flows from the East Tributary, a dedicated easement or "utility right of way" for the East Tributary will need to be maintained between the Township Road 544 crossing and the Highway 2 crossing to keep the East Tributary of Carrot Creek connected to the main reach. This study did not assess whether the Highway 2 ditch, between Township Road 544 and the Highway 2 culvert crossing, has capacity for East Tributary flows; therefore, this needs to be confirmed in the detailed design stage if use of the Highway 2 ditch is considered to convey the East Tributary. Similarly, the capacity of the recently constructed "temporary" diversion ditch along Township Road 544 and Highway 2 to convey East Tributary flows on a permanent basis was not assessed in this study but could be considered at the detailed design stage.

- Collaboration will be required amongst private site developers and the City of St. Albert to efficiently manage storm trunk and outfall requirements to Carrot Creek in new developments in west St. Albert. Outfalls or the upstream storm basins should be outfitted with stormwater treatment facilities (e.g. oil and grit separators or engineered wetlands) in order to reduce sediment and pollutant loading into the creek.
- Implementation of erosion control at key locations that are prone to erosion, and to protect infrastructure such as bridges over Carrot Creek, are recommended per Section 6.3 of this report. Funding for these proactive erosion protection measures and monitoring will need to be coordinated by the three stakeholder municipalities (City of St. Albert, Sturgeon County, Town of Morinville).
- Creek reaches will need time to adjust to their new flow regime and stakeholders should expect morphological changes during the adjustment period. As a result, erosion monitoring at key locations is recommended in order to verify that erosion and bank stability are not negatively impacted by future development. Monitoring interval should be designed to capture potential changes resulting from watershed development (e.g., annual to 5-yr interval depending on development activity) and should continue until such time that creek morphology has achieved equilibrium with the ultimate development scenario. Similar to the erosion control, funding for the proposed erosion monitoring will need to be coordinated by the three stakeholder municipalities (City of St. Albert, Sturgeon County, Town of Morinville).

- The recommended capacity increase of the Carrot Creek culverts and erosion protection at the CN Rail crossing will need to be arranged with CN Rail. It is recommended that the findings of this report be shared with CN Rail and that the process for implementing an additional or larger culvert, as well as the recommended erosion protection, be initiated with CN Rail. As this crossing occurs at the boundary between the City of St. Albert and Sturgeon County, a collaborative effort may be required. There was extensive flooding at the CN Rail crossing in April 2020 so it is likely that CN Rail may be aware of the undersized culverts.
- Peak flows in the main reach of Carrot Creek are controlled by the extensive wetlands and natural depression storage that are common throughout much of the Carrot Creek basin particularly in the Sturgeon County portion of the basin (see wetland mapping described in Section 4 and shown in Appendix B). In order to prevent an increase of peak flows in Carrot Creek, these wetlands and depression storage areas need to be preserved. If any are removed by future development, an equivalent storage must be provided such that peak flows in Carrot Creek are not increased and the UARR of 2.5 L/s/ha is maintained (Alberta Environment and Parks' wetland replacement program may apply, but it is important that the replaced wetland not only provide ecosystem improvements which is the main aim of the wetland replacement program, but also a creek flow attenuation function).
- The riparian health of Carrot Creek should be maintained as future development proceeds. In the main reach of Carrot Creek (south of Township Road 544) where there is a more defined riparian area and natural vegetative barrier between the agricultural fields and the creek, future development in east St. Albert should be set back from the creek such that the riparian area and floodway are left intact and natural. Protection of the riparian zone adjacent to the creek and its tributaries is also required further north throughout Sturgeon County and the south end of the Town of Morinville even though the creek channel is less defined in many areas. Protection of the riparian area will promote good water quality and ecosystem health.
- Beaver dam activity is unpredictable but a significant number of active and inactive beaver dams were observed along Carrot Creek in the area visited by field staff. The potential for beaver dams to impact water levels along the creek should be considered in the detailed design of the recommended erosion protection and permanent conveyance of the East Tributary through or around the North Erin Ridge development.

9 REFERENCES

AECOM. (2016). *Town of Morinville Municipal Utility Servicing Plan Update. modelingDrainage master plan*

Alberta Climate Records. (2019). *Alberta Climate Records*. Retrieved from http://www.albertaclimaterecords.com/#

Alberta Environment and Sustainable Resource Department. (2013). *Standards and Guidelines for Municipal Waterworks, Waterwater and Storm Drainage Systems: Part 5 Stormwater Management Guidelines.* Alberta Queen's Printer.

Alberta Environment and Sustainable Resource Development. (2013). *Evaporation & Evapotranspiration in Alberta.*

Alberta Environmental Protection. (1999). *Stormwater Management Guidelines for the Province of Alberta.* Alberta Queen's Printer.

Alberta Parks. (2015). *Natural Regions and Subregions of Alberta - A Framework for Alberta's Parks.* Edmonton, AB: Alberta Tourism, Parks and Recreation.

Andriashek, L. (1988). *Quaternary Stratigraphy of the Edmonton Map Area, NTS 83H.* Terrain Sciences Department, Natural Resources Division. Alberta Research Council.

Associated Engineering. (2004). *Big Lake Stormwater Mangement Plan.*

Associated Engineering. (2020). *City of St. Albert Northest Area Storm Sturgeon River Outfall Predesign Report.*

Bayrock, L. (2005). *Surficial Geology Edmonton (83H), scale 1:250,000.* Alberta Energy Regulator and Alberta Geological Survey.

Bayrock, L. (2005). *Surficial Geology Edmonton (83H), scale 1:250,000.* Alberta Energy Regulator and Alberta Geological Survey.

Bayrock, L., & Hughes, G. (1962). *Surficial Geology of the Edmonton District, Alberta.* Edmonton: Research Council of Alberta.

BEAR Land Services. (2020). *2020 Flooding and Drainage Report.* St. Albert: BEAR Land Services.

Buffington, J., & Montgomery, D. (2013). Geomorphic classification of rivers. In J. Shroder, & E. Whol (Eds.), *Treatise on Geomoprhology* (Vol. 9, pp. 730-767). San Diego, California: Academic Press.

Chow, V. T. (1959). *Open Channel Hydraulics.* New York: McGraw-Hill Inc.

Cruden, D., Tedder, K., & Thomson, S. (1989). Setbacks from the crests of slopes along the North Saskatchewan River, Alberta. *Canadian Geotechnical Journal*(26), 64-70.

Demmer, R., & Beschta, R. L. (2008). Recent history (1988-2004) of beaver dams along Bridge Creek in Central Oregon. *Northwest Science, 82*(4), 309-318.

Department of Environment and Natural Resources. (2009). *Ecological Regions of the Northwest Territories, Taiga Plains.* Government of Northwest Territories.

Dunne, T., & Leopold, L. B. (1978). *Water in Environmental Planning.* San Francisco: W.H. Freeman and Company.

Fang, X., Minke, A., Pomeroy, J., Brown, T., Westbrook, C., Guo, X., & Guangul, S. (2007). *A review of Canadian Prairie Hydrology: Principles, modeling and response to land use and drainage change.* Saskatoon: University of Saskatchewan.

Fenton, M., Waters, E., Atkinson, N., Utting, D., & Mckay, K. (2013). *Surficial Geology of Alberta.* Edmonton: Alberta Energy Regulator and the Alberta Geological Survey.

Fischenich, C. (2001, May). Stability Thresholds for Stream Restoration Materials. *EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-29)*. Vicksburg, MS: US Army Engineer Research and Development Center.

Fischenich, J. C., & McKay, S. K. (2011). Hydrologic analyses for stream restoration design. *EMRRP Technical Notes Collection. ERDC TN-EMRRP-EBA-8.* Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Garcia-Gaines, R. A., & Frankenstein, S. (2015). *USCS and the USDA soil classification system.* Vicksburg: US Army Corps of Engineers.

Government of Alberta, Transportation. (June 2011). *Erosion and Sediment Control Manual.* Government of Alberta .

Howes, D. E., & Kenk, E. (1997). *Terrain classification system for British Columbia.* Victoria: Resource Inventory Branch, British Columbia Ministry of Environment, Lands and Parks.

ISL Engineering and Land Services. (2015). *Alberta Transportation Final Report #R-1192 Highway 2 Network Review.*

ISL Engineering and Land Services. (2019). *Sturgeon County Infrastructure Master Plan.*

J.R. Paine & Associates Ltd. (2020). *Slope Stability Assessment: Tributary to Oldman Creek & Portion of Pointe-Aux-Pins Creek.* Edmonton: J.R. Paine & Associates Ltd.

Matrix Solutions Inc. (2020). *St. Albert Flood Hazard Study Sturgeon River.*

Pettapiece, W. W. (1986). *Physiographic Subdivisions of Alberta.* Ottawa: Land Resource Research Center, Research Brand, Agriculture Canada.

Plumb, B. D., Annable, W. K., Thompson, P. J., & Hassan, M. A. (2017). The impact of urbanization on temporal changes in sediment transport in a gravel bed channel in Southern Ontario, Canada. *Water Resources Research, 53*, 8443-8458.

Prior, G.J., Hathway, B., Glombic, P., Pana, D., Banks, C., . . . Weiss, J. (2013). *Bedrock geology of Alberta.* Energy Resources Conservation Board, ERCB/AGS Map 600, scale 1:1 000 000.

Rosburg, T. T. (2015). *Flow duration curves and sediment yield estimation for urbanizing watersheds.* Fort Collins: Colorado State University.

Rosgen, D. (2006). *Watershed Assessment of River Stability and Sediment Supply (WARSSS)* (1st ed.). (D. Frantila, Ed.) Fort Collins, Colorado: Wildland Hydrology.

Rosgen, D. (2008a). *River Stability Field Guide.* (D. Frantila, Ed.) Fort Collins, Colorado: Wildland Hydrology.

Rosgen, D. (2008b). *River Stability Forms & Worksheets.* (D. Frantila, Ed.) Fort Collins, Colorado: Wildland Hydrology.

Sameng Inc. (2013). *Sturgeon Valley Stormwater Update.*

Simon, A., Curini, A., Darby, S. E., & Langendoen, E. J. (2000). Bank and near-bank processes in an incised channel. *Geomorphology, 35*, 193-217.

Spencer Environmental Management Services Ltd. (2015). *St. Albert Natural Areas Assessment - 2015 Update.* Edmonton.

Stantec Consulting Ltd. (2014). *City of St. Albert 2013 Utility Master Plan Update.*

Stantec Consulting Ltd. (2019). *Bremner and LEA Utilities Master Plan.* Edmonton: Stantec.

Stantec Consulting Ltd. (2020). *Northwest Bremner Erosion and Mitigation Plan - Tributary of Oldman Creek.* Edmonton: Stantec Consulting Ltd.

USDA. (2007). *National Engineering Handbook, Part 654 - Stream Restoration Design, Technical Supplement 14B, Scour Calculations.* Washington DC: National Resources Conservation Service.

Welsh, S. B. (2012). *Geomorphic changes following beaver dam failure and abandonment.* Logan: Utah State University.

Wolman, M. G., & Miller, J. P. (1960). Magnitude and frequency of forces in geomorphic processes. *The Journal of Geology*, 54-74.

WSP Canada Group Ltd. (2018). *City of St. Albert and Sturgeon County Carrot Creek Drainage master plan.*

Yochum, S. E. (2018). *Guidance for Stream Restoration, Technical Note TN-102.4.* Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream and Aquatic Ecology Center.

APPENDICES

Appendix A Statement of General Conditions

Statement of General Conditions

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BASIS OF THE REPORT: The information, opinions, and/or recommendations made in this report are in accordance with Stantec's present understanding of the site-specific project as described by the Client. The applicability of these is restricted to the site conditions encountered at the time of the investigation or study. If the proposed site specific project differs or is modified from what is described in this report or if the site conditions are altered, this report is no longer valid unless Stantec is requested by the Client to review and revise the report to reflect the differing or modified project specifics and/or the altered site conditions.

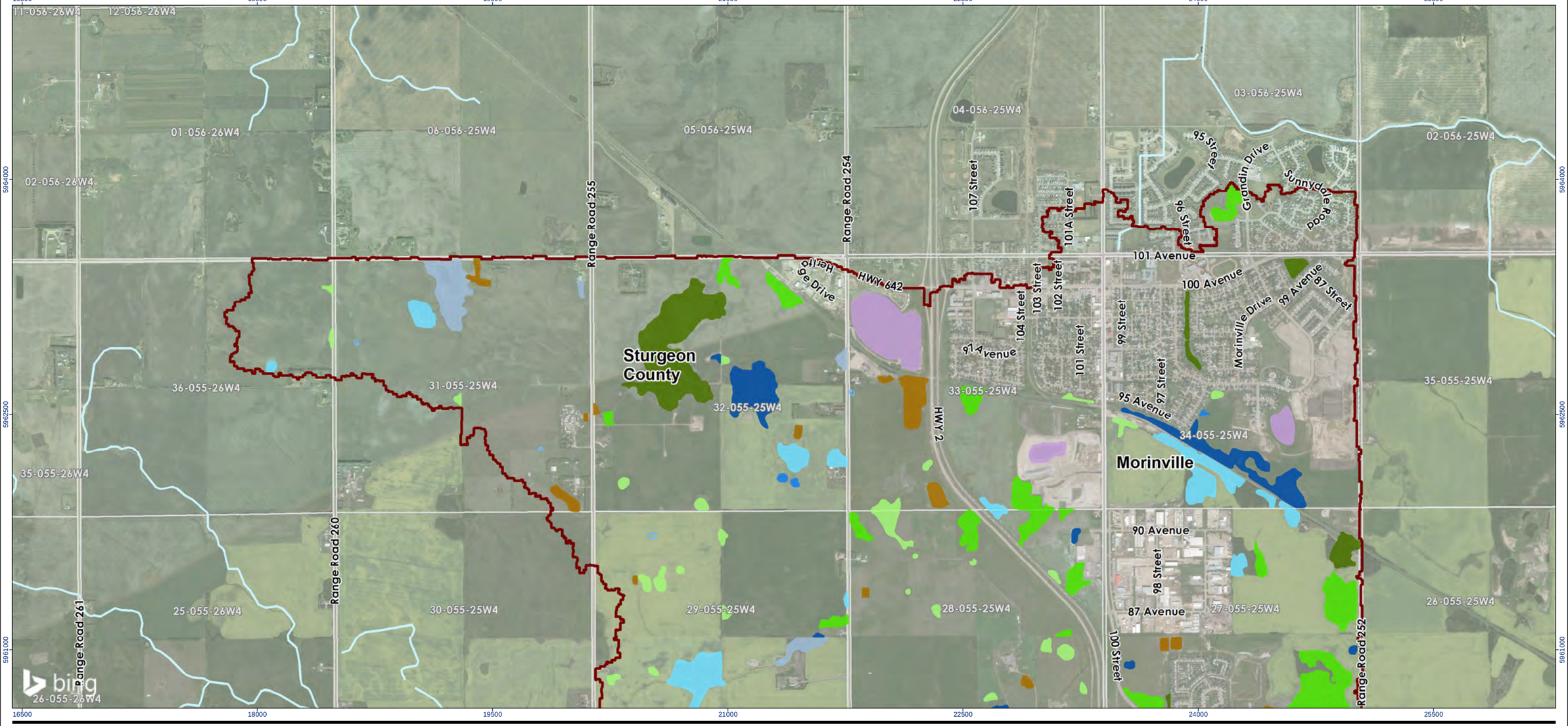
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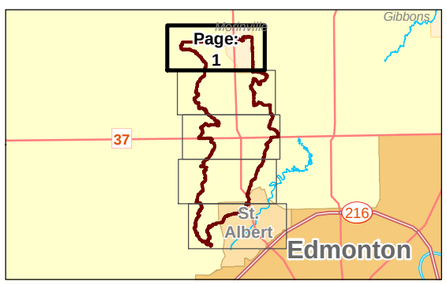
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Appendix B Desktop Wetland Delineations





- Dugout
- Ephemeral Waterbody
- Seasonal Graminoid Marsh
- Seasonal Graminoid Marsh
- Semi-Permanent Graminoid Marsh
- Temporary Shrubby Swamp
- Seasonal Shrubby Swamp
- Stormwater Management Facility
- Wooded Deciduous Swamp
- Permanent Shallow Open Water

- Study Area (Carrot Creek Basin)
- Watercourse
- Section

0 625 1,250 metres

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Notes

1. Coordinate System: NAD 1983 3TM 114

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Carrot Creek Basin,
Morinville, Alberta

Prepared by DJenkins on 2021-01-26
QR by XX on 2021-xx-xx

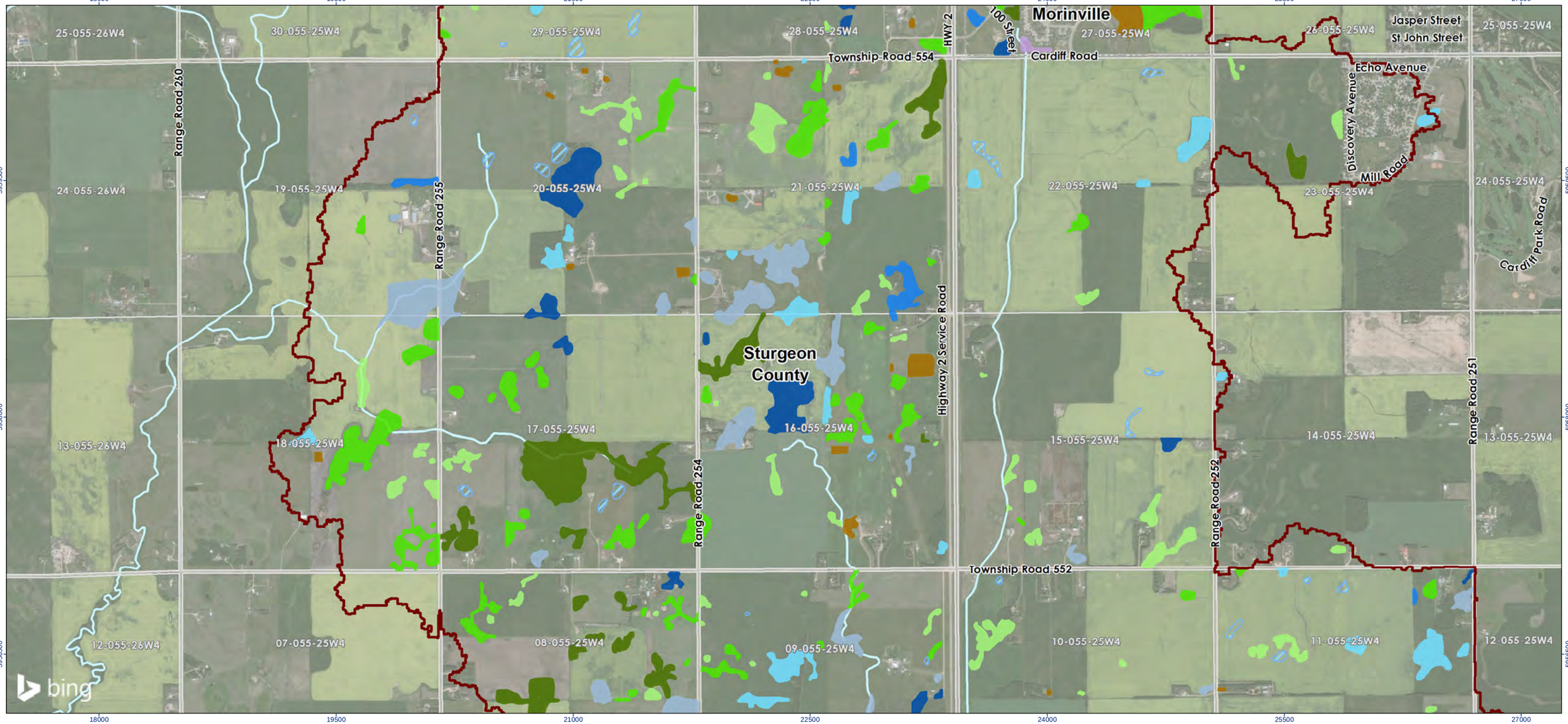
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Carrot Creek Regional Master Drainage Plan

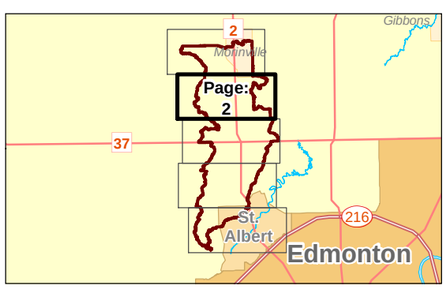
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Desktop Wetland Delineations

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- Dugout
- Ephemeral Waterbody
- Seasonal Graminoid Marsh
- Seasonal Graminoid Marsh
- Semi-Permanent Graminoid Marsh
- Temporary Shrubby Swamp
- Seasonal Shrubby Swamp
- Stormwater Management Facility
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- Watercourse
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0 625 1,250 metres

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Notes

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Project Location
Carrot Creek Basin,
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Prepared by DJenkins on 2021-01-26
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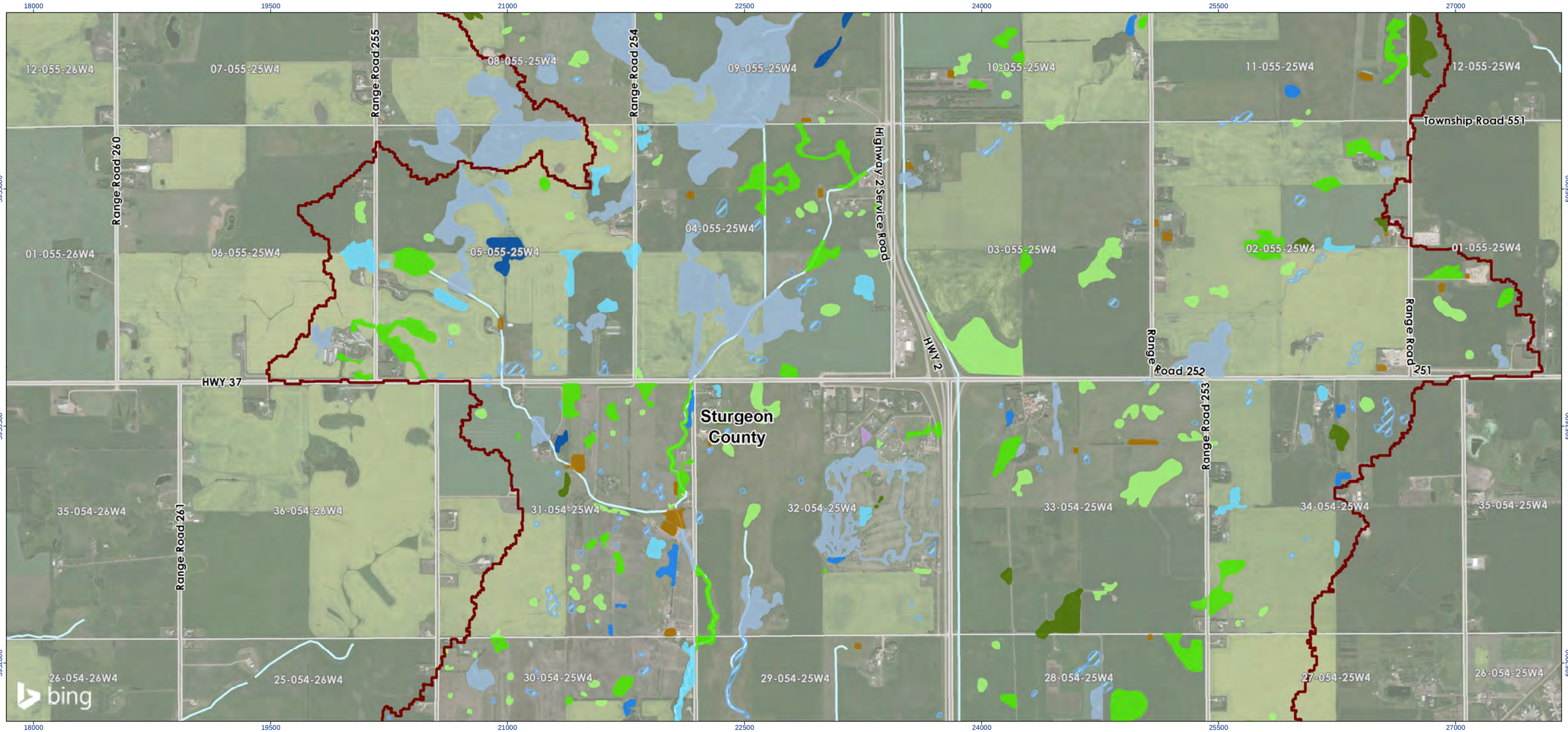
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City of St. Albert
Carrot Creek Regional Master Drainage Plan

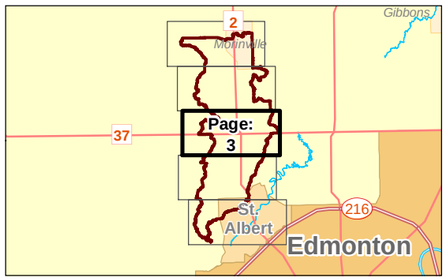
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- Dugout
- Ephemeral Waterbody
- Seasonal Graminoid Marsh
- Seasonal Graminoid Marsh
- Semi-Permanent Graminoid Marsh
- Temporary Shrubby Swamp
- Seasonal Shrubby Swamp
- Stormwater Management Facility
- Wooded Deciduous Swamp
- Permanent Shallow Open Water

- Study Area (Carrot Creek Basin)
- Watercourse
- Section

0 625 1,250 metres

(At original document size of 11x17)
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N

Notes
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Stantec

Project Location
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Morinville, Alberta

Prepared by DJenkins on 2021-01-26
QR by XX on 2021-xx-xx

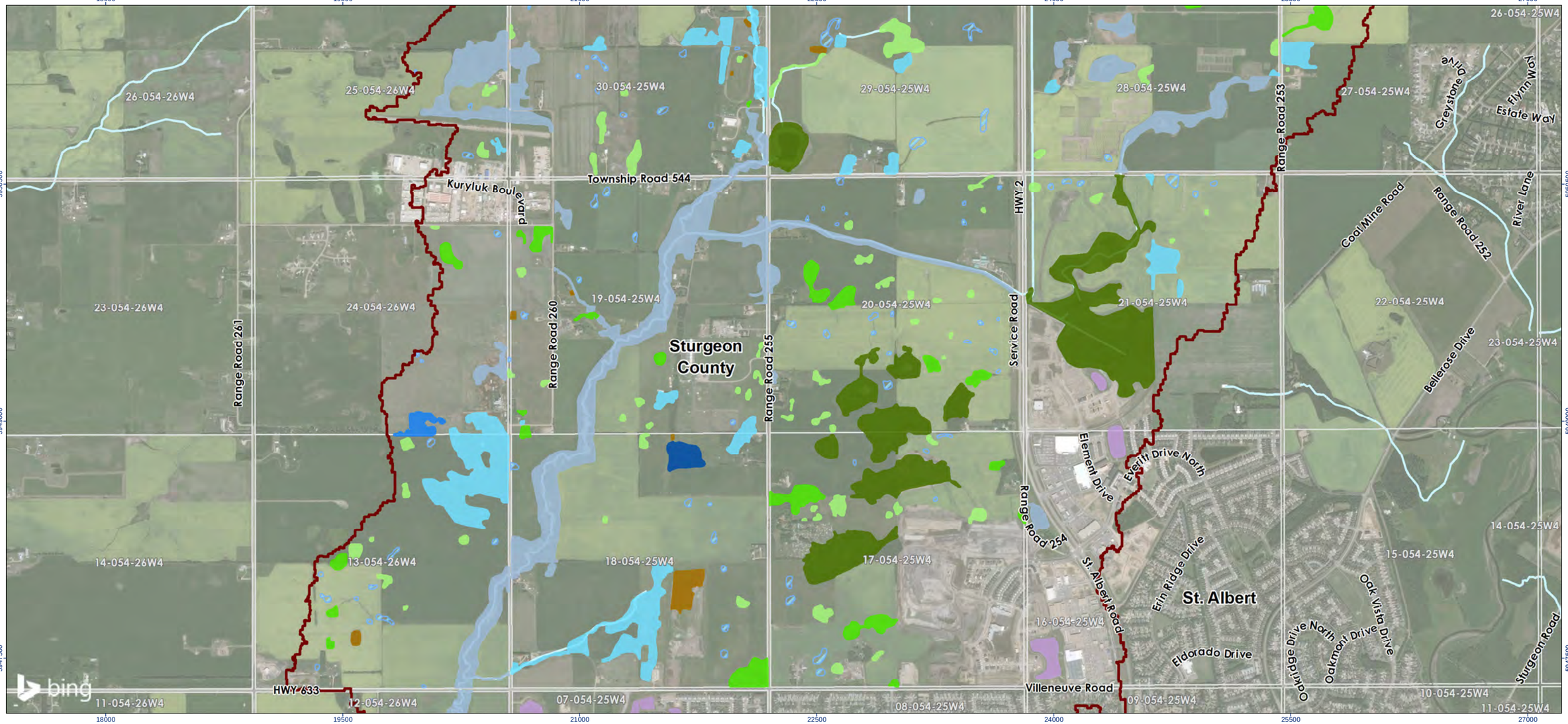
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Carrot Creek Regional Master Drainage Plan

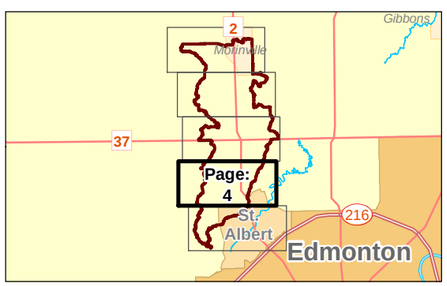
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Title
Desktop Wetland Delineations

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- Dugout
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Stantec

Project Location
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Prepared by DJenkins on 2021-01-26
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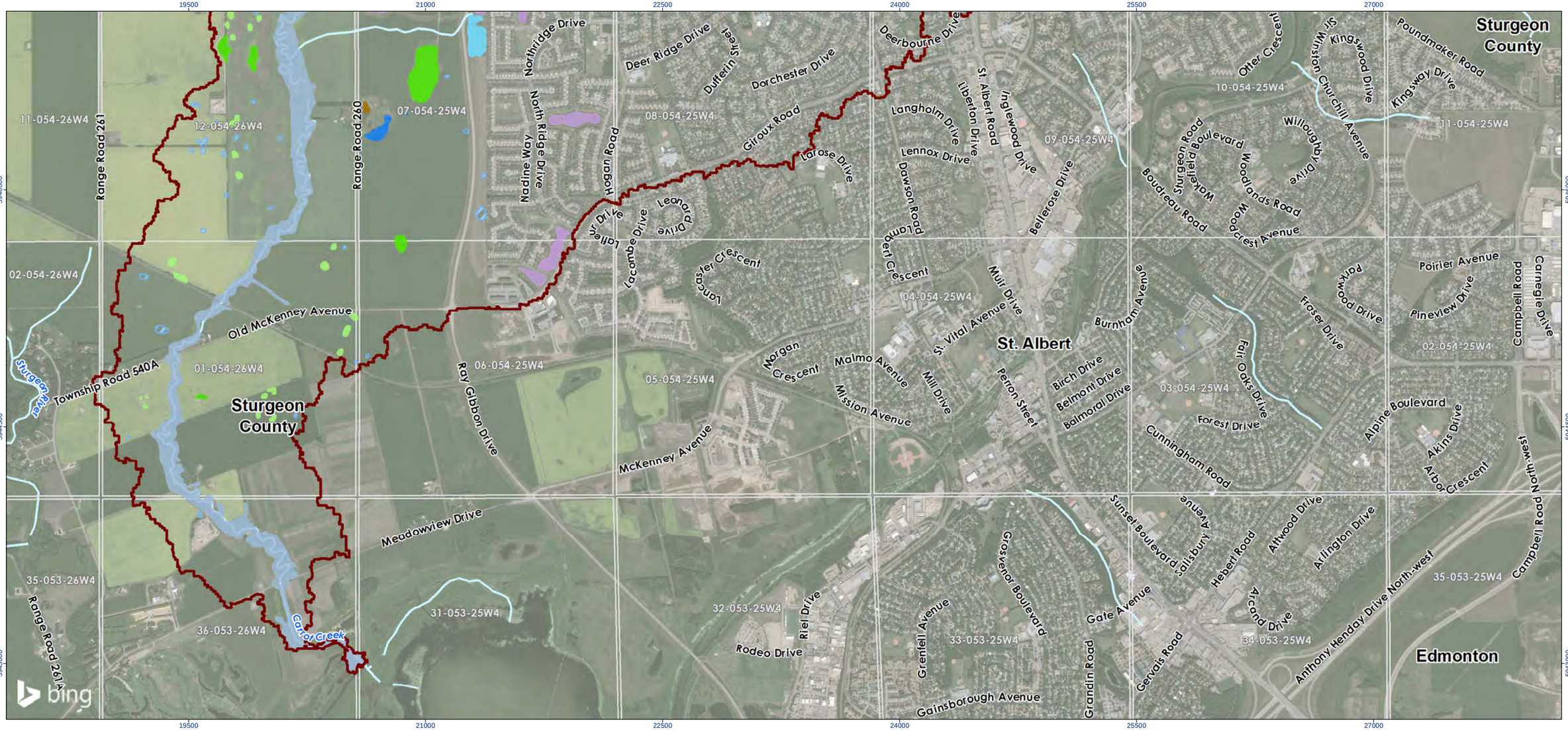
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City of St. Albert
Carrot Creek Regional Master Drainage Plan

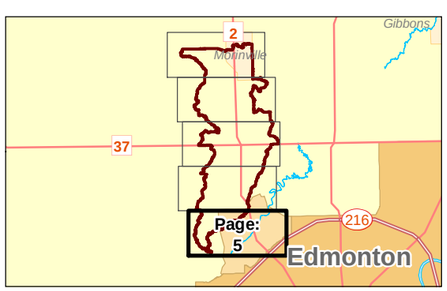
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Project Location
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Morinville, Alberta

Prepared by DJenkins on 2021-01-26
QR by XX on 2021-xx-xx

Client/Project 110149416
City of St. Albert
Carrot Creek Regional Master Drainage Plan

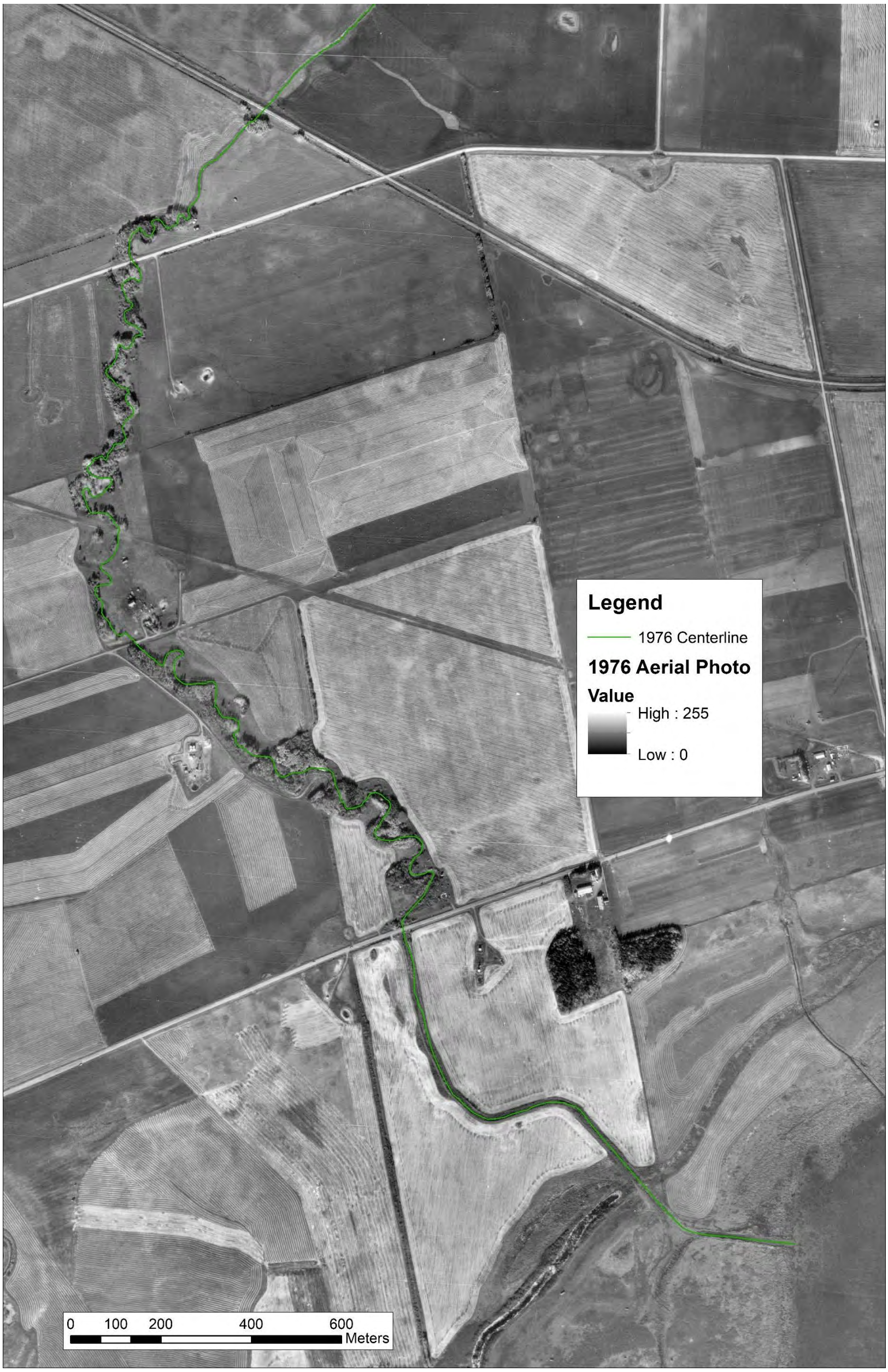
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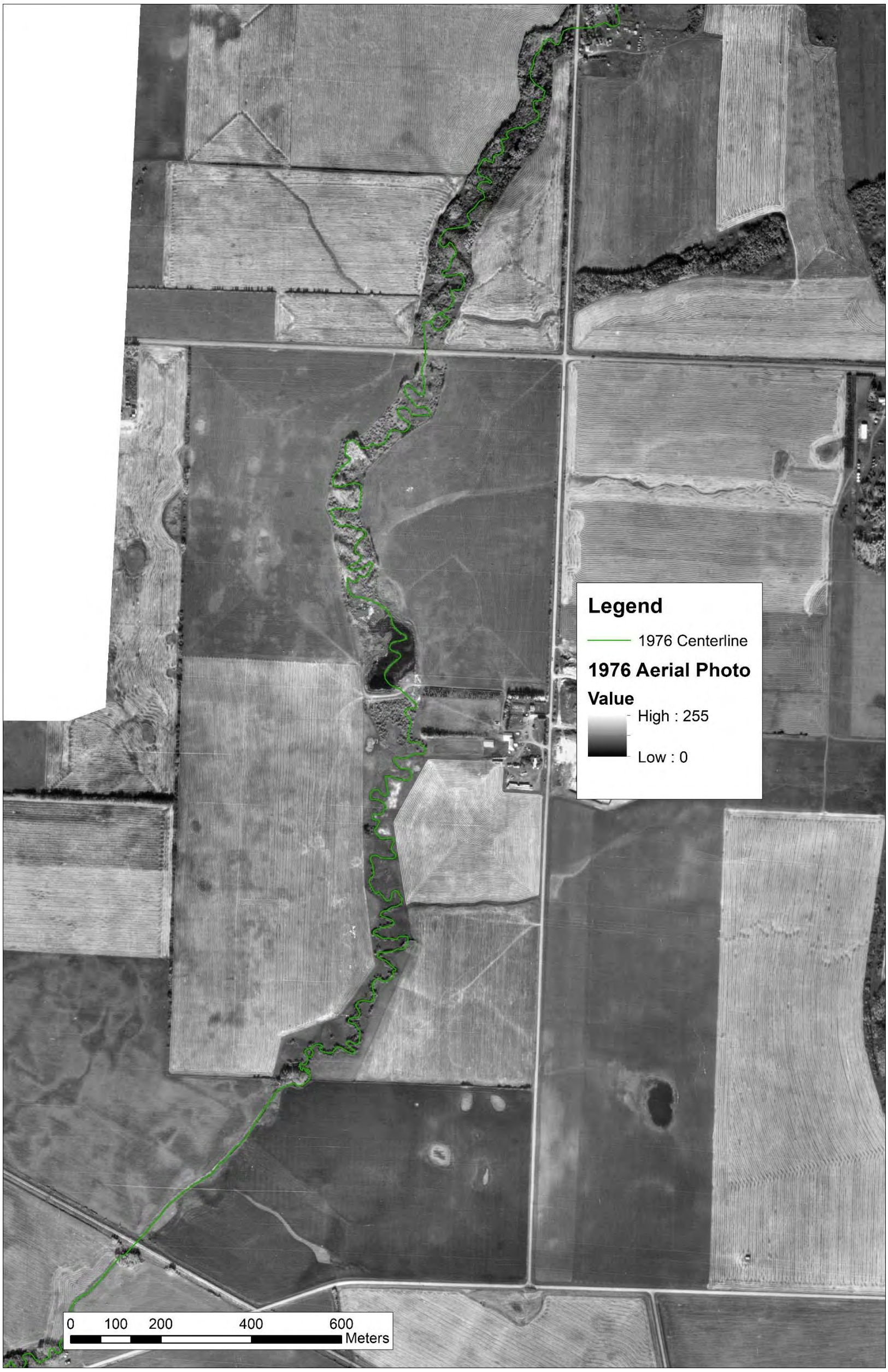
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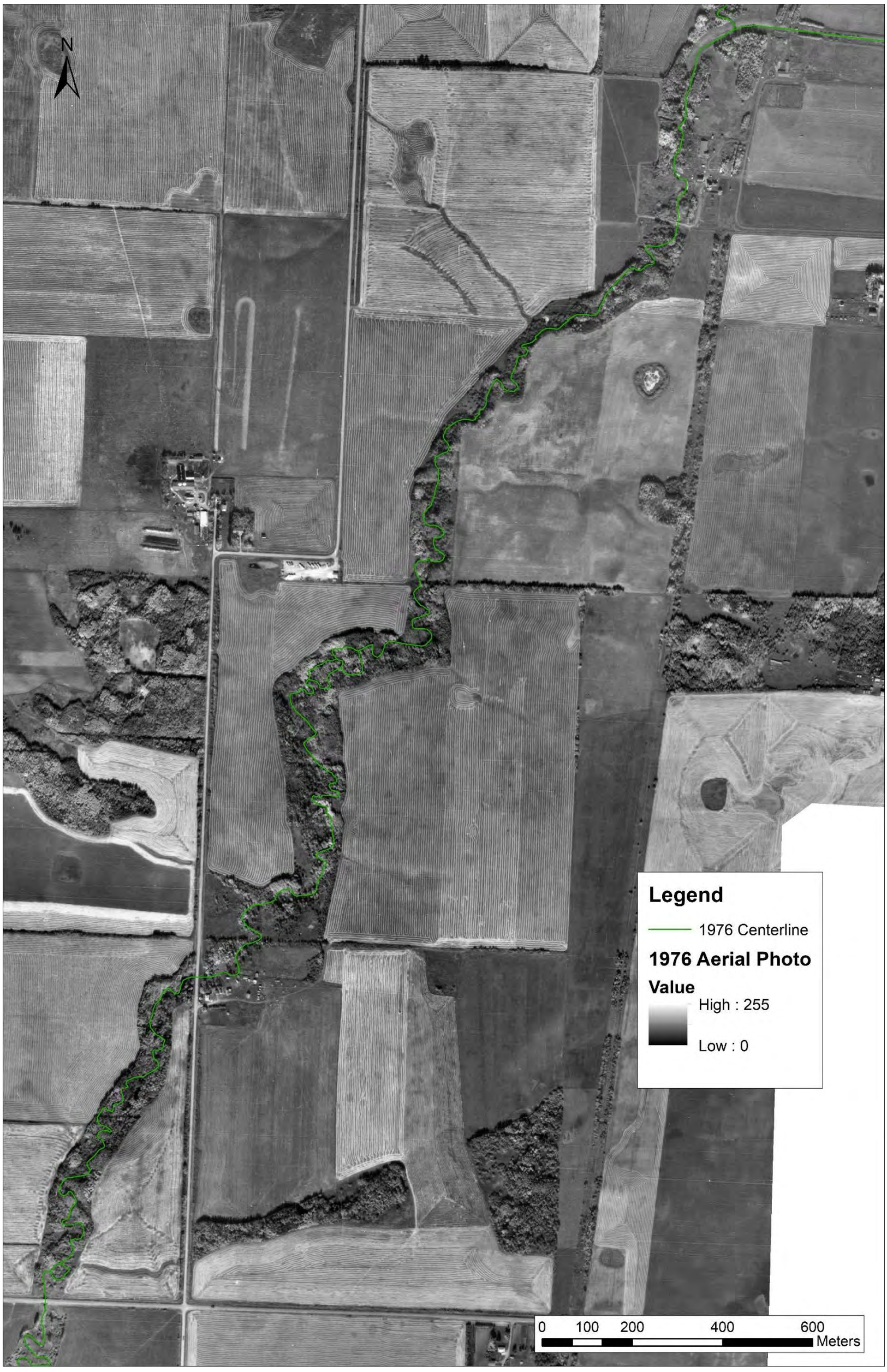
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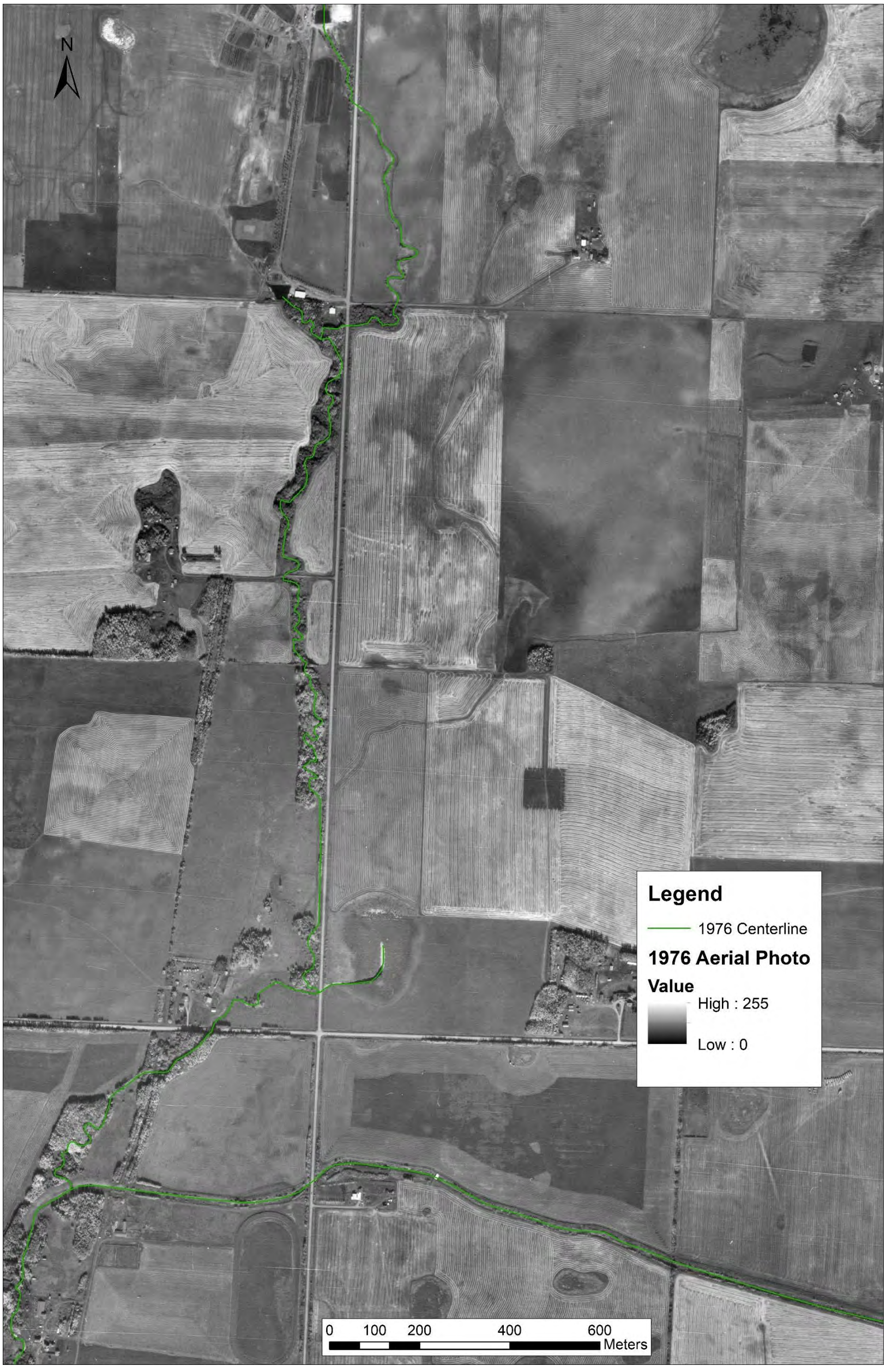
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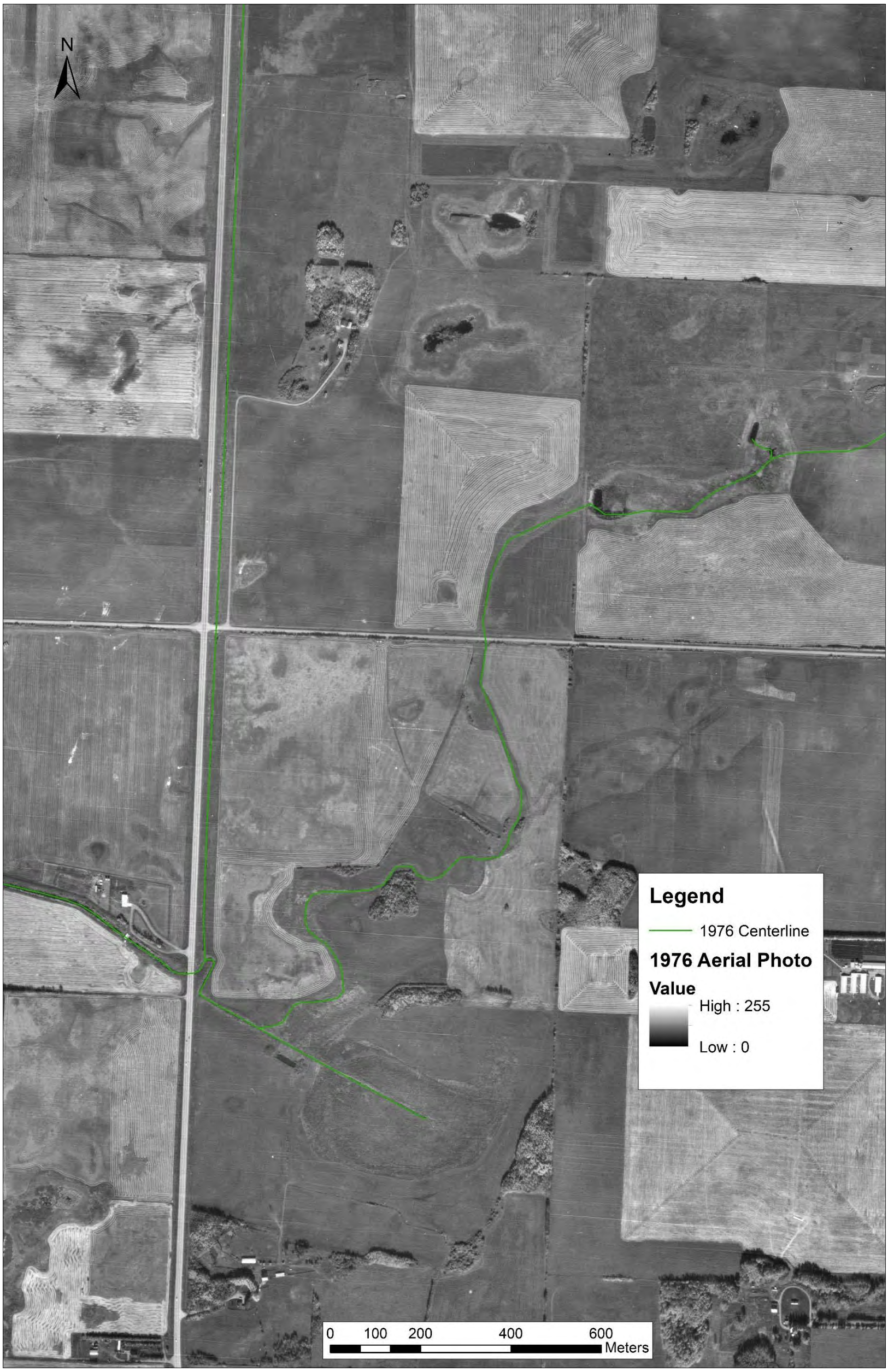
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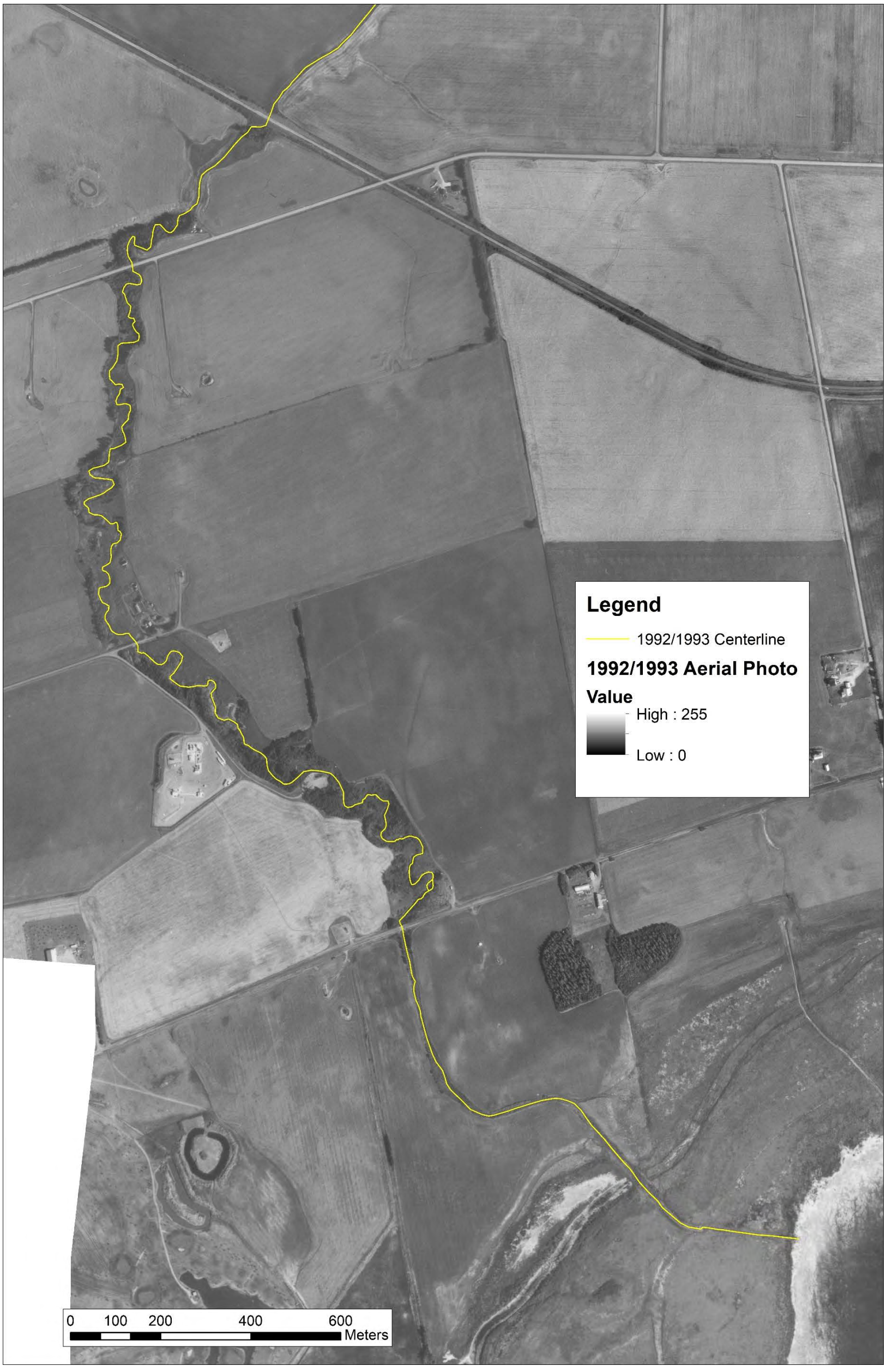
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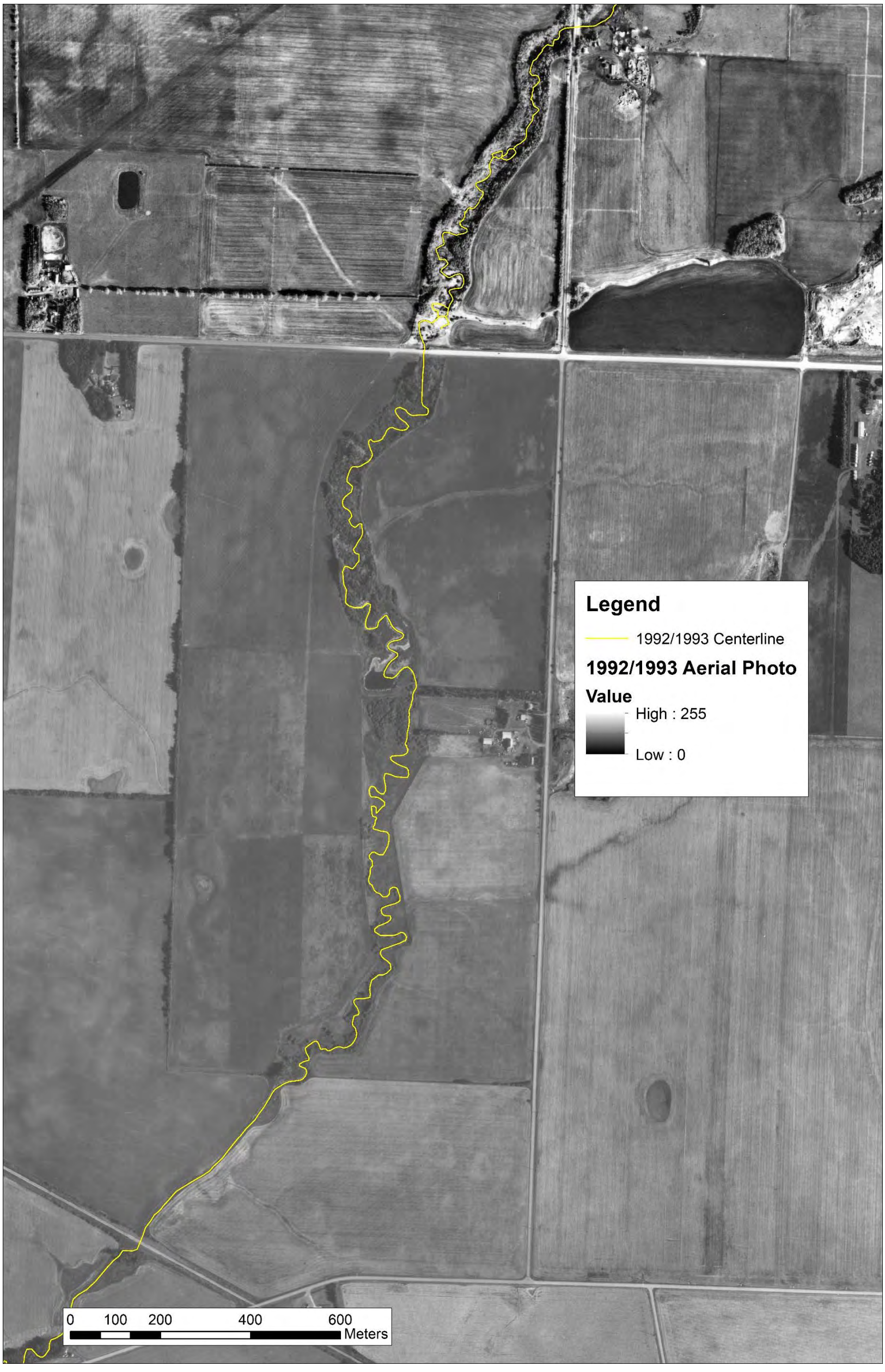
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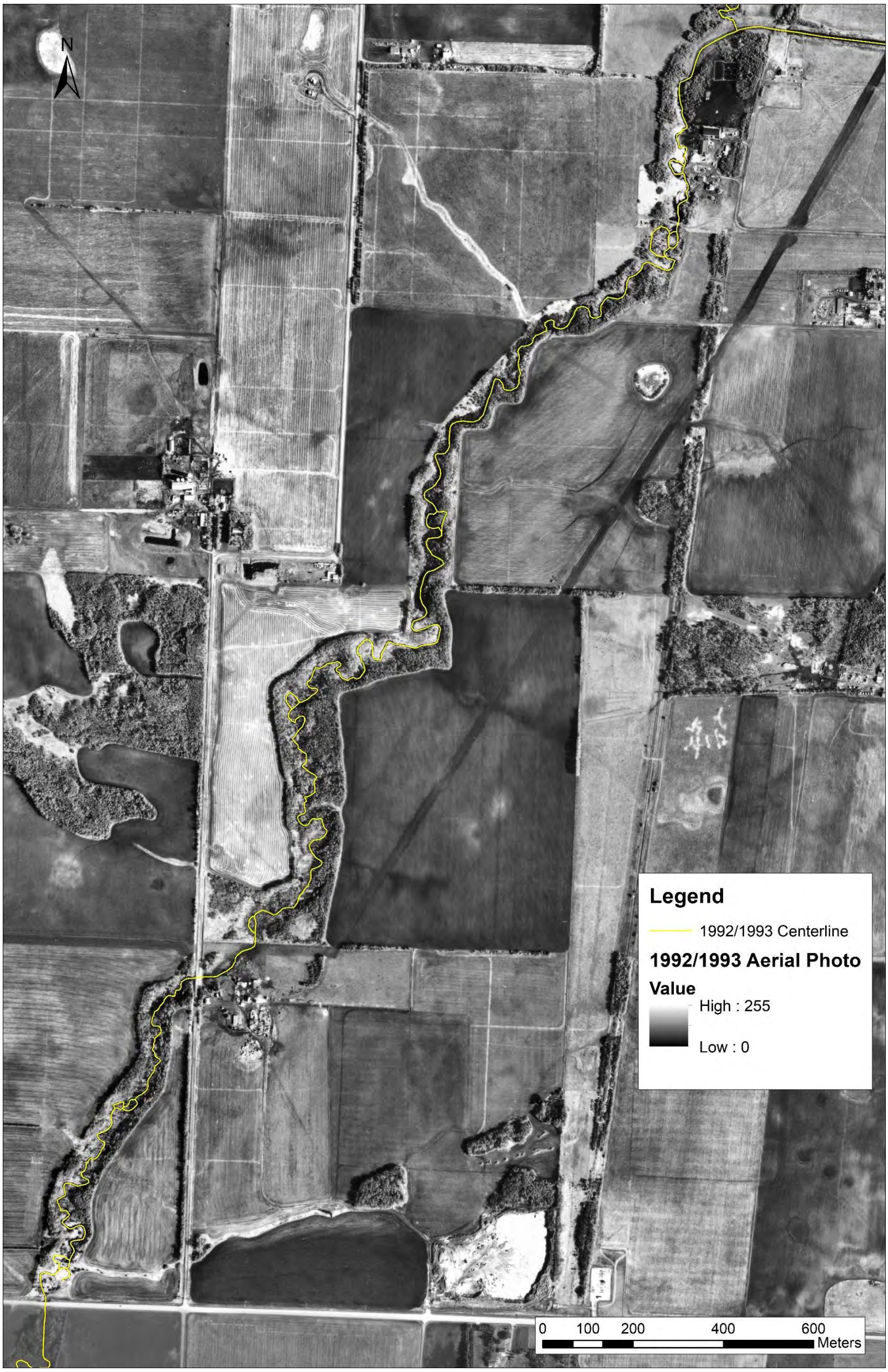
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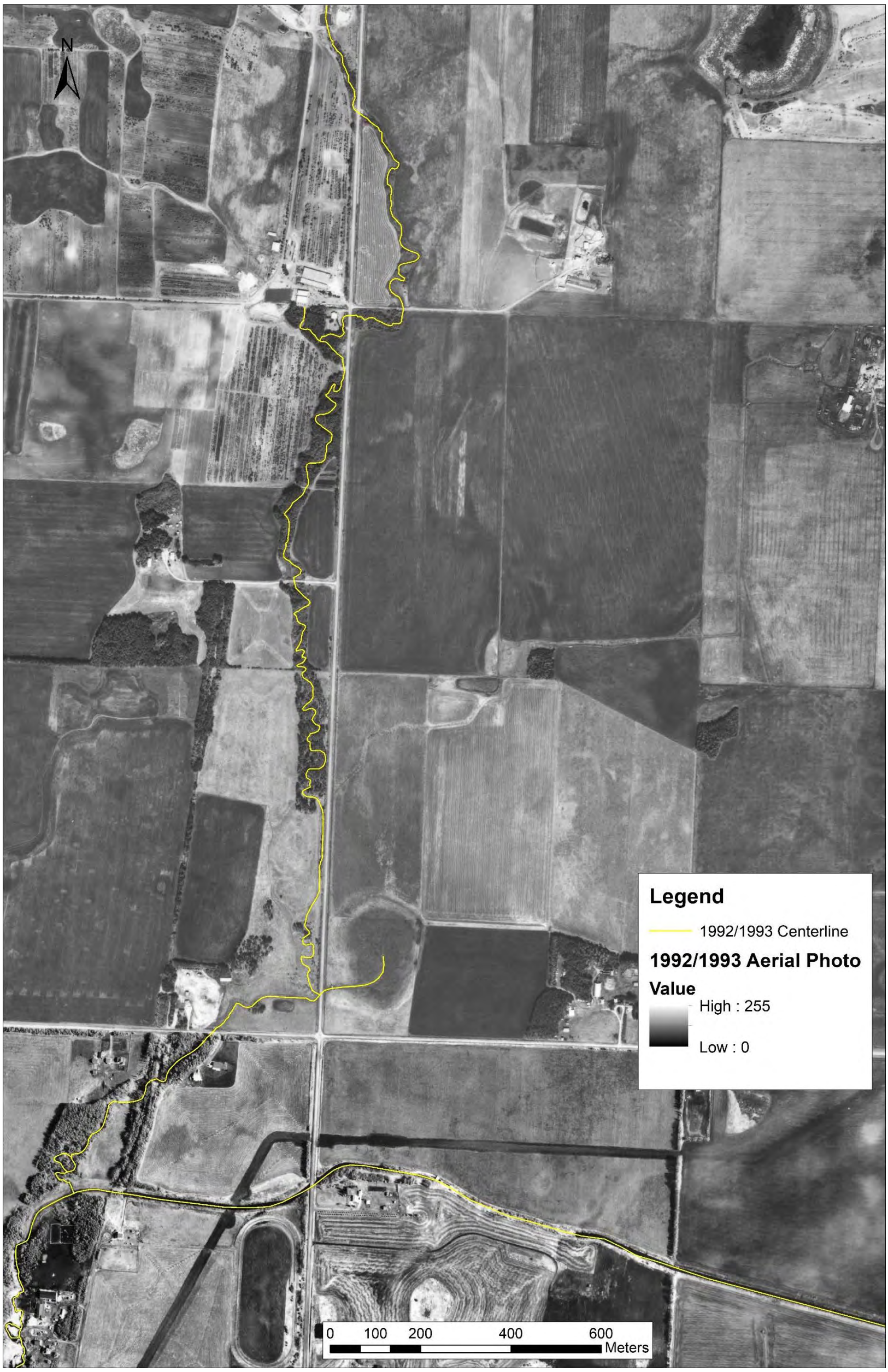
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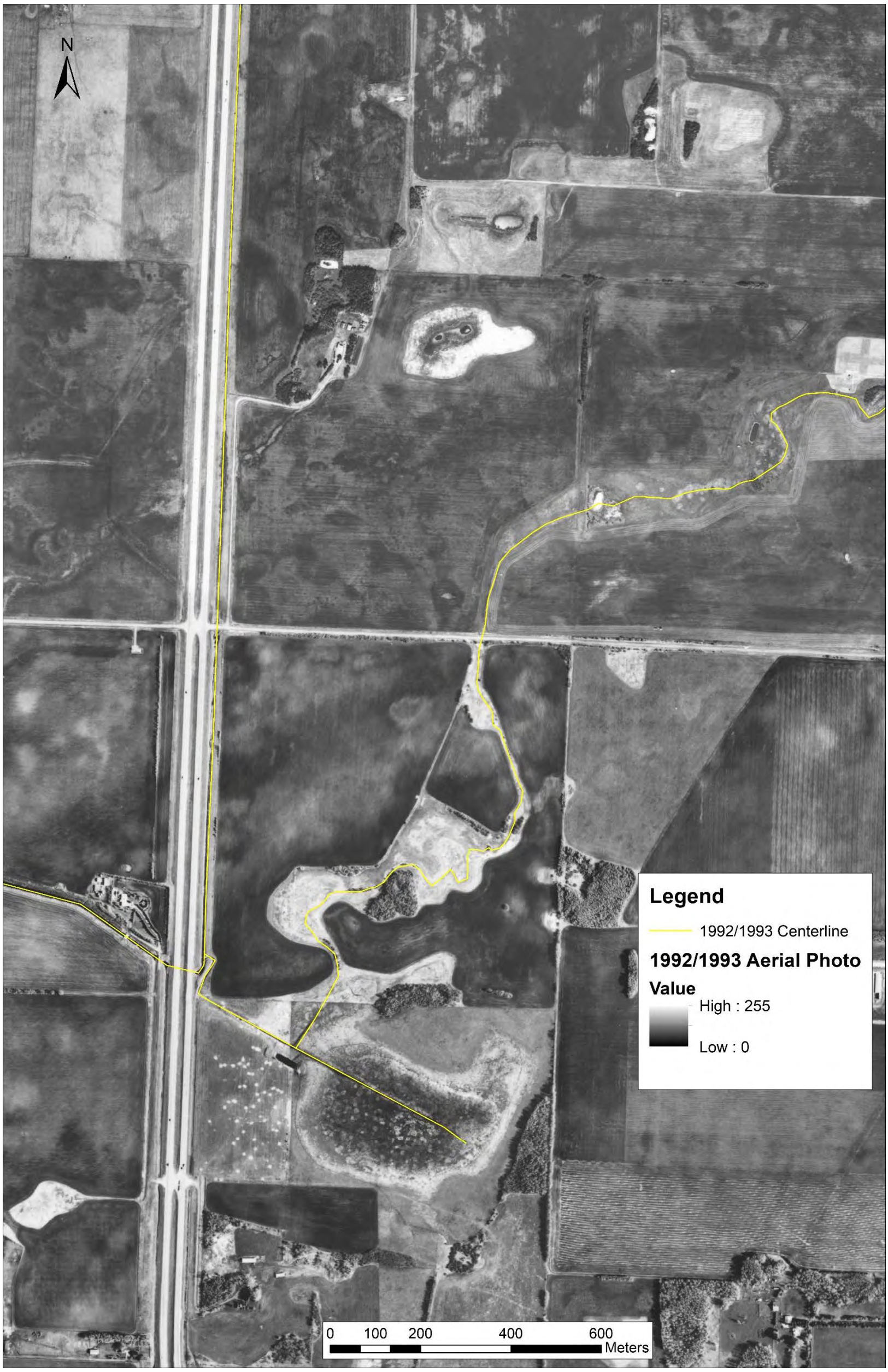
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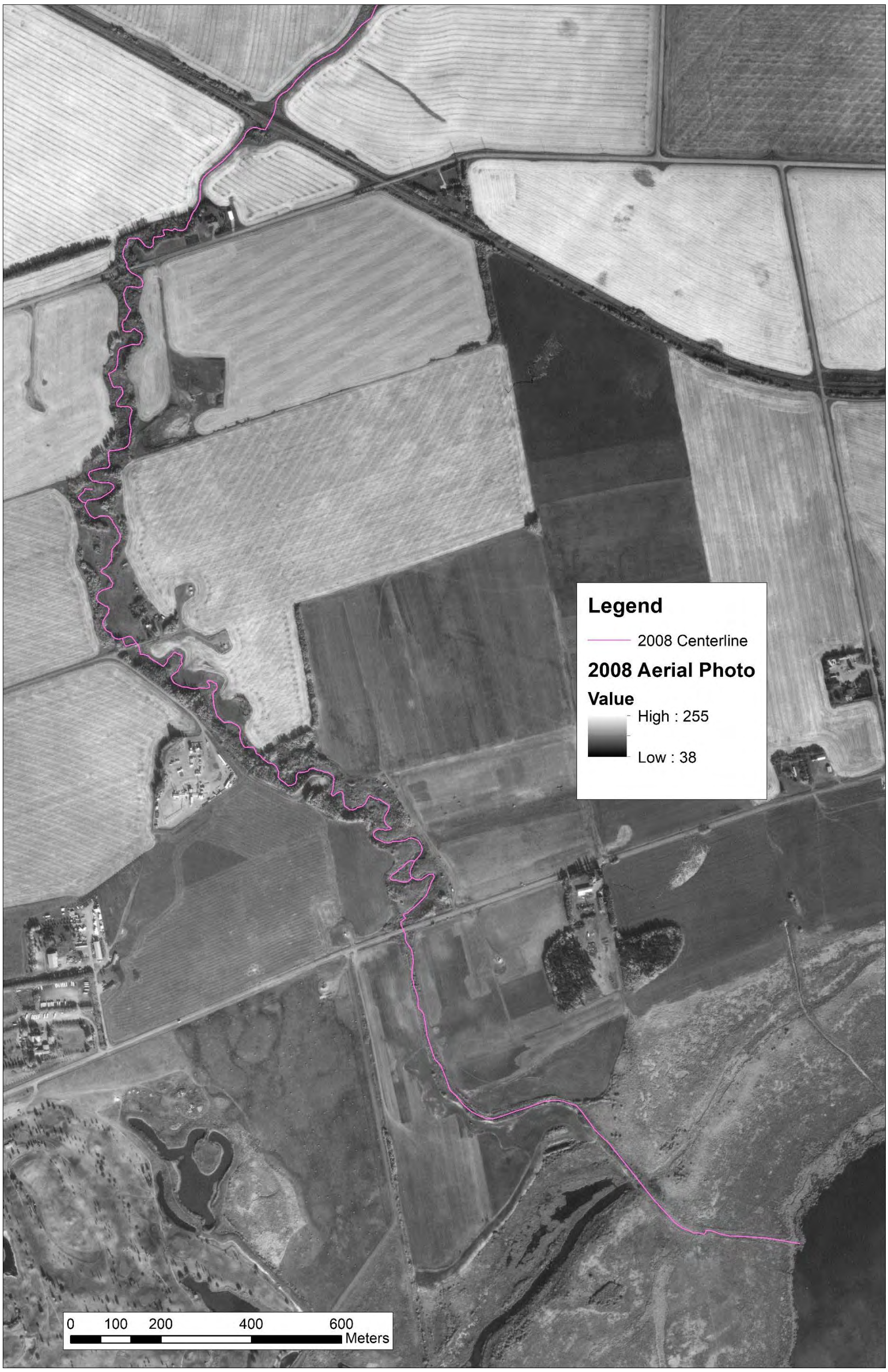
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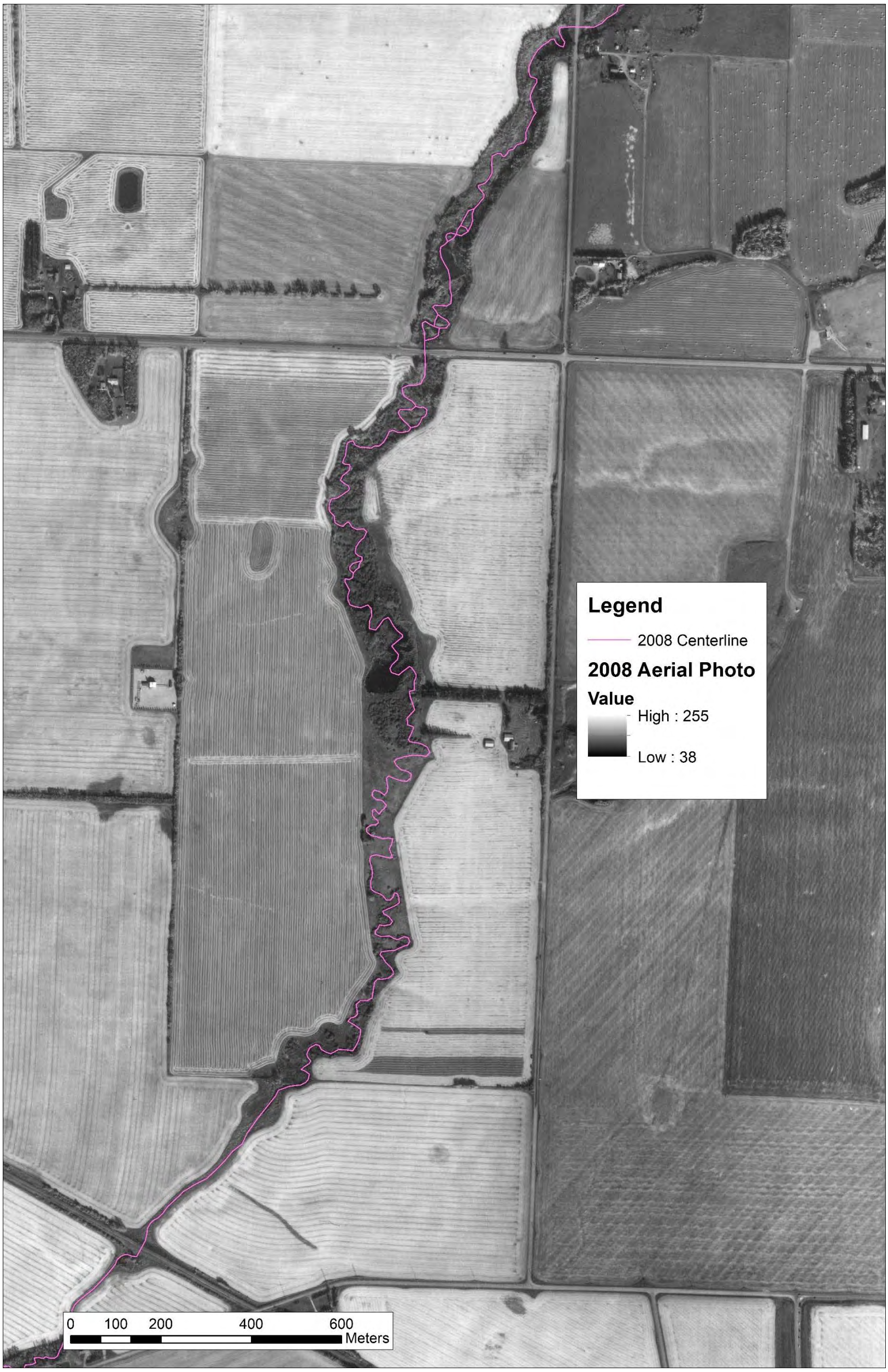
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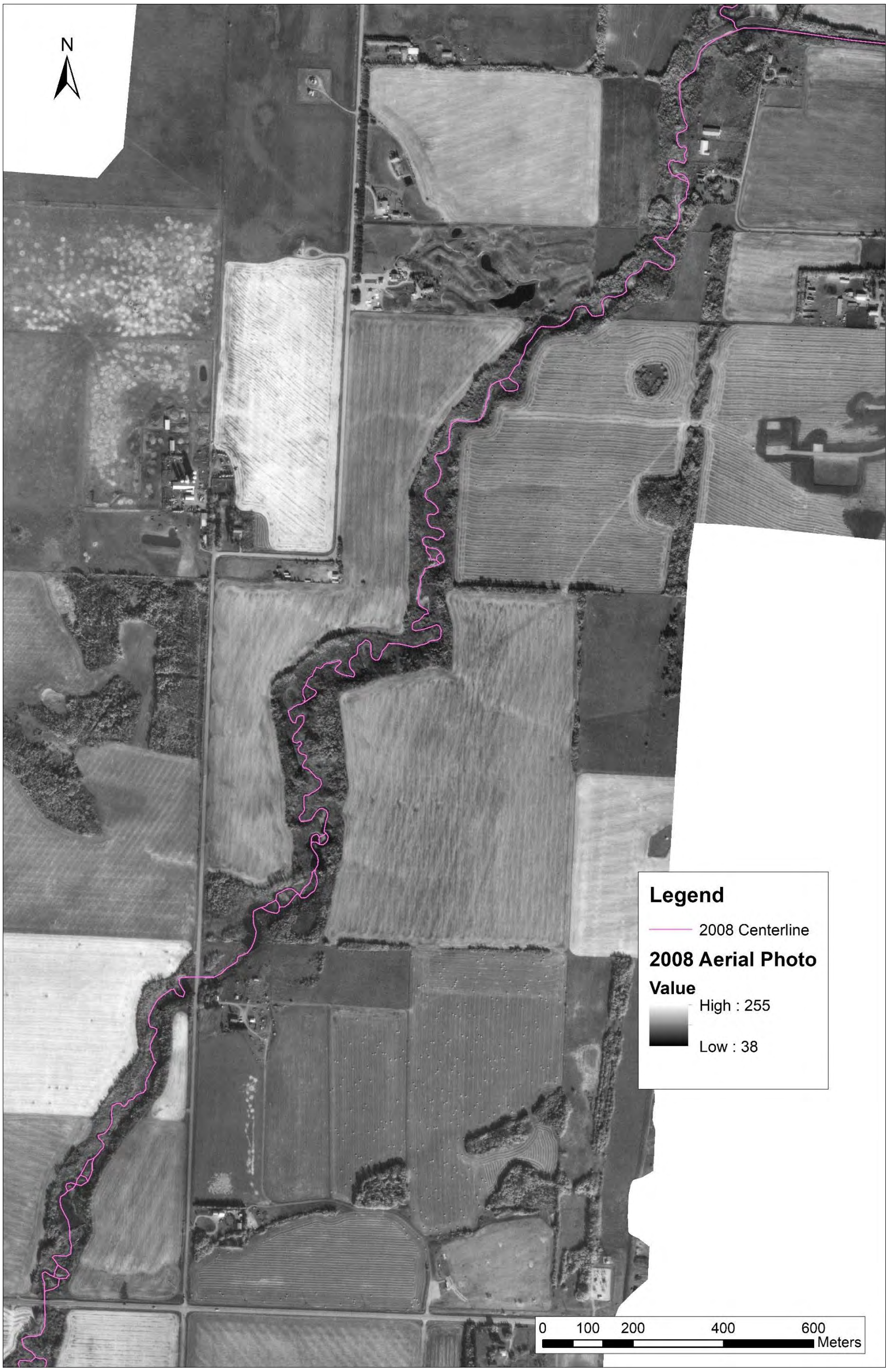
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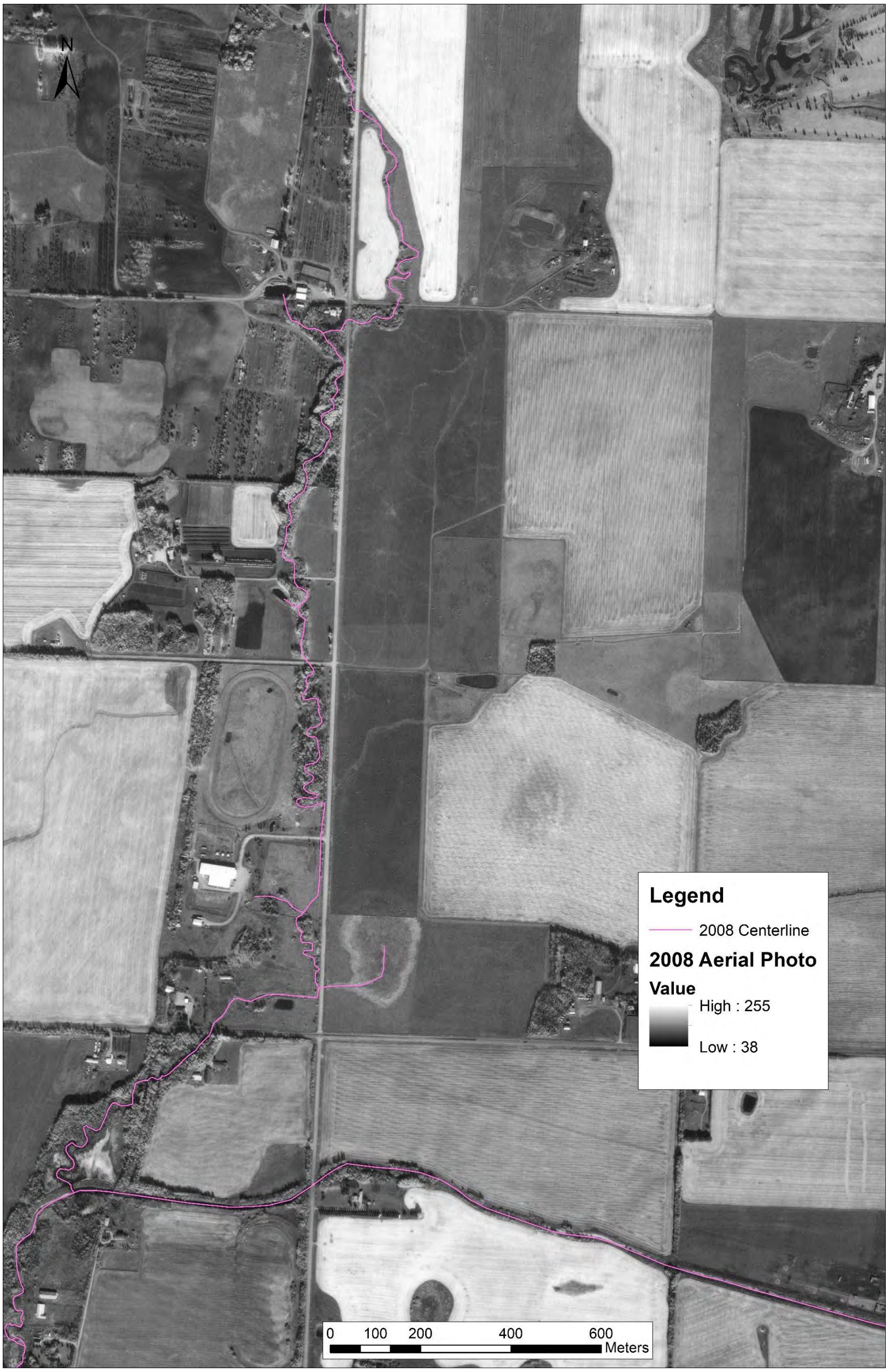
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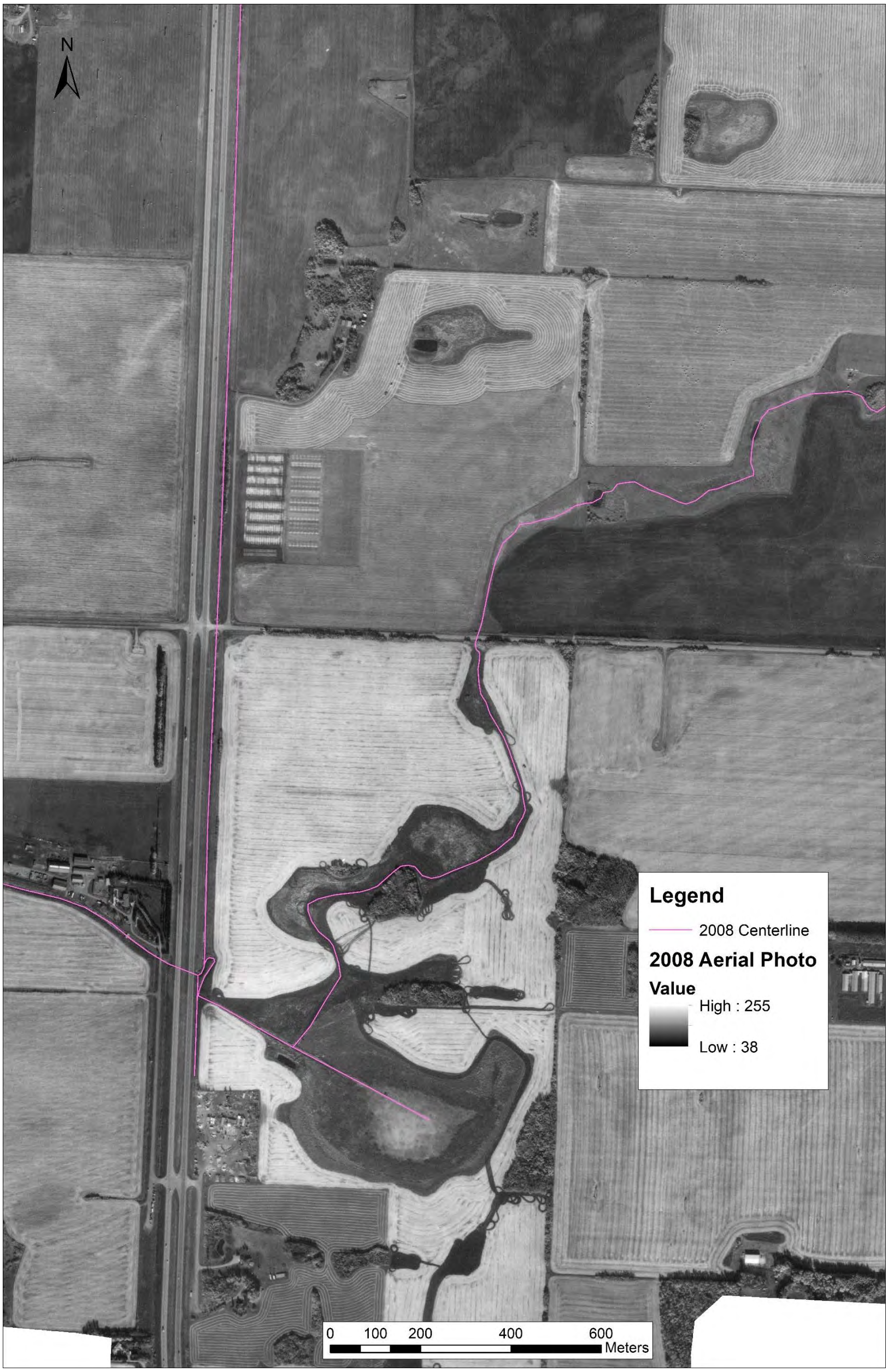
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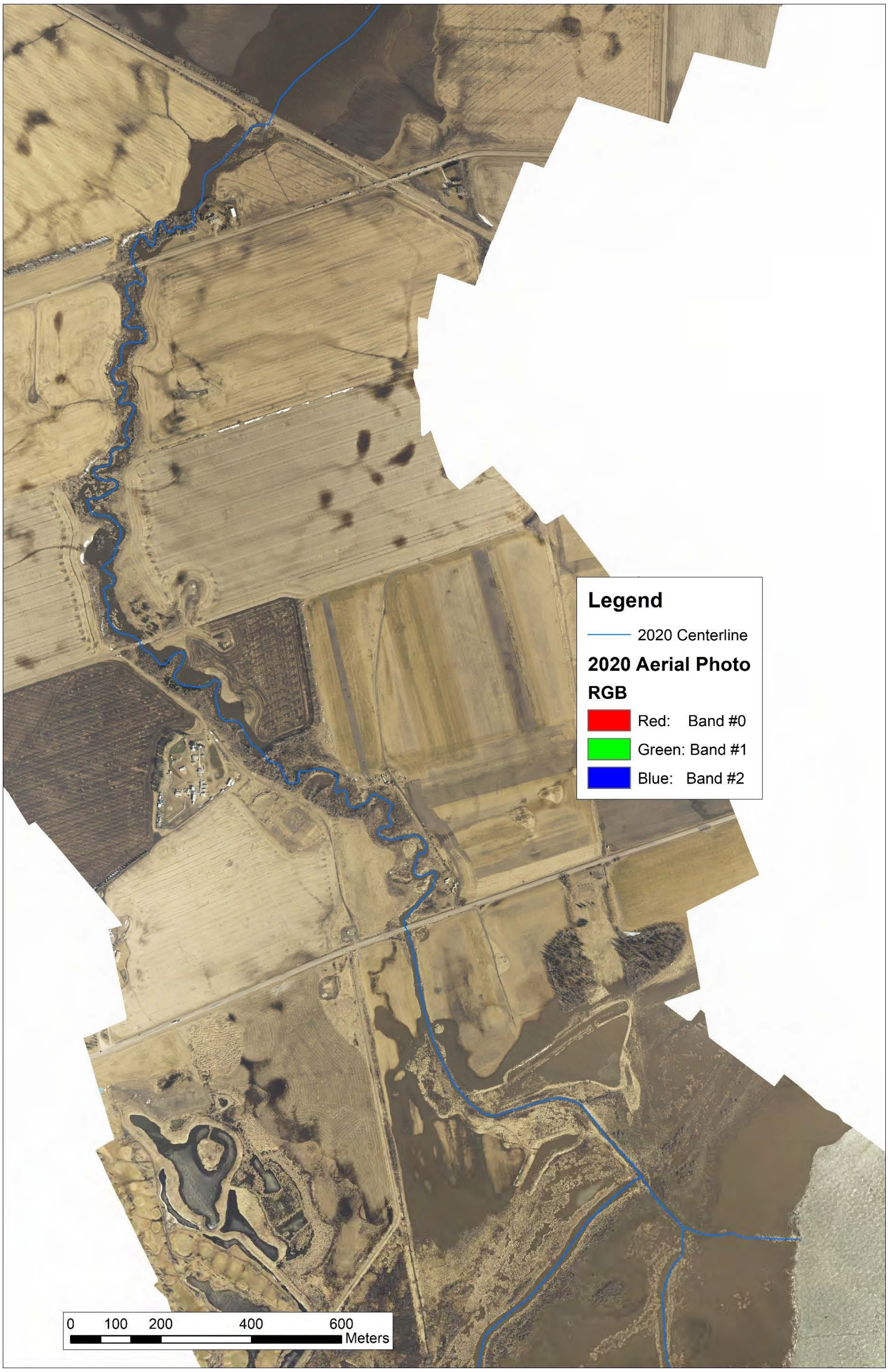
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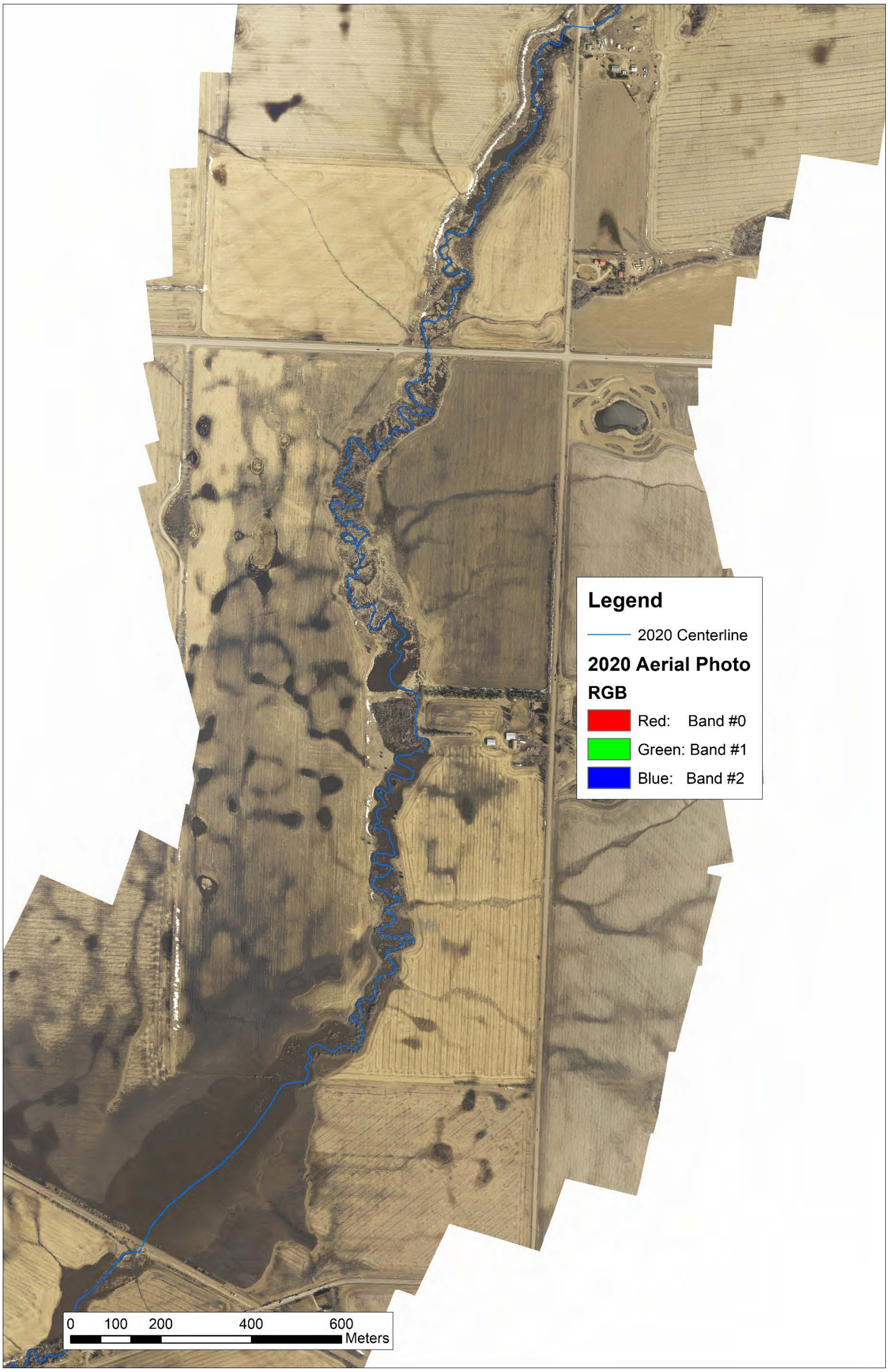
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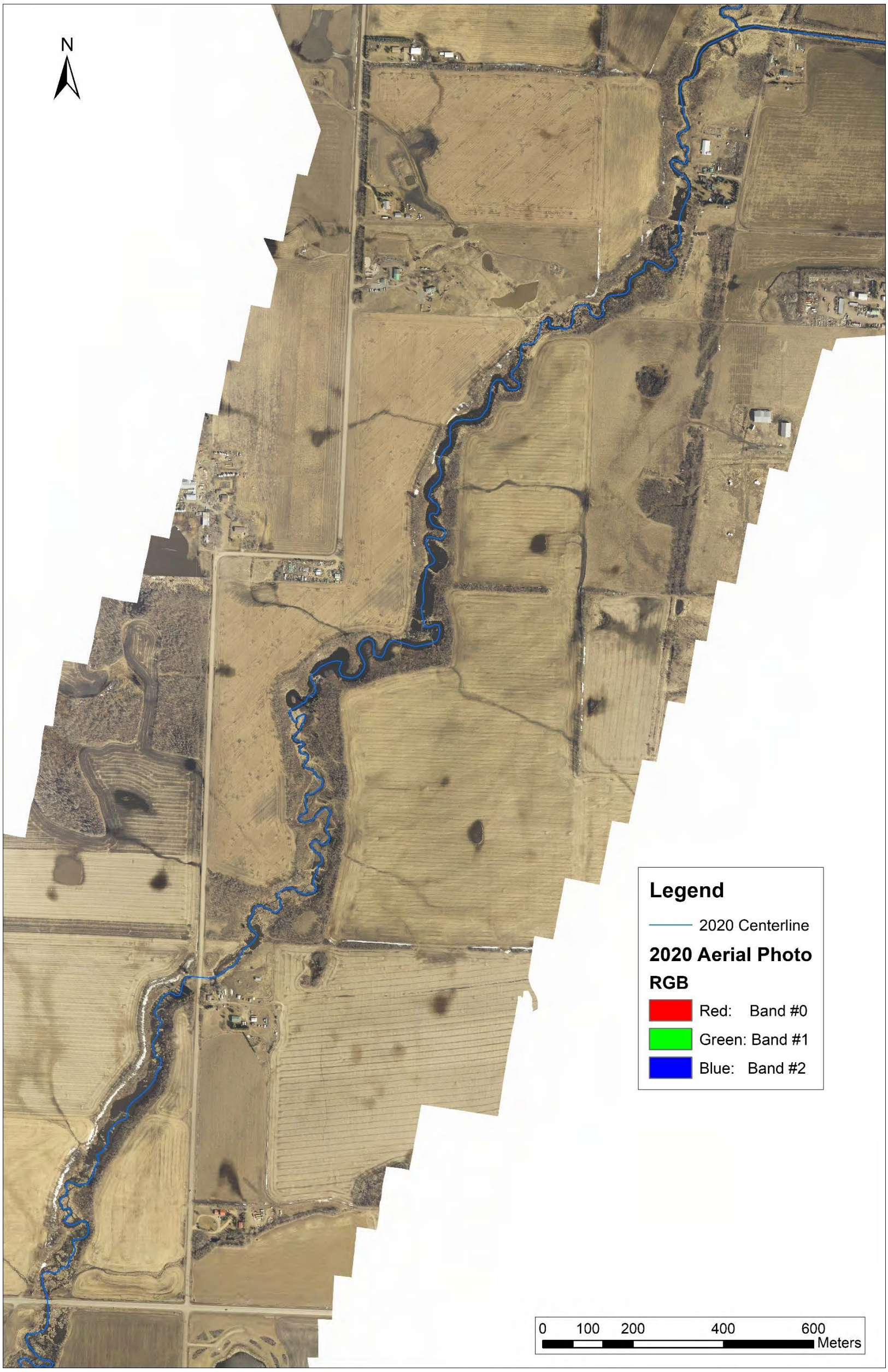
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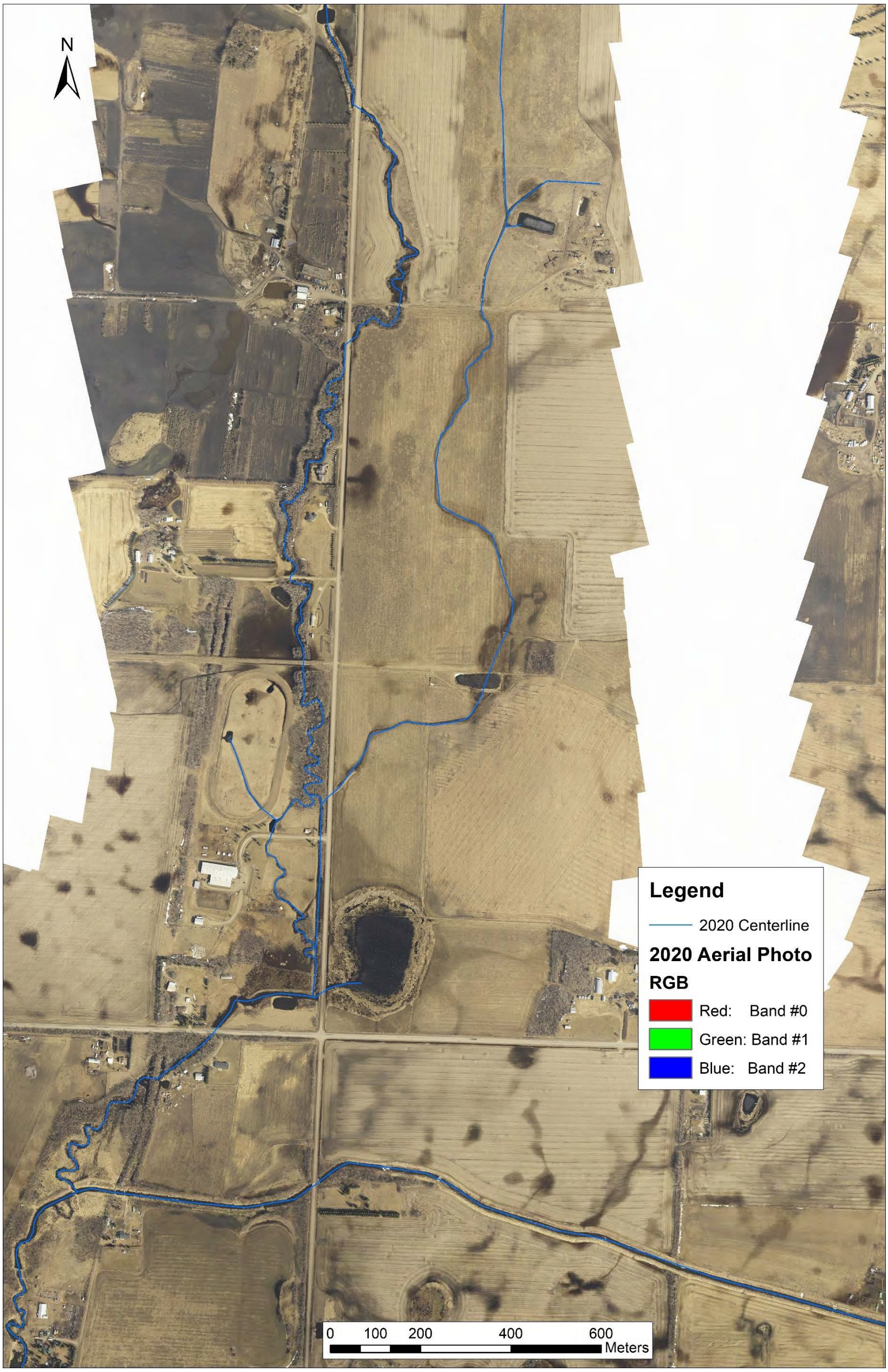
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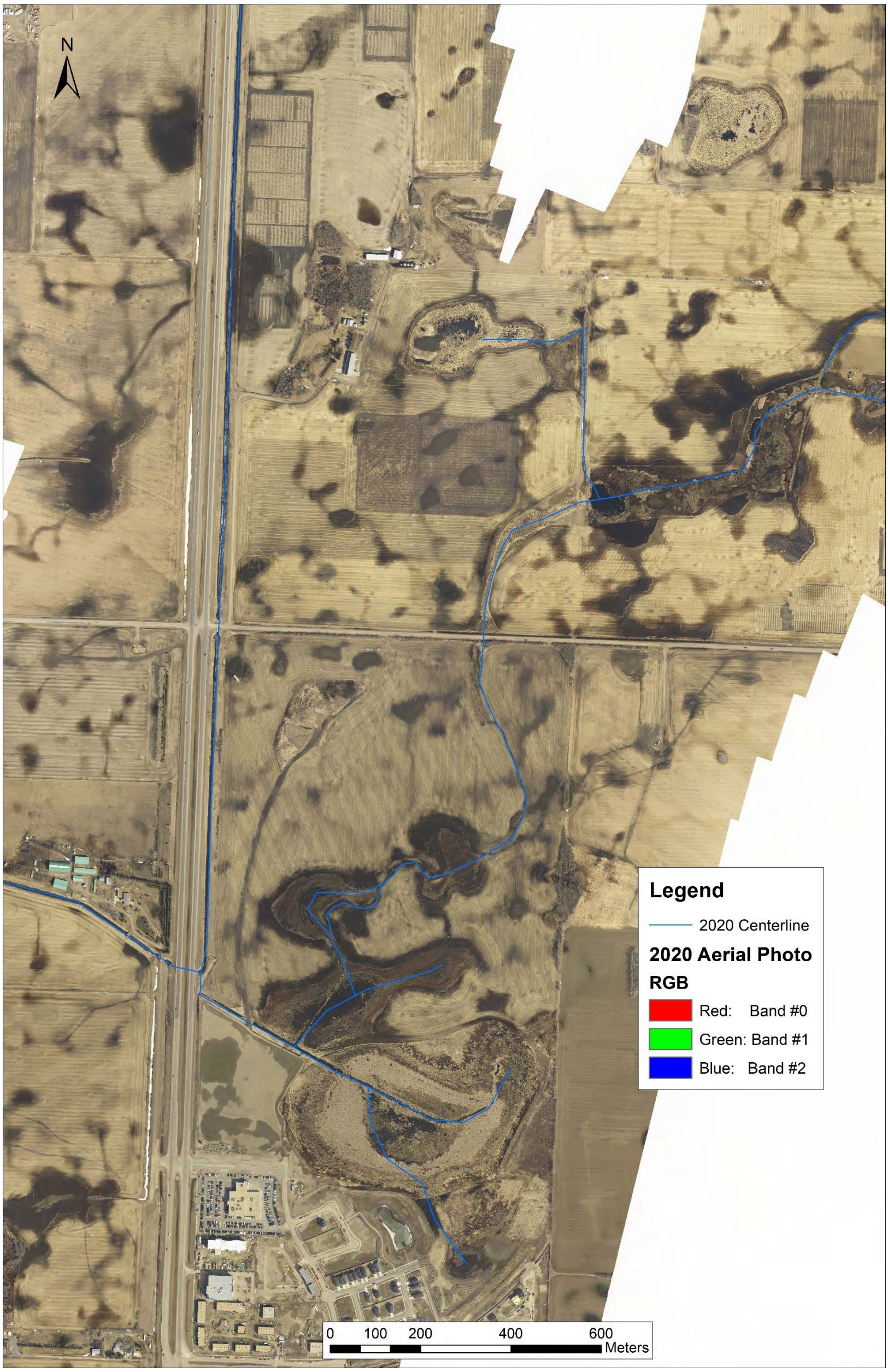
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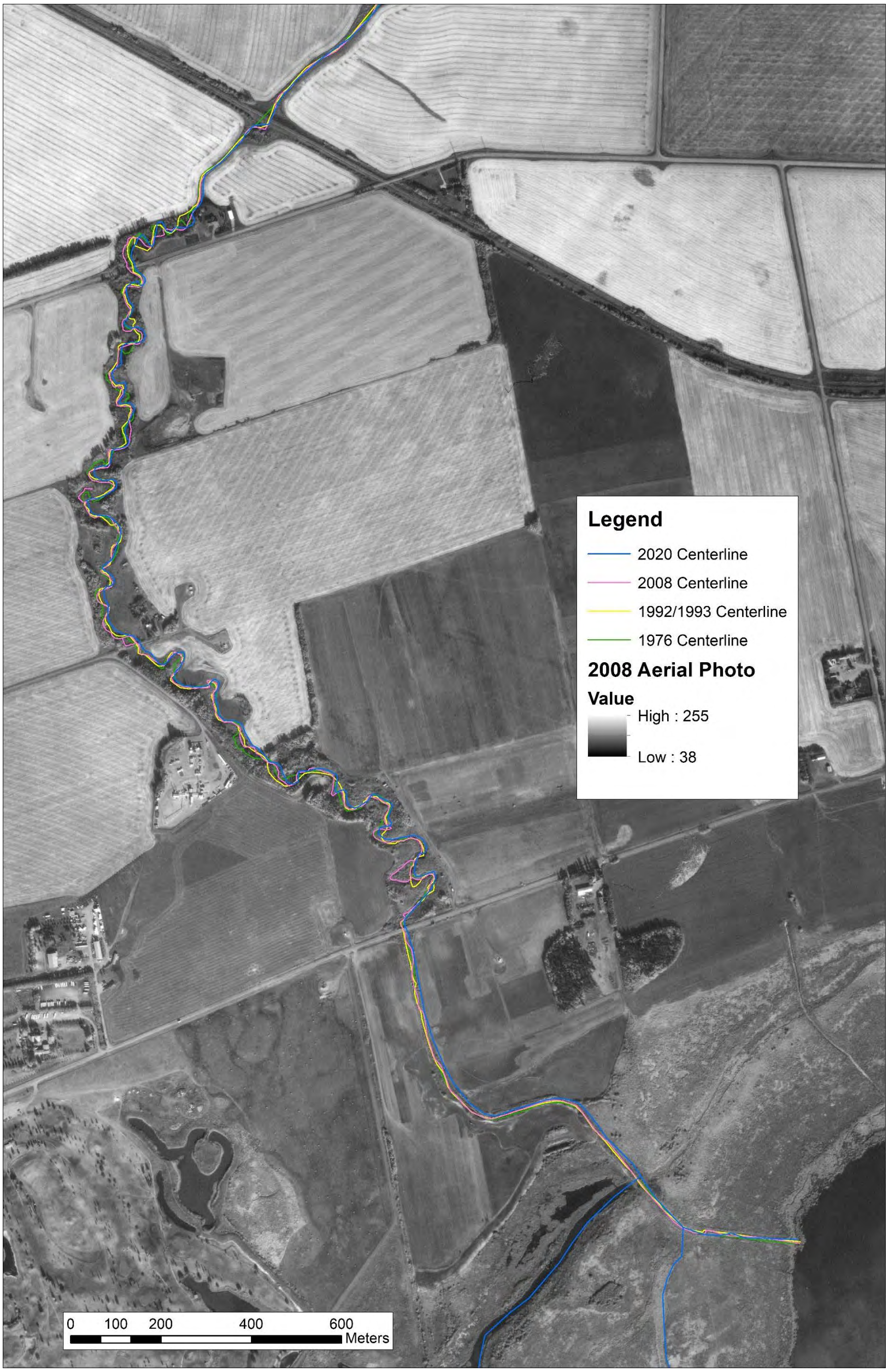
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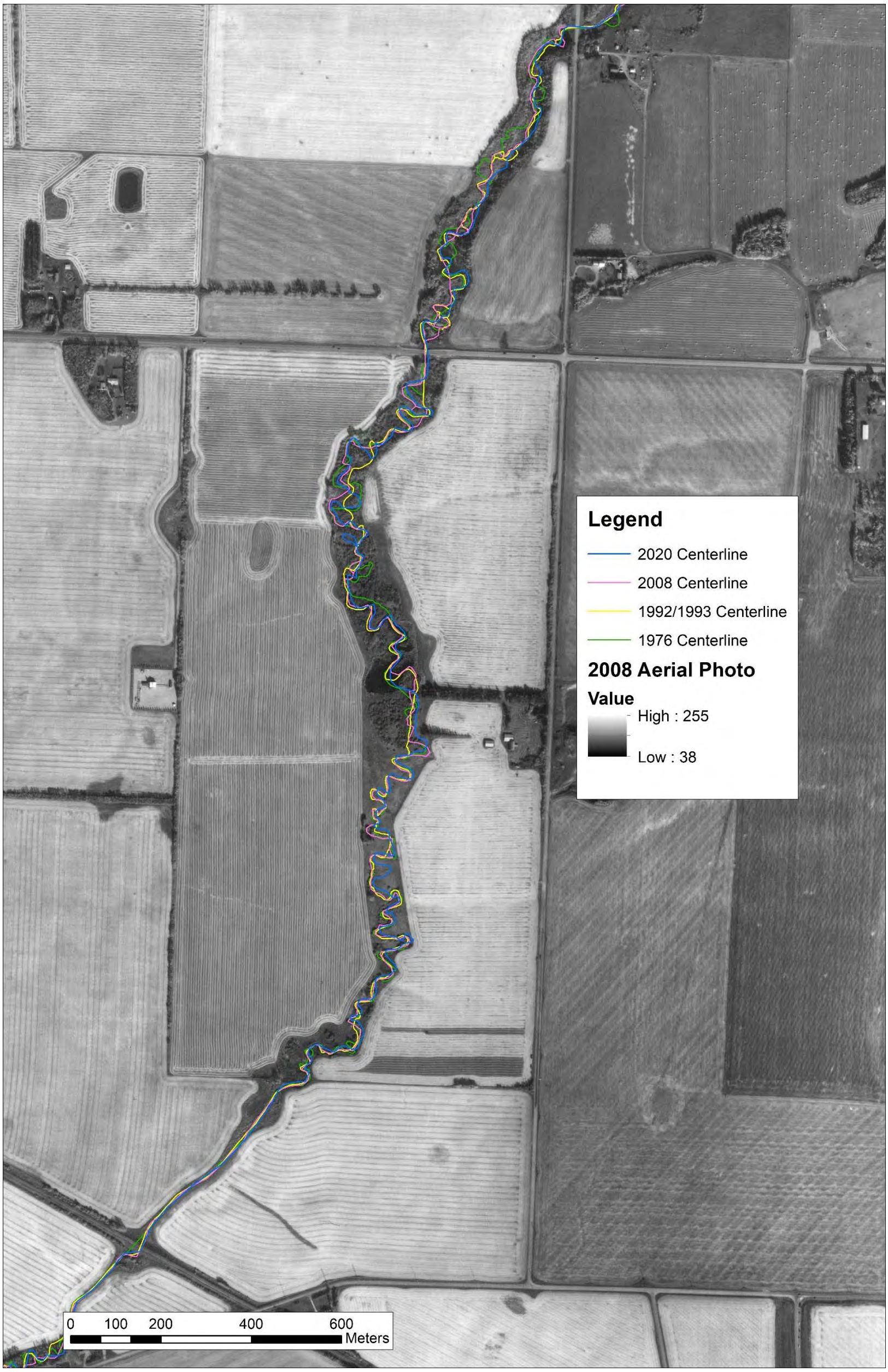
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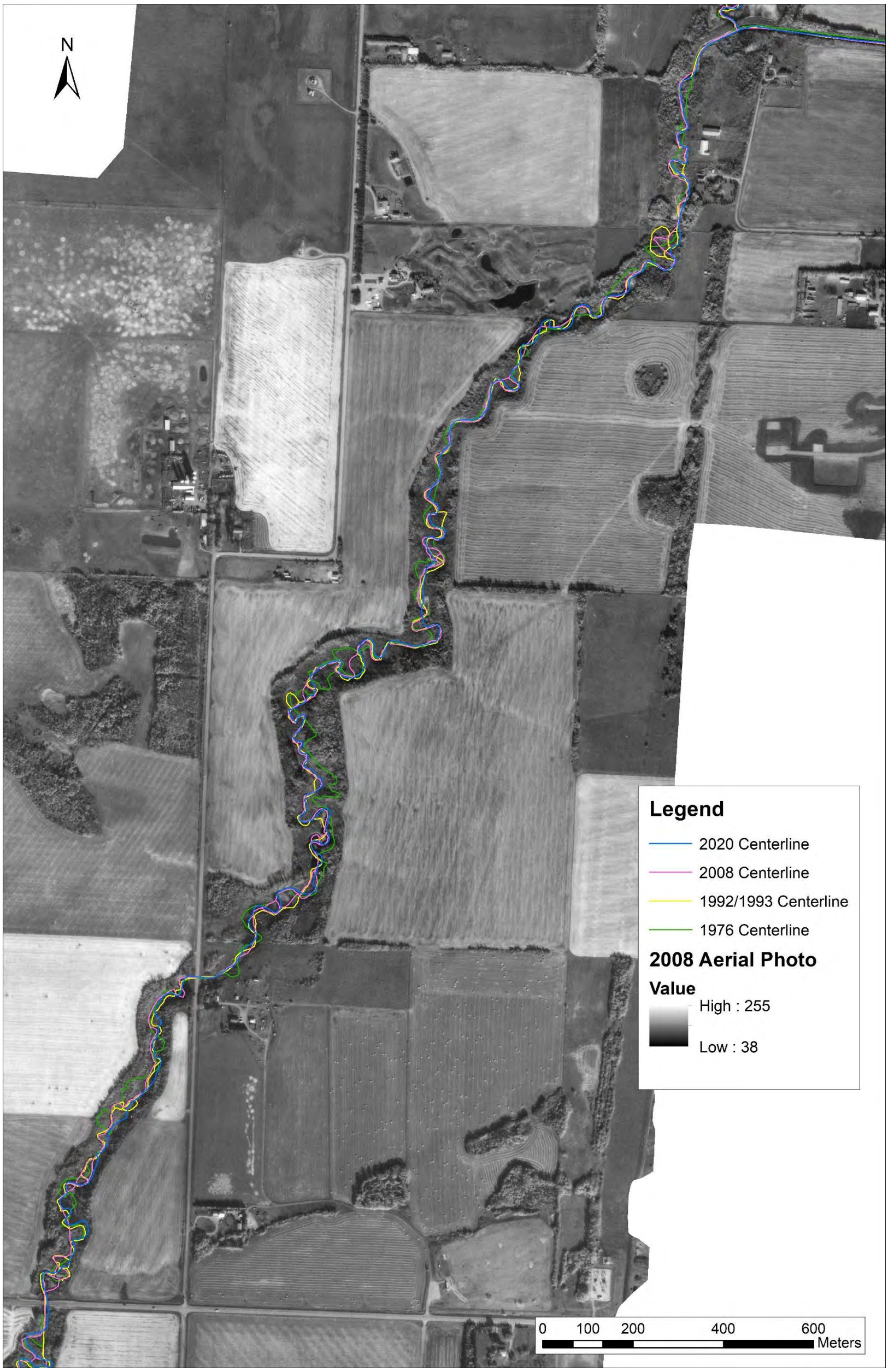
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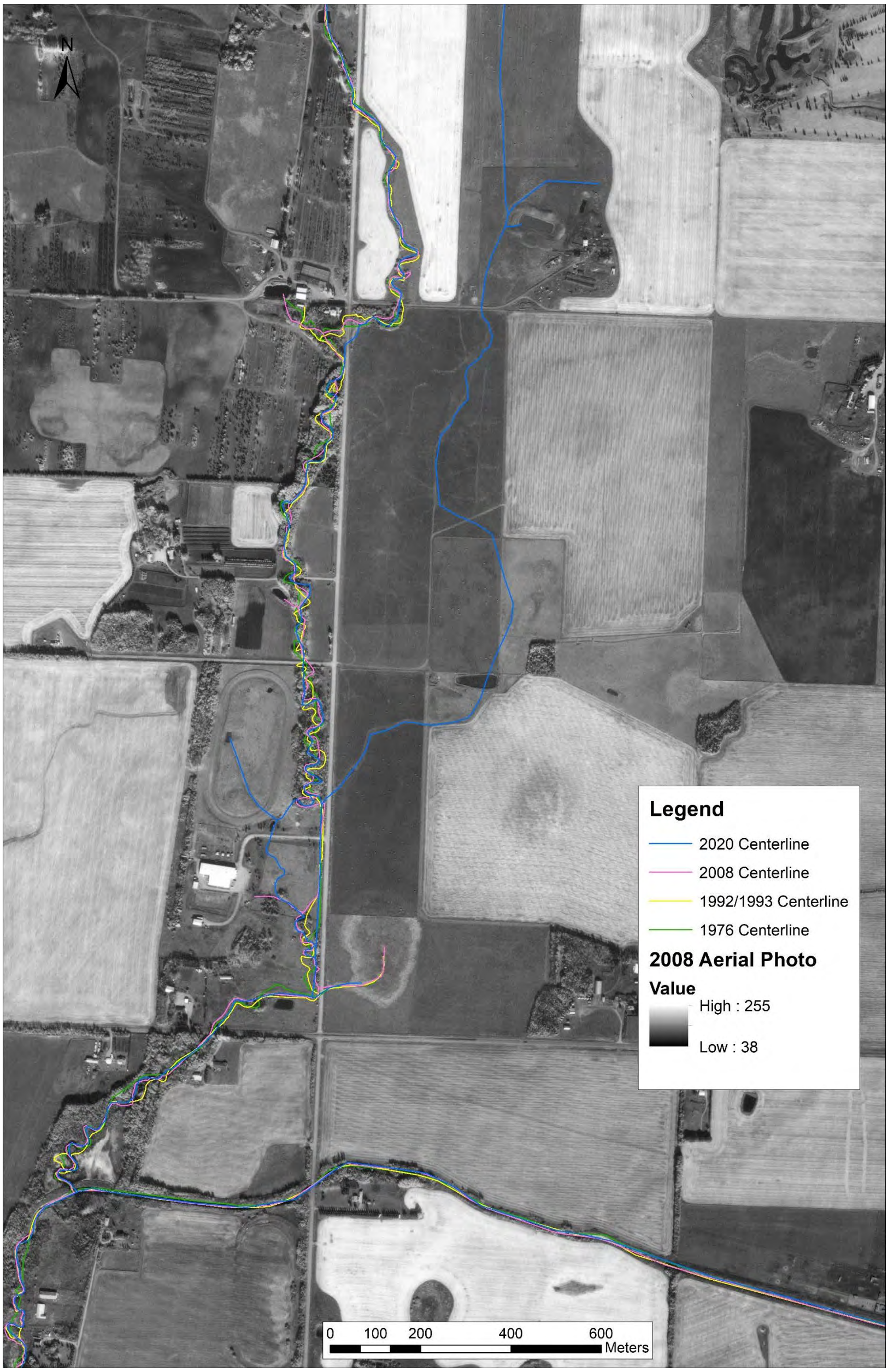
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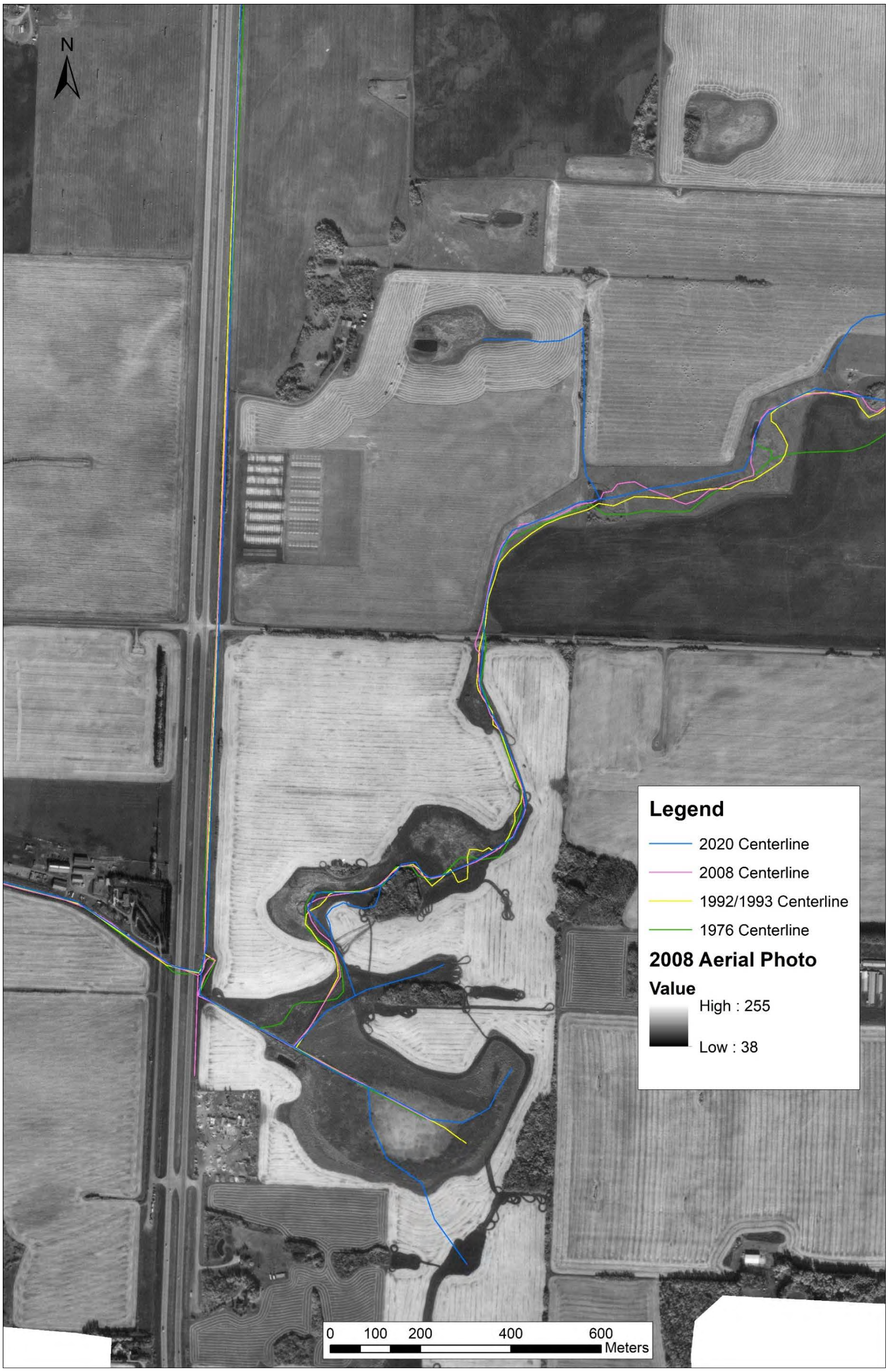
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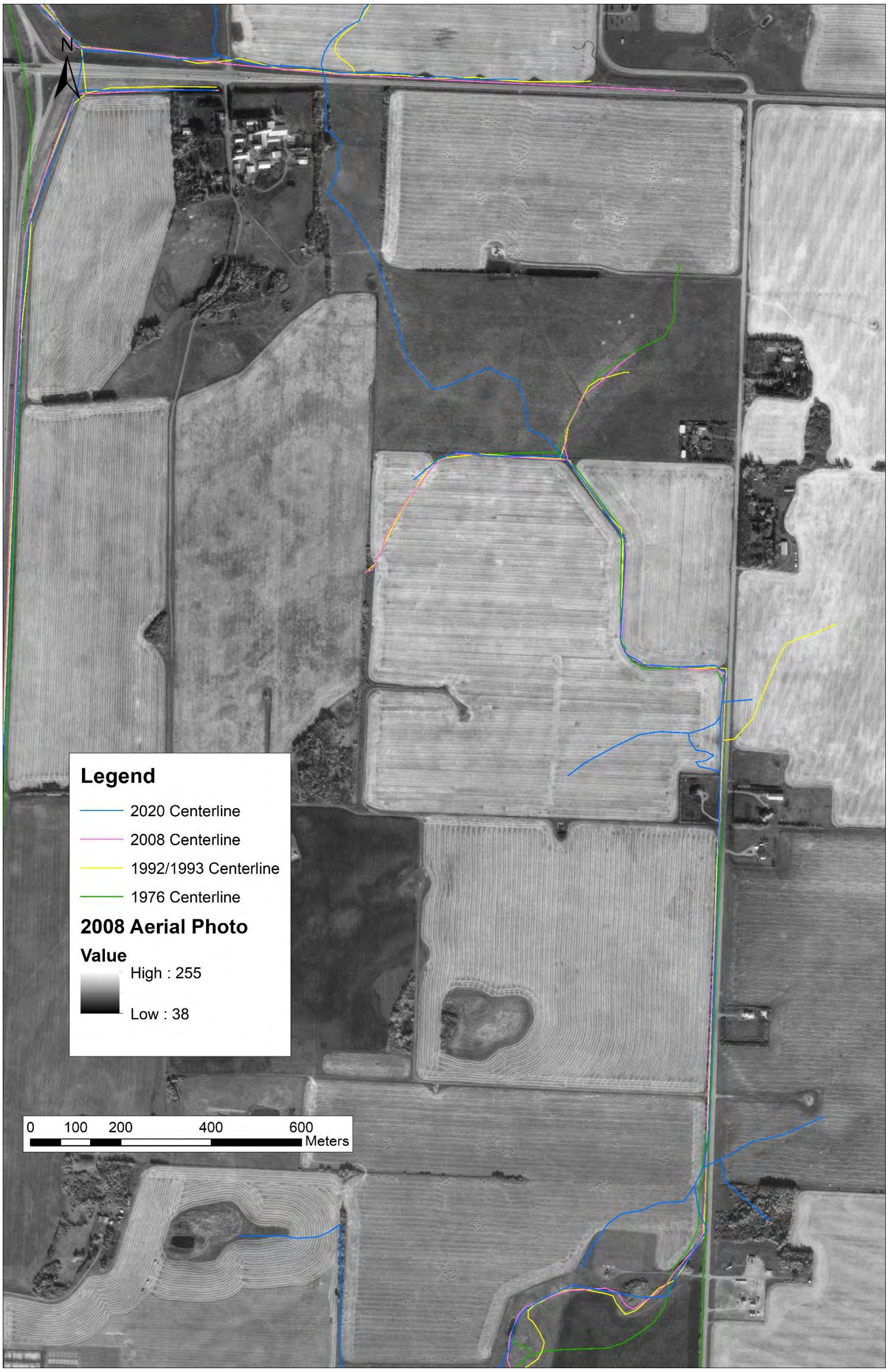
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2008 Aerial photograph showing all mapped channel centerlines of Carrot Creek (Part 4 of 6: Big Lake to north of TOWNSHIP ROAD 544)



2008 Aerial photograph showing all mapped channel centerlines of Carrot Creek (Part 5 of 6: Big Lake to north of TOWNSHIP ROAD 544)



2008 Aerial photograph showing all mapped channel centerlines of Carrot Creek (Part 6 of 6: Big Lake to north of TOWNSHIP ROAD 544)

Appendix D Geotechnical Desktop Study

Geotechnical Desktop Study for the Carrot Creek Regional Master Drainage Plan

Final Report

February 19, 2021

Prepared for:

City of St. Albert
2nd Floor
5 St. Anne Street
St. Albert, Alberta T8N 3Z9

Prepared by:

Stantec Consulting Ltd.
400 – 10220 103 Avenue NW
Edmonton, Alberta T5J 0K4

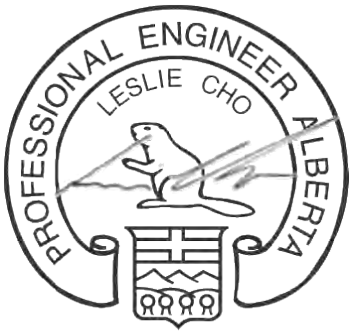
Project No. 110149416

Revision	Description
Draft	Draft issued on April 17, 2020
Final	Final Issued on February 19, 2021

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Prepared by Nathalia Ardila
(signature)

Nathalia Ardila, M.Sc., EIT



2021-02-19

Prepared by _____
(signature)

Leslie Cho, M.Eng., P.Eng. (Geotechnical Engineer)

PERMIT TO PRACTICE
STANTEC CONSULTING LTD.
Signature
Date 19-Feb-2021
PERMIT NUMBER: P 0258
The Association of Professional Engineers and Geoscientists of Alberta

Reviewed by Tom Crilly
(signature)

Thomas Crilly, M.Sc., P.Eng. (MB)

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1.0 INTRODUCTION

Stantec Consulting Ltd. (Stantec) completed a geotechnical desktop study to support the Carrot Creek Regional Master Drainage Plan (CCRMDP) project for the City of St. Albert (the City). The purpose of the geotechnical desktop study was to evaluate the general geotechnical conditions of the CCRMDP area. This report outlines our study methodology, project understanding, review findings, and recommendations.

Limitations associated with this report and its contents are outlined in the Statement of General Conditions provided in **Appendix A**.

1.1 SCOPE OF WORK

The scope of work for the geotechnical desktop study included:

- Reviewing available desktop information including geotechnical reports and geology maps.
- Preparation of a geotechnical desktop report summarizing the findings and recommendations.

1.2 PROJECT UNDERSTANDING

The City of St. Albert is mandated by its Municipal Development Plan to preserve and protect the Sturgeon River Valley and Carrot Creek corridors while accommodating future growth within the City. With respect to Carrot Creek, the City is concerned that inflowing surface drainage would cause continued bank erosion and would require substantial rehabilitation if long-term planning is not implemented. The City also wishes to increase its knowledge to assist in decision-making to permit development on lands that lie within the Carrot Creek watershed to accommodate future growth. The watershed study area, provided in **Appendix B**, consists of lands within St. Albert, Morinville, and Sturgeon County, comprising about 85 square kilometers (km) of land and approximately 30 km of Carrot Creek. The geotechnical desktop study was conducted to help inform future developments related to the CCRMDP ahead of site-specific investigations.

2.0 METHODOLOGY

The geotechnical desktop study methodology consisted of reviewing geological maps and available geotechnical information from Stantec's project database and from Alberta Transportation (AT) archives.

3.0 REVIEW OF AVAILABLE INFORMATION

3.1.1 Geological Mapping

Surficial geology, bedrock topography, and landslide susceptibility maps were reviewed for the study area.

The surficial geology consists predominantly of glaciolacustrine deposits comprised of fine sand, silt and clay (Fenton et al. 2013), Moraine deposits comprised of glacial till is also present to the southeast of Morinville, Alberta. The surficial geology of the study area is shown in Figure 1 below with the approximate study area outlined in black. The expected sediment (overburden) thickness ranges from 10 m to 40 m (MacCormack et al. 2015). Bedrock within the study area belongs to the Horseshoe Canyon Formation comprised of sandstone interlayered with siltstone and bentonitic mudstone (Prior et al. 2013).

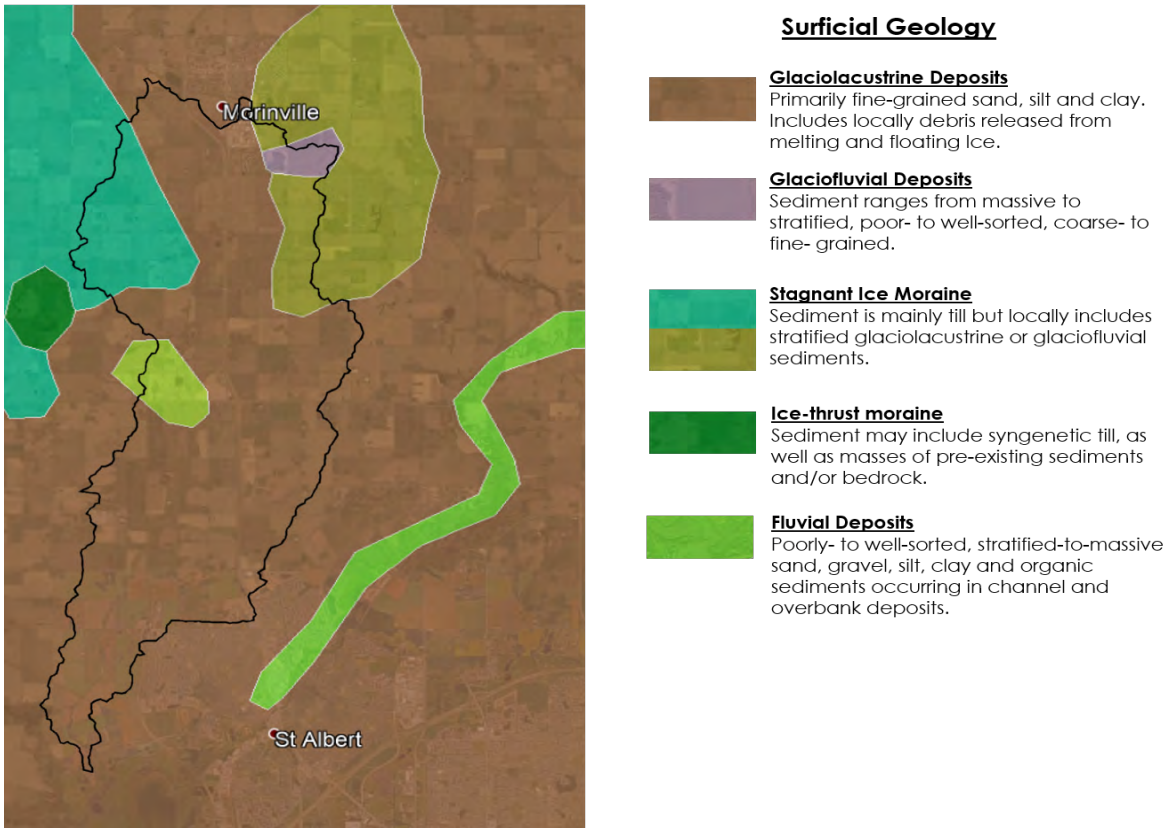


Figure 1: Surficial Geology Map of the Study Area (Fenton et al. 2013). Approximate site location outlined in black.

3.1.2 Landslide Susceptibility

Landslide susceptibility mapping data suggests that the study area has no to very low landslide susceptibility (Pawley et al. 2016). However, high susceptibility areas were identified along the Sturgeon River channel. **Figure 2** shows the landslide susceptibility map of the study area.

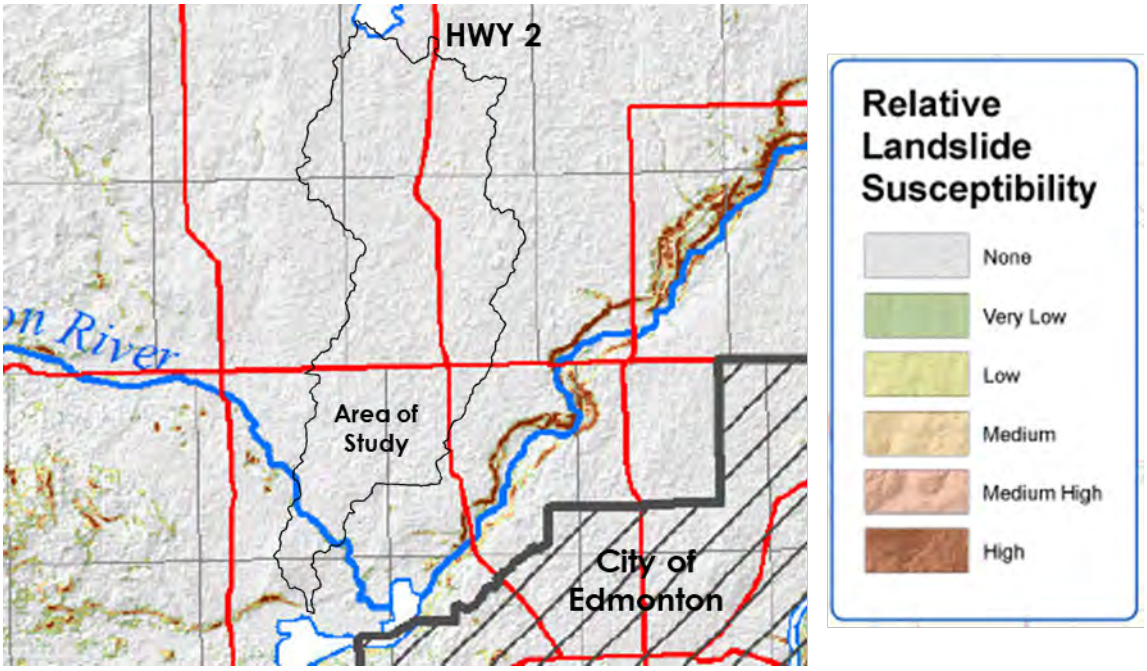


Figure 2: Relative landslide susceptibility for the Study Area (Pawley et al. 2016). Approximate site location outlined in black.

3.1.3 Erosion Susceptibility

The southern third of the CCRMDP site along Carrot Creek was assessed as part of the St. Albert Natural Areas Assessment (Spencer Environmental Management Services Ltd., 2015). That study found the potential for wind erosion of site soils to be low to moderate with low potential for water erosion. The associated figures from that study are included in **Appendix C** for reference.

3.1.4 Review of Stantec's Geotechnical Reports

A review of available geotechnical documentation from Stantec's project database was conducted to provide preliminary information on the soil and groundwater conditions immediately surrounding and within the study area. In general, the study area is comprised of soft to stiff high plastic clay overlying stiff to hard clay till underlain by sandstone with a few instances of interbedded clay shale.

Table 1 summarizes the subsurface conditions from Stantec's project database. Figure 3 shows the general location of each project referenced from Stantec's and At's database.

Table 1 Summary of Subsurface Conditions from Stantec's Project Database

Point (Refer to Figure 3)	General Soil Stratigraphy (thickness)	Groundwater Level (bgs*)
A	Up to 1.5 m of high plastic clay fill overlying 0.9 m of high plastic clay, underlain by medium plastic clay till	Dry upon completion of drilling
B	3.0 m to 3.8 m of soft to stiff clay fill overlying medium to high plastic clay	Dry upon completion of drilling
C	Up to 2.8 m of clay fill overlying 4.0 m to 6.3 m of glacio-lacustrine clay and 10.4 m to 12.0 m of high plastic clay till, underlain bedrock.	4.0 m to 7.0 m
D	Up to 1.7 m of high plastic clay fill overlaying high plastic clay.	4.5 m to 8.0 m
E	Up to 3.5 m of clay fill overlying 3.0 m of medium plastic clay followed by 3.2 m of loose silt and1.0 m of sand till underlain by low plastic clay till.	3.0 m to 7.0 m
Note – bgs refers to “below ground surface”		

3.1.5 Review of Alberta Transportation Geotechnical Reports

The following reports from AT’s project archives were reviewed:

1. Foundation Investigation for the proposed HWY.2/CNR overhead bridge and HWY.2/SR 642 interchange bridge near Morinville. Alberta Transportation. Dated July 12,1984.
2. Foundation investigation for 76102 Morinville Interchange with Hwy.2. Alberta Transportation. Dated March 12,1965.
3. Hwy 37:02 West of JCT SH 794 to West of JCT HWY 2. Alberta Transportation. Dated June 7,1989.

Table 2 Summary of Subsurface Conditions from AT’s Database

Point (Refer to Figure 3)	General Soil Stratigraphy (thickness)	Groundwater Level (bgs)
1	4.0 to 6.0 m of soft to stiff silty to sandy clay overlying clay shale and sandstone bedrock.	2.5 m
2	Approximately 2.0 m of firm to stiff high plastic clay overlying hard sandy clay (possibly bedrock). Rafted bedrock encountered at various depths ranging from 7.3 m to 8.5 m deep.	4.8 m
3	Medium to high plastic clay to a depth of 2.0 m.	Unavailable

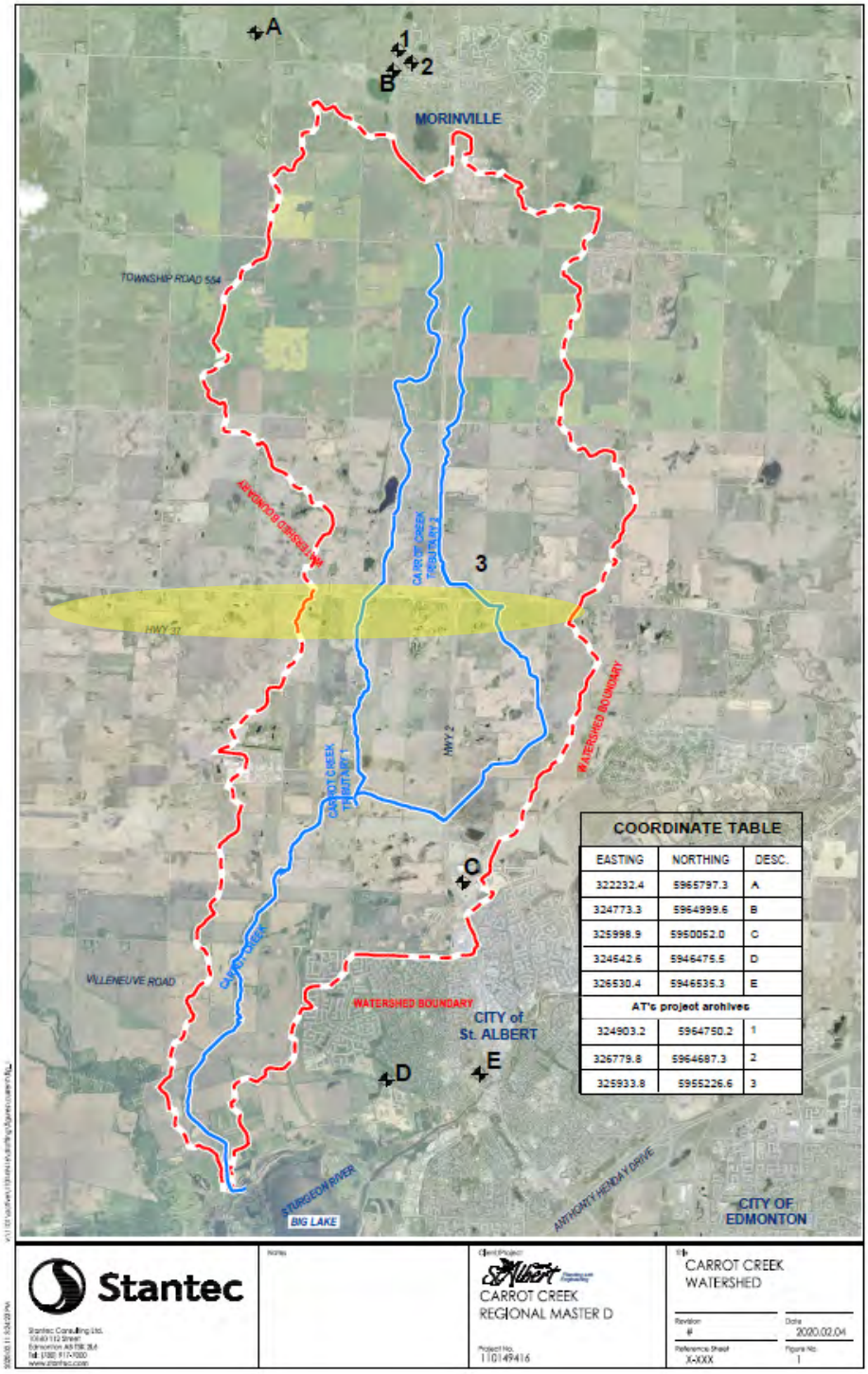


Figure 3:Proposed study area for the carrot creek basin and the location of the projects reviewed.

4.0 DISCUSSION AND RECOMMENDATIONS

The following general comments are provided for consideration of future work:

- The available soil information was limited with most information located outside the study area. What is known shows near surface stratigraphy consisting of clays of various depositional characteristics. Clayey soils are generally less susceptible to surface erosion as opposed to silt or fine-grained sand materials. Clayey soils however are more susceptible to larger scale rotational slope failures than other soil types. It is recommended that site specific geotechnical investigation programs be completed for future development of the CCRMDP.
- The groundwater table is relatively shallow ranging from 3.0 m to 7.0 m bgs. Groundwater levels fluctuate seasonally and with site use and may be higher than observed. Increased surface water flow into these channels via development and faster runoff may contribute to locally increased groundwater levels, which could impact the creek (or river) bank stability of the river channels.
- Although the landslide susceptibility maps suggest no to very low susceptibility, site specific assessments for Carrot Creek may be required to confirm the presence of landslides. It is understood that a site-specific geohazard and geomorphology (G&G) study will be completed for development of the CCRMDP. Findings from the G&G study should be incorporated into future development plans. Slope movements related to riverbank erosion or increased groundwater levels can be very site specific and not related to landslides or soil movement. Developments such as buildings, roads, etc. near creekbanks or other slopes should be evaluated.
- Loss of surface vegetation (especially near creek banks) can have a significant detrimental impact on creek bank stability. It is recommended that development offset limits from top of creekbank areas be evaluated to maintain creek bank stability.

5.0 REFERENCES

Fenton, M.M., Waters, E.J., Pawley, S.M., Atkinson, N., Utting, D.J. and Mckay, K. (2013): Surficial geology of Alberta; Alberta Energy Regulator, AER/AGS Map 601.

Prior, G.J., Hathway, B., Glombick, P.M., Pana, D.I., Banks, C.J., Hay, D.C., Schneider, C.L., Grobe, M., Elgr, R. and Weiss, J.A. (2013): Bedrock geology of Alberta; Alberta Energy Regulator, AER/AGS Map 600.

MacCormack, K.E. Atkinson, N. Lyster, S. (2015): Sediment thickness of Alberta; Alberta Energy Regulator, AER/AGS Map 603.

Pawley, S.M., Hartman, G.M.D. and Chao, D.K. (2016): Relative landslide susceptibility model of the Alberta Plains and shield regions; Alberta Energy Regulator, AER/AGS Map 605, scale 1:1,000,000.

Spencer Environmental Management Services Ltd. (2015). St. Albert Natural Areas Assessment – 2015 Update. Prepared for City of St. Albert.

Appendix A STATEMENT OF GENERAL CONDITIONS

USE OF THIS REPORT: This report has been prepared for the sole benefit of the Client or its agent and may not be used by any third party without the express written consent of Stantec and the Client. Any use which a third party makes of this report is the responsibility of such third party.

BASIS OF THE REPORT: The information, opinions, and/or recommendations made in this report are in accordance with Stantec's present understanding of the site-specific project as described by the Client. The applicability of these is restricted to the site conditions encountered at the time of the investigation or study. If the proposed site specific project differs or is modified from what is described in this report or if the site conditions are altered, this report is no longer valid unless Stantec is requested by the Client to review and revise the report to reflect the differing or modified project specifics and/or the altered site conditions.

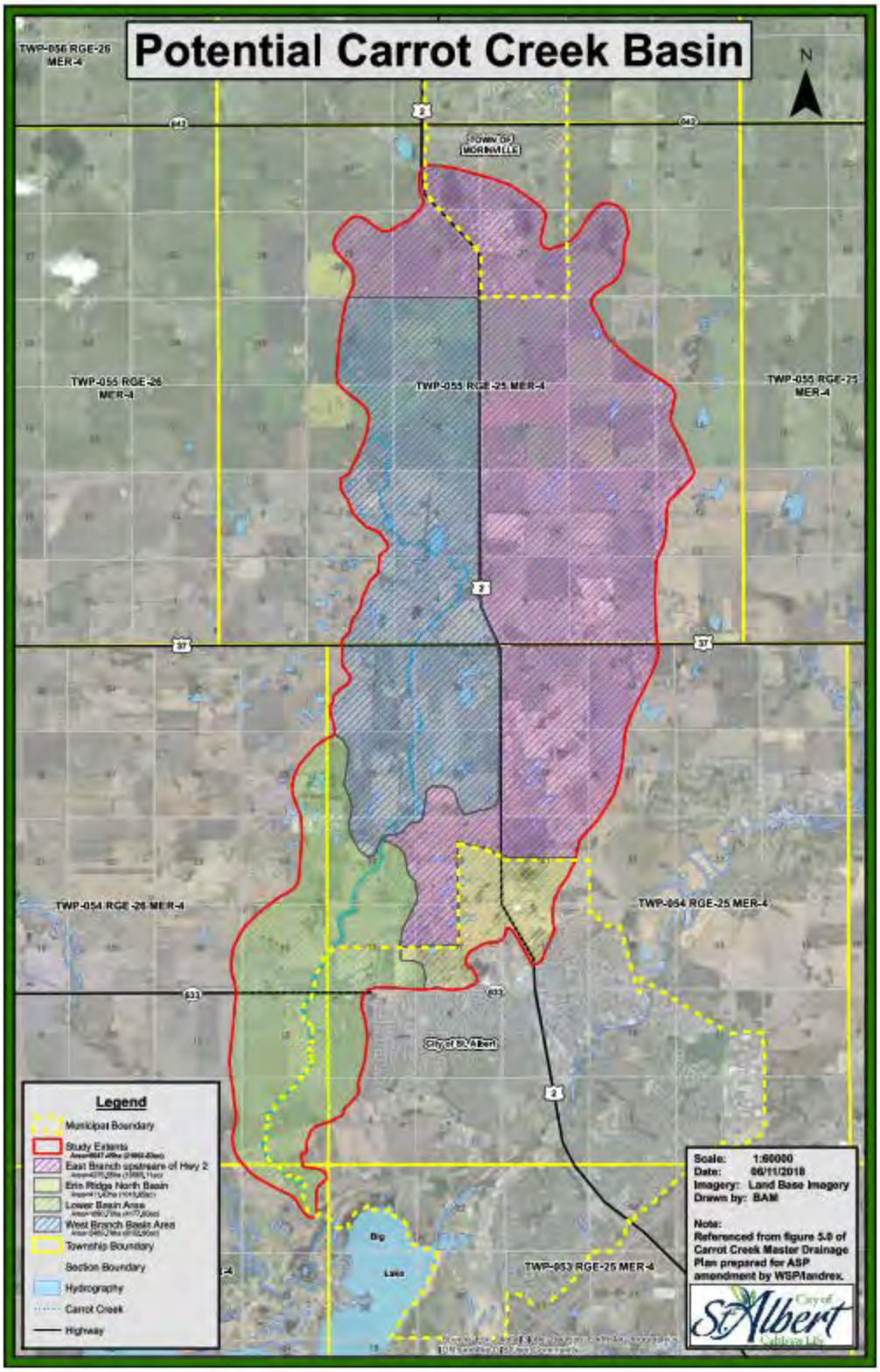
STANDARD OF CARE: Preparation of this report, and all associated work, was carried out in accordance with the normally accepted standard of care in the state or province of execution for the specific professional service provided to the Client. No other warranty is made.

INTERPRETATION OF SITE CONDITIONS: Soil, rock, or other material descriptions, and statements regarding their condition, made in this report are based on site conditions encountered by Stantec at the time of the work and at the specific testing and/or sampling locations. Classifications and statements of condition have been made in accordance with normally accepted practices which are judgmental in nature; no specific description should be considered exact, but rather reflective of the anticipated material behaviour. Extrapolation of in situ conditions can only be made to some limited extent beyond the sampling or test points. The extent depends on variability of the soil, rock and groundwater conditions as influenced by geological processes, construction activity, and site use.

VARYING OR UNEXPECTED CONDITIONS: Should any site or subsurface conditions be encountered that are different from those described in this report or encountered at the test locations, Stantec must be notified immediately to assess if the varying or unexpected conditions are substantial and if reassessments of the report conclusions or recommendations are required. Stantec will not be responsible to any party for damages incurred as a result of failing to notify Stantec that differing site or sub-surface conditions are present upon becoming aware of such conditions.

PLANNING, DESIGN, OR CONSTRUCTION: Development or design plans and specifications should be reviewed by Stantec, sufficiently ahead of initiating the next project stage (property acquisition, tender, construction, etc), to confirm that this report completely addresses the elaborated project specifics and that the contents of this report have been properly interpreted. Specialty quality assurance services (field observations and testing) during construction are a necessary part of the evaluation of sub-subsurface conditions and site preparation works. Site work relating to the recommendations included in this report should only be carried out in the presence of a qualified geotechnical engineer; Stantec cannot be responsible for site work carried out without being present.

Appendix B DESKTOP STUDY AREA


Potential Carrot Creek Basin
N
TWP-056 RGE-26 MER-4
TOWN OF MORINVILLE
TWP-055 RGE-26 MER-4
TWP-055 RGE-25 MER-4
TWP-055 RGE-25 MER-4
TWP-054 RGE-26 MER-4
TWP-054 RGE-25 MER-4
TWP-053 RGE-25 MER-4
City of St. Albert
Big Lake
Legend
Municipal Boundary
Study Extents
East Branch upstream of Hwy 2
Erin Ridge North Basin
Lower Basin Area
West Branch Basin Area
Township Boundary
Section Boundary
Hydrography
Carrot Creek
Highway
Scale: 1:60000
Date: 06/11/2018
Imagery: Land Base Imagery
Drawn by: BAM
Note:
Referenced from figure 5.0 of Carrot Creek Master Drainage Plan prepared for ASP amendment by WSP/Isndrex.
City of St. Albert

Appendix C EROSION ASSESSMENT FIGURES



Figure 12. Detailed Study Area - Wind Erosion Rating

PARAGON

Paragon Project No. 15-053

Projection:	Scale:
UTM 12N NAD83	1:36,000
Drawn: SD	Approved: SM

Legend

Wind Erosion Rating
- Moderate
- Low
- No Rating (Water/Disturbed Land)

- Road
- Townships
- City of St. Albert
- Detailed Study Area

0 250 500 1,000 Metres

Date: 27/07/2015 Time: 1:45:58 PM



Figure 13. Detailed Study Area - Water Erosion Rating

PARAGON

Paragon Project No. 15-053

Projection:	Scale:
UTM 12N NAD83	1:36,000
Drawn: SD	Approved: SM

Legend

Water Erosion Rating
- Low
- No Rating (Water/Disturbed Land)

- Road
- Townships
- City of St. Albert
- Detailed Study Area

0 250 500 1,000 Metres

Date: 27/07/2015 Time: 1:47:02 PM

Appendix E Rosgen Worksheets (used to calculate the BEHI Value)

Chapter 5 Worksheets *The Prediction Level Assesment (PLA)*

Worksheet 5-16. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating (Rosgen, 1996, 2001a). Use **Figure 5-15** with BEHI variables to determine BEHI score.

Stream:	Location:	
Station:	Observers:	
Date:	Stream Type:	Valley Type:

BEHI Score (Fig. 5-15)

Study Bank Height / Bankfull Height (C)

Study Bank Height (ft) =	(A)	Bankfull Height (ft) =	(B)	(A) / (B) =	(C)	

Root Depth / Study Bank Height (E)

Root Depth (ft) =	(D)	Study Bank Height (ft) =	(A)	(D) / (A) =	(E)	

Weighted Root Density (G)

Root Density as % =	(F)	(F) x (E) =	(G)	

Bank Angle (H)

Bank Angle as *Degrees* =	(H)	

Surface Protection (I)

Surface Protection as % =	(I)	

Bank Material Adjustment:

Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform med. to large cobble)
Gravel or Composite Matrix (Add 5-10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (No adjustment)

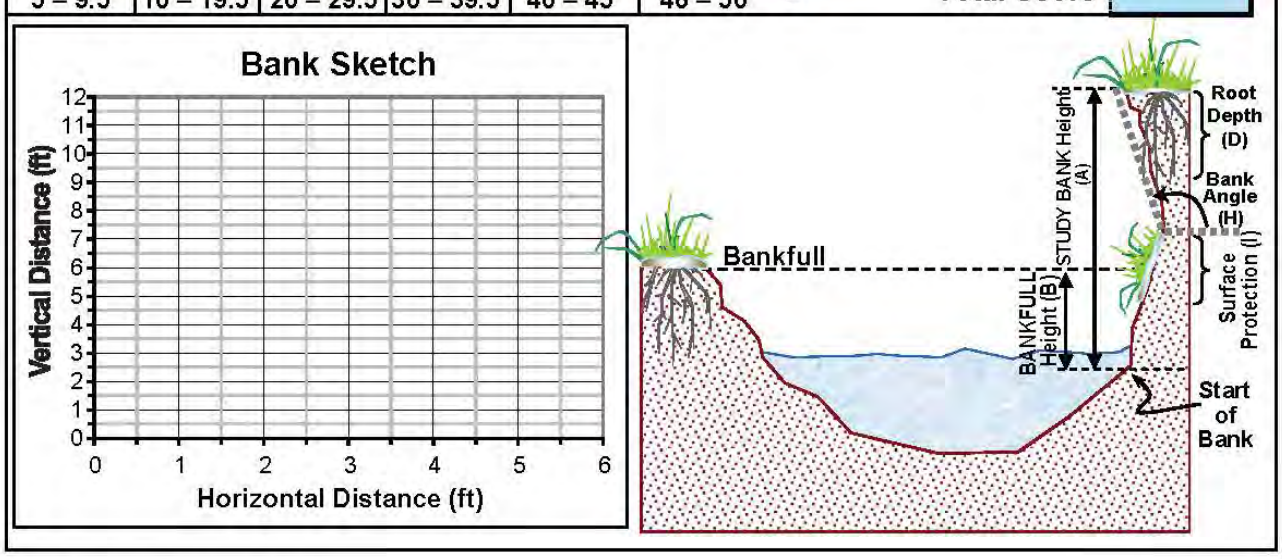
→ **Bank Material Adjustment**

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage

Very Low	Low	Moderate	High	Very High	Extreme
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50

→ **Adjective Rating** and **Total Score**

Bank Sketch



Copyright © 2009 Wildland Hydrology

Worksheet used to record bank measurements from field work in order to calculate the BEHI value for each reach

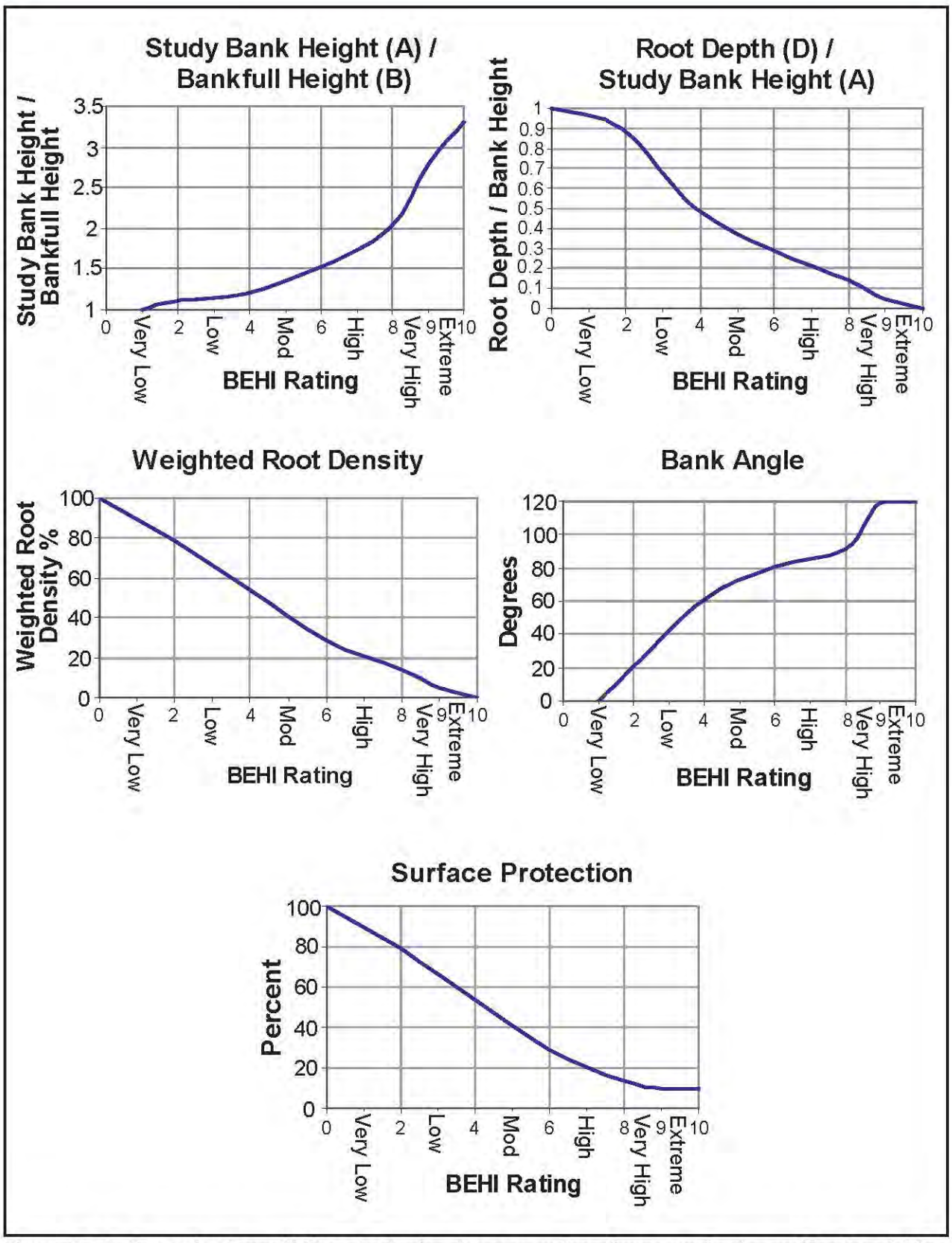


Figure 5-15. Streambank erodibility criteria showing conversion of measured ratios and bank variables to a BEHI rating (Rosgen, 1996, 2001a). Use **Worksheet 5-16** variables to determine BEHI score.

Copyright © 2009 Wildland Hydrology

Figure used to convert the measured ratios and variables from Worksheet 5-26 into BEHI ratings that could be added together to get the total BEHI score and adjective rating

Appendix F Associated Engineering Flood versus Drainage Area Figures

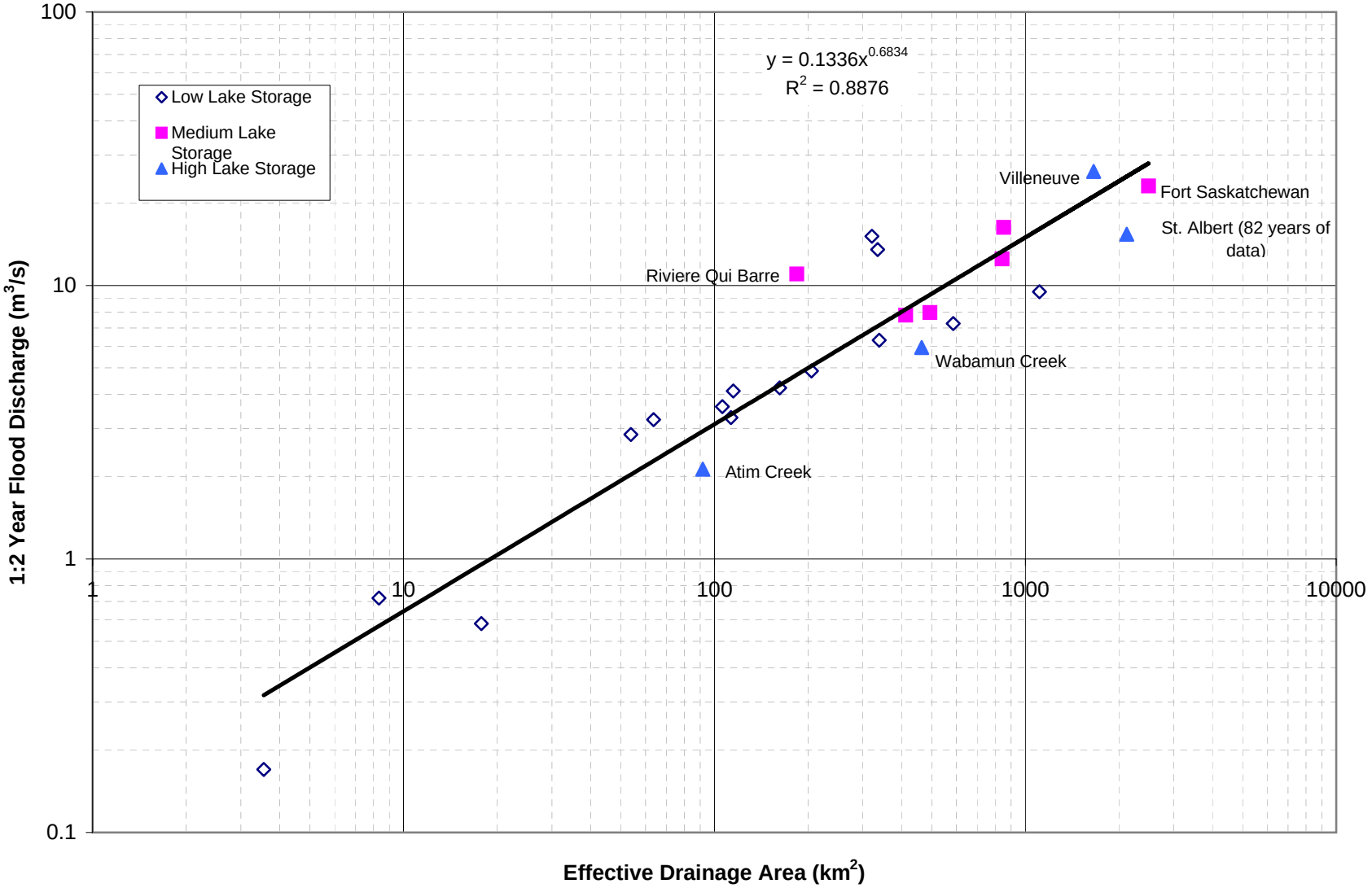


FIGURE 4.4
1:2 YEAR FLOOD Vs. EFFECTIVE DRAINAGE AREA

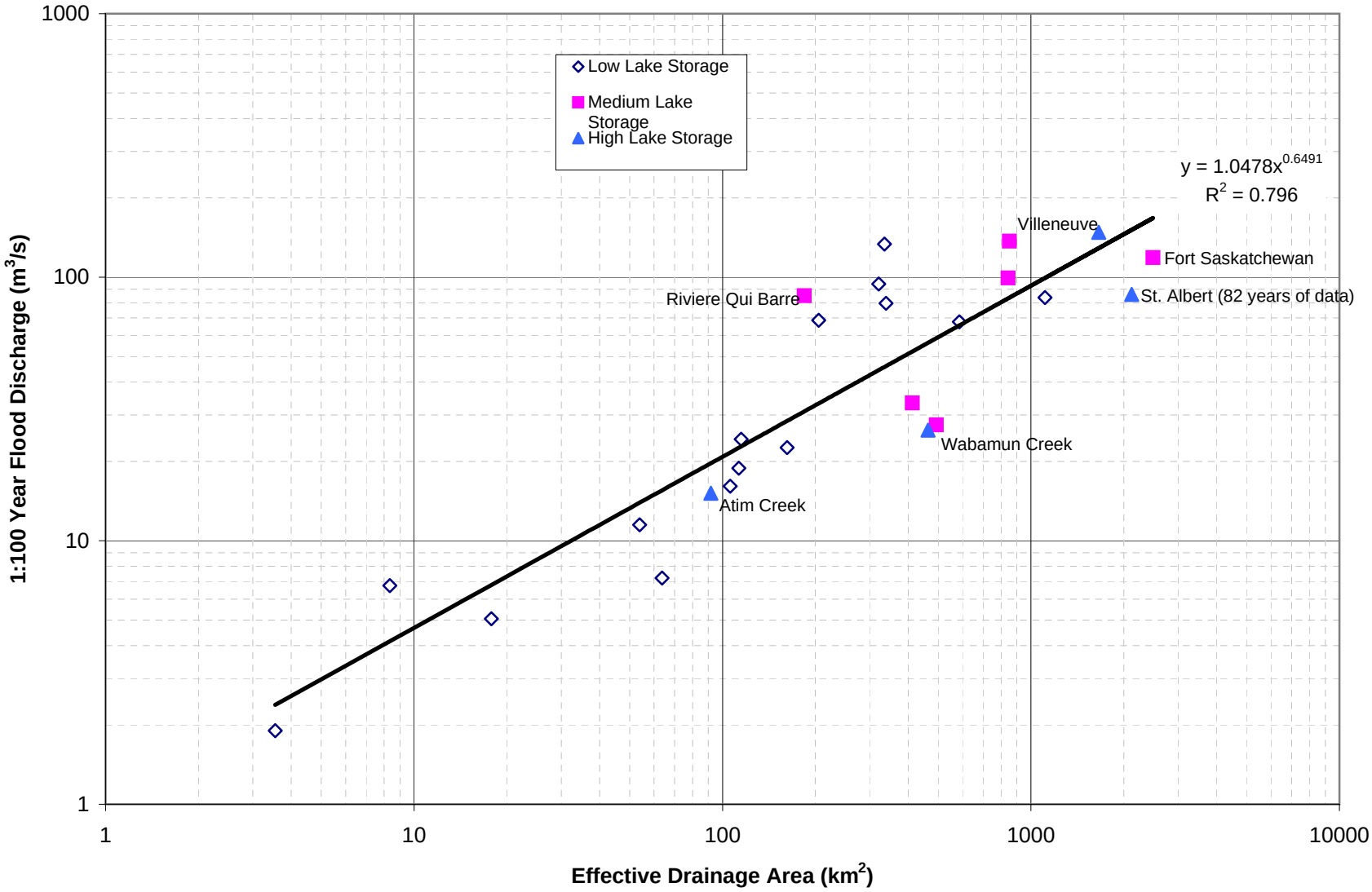


FIGURE 4.5
REGIONAL CURVE FOR 1:100 YEAR FLOOD

Appendix G Carrot Creek Frequency Analysis

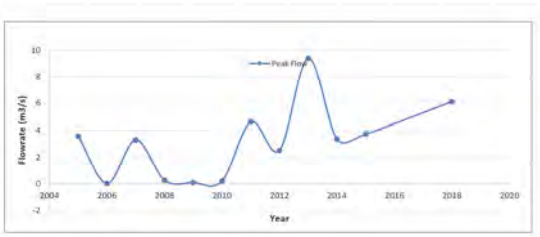
Statistics

	Based on Log10(Q)	Based on Q
Mean	0.04	3.1
Median	0.52	3.3
Standard Deviation	0.95	2.8
Sample Variance	0.90	7.9
Kurtosis	0.75	0.9
Skewness	-1.28	0.9
Range	3.07	0.0
Minimum	-2.10	0.0
Maximum	0.97	9.4
Sum (Q)	0	37.1
Sum(Q^2)	-	201.8
Count (N)	12	12
σ_q^2	-	7.92

Station ID	05EA011	
Drainage Area, km^2	87.9	(Gross Area)

Station Data

Year	Q (m3/s)	Log10(Q)	Q^2
2005	3.56	0.55	12.7
2006	0.008	-2.10	0.0
2007	3.3	0.52	10.9
2008	0.26	-0.59	0.1
2009	0.067	-1.17	0.0
2010	0.196	-0.71	0.0
2011	4.62	0.66	21.3
2012	2.52	0.40	6.4
2013	9.38	0.97	88.0
2014	3.36	0.53	11.3
2015	3.72	0.57	13.8
2018	6.11	0.79	37.3



Return Period, T	Skew Coefficient			Discharge (m^3/s)			Unit Discharge for 05EA011 (L/s/ha)		
(years)	(Ks) Log Pearson III	(Ks) Log Normal	K (Gumbel)	Log Pearson III	Log Normal	Gumbel	Log Pearson III	Log Normal	Gumbel
1.0101	-3.211	-2.326	-1.64	0	0	-1.5	0.00	0.00	-0.17
2	0.21	0	-0.16	2	1	2.6	0.20	0.12	0.30
5	0.838	0.842	0.72	7	7	5.1	0.77	0.78	0.58
10	1.064	1.282	1.31	11	18	6.8	1.27	2.04	0.77
25	1.24	1.751	2.04	16	50	8.8	1.86	5.71	1.01
50	1.324	2.054	2.59	20	97	10.4	2.24	11.08	1.18
100	1.383	2.326	3.14	22	177	11.9	2.55	20.10	1.36
200	1.424	2.576	3.68	25	305	13.4	2.79	34.75	1.53

Appendix H 1:100-Year Flood Inundation Extents

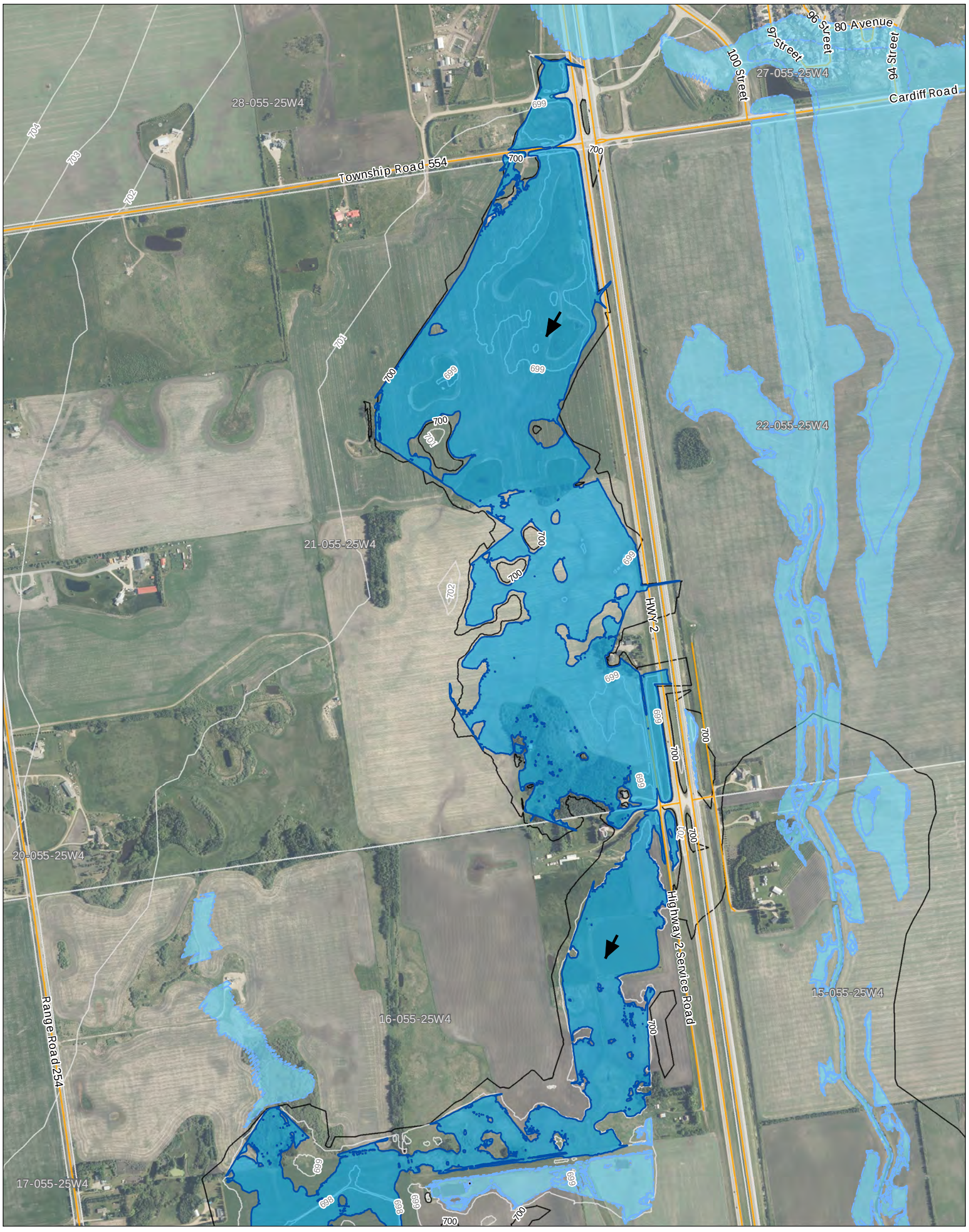
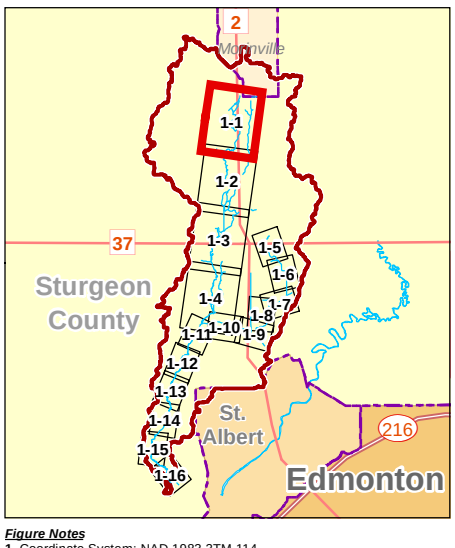


Figure 1-2



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Inundation Notes:

1. The potential ponding areas represent shallow waters less than 0.2 m deep and disconnected from the main channel.
2. The 100 year inundation extent represents areas that are connected to the main channel of Carrot Creek.
3. The areas of interest indicate areas of concern and observed erosion areas.

0 200 400 metres
(At original document size of 11x17)
1:10,000

N

Stantec

City of St. Albert Planning and Engineering

Project Location
Carrot Creek Basin,
Sturgeon County, Alberta

Prepared by SS on 2021-02-24
QR by XX on 2021-xx-xx

Client/Project 110149416-0001
City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
1-1

Title
100 Year Flood Inundation Extents

Figure Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Stantec, Sturgeon County, Government of Alberta, Geogratis, ©Department of Natural Resources Canada, All rights reserved. Watercourse, AltaLIS (1:20 000 Provincial Digital Mapping Program)
3. Background: Sturgeon County 2019 Aerials

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Figure 1-1

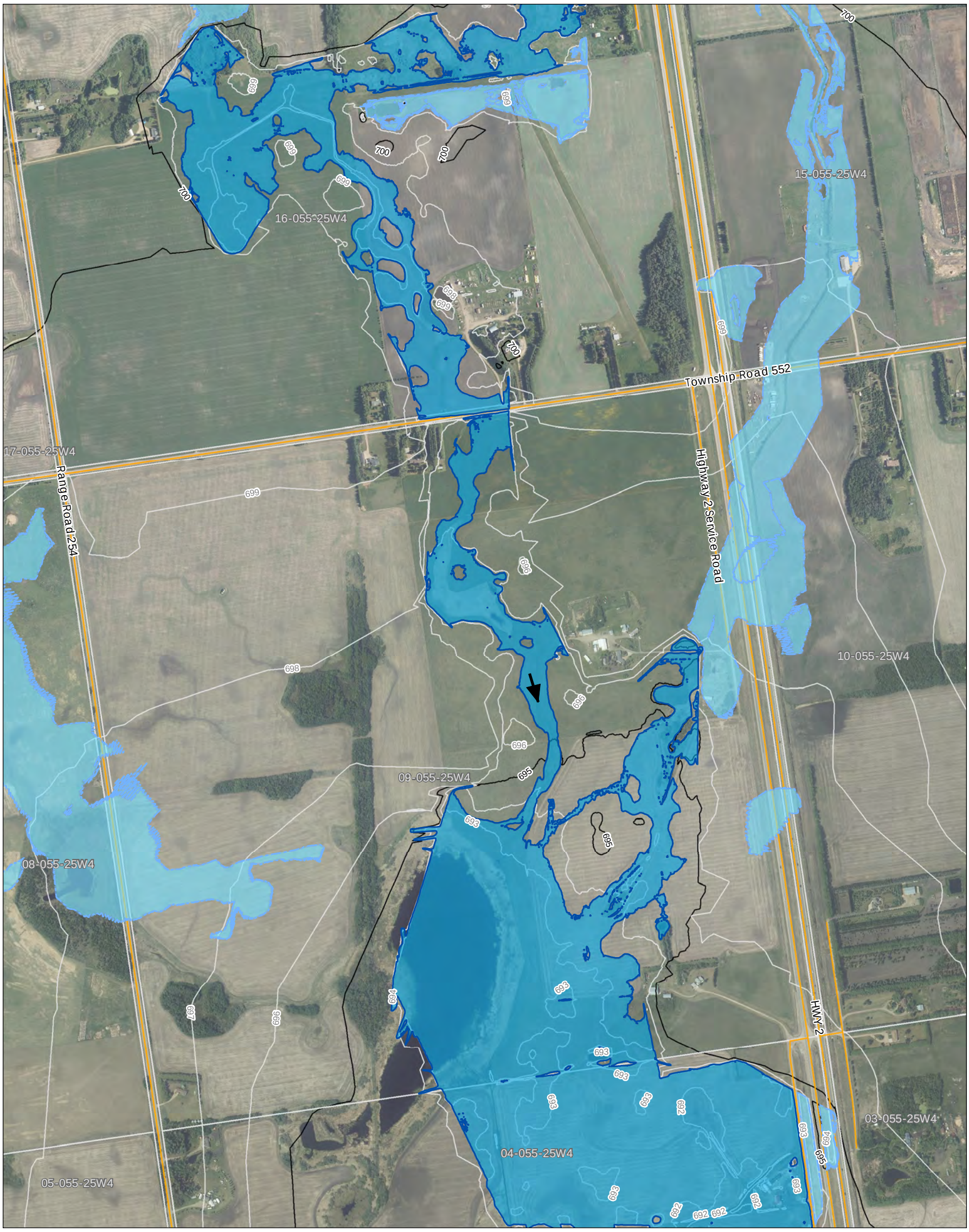
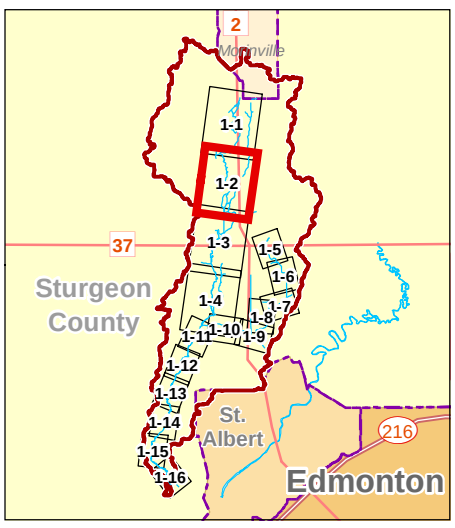


Figure 1-3



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

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2. Data Sources: Stantec, Sturgeon County, Government of Alberta, Geogratis, ©Department of Natural Resources Canada, All rights reserved. Watercourse, AltaLIS (1:20 000 Provincial Digital Mapping Program)
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Title
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Figure 1-2

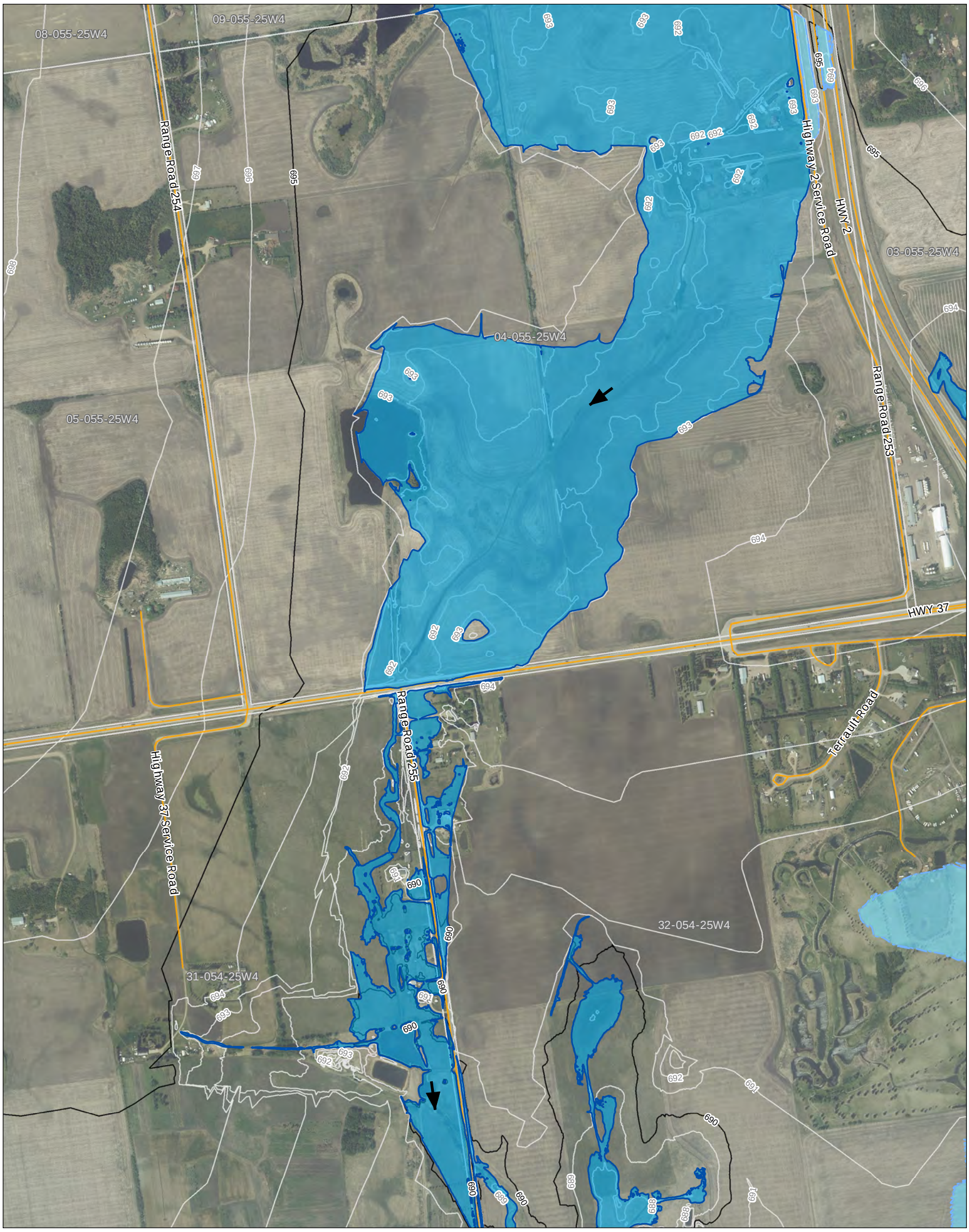
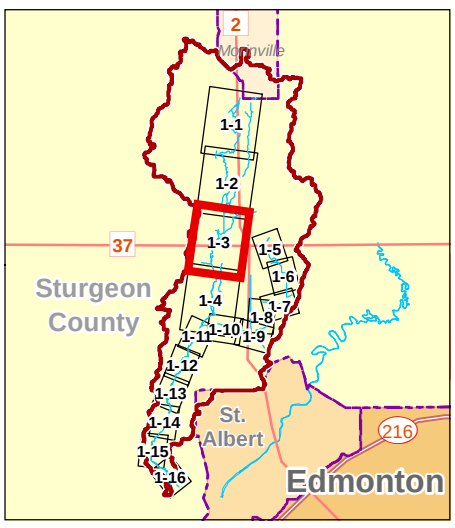


Figure 1-4



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Stantec, Sturgeon County, Government of Alberta, Geogratis, ©Department of Natural Resources Canada, All rights reserved. Watercourse, AltaLIS (1:20 000 Provincial Digital Mapping Program)
3. Background: Sturgeon County 2019 Aerials

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0 200 400 metres

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Client/Project
110149416-0001
City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
1-3

Title
100 Year Flood Inundation Extents

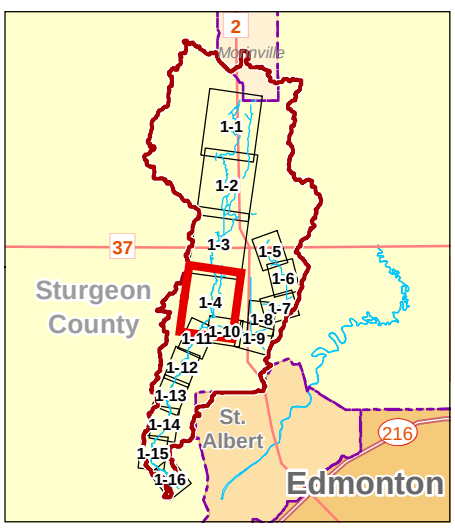
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Figure 1-3



Figure 1-11



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

Areas of Interest

Township Road 544 East of Highway 2

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Stantec, Sturgeon County, Government of Alberta, Geogratis, ©Department of Natural Resources Canada, All rights reserved. Watercourse, AltaLIS (1:20 000 Provincial Digital Mapping Program)
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Carrot Creek Basin,
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City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
1-4

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Title
100 Year Flood Inundation Extents

Figure 1-10

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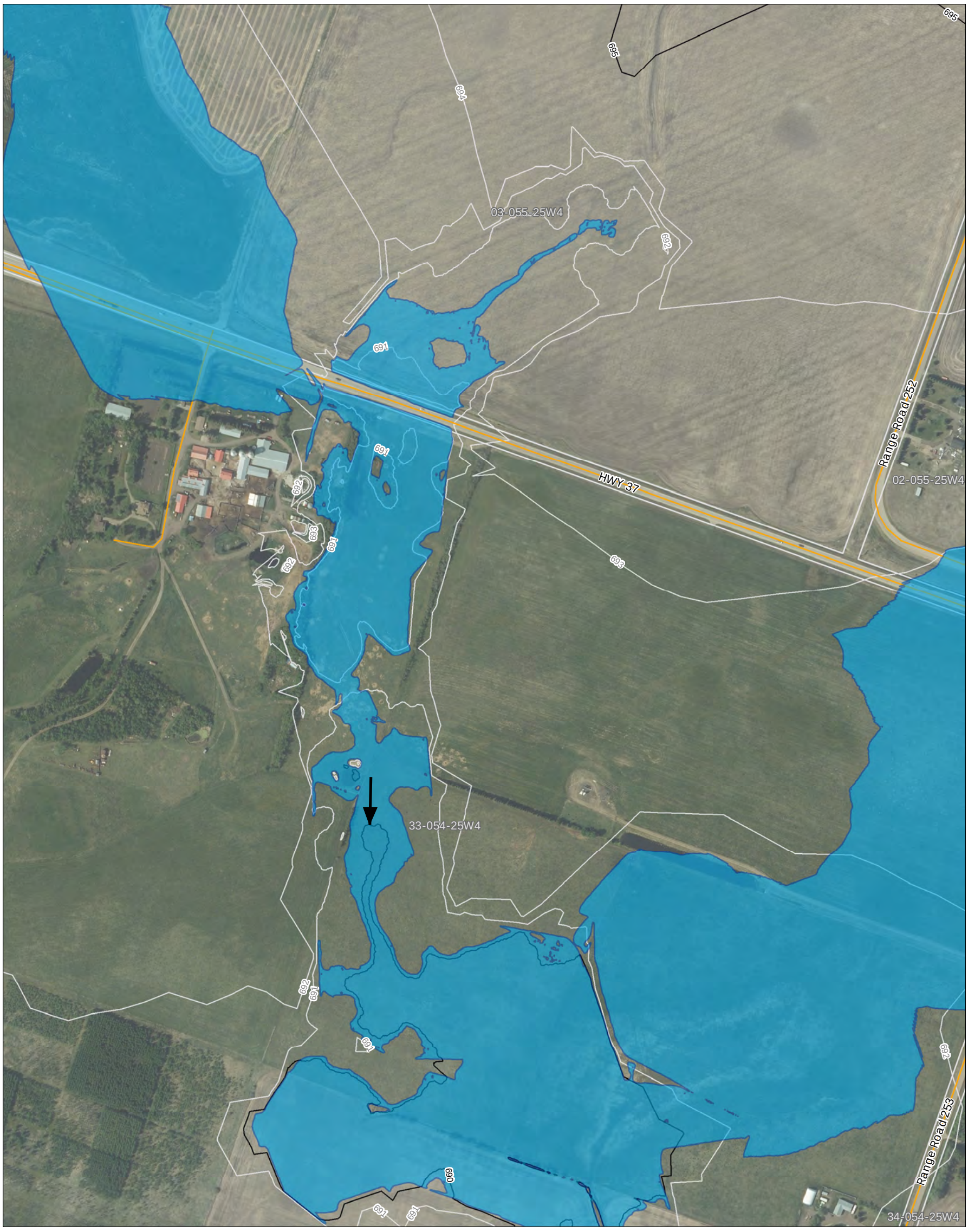
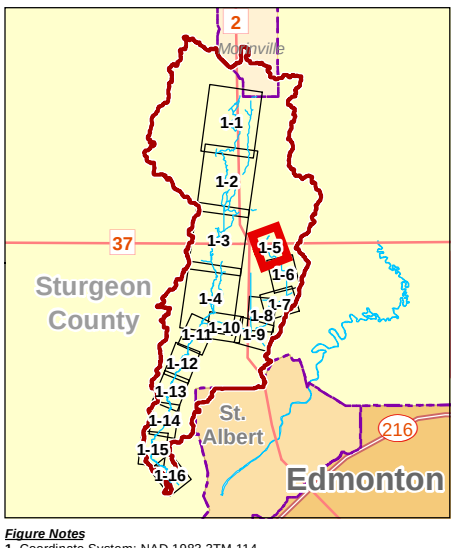


Figure 1-6



- Municipal Boundary
- Section
- Watershed Boundary
- Major Road
- Local Road
- 5m Contours
- 1m Contours
- Flow Direction

100 Year Flood Inundation Extent

- Potential Ponding Areas
- 100 Year Inundation Extent

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Carrot Creek Regional Master Drainage Plan

Figure No.
1-5

Title
100 Year Flood Inundation Extents

Figure Notes
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2. Data Sources: Stantec, Sturgeon County, Government of Alberta, Geogratis, ©Department of Natural Resources Canada, All rights reserved. Watercourse, AltaLIS (1:20 000 Provincial Digital Mapping Program)
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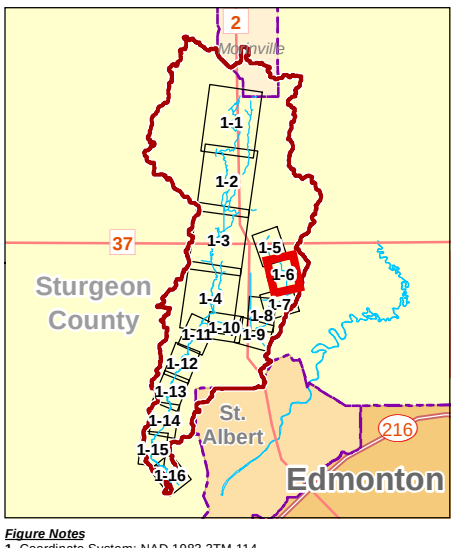
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Figure 1-5



Figure 1-7



- Municipal Boundary
- Section
- Watershed Boundary
- Major Road
- Local Road
- 5m Contours
- 1m Contours
- Flow Direction

100 Year Flood Inundation Extent

- Potential Ponding Areas
- 100 Year Inundation Extent

Figure Notes
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Figure No.
1-6

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Title
100 Year Flood Inundation Extents

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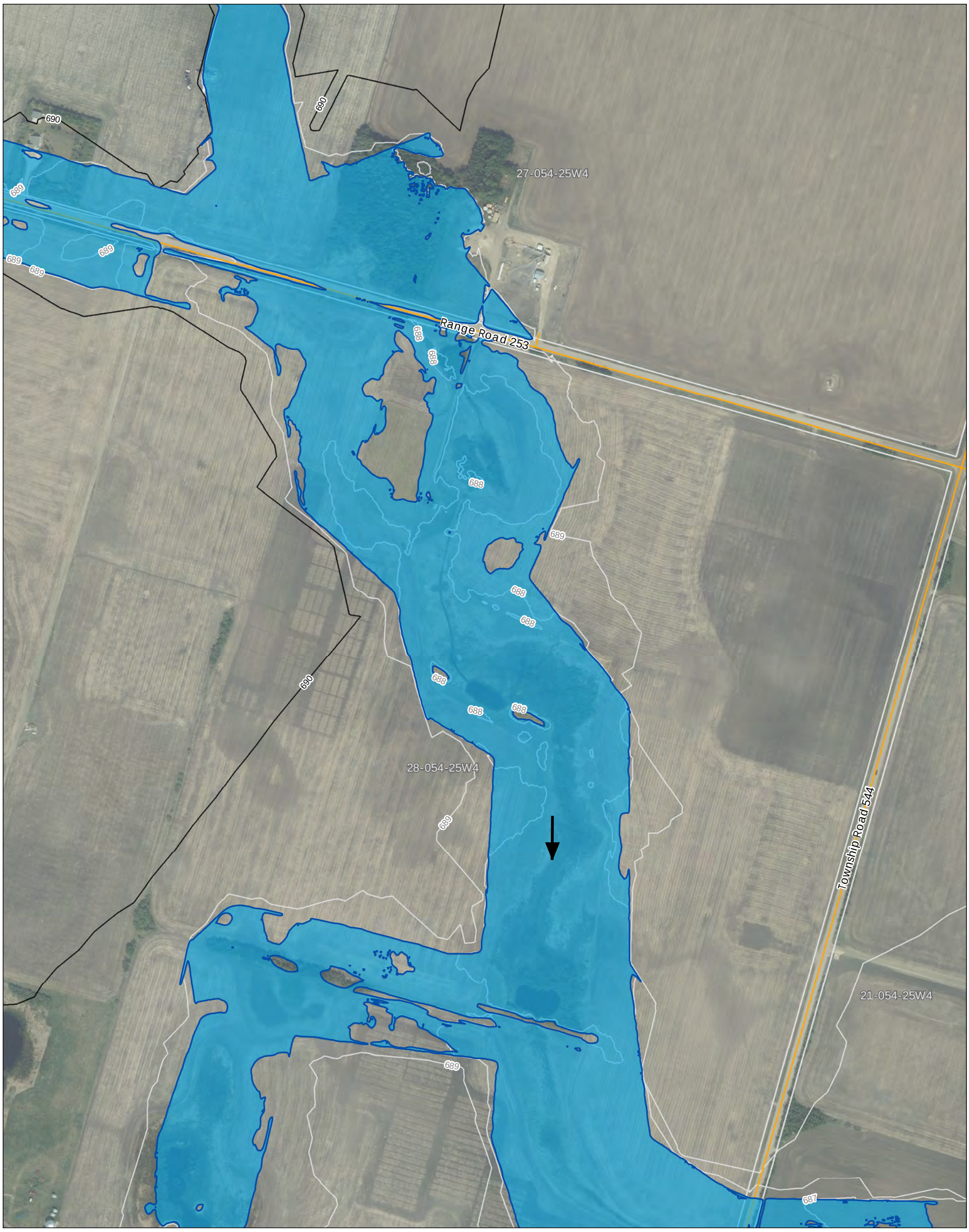
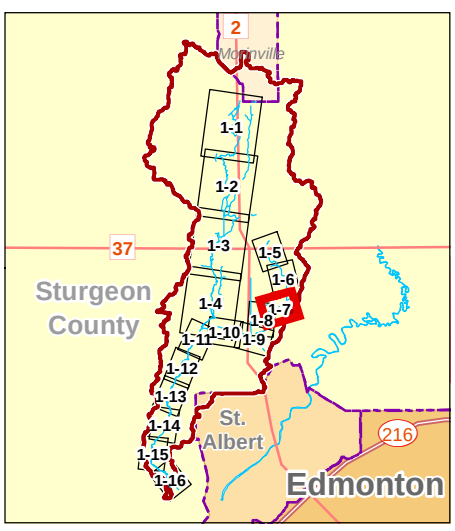


Figure 1-6

Figure 1-8



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes
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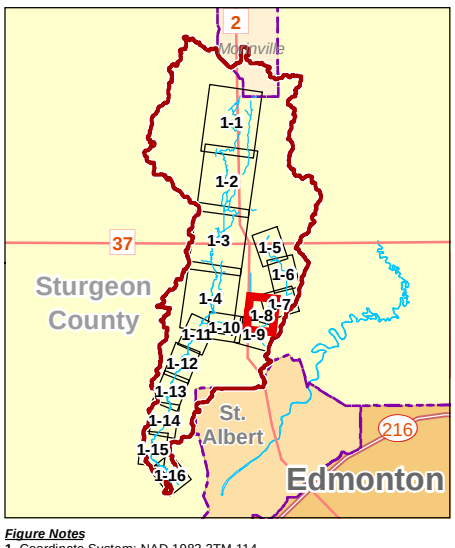
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Figure 1-7



Figure 1-9



- Municipal Boundary
- Section
- Watershed Boundary
- Major Road
- Local Road
- 5m Contours
- 1m Contours
- Flow Direction

Areas of Interest

- Highway 2

100 Year Flood Inundation Extent

- Potential Ponding Areas
- 100 Year Inundation Extent

Figure Notes

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1-8

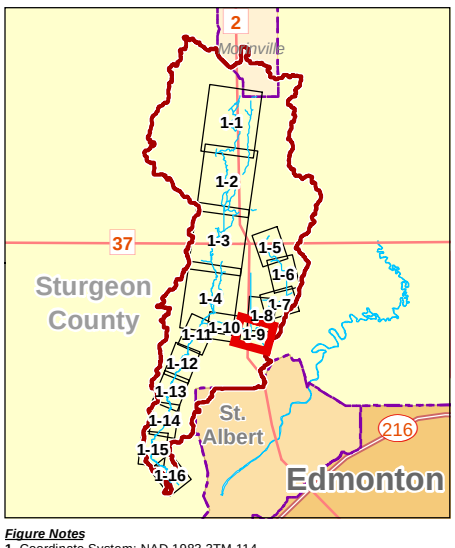
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Figure 1-10



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

Areas of Interest

Highway 2

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

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Figure No.
1-9

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Title
100 Year Flood Inundation Extents

Figure 1-8

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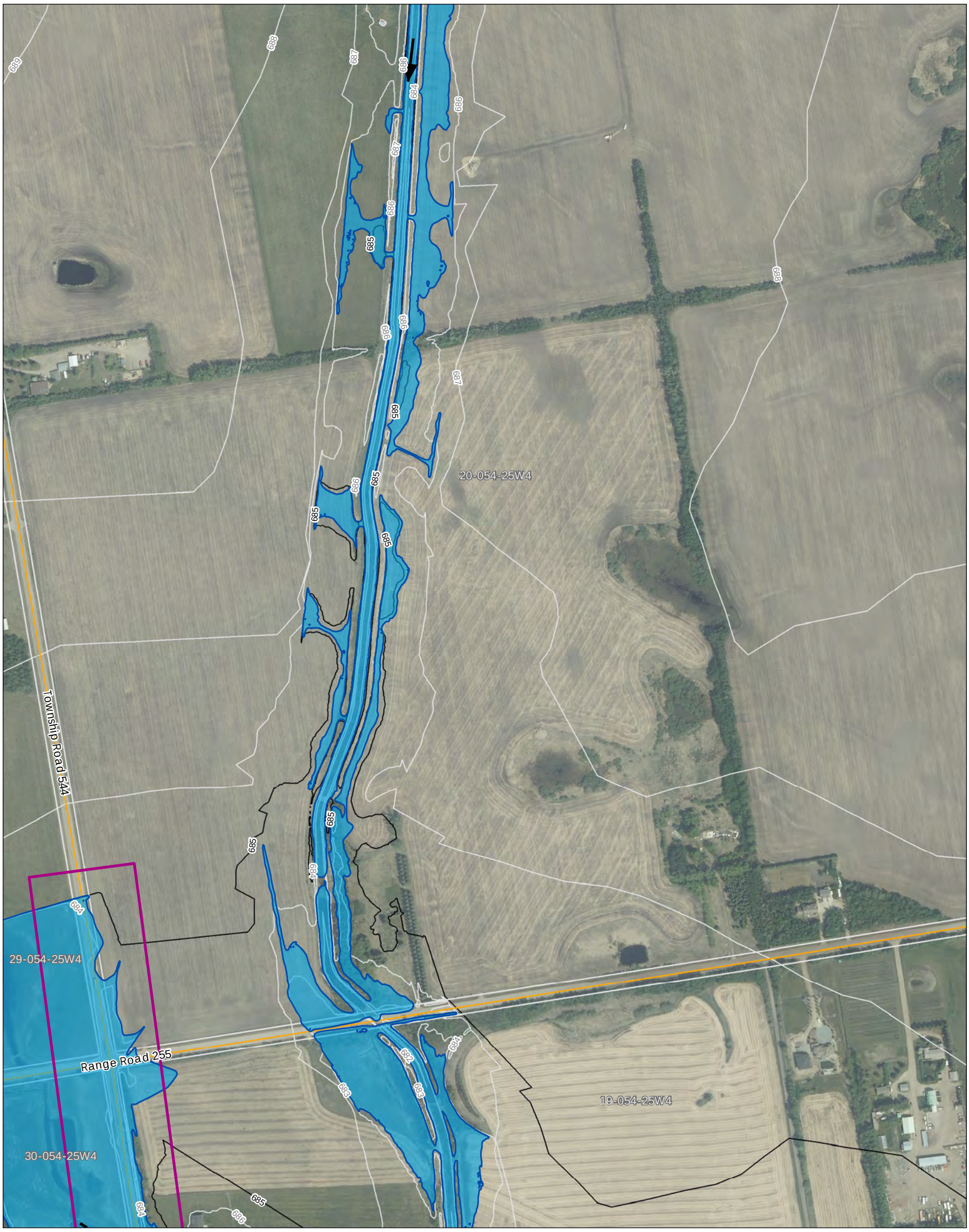
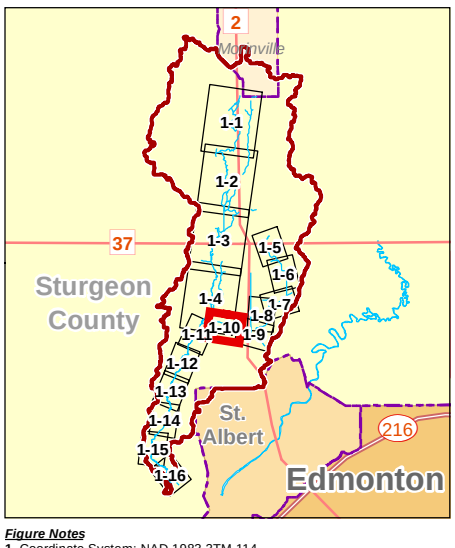


Figure 1-4

Figure 1-11



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

Areas of Interest

Township Road 544 East of Highway 2

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

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100 Year Flood Inundation Extents

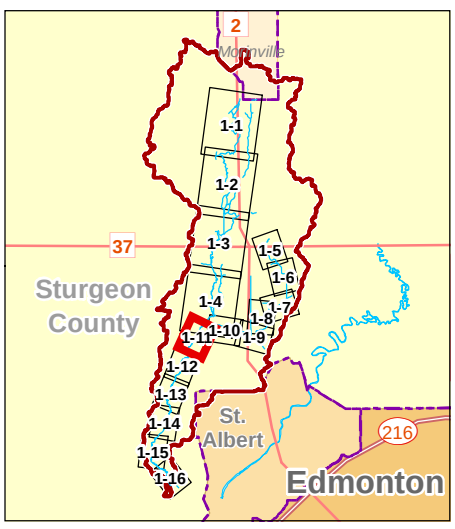
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Figure 1-4



Figure 1-12



- Municipal Boundary
- Section
- Watershed Boundary
- Major Road
- Local Road
- 5m Contours
- 1m Contours
- Flow Direction

100 Year Flood Inundation Extent

- Potential Ponding Areas
- 100 Year Inundation Extent

Figure Notes

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Figure No.
1-11

Page 11 of 16

Title
100 Year Flood Inundation Extents

Figure 1-10

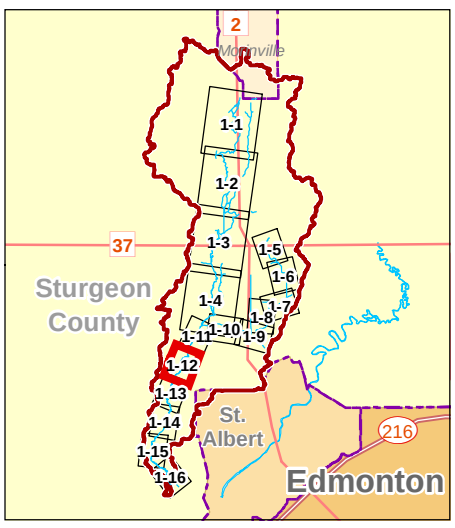
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Figure 1-11



Figure 1-13



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

Areas of Interest

South of Confluence at Range Road 260

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

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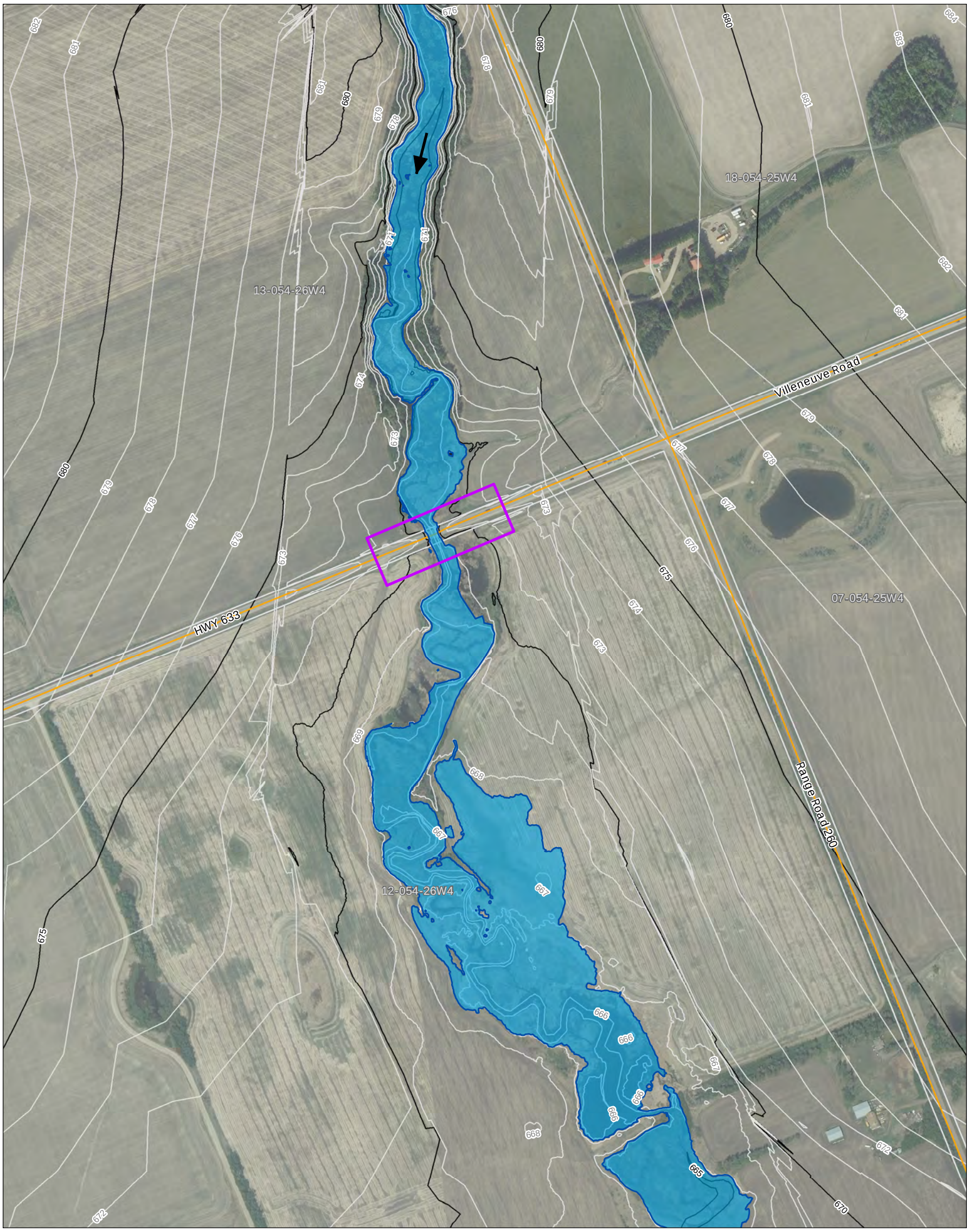
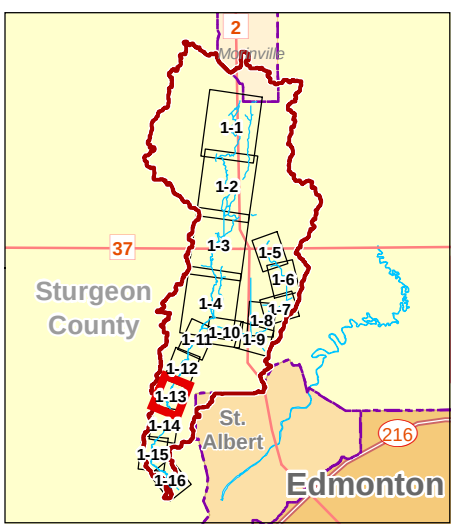


Figure 1-14



- Municipal Boundary
- Section
- Watershed Boundary
- Major Road
- Local Road
- 5m Contours
- 1m Contours
- Flow Direction

Areas of Interest

- Villeneuve Road

100 Year Flood Inundation Extent

- Potential Ponding Areas
- 100 Year Inundation Extent

Figure Notes

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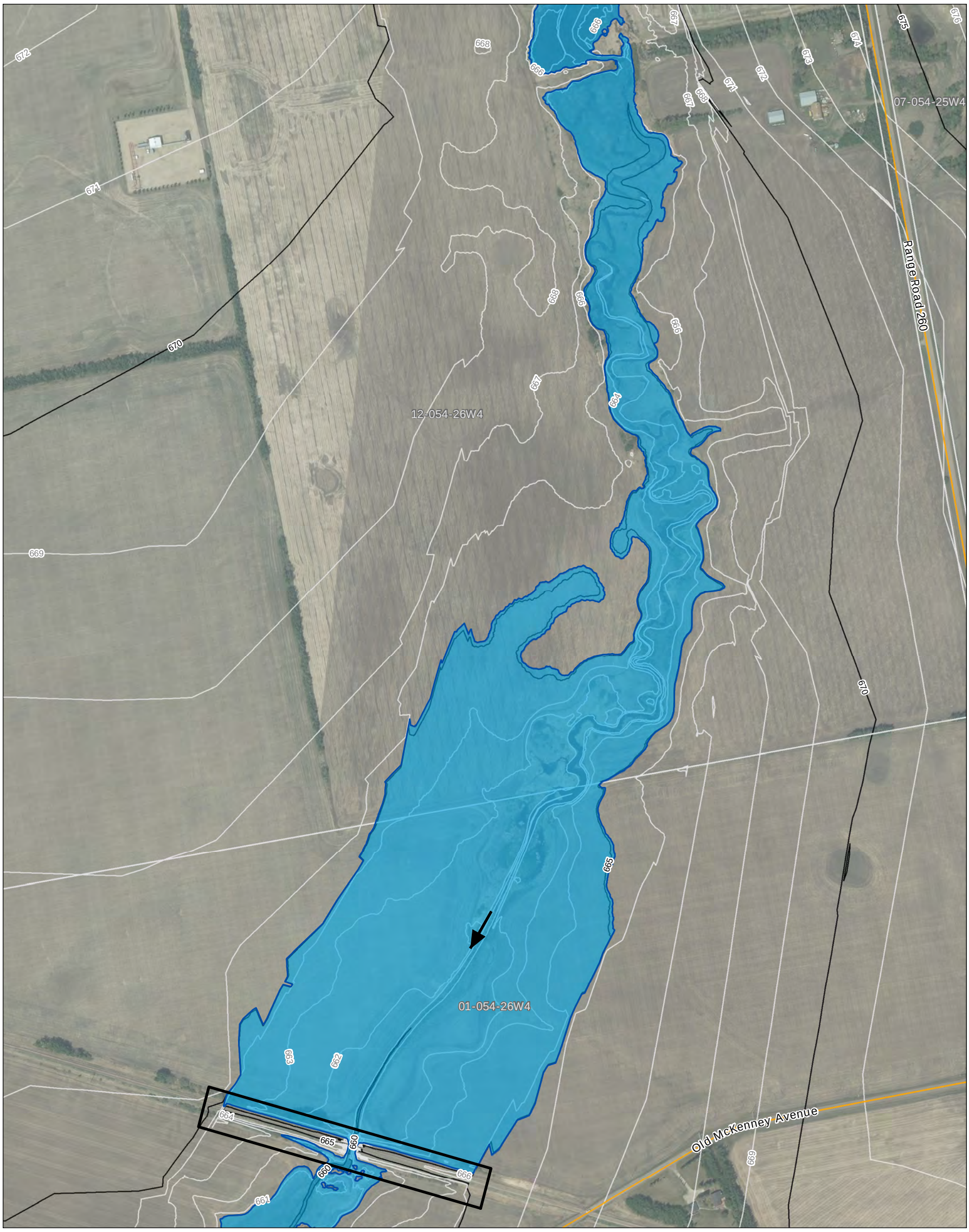
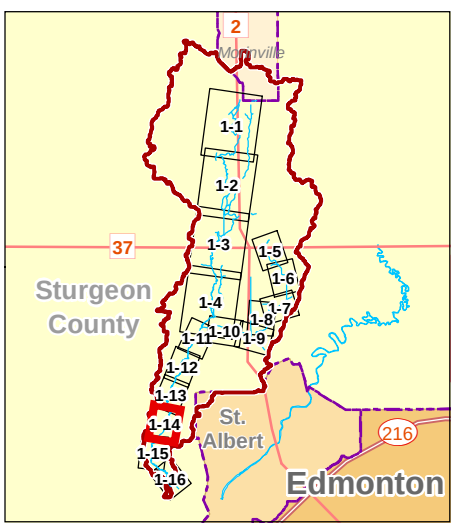


Figure 1-15



Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

Areas of Interest

CN Culvert

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

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Title
100 Year Flood Inundation Extents

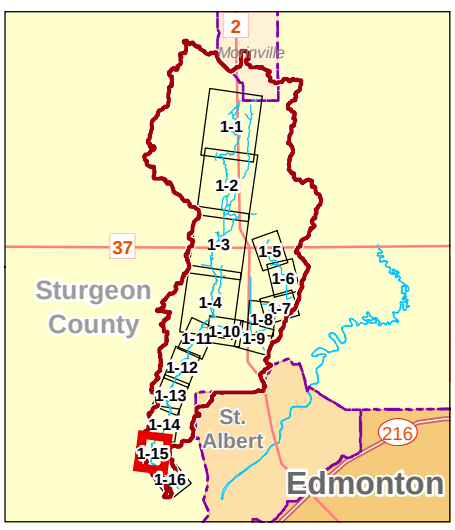
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Figure 1-14



Figure 1-16



- Municipal Boundary
- Section
- Watershed Boundary
- Major Road
- Local Road
- 5m Contours
- 1m Contours
- Flow Direction

Areas of Interest

- CN Culvert
- Old McKenney Avenue

100 Year Flood Inundation Extent

- Potential Ponding Areas
- 100 Year Inundation Extent

Inundation Notes:

1. The potential ponding areas represent shallow waters less than 0.2 m deep and disconnected from the main channel.
2. The 100 year inundation extent represents areas that are connected to the main channel of Carrot Creek.
3. The areas of interest indicate areas of concern and observed erosion areas.

0 100 200 metres

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1:5,000

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Stantec

St. Albert Planning and Engineering

Project Location
Carrot Creek Basin,
Sturgeon County, Alberta

Prepared by SS on 2021-02-24
QR by XX on 2021-xx-xx

Client/Project
110149416-0001
City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
1-15

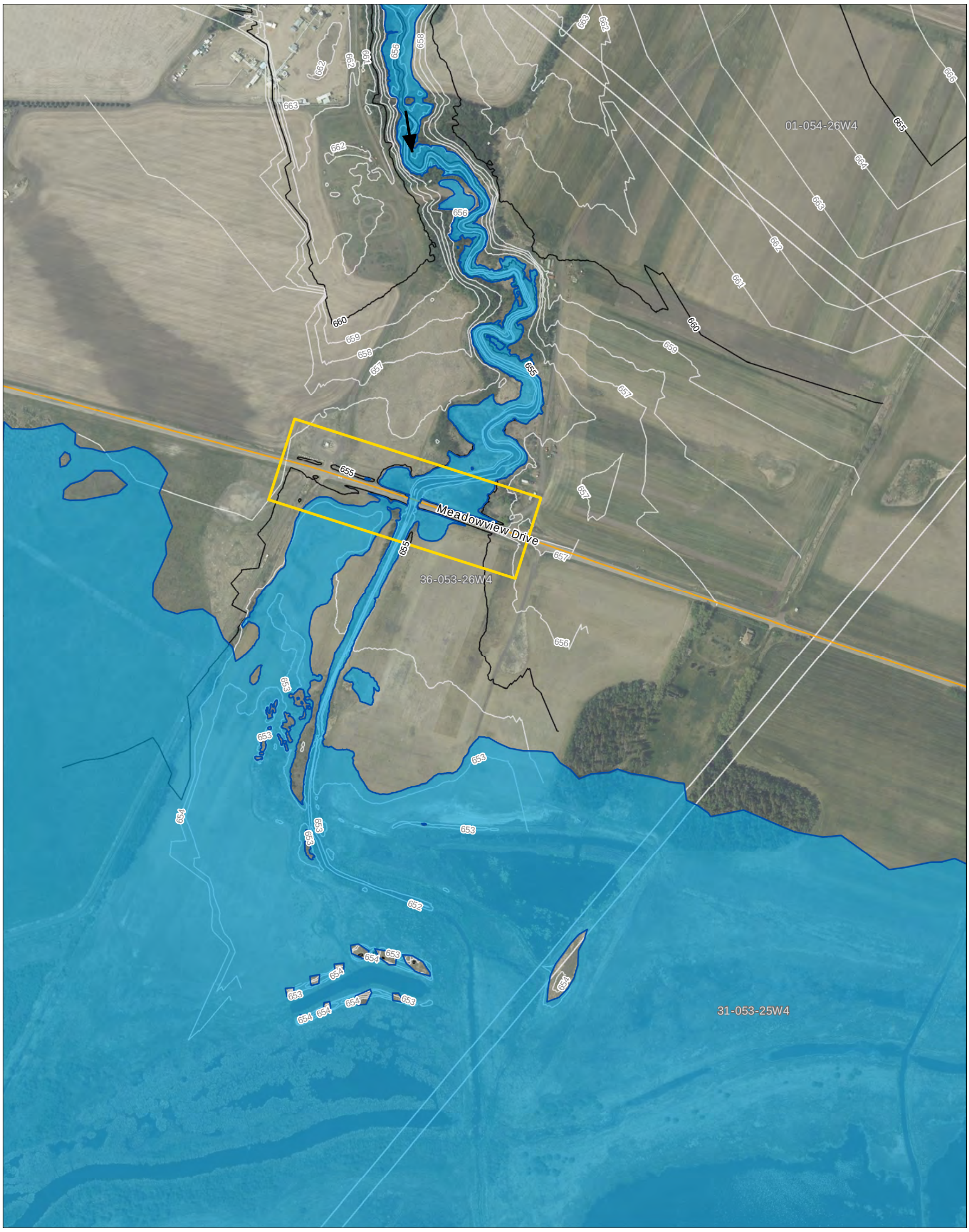
Title
100 Year Flood Inundation Extents

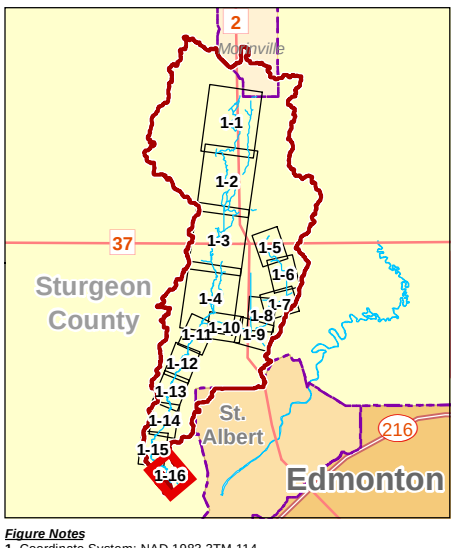
Figure Notes
1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Stantec, Sturgeon County, Government of Alberta, Geogratis, ©Department of Natural Resources Canada, All rights reserved. Watercourse, AltaLIS (1:20 000 Provincial Digital Mapping Program)
3. Background: Sturgeon County 2019 Aerials

\\cd1001-c200\workgroup\1101\active\110149416\drafting\figures\gis\1 in 100 Flood\110149416_001_b_P_100YearInundationExtents_Mapbook_Pgs1-15.mxd Revised: 2021-03-11 By: ssteenbergen

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Figure 1-15





Municipal Boundary
Section
Watershed Boundary
Major Road
Local Road
5m Contours
1m Contours
Flow Direction

Areas of Interest

Meadowview Drive

100 Year Flood Inundation Extent

Potential Ponding Areas
100 Year Inundation Extent

Figure Notes

1. Coordinate System: NAD 1983 3TM 114
2. Data Sources: Stantec, Sturgeon County, Government of Alberta, Geogratis, ©Department of Natural Resources Canada, All rights reserved. Watercourse, AltaLIS (1:20 000 Provincial Digital Mapping Program)
3. Background: Sturgeon County 2019 Aerials

Inundation Notes:

1. The potential ponding areas represent shallow waters less than 0.2 m deep and disconnected from the main channel.
2. The 100 year inundation extent represents areas that are connected to the main channel of Carrot Creek.
3. The areas of interest indicate areas of concern and observed erosion areas.
4. The downstream boundary condition was selected based off the Province of Alberta's flood hazard mapping completed in 2020. the 1:100-year open water surface elevation at Big Lake was 653.2 m (Government of Alberta 2020).

0 100 200 metres
(At original document size of 11x17)
1:5,000

Stantec

Project Location
Carrot Creek Basin,
Sturgeon County, Alberta

Prepared by SS on 2021-02-24
QR by XX on 2021-xx-xx

Client/Project 110149416-0001
City of St. Albert
Carrot Creek Regional Master Drainage Plan

Figure No.
1-16 **16 of 16**

Title
100 Year Flood Inundation Extents

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Appendix I Opinion of Probable Cost Details

Option 1A
East Tributary Diversion to Sturgeon Rive
UARR = 1.8 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	42.3	$ 50	$ 2,115,000
SU3	43.8	$ 50	$ 2,190,000
SU4	30.1	$ 50	$ 1,505,000
SU5	70.8	$ 50	$ 3,540,000
SU6	38.5	$ 50	$ 1,925,000
SU7	71.1	$ 50	$ 3,555,000
SU8	72.7	$ 50	$ 3,635,000
SU9	57	$ 50	$ 2,850,000
SU10	227.6	$ 50	$ 11,380,000
SU11	318.7	$ 50	$ 15,935,000
SU12	12.5	$ 50	$ 625,000
SU13	148.7	$ 50	$ 7,435,000
SU14	67	$ 50	$ 3,350,000
SU15	86.9	$ 50	$ 4,345,000
SU16	166.8	$ 50	$ 8,340,000
SU17	17.8	$ 50	$ 890,000
SU18	16.9	$ 50	$ 845,000
SU19	19.5	$ 50	$ 975,000
SU20	23.6	$ 50	$ 1,180,000
SU21	178	$ 50	$ 8,900,000
SU22	72.4	$ 50	$ 3,620,000
SU23	306.6	$ 50	$ 15,330,000
SU24	107.3	$ 50	$ 5,365,000
		Subtotal:	**$ 109,830,000**
		50% Eng/Contingency	**$ 54,915,000**
		Total:	**$ 164,745,000**

Part 2: Storm Trunks

	Length (linear or vertical m)	All Inslusive Unit Cost ($/m)	Cost ($)
East Tributary Diversion (1.8 m x 1.2 m box)	3240	$ 5,000	$ 16,200,000
Manholes	40.5	$ 12,000	$ 486,000
New Stormwater Outfal			$ 2,000,000
		Subtotal:	**$ 18,686,000**
		50% Eng/Contingency	**$ 9,343,000**
		Total:	**$ 28,029,000**

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimate

Option 1B
East Tributary Diversion to Sturgeon Rive
UARR = 2.5 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	40.2	$ 50	$ 2,010,000
SU3	41.7	$ 50	$ 2,085,000
SU4	28.6	$ 50	$ 1,430,000
SU5	67.4	$ 50	$ 3,370,000
SU6	36.6	$ 50	$ 1,830,000
SU7	67.3	$ 50	$ 3,365,000
SU8	69.1	$ 50	$ 3,455,000
SU9	54.3	$ 50	$ 2,715,000
SU10	217.5	$ 50	$ 10,875,000
SU11	305.5	$ 50	$ 15,275,000
SU12	11.9	$ 50	$ 595,000
SU13	142.4	$ 50	$ 7,120,000
SU14	63.7	$ 50	$ 3,185,000
SU15	82.5	$ 50	$ 4,125,000
SU16	158.4	$ 50	$ 7,920,000
SU17	16.9	$ 50	$ 845,000
SU18	16	$ 50	$ 800,000
SU19	18.5	$ 50	$ 925,000
SU20	22.5	$ 50	$ 1,125,000
SU21	169.8	$ 50	$ 8,490,000
SU22	69.2	$ 50	$ 3,460,000
SU23	292.4	$ 50	$ 14,620,000
SU24	102.4	$ 50	$ 5,120,000
		Subtotal:	**$ 104,740,000**
		50% Eng/Contingency	**$ 52,370,000**
		Total:	**$ 157,110,000**

Part 2: Storm Trunks

	Length (linear or vertical m)	All Inslusive Unit Cost ($/m)	Cost ($)
East Tributary Diversion (1.8 m x 1.2 m box)	3240	$ 5,000	$ 16,200,000
Manholes	40.5	$ 12,000	$ 486,000
New Stormwater Outfal			$ 2,000,000
		Subtotal:	**$ 18,686,000**
		50% Eng/Contingency	**$ 9,343,000**
		Total:	**$ 28,029,000**

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimate

Option 1C
East Tributary Diversion to Sturgeon Rive
UARR = 5 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	34.8	$ 50	$ 1,740,000
SU3	36	$ 50	$ 1,800,000
SU4	24.7	$ 50	$ 1,235,000
SU5	58.2	$ 50	$ 2,910,000
SU6	31.6	$ 50	$ 1,580,000
SU7	58.8	$ 50	$ 2,940,000
SU8	59.9	$ 50	$ 2,995,000
SU9	47	$ 50	$ 2,350,000
SU10	188.8	$ 50	$ 9,440,000
SU11	264.9	$ 50	$ 13,245,000
SU12	10.2	$ 50	$ 510,000
SU13	123.2	$ 50	$ 6,160,000
SU14	55.3	$ 50	$ 2,765,000
SU15	71.5	$ 50	$ 3,575,000
SU16	137.9	$ 50	$ 6,895,000
SU17	14.5	$ 50	$ 725,000
SU18	13.8	$ 50	$ 690,000
SU19	15.9	$ 50	$ 795,000
SU20	19.5	$ 50	$ 975,000
SU21	146.8	$ 50	$ 7,340,000
SU22	59.8	$ 50	$ 2,990,000
SU23	253.6	$ 50	$ 12,680,000
SU24	88.3	$ 50	$ 4,415,000
		Subtotal:	**$ 90,750,000**
		50% Eng/Contingency	**$ 45,375,000**
		Total:	**$ 136,125,000**

Part 2: Storm Trunks

	Length (linear or vertical m)	All Inslusive Unit Cost ($/m)	Cost ($)
East Tributary Diversion (1.8 m x 1.2 m box)	3240	$ 5,000	$ 16,200,000
Manholes	40.5	$ 12,000	$ 486,000
New Stormwater Outfal			$ 2,000,000
		Subtotal:	**$ 18,686,000**
		50% Eng/Contingency	**$ 9,343,000**
		Total:	**$ 28,029,000**

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimate

Option 2A
East Tributary and Highway 2 Ditch Diversion to Sturgeon Rive
UARR = 1.8 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Uni Cost ($/$m^3$)	Cost ($)
SU2	42.3	$ 50	$ 2,115,000
SU3	43.8	$ 50	$ 2,190,000
SU4	30.1	$ 50	$ 1,505,000
SU5	70.8	$ 50	$ 3,540,000
SU6	38.5	$ 50	$ 1,925,000
SU7	71.1	$ 50	$ 3,555,000
SU8	72.7	$ 50	$ 3,635,000
SU9	57	$ 50	$ 2,850,000
SU10	227.6	$ 50	$ 11,380,000
SU11	318.7	$ 50	$ 15,935,000
SU12	12.5	$ 50	$ 625,000
SU13	148.7	$ 50	$ 7,435,000
SU14	67	$ 50	$ 3,350,000
SU15	86.9	$ 50	$ 4,345,000
SU16	166.8	$ 50	$ 8,340,000
SU17	17.8	$ 50	$ 890,000
SU18	16.9	$ 50	$ 845,000
SU19	19.5	$ 50	$ 975,000
SU20	23.6	$ 50	$ 1,180,000
SU21	178	$ 50	$ 8,900,000
SU22	72.4	$ 50	$ 3,620,000
SU23	306.6	$ 50	$ 15,330,000
SU24	107.3	$ 50	$ 5,365,000
		Subtotal:	**$ 109,830,000**
		50% Eng/Contingency	**$ 54,915,000**
		Total:	**$ 164,745,000**

Part 2: Storm Trunks

	Length (linear or vertical m)	All Inslusive Uni Cost ($/m)	Cost ($)
East Tributary/Hwy 2 Ditch Diversion (2.4 m x 1.8 m box)	3820	$ 7,000	$ 26,740,000
Manholes	47.75	$ 12,000	$ 573,000
New Stormwater Outfal			$ 3,000,000
		Subtotal:	**$ 30,313,000**
		50% Eng/Contingency	**$ 15,156,500**
		Total:	**$ 45,469,500**

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimate

Option 2B
East Tributary and Highway 2 Ditch Diversion to Sturgeon Rive
UARR = 2.5 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Uni Cost ($/$m^3$)	Cost ($)
SU2	40.2	$ 50	$ 2,010,000
SU3	41.7	$ 50	$ 2,085,000
SU4	28.6	$ 50	$ 1,430,000
SU5	67.4	$ 50	$ 3,370,000
SU6	36.6	$ 50	$ 1,830,000
SU7	67.3	$ 50	$ 3,365,000
SU8	69.1	$ 50	$ 3,455,000
SU9	54.3	$ 50	$ 2,715,000
SU10	217.5	$ 50	$ 10,875,000
SU11	305.5	$ 50	$ 15,275,000
SU12	11.9	$ 50	$ 595,000
SU13	142.4	$ 50	$ 7,120,000
SU14	63.7	$ 50	$ 3,185,000
SU15	82.5	$ 50	$ 4,125,000
SU16	158.4	$ 50	$ 7,920,000
SU17	16.9	$ 50	$ 845,000
SU18	16	$ 50	$ 800,000
SU19	18.5	$ 50	$ 925,000
SU20	22.5	$ 50	$ 1,125,000
SU21	169.8	$ 50	$ 8,490,000
SU22	69.2	$ 50	$ 3,460,000
SU23	292.4	$ 50	$ 14,620,000
SU24	102.4	$ 50	$ 5,120,000
		Subtotal:	**$ 104,740,000**
		50% Eng/Contingency	**$ 52,370,000**
		Total:	**$ 157,110,000**

Part 2: Storm Trunks

	Length (linear or vertical m)	All Inslusive Uni Cost ($/m)	Cost ($)
East Tributary/Hwy 2 Ditch Diversion (2.4 m x 1.8 m box)	3820	$ 7,000	$ 26,740,000
Manholes	47.75	$ 12,000	$ 573,000
New Stormwater Outfal			$ 3,000,000
		Subtotal:	**$ 30,313,000**
		50% Eng/Contingency	**$ 15,156,500**
		Total:	**$ 45,469,500**

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimate

Option 2C
East Tributary and Highway 2 Ditch Diversion to Sturgeon Rive
UARR = 5 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Uni Cost ($/$m^3$)	Cost ($)
SU2	34.8	$ 50	$ 1,740,000
SU3	36	$ 50	$ 1,800,000
SU4	24.7	$ 50	$ 1,235,000
SU5	58.2	$ 50	$ 2,910,000
SU6	31.6	$ 50	$ 1,580,000
SU7	58.8	$ 50	$ 2,940,000
SU8	59.9	$ 50	$ 2,995,000
SU9	47	$ 50	$ 2,350,000
SU10	188.8	$ 50	$ 9,440,000
SU11	264.9	$ 50	$ 13,245,000
SU12	10.2	$ 50	$ 510,000
SU13	123.2	$ 50	$ 6,160,000
SU14	55.3	$ 50	$ 2,765,000
SU15	71.5	$ 50	$ 3,575,000
SU16	137.9	$ 50	$ 6,895,000
SU17	14.5	$ 50	$ 725,000
SU18	13.8	$ 50	$ 690,000
SU19	15.9	$ 50	$ 795,000
SU20	19.5	$ 50	$ 975,000
SU21	146.8	$ 50	$ 7,340,000
SU22	59.8	$ 50	$ 2,990,000
SU23	253.6	$ 50	$ 12,680,000
SU24	88.3	$ 50	$ 4,415,000
		Subtotal:	**$ 90,750,000**
		50% Eng/Contingency	**$ 45,375,000**
		Total:	**$ 136,125,000**

Part 2: Storm Trunks

	Length (linear or vertical m)	All Inslusive Uni Cost ($/m)	Cost ($)
East Tributary/Hwy 2 Ditch Diversion (2.4 m x 1.8 m box)	3820	$ 7,000	$ 26,740,000
Manholes	47.75	$ 12,000	$ 573,000
New Stormwater Outfal			$ 3,000,000
		Subtotal:	**$ 30,313,000**
		50% Eng/Contingency	**$ 15,156,500**
		Total:	**$ 45,469,500**

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimate

Option 3A
East Tributary continues to Carrot Creek via ditch through North Erin Ridge
UARR = 1.8 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	42.3	$ 50	$ 2,115,000
SU3	43.8	$ 50	$ 2,190,000
SU4	30.1	$ 50	$ 1,505,000
SU5	70.8	$ 50	$ 3,540,000
SU6	38.5	$ 50	$ 1,925,000
SU7	71.1	$ 50	$ 3,555,000
SU8	72.7	$ 50	$ 3,635,000
SU9	57	$ 50	$ 2,850,000
SU10	227.6	$ 50	$ 11,380,000
SU11	318.7	$ 50	$ 15,935,000
SU12	12.5	$ 50	$ 625,000
SU13	148.7	$ 50	$ 7,435,000
SU14	67	$ 50	$ 3,350,000
SU15	86.9	$ 50	$ 4,345,000
SU16	166.8	$ 50	$ 8,340,000
SU17	17.8	$ 50	$ 890,000
SU18	16.9	$ 50	$ 845,000
SU19	19.5	$ 50	$ 975,000
SU20	23.6	$ 50	$ 1,180,000
SU21	178	$ 50	$ 8,900,000
SU22	72.4	$ 50	$ 3,620,000
SU23	306.6	$ 50	$ 15,330,000
SU24	107.3	$ 50	$ 5,365,000
		Subtotal:	**$ 109,830,000**
		50% Eng/Contingency:	**$ 54,915,000**
		Total:	**$ 164,745,000**

Part 2: Storm Trunks Not required

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
Additional Erosion Allowance for higher peak flows				$ 3,000,000
			Subtotal:	**$ 5,360,000**
			50% Eng/Contingency:	**$ 2,680,000**
			Total:	**$ 8,040,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimated

Option 3B
East Tributary continues to Carrot Creek via ditch through North Erin Ridge
UARR = 2.5 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	40.2	$ 50	$ 2,010,000
SU3	41.7	$ 50	$ 2,085,000
SU4	28.6	$ 50	$ 1,430,000
SU5	67.4	$ 50	$ 3,370,000
SU6	36.6	$ 50	$ 1,830,000
SU7	67.3	$ 50	$ 3,365,000
SU8	69.1	$ 50	$ 3,455,000
SU9	54.3	$ 50	$ 2,715,000
SU10	217.5	$ 50	$ 10,875,000
SU11	305.5	$ 50	$ 15,275,000
SU12	11.9	$ 50	$ 595,000
SU13	142.4	$ 50	$ 7,120,000
SU14	63.7	$ 50	$ 3,185,000
SU15	82.5	$ 50	$ 4,125,000
SU16	158.4	$ 50	$ 7,920,000
SU17	16.9	$ 50	$ 845,000
SU18	16	$ 50	$ 800,000
SU19	18.5	$ 50	$ 925,000
SU20	22.5	$ 50	$ 1,125,000
SU21	169.8	$ 50	$ 8,490,000
SU22	69.2	$ 50	$ 3,460,000
SU23	292.4	$ 50	$ 14,620,000
SU24	102.4	$ 50	$ 5,120,000
		Subtotal:	**$ 104,740,000**
		50% Eng/Contingency:	**$ 52,370,000**
		Total:	**$ 157,110,000**

Part 2: Storm Trunks Not required

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
Additional Erosion Allowance for higher peak flows				$ 3,000,000
			Subtotal:	**$ 5,360,000**
			50% Eng/Contingency:	**$ 2,680,000**
			Total:	**$ 8,040,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimated

Option 3C
East Tributary continues to Carrot Creek via ditch through North Erin Ridge
UARR = 5 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	34.8	$ 50	$ 1,740,000
SU3	36	$ 50	$ 1,800,000
SU4	24.7	$ 50	$ 1,235,000
SU5	58.2	$ 50	$ 2,910,000
SU6	31.6	$ 50	$ 1,580,000
SU7	58.8	$ 50	$ 2,940,000
SU8	59.9	$ 50	$ 2,995,000
SU9	47	$ 50	$ 2,350,000
SU10	188.8	$ 50	$ 9,440,000
SU11	264.9	$ 50	$ 13,245,000
SU12	10.2	$ 50	$ 510,000
SU13	123.2	$ 50	$ 6,160,000
SU14	55.3	$ 50	$ 2,765,000
SU15	71.5	$ 50	$ 3,575,000
SU16	137.9	$ 50	$ 6,895,000
SU17	14.5	$ 50	$ 725,000
SU18	13.8	$ 50	$ 690,000
SU19	15.9	$ 50	$ 795,000
SU20	19.5	$ 50	$ 975,000
SU21	146.8	$ 50	$ 7,340,000
SU22	59.8	$ 50	$ 2,990,000
SU23	253.6	$ 50	$ 12,680,000
SU24	88.3	$ 50	$ 4,415,000
		Subtotal:	**$ 90,750,000**
		50% Eng/Contingency:	**$ 45,375,000**
		Total:	**$ 136,125,000**

Part 2: Storm Trunks Not required

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
Additional Erosion Allowance for higher peak flows				$ 3,000,000
			Subtotal:	**$ 5,360,000**
			50% Eng/Contingency:	**$ 2,680,000**
			Total:	**$ 8,040,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimated

Option 4A
Keep basin intact, provide new storage west of Hwy 2 along East Tributary
UARR = 1.8 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	42.3	$ 50	$ 2,115,000
SU3	43.8	$ 50	$ 2,190,000
SU4	30.1	$ 50	$ 1,505,000
SU5	70.8	$ 50	$ 3,540,000
SU6	38.5	$ 50	$ 1,925,000
SU7	71.1	$ 50	$ 3,555,000
SU8	72.7	$ 50	$ 3,635,000
SU9	57	$ 50	$ 2,850,000
SU10	227.6	$ 50	$ 11,380,000
SU11	318.7	$ 50	$ 15,935,000
SU12	12.5	$ 50	$ 625,000
SU13	148.7	$ 50	$ 7,435,000
SU14	67	$ 50	$ 3,350,000
SU15	86.9	$ 50	$ 4,345,000
SU16	166.8	$ 50	$ 8,340,000
SU17	17.8	$ 50	$ 890,000
SU18	16.9	$ 50	$ 845,000
SU19	19.5	$ 50	$ 975,000
SU20	23.6	$ 50	$ 1,180,000
SU21	178	$ 50	$ 8,900,000
SU22	72.4	$ 50	$ 3,620,000
SU23	306.6	$ 50	$ 15,330,000
SU24	107.3	$ 50	$ 5,365,000
Replacement Storage West of Hwy 2	60.5	$ 50	$ 3,025,000
		Subtotal:	**$ 112,855,000**
		50% Eng/Contingency:	**$ 56,427,500**
		Total:	**$ 169,282,500**

Part 2: Storm Trunks - Not Required

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency:	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimated

Option 4B
Keep basin intact, provide new storage west of Hwy 2 along East Tributary
UARR = 2.5 L/s/ha

Part 1: Stormwater Management Facilities

SWMF ID	Volume (1000 m^3)	All Inslusive Unit Cost ($/$m^3$)	Cost ($)
SU2	40.2	$ 50	$ 2,010,000
SU3	41.7	$ 50	$ 2,085,000
SU4	28.6	$ 50	$ 1,430,000
SU5	67.4	$ 50	$ 3,370,000
SU6	36.6	$ 50	$ 1,830,000
SU7	67.3	$ 50	$ 3,365,000
SU8	69.1	$ 50	$ 3,455,000
SU9	54.3	$ 50	$ 2,715,000
SU10	217.5	$ 50	$ 10,875,000
SU11	305.5	$ 50	$ 15,275,000
SU12	11.9	$ 50	$ 595,000
SU13	142.4	$ 50	$ 7,120,000
SU14	63.7	$ 50	$ 3,185,000
SU15	82.5	$ 50	$ 4,125,000
SU16	158.4	$ 50	$ 7,920,000
SU17	16.9	$ 50	$ 845,000
SU18	16	$ 50	$ 800,000
SU19	18.5	$ 50	$ 925,000
SU20	22.5	$ 50	$ 1,125,000
SU21	169.8	$ 50	$ 8,490,000
SU22	69.2	$ 50	$ 3,460,000
SU23	292.4	$ 50	$ 14,620,000
SU24	102.4	$ 50	$ 5,120,000
Replacement Storage West of Hwy 2	60.5	$ 50	$ 3,025,000
		Subtotal:	**$ 107,765,000**
		50% Eng/Contingency:	**$ 53,882,500**
		Total:	**$ 161,647,500**

Part 2: Storm Trunks - Not Required

Part 3: Creek Erosion Protection and Culvert Upgrades

	Units	Quantity	Unit Cost	Cost
CN Rail Crossing - New Culvert	Linear Metre	20	$ 8,000	$ 160,000
CN Rail Crossing - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Meadowview Drive Bridge - Erosion Protection	Square Metre	1600	$ 500	$ 800,000
Near Range Road 260 - Erosion Protection	Square Metre	500	$ 500	$ 250,000
Highway 2 Crossing - Erosion Protection Upstream of Culvert	Square Metre	300	$ 500	$ 150,000
Old McKenney Avenue - Erosion Protection	Square Metre	400	$ 500	$ 200,000
			Subtotal:	**$ 2,360,000**
			50% Eng/Contingency:	**$ 1,180,000**
			Total:	**$ 3,540,000**

Part 4: Erosion Monitoring at Geomorphic Areas of Concern: $25,000 per year estimated