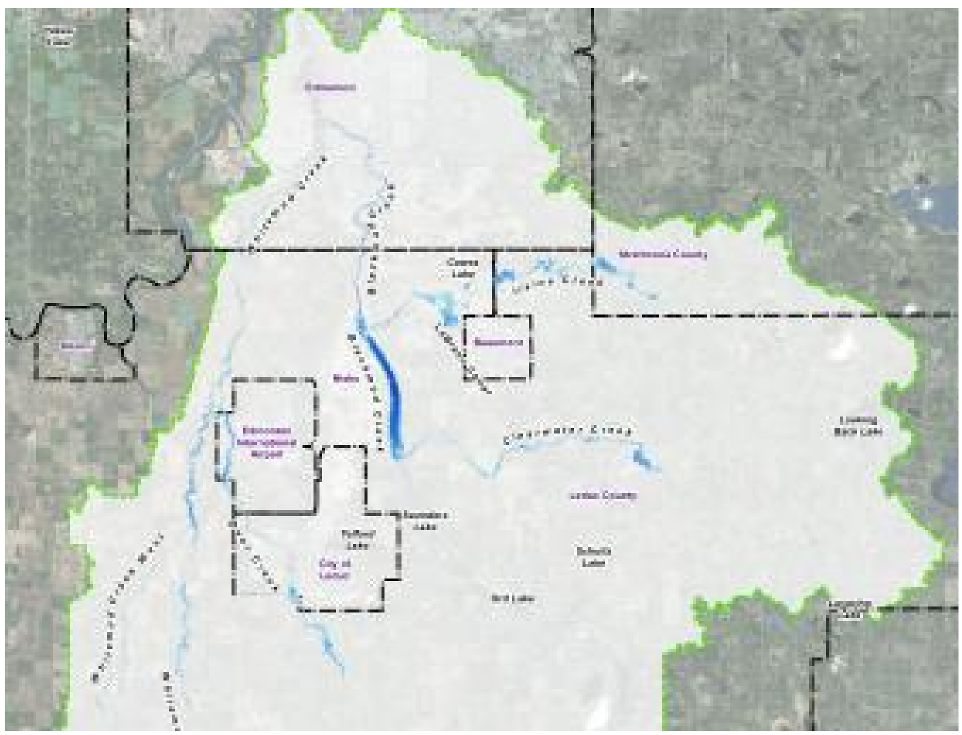
Associated Engineering

GLOBAL PERSPECTIVE.
LOCAL FOCUS.

TECHNICAL MEMORANDUM NO. 4

Blackmud/Whitemud Creek
Surface Water Management Group

Blackmud/Whitemud Creek
Surface Water Management Study
Hydrologic and Hydraulic Modelling



January 2017

Executive Summary

The Blackmud/Whitemud Surface Water Management Group retained Associated Engineering (AE) to complete a Surface Water Management Study. This study involves hydrologic, hydraulic, hydrogeologic and environmental analyses of the Blackmud and Whitemud Creek basins.

This technical memo summarizes the development of the Blackmud/Whitemud basin model and the evaluation of existing hydraulic conditions and constraints. The purpose of the basin model was to estimate flows, water levels, and velocities at various locations throughout the basin for the existing conditions of development. The results of the model developed will form a basis to be used in simulating the potential impacts of further development in the basin. These will also be used to develop a surface water management strategy to minimize and mitigate those impacts.

The model development involved the following steps:

1. Cross sections of the creeks were obtained from surveyed data, 1m LiDAR resolution, Northwest Hydraulic Consultant's (NHC's) HEC-RAS model of Blackmud Creek, and Stantec's MIKE 11 model of Irvine Creek (TM 3). These were used to build the model.
2. A 1D model was developed to simulate water levels and flows in all the creeks.
3. A 2D model was developed for the lower reaches of the Whitemud and Blackmud Creeks. This was to simulate local hydraulic conditions in more detail and to give a qualitative assessment of erosion potential.
4. Each sub-catchment was divided into one of three categories, namely: developed-controlled, developed-uncontrolled, and undeveloped areas.
5. Boundary conditions (model inflows) were based on the hydrologic analysis provided in TM 3 which accounted for peak flows generated by snowmelt and rainfall events used for the statistical analysis.
6. The model was simulated in a steady state (constant) condition for the design events.

The accuracy of the models developed in this task is affected limited by several assumptions and limitations, principally the following:

- Design flows were estimated from a statistical analysis of limited hydrometric data at three locations (and more recently a fourth location) in the basin having approximately 45 years of data, which was significantly skewed by one single runoff event (1974) and had to be extrapolated to a 1:100 year return period. Furthermore, the historic discharge data have already been impacted by development in the basin and this development impact has increased over the time frame of the monitor data. The design flows presented herein are AE's best estimates based on engineering judgement and the available data.

- Channel cross-sections were developed from LiDAR data, previous studies, and limited channel surveys and may not accurately represent the actual cross-section or the capacity of the smaller channels at low to intermediate flows. This effect of this approximation diminishes at higher flows where a larger portion of the total flow is carried by the floodplain.

- The models are essentially un-calibrated, for lack of data required to do so. Some calibration was previously completed in the Flood Hazard Study which provided guidance for the model parameters adopted herein.

Notwithstanding these limitations, the models are deemed to be adequate for planning purposes and for development of an overall water management strategy for the basin. They are no substitute for more detailed site-specific analyses that will be required during implementation of the strategy. They do provide an assessment of baseline hydraulic conditions against which the potential impacts of future development can be measured.

The models are steady-state based on AE's best estimate of a peak design flow rate for current conditions. The software is capable of fully-dynamic simulation which could be used to simulate flows and water levels using precipitation and weather data from the Edmonton International Airport, to extend the period of recorded flow data, and to better define the interactions between the runoff from urban and rural areas. Ultimately this option is limited by the availability of the required weather data at only one location within a basin of approximately 1,000 km^2 and by the uncertainties involved in rainfall-runoff modelling. In particular, the runoff from snowmelt events in a cold climate, with frozen ground conditions during snowmelt such as occur in Edmonton, is poorly understood and not well simulated with currently available software although some progress has been made in recent years and a practical snowmelt model may soon be available. These limitations provide a severe impediment to improving the estimates that are possible with a steady-state model.

Generally, the project area creeks have capacity for peak flows that will occur in a 1:2 to 1:5 year return period flood. Localized flooding occurs in the 1:100 year event but is mostly confined to the natural creek floodplains except in portions of Irvine Creek, Leblanc Canal, Deer Creek, and the glacial spillway valley of Blackmud Creek in the vicinity of Leduc where extensive overbank flooding will occur. Previous attempts to improve the drainage in these areas has provided capacity for at best the 1:5 year flood.

The majority of the creeks within the basin have complex geometry, are small, lack well defined channels, and have limited channel capacity to convey runoff flows from the existing development. These conditions will constrain future development in the following ways:

- The extent of flooding will constrain development. In some locations along the Blackmud Creek, Irvine Creek, Deer Creek, and Leblanc Canal the flood-risk areas are extensive. The Municipal Government Act empowers municipalities to preserve floodplain areas as Environmental Reserve (land subject to flooding) at the time of development but these powers are not always applied consistently or uniformly. Where extensive overland flooding occurs it is not always practical to sterilize large areas from development, and these locations should be considered as possible sites for stormwater management ponds or wetlands. A policy for protecting floodplains that recognizes the flood risk and the environment values they create should be developed.

- Along with the extensive flooding, some of the creek channels, in the same locations as above, are too shallow to permit drainage of adjacent development using a conventional underground pipe system. Typically, a depth of 4 m from adjacent land areas to channel bottom is required and in many places this does not exist. Alternatives need to be considered such as:

  - a surface drainage system
  - channel deepening and widening to provide the required capacity (a drainage parkway)
  - a trunk storm sewer system to carry outflows from stormwater management facilities to a safe and reliable discharge point
  - Low-Impact Development standards to reduce the volume and peak runoff rates to pre-development levels

- Erosion issues in Whitemud and Blackmud Creek are understood in only a general way and could be aggravated by increasing runoff volumes and flood peak discharges resulting from further development in the basin. There are no reliable models of the erosion process to give quantitative estimates of the erosion rates and the impacts of the changing flow regime that will occur with development, but a qualitative estimate is possible from the model-simulated velocities and shear stresses and morphological principles that relate these hydraulic parameters to the rate of sediment transport.

Existing development in the basin has undoubtedly increased the runoff volume and may have increased peak flows, flood risk, and erosion rates. Some of the older areas were developed before these impacts and the importance of managing stormwater were understood and these older areas discharge directly into the receiving streams without any control. More recent developments have been completed with differing discharge rates in different municipalities and have changed over time for lack of an overall basin water management plan. We have not attempted to quantify these historic impacts but the possibility of further impacts due to anticipated development should be recognized going forward.

Channel velocities in Blackmud and Whitemud Creeks generally increase from upstream to downstream, reflecting the increase in discharge and longitudinal slope, and generally correlate with the bank erosion processes that have been observed. These erosion processes are the results of natural and human influences including previous historic development in the basin since the land was first cleared for agriculture and urban development.

The City of Edmonton has developed and has begun to implement a strategy for erosion control in Whitemud and Blackmud Creek but much work remains to be done. There is significant potential for the existing conditions to worsen if runoff from future development is not adequately managed. Streambank erosion is very sensitive to increases in velocity and flow and could potentially be impacted by development upstream. These potential impacts will be further evaluated in the next phase of this project.

Table of Contents

List of Tables

List of Figures

1 Introduction

The Blackmud/Whitemud Surface Water Management Group (Group) retained Associated Engineering (AE) to complete a Surface Water Management Study. This study involves hydrologic, hydraulic, hydrogeologic and environmental analyses of the Blackmud and Whitemud Creek basins.

A series of Technical Memoranda (TM) was planned to be issued at key stages of the study to document the interim findings. These memoranda were also meant to form the basis for discussions and deliberations with the Group. AE completed development of the Blackmud/Whitemud basin model.

The purpose of the basin model was to estimate flows, water levels, and velocities at various locations throughout the basin for the existing conditions of development. The results of the model developed will form a basis to be used in simulating the potential impacts of further development in the basin. These will also be used to develop a surface water management strategy to minimize and mitigate those impacts.

This technical memo summarizes the development of the Blackmud/Whitemud basin model and the evaluation of existing hydraulic conditions and constraints.

Figure 1-1 provides an outline of the Blackmud/Whitemud basin, the sub-catchments and the major creeks within it, which were all included in the model. The basin encompasses five municipalities, the City of Edmonton, the City of Leduc, Leduc County, the Town of Beaumont and Strathcona County.

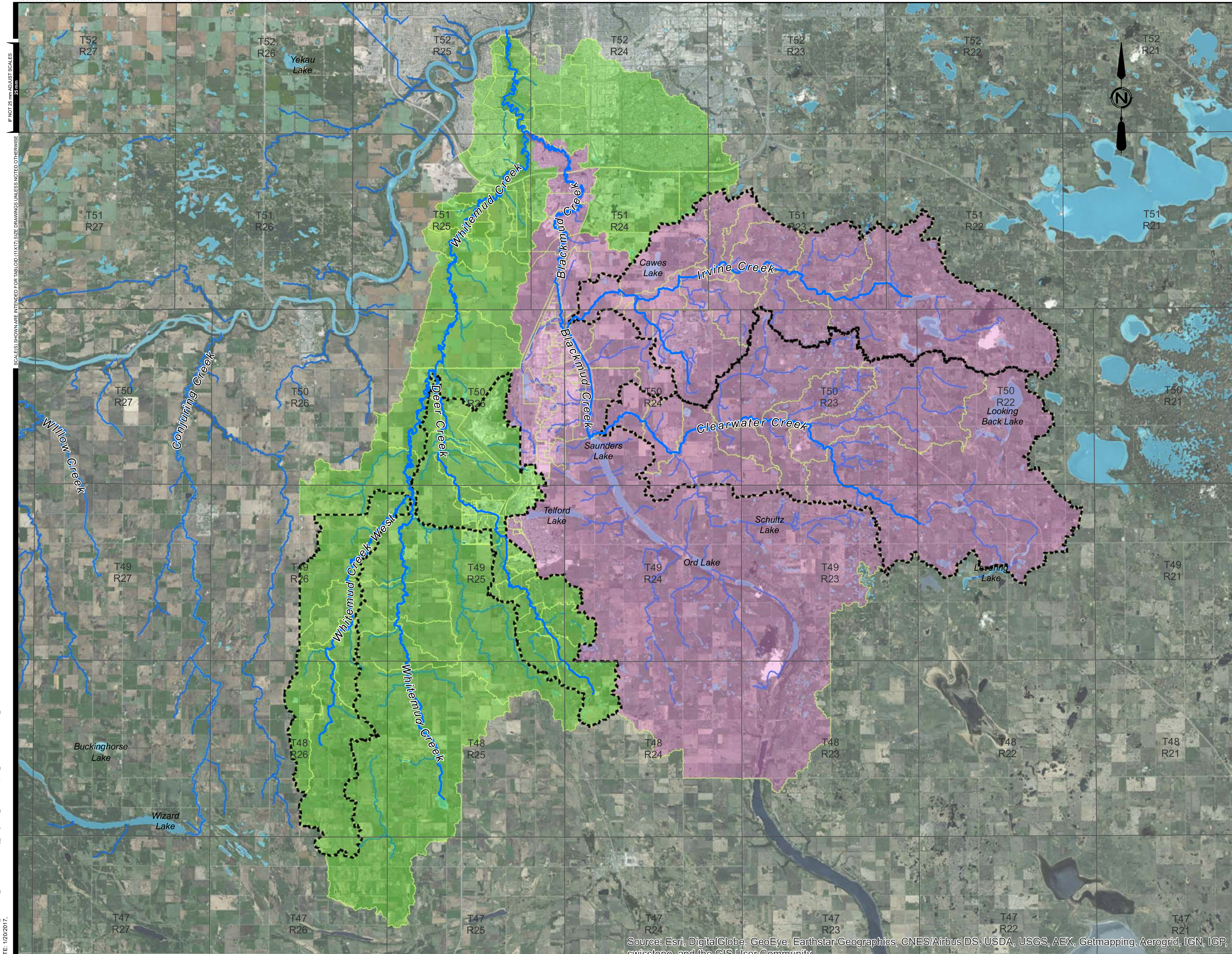
Based on the project scope and objectives, a lumped[1] model was adopted with an intermediate level of detail to simulate the key hydraulic processes in sections within the basin. The model included:

- West Whitemud Creek to Whitemud Creek.
- Whitemud Creek to the North Saskatchewan River.
- Deer Creek to Whitemud Creek.
- Blackmud Creek from the Sauders Lake outlet to Whitemud Creek.
- Clearwater Creek to Blackmud Creek.
- LeBlanc Canal from the Town of Beaumont to Irvine Creek.
- Irvine Creek to Blackmud Creek.
- The developed and undeveloped areas or sub-catchments within the basin that drain into the modelled creeks

Figure 1-2 provides a schematic plan of the basin model and its principal components.

Note that for simplicity not all sub-catchments are shown in **Figure 1-2**.

[1] Lumped model - Parameters not Spatially dependent.



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Legend:

- Whitemud Creek Watershed
- Blackmud Creek Watershed
- Catchment
- Subcatchment
- Creek Centreline

FIGURE No. 1-1

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

CATCHMENT BOUNDARIES

AE PROJECT No.	2016-3785
SCALE	1:200,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

IF NOT 25 mm ADJUST SCALES
25 mm
SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

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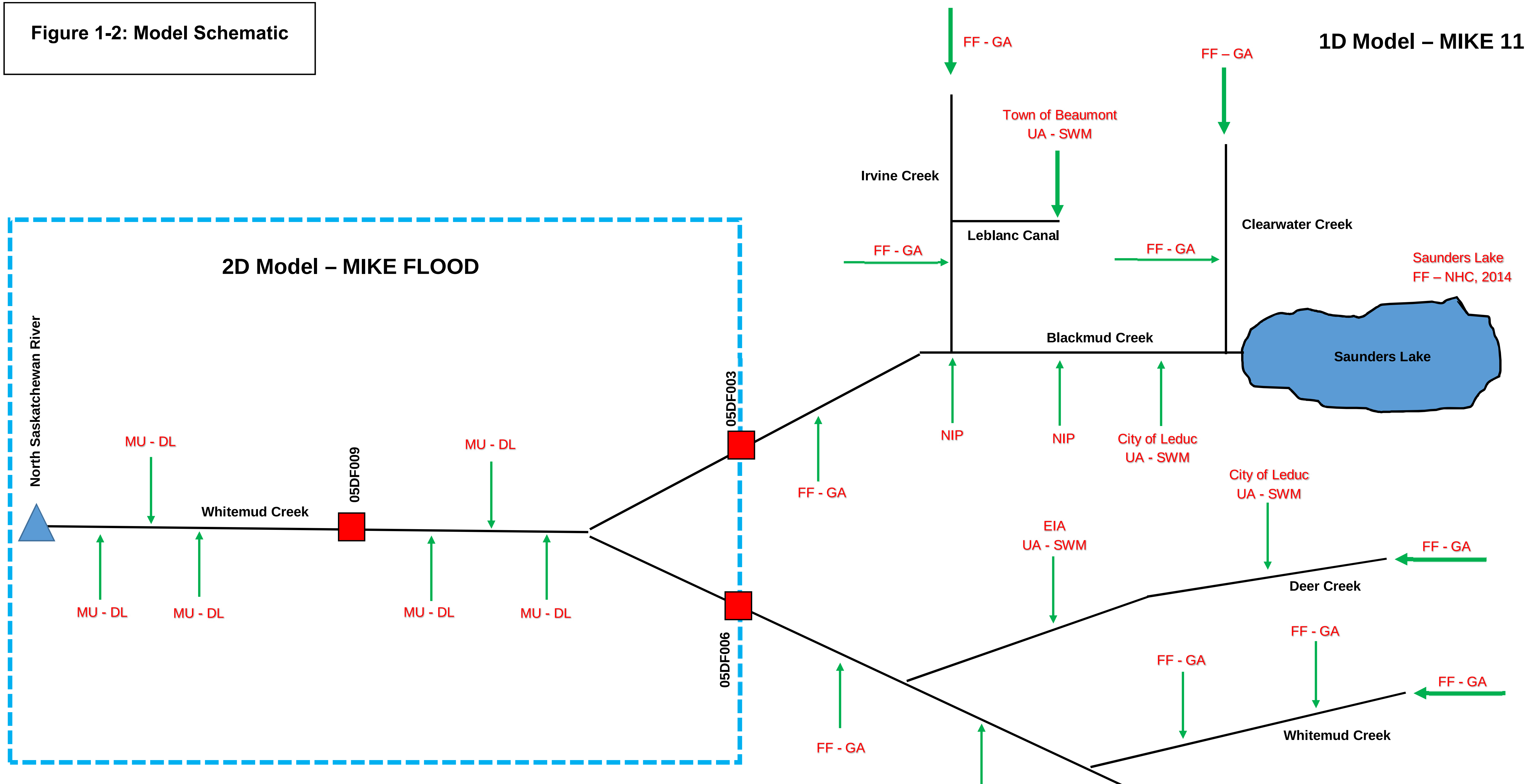
DATE: 1/20/2017,

Figure 1-2: Model Schematic



Model Input:

- Peak flows from development areas within the City of Edmonton
- Models – City Wide Model by Sameng, SW Edmonton Flow Study (Models to be validated)
- Downstream boundary – NS water levels
- Upstream boundary – Flow frequency flows (based on gross area) from the Hydrology Study.
- Peak flows from flow frequency analysis
- Input from the Town of Beaumont – SWM plan PCSWMM model
- Surveyed cross-sections and Lidar data
- Input from Nisku Industrial Park (if available)

Legend:

FF – GA = Flow Frequency Input based on Gross Area
MU – DL = Mike Urban peak flows for Developed Land
NIP = Nisku Industrial Park input (if available)
EIA = Edmonton International Airport
UA – SWM = Urban Area Stormwater Management Release Rate

2 Model Development

2.1 METHODOLOGY FOR MODEL DEVELOPMENT

The following summarizes the methodology used in model development, setting of the boundary conditions, and the assumptions made:

1. Cross sections of the creeks were obtained from surveyed data, 1m LiDAR resolution, Northwest Hydraulic Consultant's (NHC's) HEC-RAS model of Blackmud Creek, and Stantec's MIKE 11 model of Irvine Creek (TM 3). These were used to build the model.
2. A 1D model was developed to simulate water levels and flows in all the creeks.
3. A 2D model was developed for the lower reaches of the Whitemud and Blackmud Creeks as shown in **Figure 1-2**. This was to simulate local hydraulic conditions in more detail and to give a qualitative assessment of erosion potential.
4. Each sub-catchment was divided into one of three categories, namely: developed-controlled, developed-uncontrolled, and undeveloped areas. Sub-catchments are discussed in detail in **Section 2.3.3**.
5. Boundary conditions (model inflows) were based on the hydrologic analysis provided in TM 3 which accounted for peak flows generated by snowmelt and rainfall events used for the statistical analysis. Boundary conditions are discussed in detail in **Section 2.3.3**.
6. The model was simulated in a steady state[2] (constant) condition for the design events.

As described above a lumped and steady state approach was adopted for the hydrologic and hydraulic modelling phase of the study. This approach required a number of simplifying assumptions compared to a long-term simulation based on a fully dynamic modelling approach. As part of the hydrologic and hydraulic model development, AE developed a pilot model to define the key hydrologic processes, to explore the feasibility of a fully dynamic model, and to try to estimate how conservative the steady-state model would be. **Appendix A** summarizes the pilot model development and simulation results.

2.2 MODEL SOFTWARE

Flood depths, flood extents, velocities, and shear stresses were estimated using the commercially available MIKE software-modeling package developed and marketed by Danish Hydraulic Institute (DHI). This software is widely used and contains one dimensional (1D), two dimensional (2D) and three dimensional (3D) modules for urban and rural environments. The MIKE11 – 1D and MIKE21 FM – 2D modules were used for this study as shown in **Figure 1-2**.

MIKE11 is a 1D model developed with a variety of basic modules each simulating a particular phenomenon in a river system. The hydrodynamic module uses an implicit finite difference scheme to solve the non-linear equations of open channel flow. It can be run in a fully dynamic mode that accounts for backwater effects, or in a kinematic mode that simulates the principal routing processes but cannot simulate backwater

[2] Steady State - Depth of flow does not change with time.

effects or highly dynamic conditions. This study used the fully dynamic mode to simulate steady-state flows and water levels.

Similar to MIKE11, MIKE21FM is a 2D model with a variety of basic modules each simulating a particular phenomenon in a river system. However, the hydrodynamic module in MIIKE21FM is based on solving the 2D shallow water equations, the depth-integrated incompressible Reynolds averaged Navier-Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity and density equations. The creek and floodplain are represented by a flexible and quadrangular mesh and the equations are solved from cell to cell to simulate flow, water level, velocity, and other optional parameters in each cell. It provides more detailed output than the 1D MIKE11 model but is considerably more detailed and requires much longer run times.

2.3 1D - MODEL

2.3.1 Model Network

Figure 2-1 illustrates the 1D model network developed for this study. The model network and extent consist of the following:

- Whitemud Creek - 83 km.
- West Whitemud Creek - 22 km.
- Deer Creek - 27 km.
- Blackmud Creek - 34 km.
- Clearwater Creek - 29 km.
- Irvine Creek - 20 km.
- LeBlanc Canal - 2 km.

2.3.2 Cross-sections

The model required cross-sections of the creeks in order to simulate the flood depths, flood extents, and velocities. A total of 478 cross-sections were used in the 1D model averaging approximately one cross-section for every 500 m. **Figure 2-1** and **2-2** show the approximate locations from which cross sections were taken.

In generating the cross-sections for the model, a combination of surveyed data, 1m resolution LiDAR, and existing cross-section data from previous studies was used as follows:

- Cross-sections for Blackmud Creek and Irvine Creek downstream of Beaumont were extracted from previous studies. The Nisku Flood Hazard Study (NHC, 2014) provided cross-sections for Blackmud Creek, which were originally derived from channel surveys extended across the floodplains using LiDAR data. The Irvine Creek cross-sections were obtained from the Irvine Creek and Cawes Lake Watershed Study (Stantec, 2014) which was based on LiDAR data.

- AE used 1m resolution LiDAR data to generate cross-sections along Whitemud Creek, West Whitemud Creek, Deer Creek, LeBlanc Canal, and Irvine Creek upstream of Beaumont.

- Seventy-two cross-sections were surveyed for this study: 29 along Whitemud Creek, 36 along West Whitemud Creek, and 7 along Blackmud Creek. **Figure 2-2** shows the approximate locations and sources of the cross-sections. The surveyed channel cross-sections were extended using LiDAR data across the floodplains. The surveyed channel inverts were used to estimate the channel bottom elevations for the intervening LiDAR cross-sections, where the LiDAR data represents the water surface which obscures the channel bottom. LiDAR cross-sections along Whitemud Creek within the City of Edmonton were modified based on channel bottom elevations taken from the Blackmud and Whitemud Creek Erosion Study (AMEC, 2006).

Table 2-1 shows typical cross-sections that were used in developing the model. In addition, **Photos 2-1** to **2-17** provide typical views of the creeks and floodplains within the basin during low and high flows.

The Whitemud Creek and Blackmud Creek cross-sections were divided into three zones as follows:

- the channel
- the right floodplain
- the left floodplain

A roughness coefficient (Manning's n) of 0.035 was used for the two creek channels. A roughness coefficient of 0.10 was used for the floodplain in the lower reach of Blackmud Creek and 0.050 in the upper reaches of Blackmud Creek and in Whitemud Creek per NHC's floodplain study.

The channel topography for all creeks, except in the Whitemud and Blackmud Creeks, is poorly-defined and therefore a single-zone definition with an n-value of 0.050 was used.

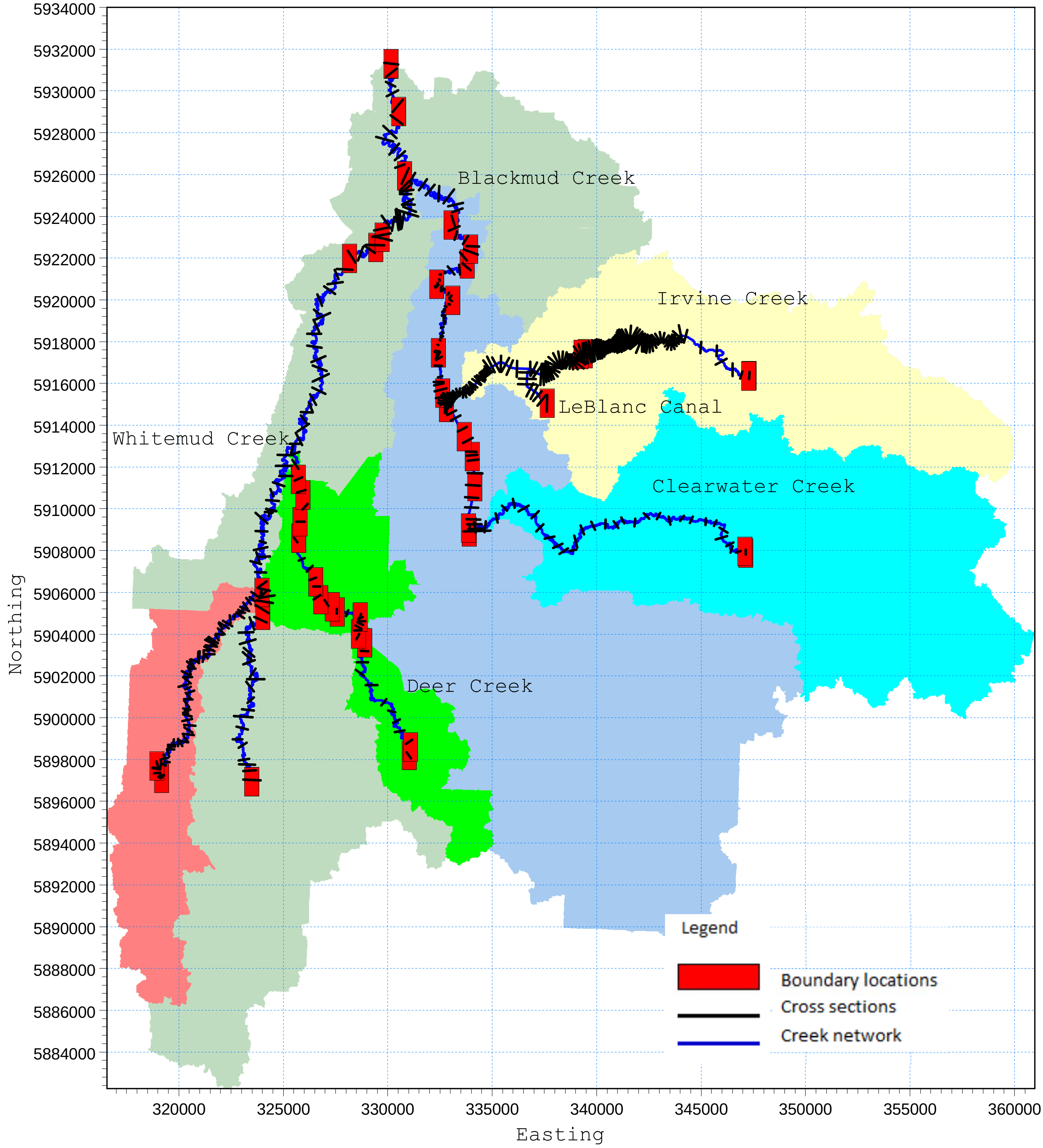
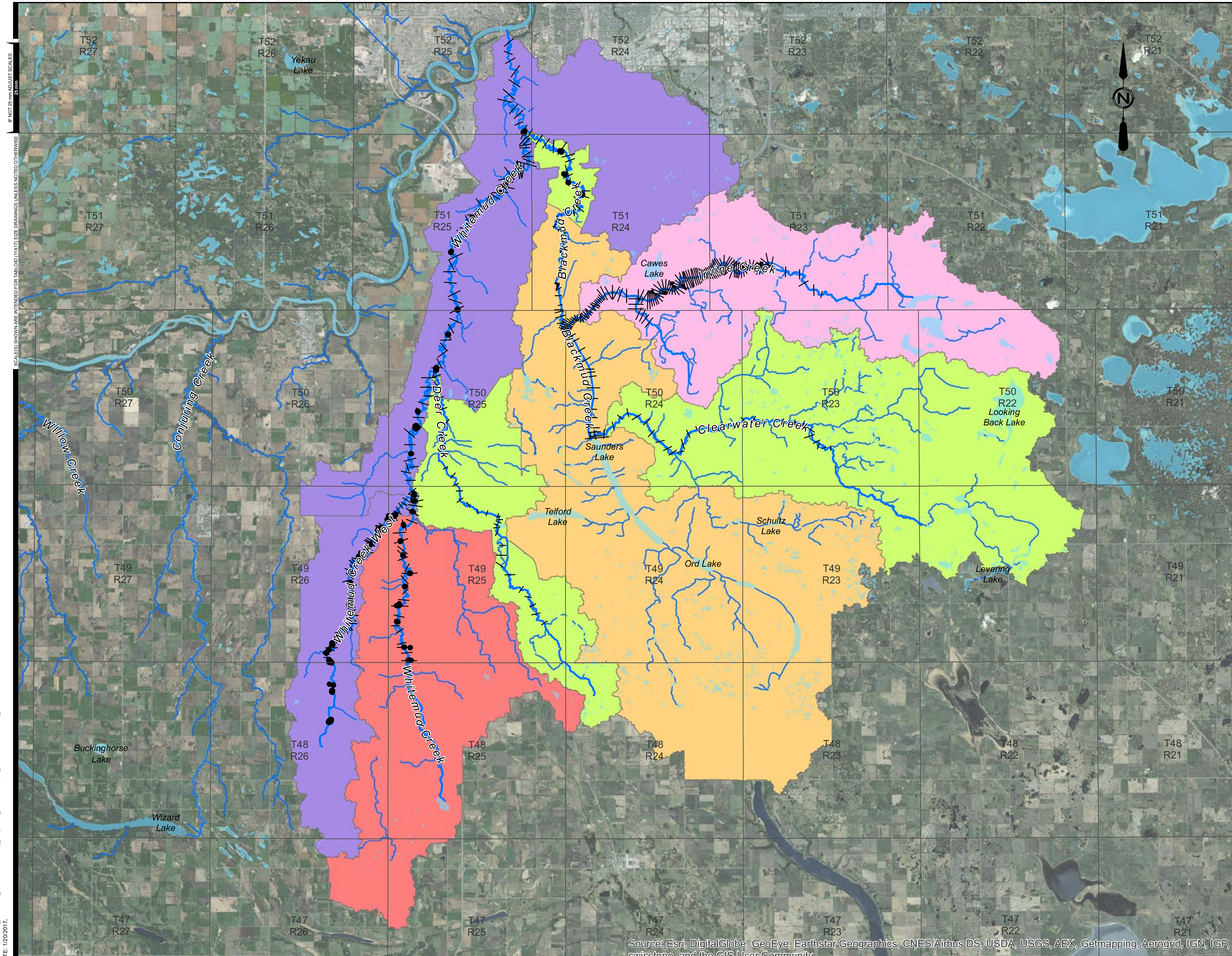


Figure 2-1: 1D Model Network



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Legend:

- Survey Points

Watershed Data Source

- LiDAR & Surveyed
- Surveyed
- LiDAR
- NHC
- STANTEC
- Cross Section
- Creek Centreline

FIGURE No. 2-2

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

DATA SOURCES

AE PROJECT No.	2016-3785
SCALE	1:200,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

IF NOT 25 mm ADJUST SCALES 25 mm

SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

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DATE: 1/20/2017,

Table 2-1: Typical Cross Sections

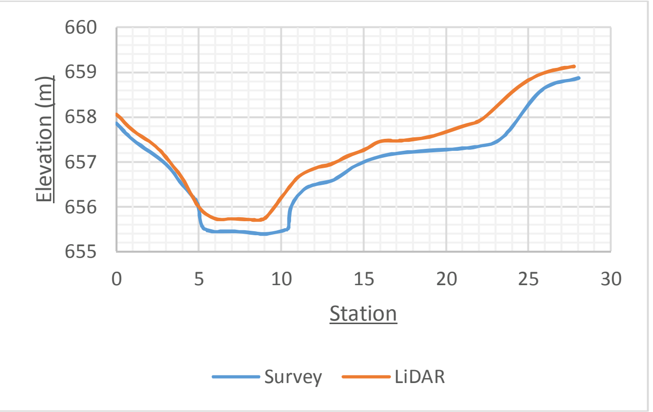
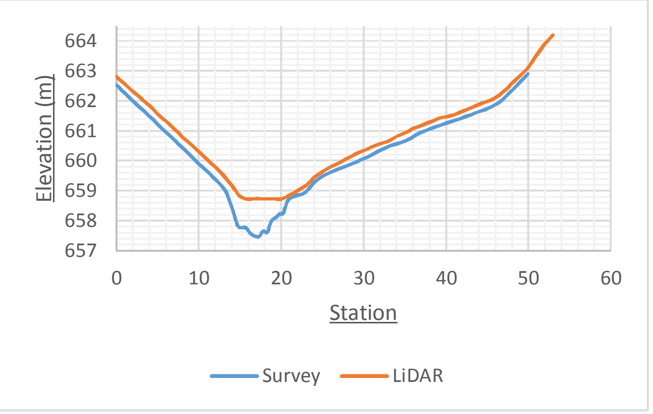
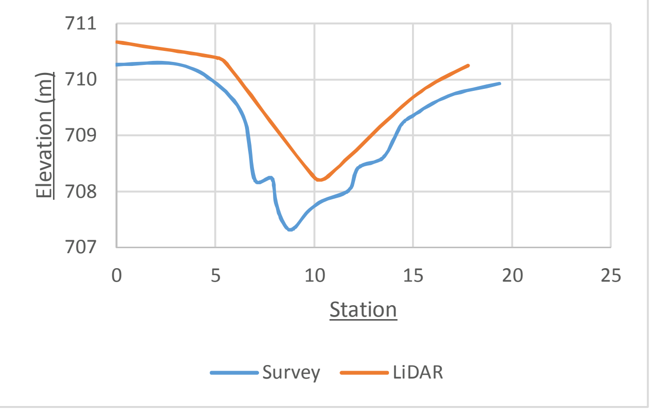
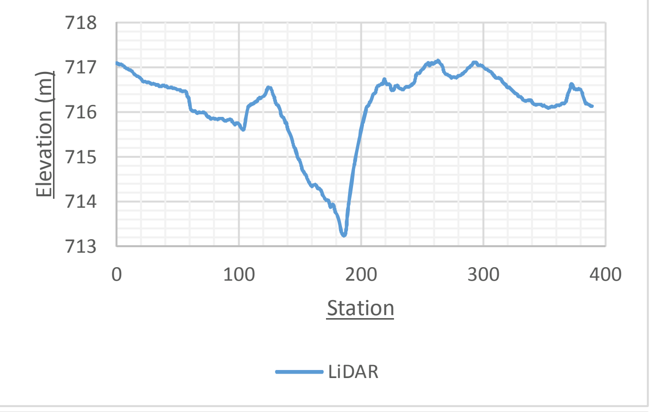
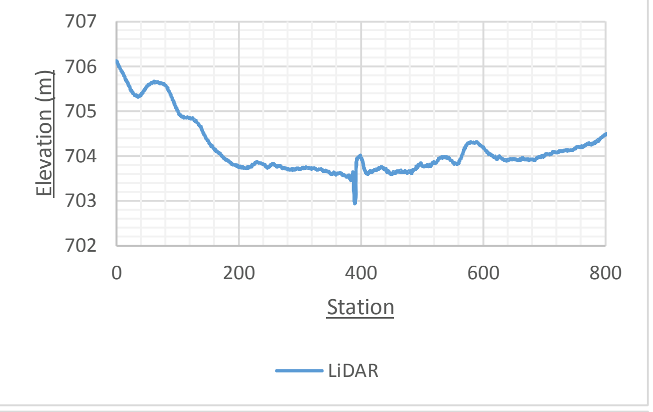
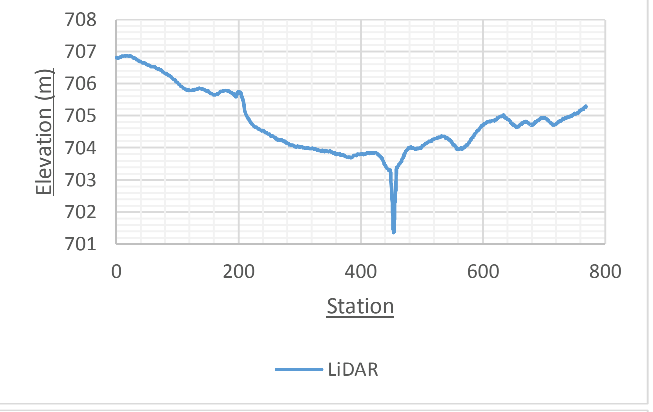
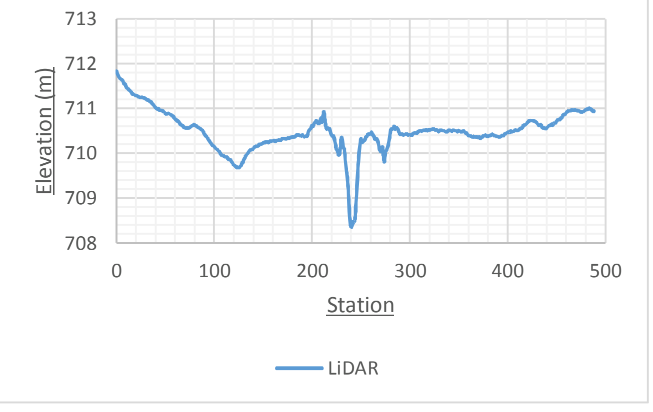
Blackmud Creek	
Whitemud Creek	
West Whitemud Creek	
Deer Creek	
LeBlanc Canal	
Irvine Creek	
Clearwater Creek	

Photo 2-1. Saunders Lake Outlet South of Township Road 502 (2016)

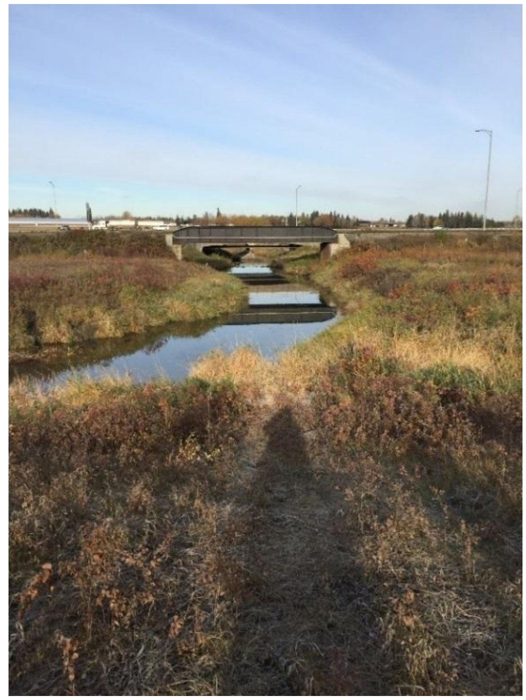


Photo 2-2. Whitemud Creek at Township Road 510 (2016)

Photo 2-3. Blackmud Creek North of Township Road 510 (2016)

Photo 2-4. Deer Creek West of Range Road 254 (2016)

Photo 2-5. Irvine Creek West of Range Road 243 (2016)

Photo 2-6. Clearwater Creek North of Township Road 502 (2016)

Photo 2-7. LeBlanc at Township Road 505 (2016)

Photo 2-8. 300 yd East of Clearwater Creek (2013)

Photo 2-9. Floodplain at Highway 625 (2013)

Photo 2-10. At Highway 625 Looking South (2013)

Photo 2-11. Floodplain at Highway 625 (2013)

Photo 2-12. Blackmud Creek at Airport Road Bridge (2013)

Photo 2-13. At Highway 625 Looking South (2005)

Photo 2-14. At Highway 625 Looking South (2005)

Photo 2-15. At Highway 625 Looking North (2005)

Photo 2-16. At Highway 625 Looking North (2005)

Photo 2-17. At Highway 625 Looking North (2005)

2.3.3 Boundary Conditions

The hydrodynamic module in MIKE11-1D model requires that boundary conditions be specified upstream and downstream of the model extent. In developing this model the upstream boundary represented inflow into the creek system from rural areas. The downstream boundary represented the water level at the North Saskatchewan River. In addition, inflow boundaries were applied along the creeks to represent runoff from different sub-catchments and were specified as point inflows or distributed along some sections of the channels.

A total of 70 inflow boundaries were defined and applied within the 1D model. Design flow rates for the 1:2, 1:5, and 1:100 year return periods were estimated at the various inflow boundaries, based on the results of the hydrology study presented in TM 3 Basin Hydrology. Table 2-2 summarizes the existing design flows at key locations within the basin.

Table 2-2
Existing Design Flows at Key Locations

*UD – Undeveloped, Duc – Developed Uncontrolled, DC – Developed Controlled

			Unit Flow (L/s/ha)			Design Flow (m^3/s)		
Basin	Type	Area (km2)	2 year	5 year	100 year	2 year	5 year	100 year
Beaumont (to Irvine Creek)	Urban controlled + U/S rural	18	0.38	0.57	3.00	0.68	1.03	5.40
Irvine	Rural	140	0.07	0.26	1.11	0.98	3.64	15.54
Saunders	Rural lake controlled	153	0.13	0.32	1.05	1.93	4.94	16.10
Clearwater	Rural	207	0.07	0.26	1.11	1.45	5.38	22.98
Leduc + Nisku	Urban direct	18.5	2.85	3.75	7.92	5.27	6.94	14.65
	Urban controlled	15.4	0.61	0.91	4.80	0.94	1.40	7.39
Blackmud Local excl Beaumont and Saunders)	Rural	91.1	0.07	0.26	1.11	0.64	2.37	10.11
Total		643				11.9	25.7	92.2
Blackmud WSC Gauge		643				4.6	16.6	71.5
NHC estimate		643				9.4	23.4	78.0
West Whitemud	Rural (UD)	65.4	0.31	0.75	2.88	2.03	4.91	18.84
West Leduc (to Deer Creek)	Urban direct (Duc)	2.75	3.65	4.84	10.10	1.00	1.33	2.78
	Urban controlled (DC)	3.84	0.95	1.43	7.50	0.36	0.55	2.88
	Leduc Reservoir	2.59	0.31	0.75	2.88	0.08	0.19	0.75
EIA (to Deer Creek)	Semi-urban controlled	10.23	0.31	0.75	2.88	0.32	0.77	2.95
Deer Creek	Rural (UD)	55.09	0.31	0.75	2.88	1.71	4.13	15.87
Whitemud	Rural (UD)	190.5	0.31	0.75	2.88	5.91	14.29	54.86
Total at WSC gauge		330.4				11.4	26.2	98.9
Whitemud WSC Gauge		330.4	0.31	0.75	2.88	10.1	24.9	95.0
Lower Basin (WSC gauges to NSR)	Rural	15.18	0.31	0.75	2.88	0.47	1.14	4.37
	Urban Direct D/S of 23 Ave	16.2	2.14	2.81	5.94	3.46	4.56	9.62
	Urban controlled (U/S of 23 Ave)	48.5	0.63	0.95	5.00	3.07	4.61	24.25
Whitemud at NSR		1053.3				30.3	62.2	229.3

2.3.3.1 Sub-catchment Areas

Detailed Geographical Information System (GIS) analysis was conducted to determine drainage patterns and catchment areas towards the boundary points. Catchment areas and detailed contours were generated from the available LIDAR data using Manifold and Global Mapper GIS software. Developed areas were lumped into large sub-catchments based on details of their internal drainage systems (storm sewers, culverts, and stormwater ponds).

Sub-catchments were classified according to their existing land use and stormwater management (SWM) practices as shown in **Figure 2-3** and summarized as follows:

- Urban Controlled - defined as developed areas where runoff is controlled by SWM facilities before discharging into the creek.
- Urban Direct - defined as developed areas where runoff drains directly into the creek without any control with SWM.
- Rural includes all currently undeveloped areas.

2.3.3.2 Urban Direct Runoff

Peak flow rates from developed areas were estimated using a combination of the following:

- Existing PCSWMM and MIKE URBAN modelling results.
- Rational Method.
- SWM release rates specified in existing standards.

A detailed PCSWMM model, provided by the Town of Beaumont and completed as part of the Town's Master Plan, was used to determine inflow rates into the LeBlanc Canal and Irvine Creek. The model setup included the entire length of the LeBlanc Canal up to its confluence with Irvine Creek. This comprised of approximately 28 SWM facilities, the Town of Beaumont storm sewer system and 5 outfalls, as shown in **Figure 2-4** (Model Schematic). The PCSWMM model was run for the 1:2, 1:5 and 1:100-year, 24 hour duration storm events, and flows were extracted immediately upstream of the confluence with Blackmud Creek (Range Road 243).

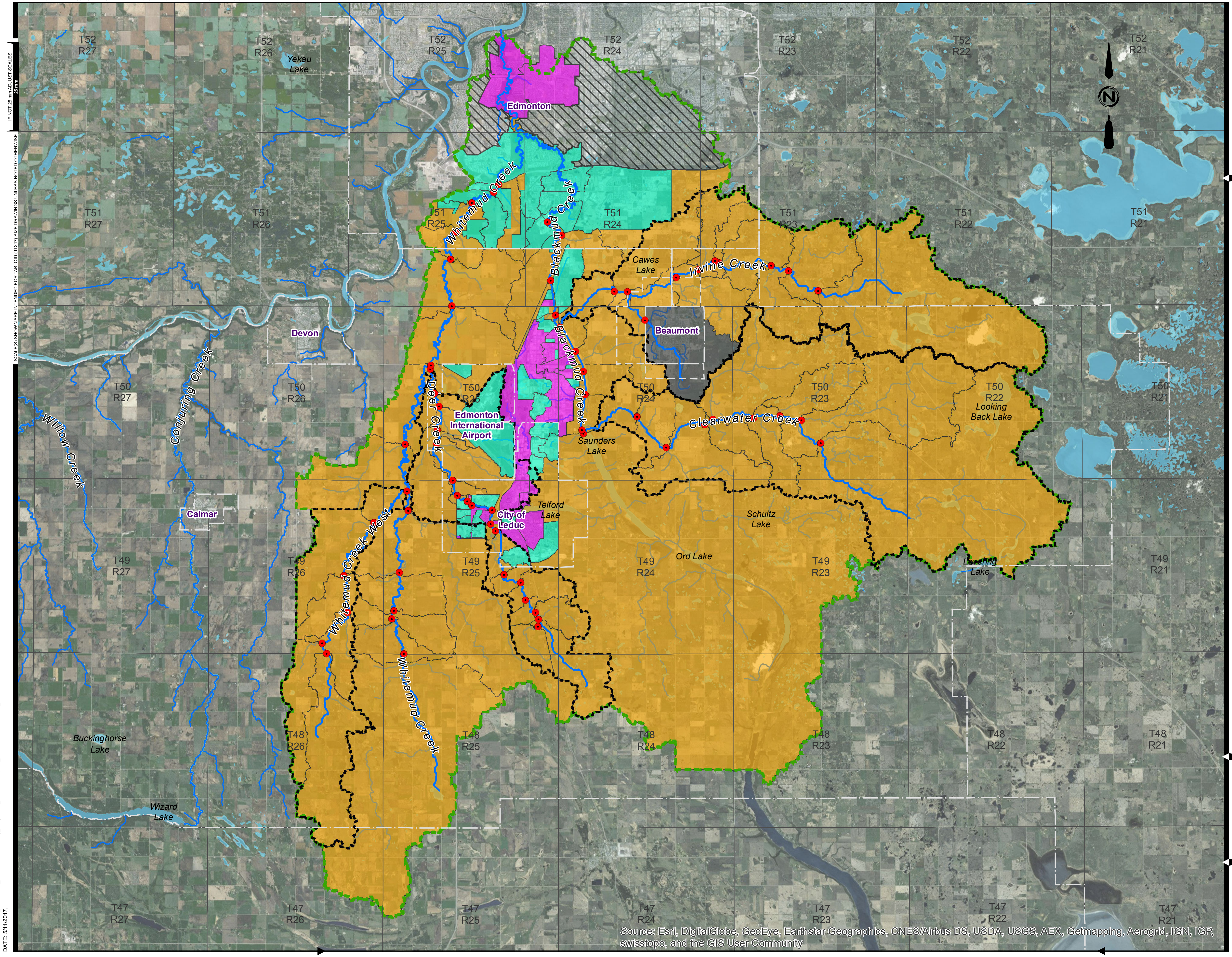
Flows from undeveloped areas downstream of Beaumont were excluded as they were computed separately using the flood frequency analysis and the unit rate flows as noted below.

The City of Edmonton provided a detailed MIKE-URBAN storm drainage model for the entire City of Edmonton which included those portions which lie within the Blackmud/Whitemud basin. This model is too detailed and cumbersome to use for planning purposes and therefore AE estimated the unit flow rates from direct-draining sub-catchments using the Rational Method. The 24-hour duration storm intensities were used to generate daily flows consistent with rest of the basin model.

For developed urban areas where previous models were not available, urban direct flows were estimated for the 1:2, 1:5 and 1:100 year return period 24 hour storms using the Rational Method. These areas include portion of Leduc and Nisku Industrial areas. Land use maps were reviewed and runoff coefficients were assigned to each sub-catchment using the runoff coefficients provided in **Table 2-3**. The Edmonton International Airport (EIA) IDF parameters and a time of concentration equal to 1440 minutes, corresponding to a 24 hour storm duration, were used in the calculation of peak daily flows. For the 1:100 year storm, runoff coefficients were increased by 25% to a maximum of 1.0.

Table 2-3
Urban Area Runoff Coefficients

Land Use	Runoff Coefficient	
	1:2 – 1:5 Year Storm	1:100 Year Storm
Industrial	0.6	0.75
Commercial	0.8	1
Park/Golf Course	0.1	0.125
Residential	0.55	0.6875



Associated Engineering

Legend:
- Mike11 Inflow Boundary Location
- Catchment

Subcatchment Classification
- Urban Controlled
- Urban Direct
- Rural
- Town of Beaumont
- Draining to Trunk
- Creek Centreline
- Municipal Boundary

FIGURE No. 2-3

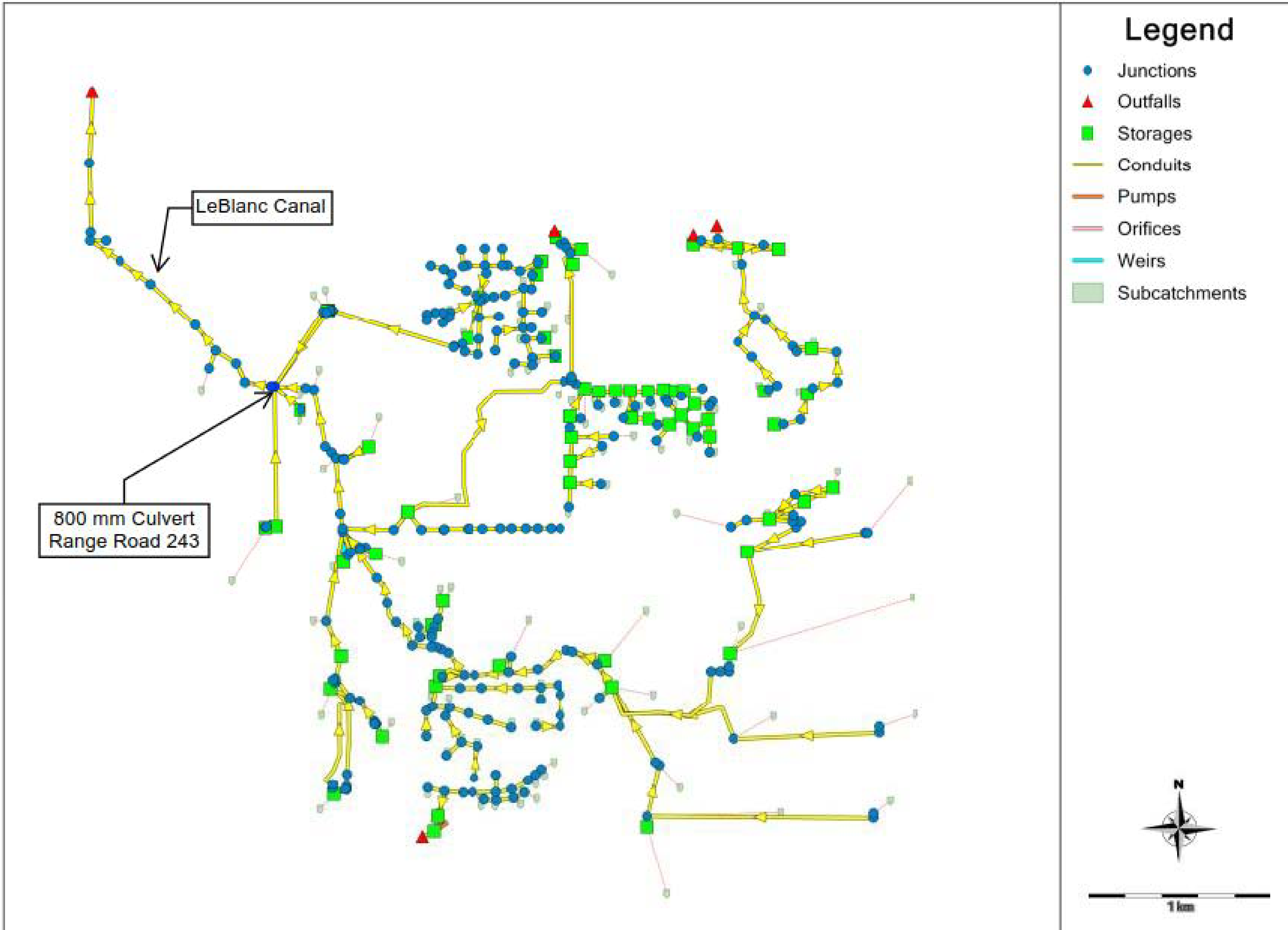
BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

CATCHMENT AREA CLASSIFICATIONS

AE PROJECT No.	2016-3785
SCALE	1:200,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

P:\20163785\00_Blackmud_Whitemud\Working_Dwgs\010_GIS\ArcMap\02_WaterResources\xxx_CatchmentSubcatchmentBoundaries.mxd
DATE: 5/11/2017

Figure 2-4: Town of Beaumont – PCSWMM Model Schematic



2.3.3.3 Urban Controlled Runoff

Flows from urban controlled areas were estimated using the allowable release rate of the existing SWM facilities for the 1:100 year storm. A release rate of 7 L/s/ha was used for controlled areas within the City of Leduc based on the design standards. A release rate of 5 L/s/ha was used for urban controlled areas within the City of Edmonton (upstream of 23rd Avenue) based on the City's current design standards. Peak flows for the 1:2 year and 1:5 year storm event were estimated for the study extent based on the Town of Beaumont PCSWMM model results.

Runoff from the EIA was assumed to be controlled to pre-development rates similar to the Whitemud Creek unit peak flows for the basin. It is understood that the EIA has a defined stormwater management plan which includes a series of SWM facilities that collect and treat runoff before releasing to the creek at pre-development rates. Details of this operation were not available at the time of this analysis.

2.3.3.4 Rural Areas

Peak flows from undeveloped areas were based on the flood frequency analysis of the available data at the Water Survey of Canada (WSC) gauge stations (05DF003, 05DF006). Unit peak flows were calculated from the peak flow estimates and gross drainage areas outlined in the TM 3 Basin Hydrology, after subtracting the contribution from developed urban areas.

Flows from undeveloped areas within the Blackmud Creek, Irvine Creek, and Clearwater Creek were computed using the unit rate estimated from gauge 05DF003 (Blackmud Creek near Ellerslie). Flows from undeveloped areas within Whitemud Creek, Deer Creek, and West Whitemud Creek were calculated based on the unit rate estimated from gauge 05DF006 (Whitemud Creek near Ellerslie).

A major input boundary within the 1D model was located at the upstream of the Blackmud reach to represent the outflow from Saunders Lake. Peak outflows from Saunders Lake for the various return periods were adopted from the 2014 Nisku Flood Hazard Study.

2.3.3.5 Downstream Boundary

The downstream boundary in the model was set as the North Saskatchewan River. The boundary water level was fixed at the water surface elevation in the LiDAR data (617.5 m) and was assumed to represent typical river water levels. This approximation only affects a short reach of Whitemud Creek immediately upstream of the confluence with the river.

2.3.3.6 Design Flows for Existing Conditions

Table 2-4 presents the boundary inflow rates from each of the model sub-catchments. Upstream rural inflows and flows from urban areas were applied as point inflows while other rural sub-catchments were applied as a distributed flow to a reach of channel.

Table 2-4: Existing Design Flows - Model Inputs

				RATE (L/S/HA)			COMPONENT FLOW (L/s)			TOTAL FLOWS FOR MODEL (m3/s)			BOUNDARY INFLOW (m3/s)		
	INFLOW POINT	AREA (HA)	AREA TYPE	2 YEAR	5 YEAR	100 YEAR	2 YEAR	5 YEAR	100 YEAR	2 YEAR	5 YEAR	100 YEAR	2 YEAR	5 YEAR	100 YEAR
WEST WHITEMUD CREEK	P1_WW	2394.57	UD	0.31	0.75	2.88	742.32	1795.93	6896.36	0.74	1.80	6.90	0.74	1.80	6.90
	P2_WW	996.92	UD	0.31	0.75	2.88	309.05	747.69	2871.13	0.31	0.75	2.87	0.31	0.75	2.87
	P3_WW	629.36	UD	0.31	0.75	2.88	195.10	472.02	1812.56	0.20	0.47	1.81	0.20	0.47	1.81
	P4_WW	682.97	UD	0.31	0.75	2.88	211.72	512.23	1966.95	0.21	0.51	1.97	0.21	0.51	1.97
	P5_WW	1476.01	UD	0.31	0.75	2.88	457.56	1107.01	4250.91	0.46	1.11	4.25	0.46	1.11	4.25
DEER CREEK	P1_DC	407.09	UD	0.31	0.75	2.88	126.20	305.32	1172.42	0.13	0.31	1.17	0.13	0.31	1.17
	P2_DC	1037.41	UD	0.31	0.75	2.88	321.60	778.06	2987.74	0.32	0.78	2.99	0.32	0.78	2.99
	P3_DC	476.28	UD	0.31	0.75	2.88	147.65	357.21	1371.69	0.15	0.36	1.37	0.15	0.36	1.37
	P4_DC	156.69	UD	0.31	0.75	2.88	48.57	117.52	451.27	0.05	0.12	0.45	0.05	0.12	0.45
	P5_DC	511	UD	0.31	0.75	2.88	158.41	383.25	1471.68	0.16	0.38	1.47	0.16	0.38	1.47
	P6_DC	209.05	UD	0.31	0.75	2.88	64.81	156.79	602.06	0.06	0.16	0.60	0.06	0.16	0.60
	P7_DC	129.35	DC to Reservoir	0.31	0.75	2.88	40.10	97.01	372.53	0.04	0.10	0.37	0.13	0.32	1.24
		300.23	UD	0.31	0.75	2.88	93.07	225.17	864.66	0.09	0.23	0.86			
	P8_DC	52.54	UD	0.31	0.75	2.88	16.29	39.41	151.32	0.02	0.04	0.15	0.02	0.04	0.15
	P9_DC	130.3	DC_Duc to Reservoir	0.31	0.75	2.88	40.39	97.73	375.26	0.04	0.10	0.38	0.05	0.12	0.46
		28.75	UD	0.31	0.75	2.88	8.91	21.56	82.80	0.01	0.02	0.08			
	P10_DC	127.4	DC	0.95	1.43	7.50	121.03	182.18	955.50	0.12	0.18	0.96	0.38	0.54	1.71
		10.84	UD	0.31	0.75	2.88	3.36	8.13	31.22	0.00	0.01	0.03			
		71.26	Duc	3.65	4.84	10.10	260.10	344.90	719.73	0.26	0.34	0.72			
	P11_DC	63.1	DC	0.95	1.43	7.50	59.95	90.23	473.25	0.06	0.09	0.47	0.08	0.12	0.54
		4.14	Duc	3.65	4.84	10.10	15.11	20.04	41.81	0.02	0.02	0.04			
		8.37	UD	0.31	0.75	2.88	2.59	6.28	24.11	0.00	0.01	0.02			
	P12_DC	35.79	DC	0.95	1.43	7.50	34.00	51.18	268.43	0.03	0.05	0.27	0.04	0.06	0.31
		13.74	UD	0.31	0.75	2.88	4.26	10.31	39.57	0.00	0.01	0.04			
	P13_DC	128.79	UD	0.31	0.75	2.88	39.92	96.59	370.92	0.04	0.10	0.37	0.04	0.10	0.37
	P14_DC	823.7	UD	0.31	0.75	2.88	255.35	617.78	2372.26	0.26	0.62	2.37	0.97	1.58	4.57
		186.01	Duc	3.65	4.84	10.10	678.94	900.29	1878.70	0.68	0.90	1.88			
		42.47	DC	0.95	1.43	7.50	40.35	60.73	318.53	0.04	0.06	0.32			
	P15_DC	924.42	UD	0.31	0.75	2.88	286.57	693.32	2662.33	0.29	0.69	2.66	0.29	0.69	2.66
	P16_DC	198.2	UD	0.31	0.75	2.88	61.44	148.65	570.82	0.06	0.15	0.57	0.38	0.92	3.52
		1022.95	AIRPORT	0.31	0.75	2.88	317.11	767.21	2946.10	0.32	0.77	2.95			
	P17_DC	281.99	UD	0.31	0.75	2.88	87.42	211.49	812.13	0.09	0.21	0.81	0.09	0.21	0.81
WHITEMUD CREEK	P1_WC	7904.07	UD	0.31	0.75	2.88	2450.26	5928.05	22763.72	2.450	5.93	22.76	2.45	5.93	22.76
	P2_WC	730.55	UD	0.31	0.75	2.88	226.47	547.91	2103.98	0.226	0.55	2.10	0.23	0.55	2.10
	P3_WC	757.71	UD	0.31	0.75	2.88	234.89	568.28	2182.20	0.235	0.57	2.18	0.23	0.57	2.18
	P4_WC	965.66	UD	0.31	0.75	2.88	299.35	724.25	2781.10	0.299	0.72	2.78	0.30	0.72	2.78
	P5_WC	4479.79	UD	0.31	0.75	2.88	1388.73	3359.84	12901.80	1.389	3.360	12.902	1.55	3.59	13.91
		115.95	DC	0.95	1.43	7.50	110.15	165.81	869.63	0.110	0.166	0.870			
		13.34	Duc	3.65	4.84	10.10	48.69	64.57	134.73	0.049	0.065	0.135			
	P6_WC	41.4	UD	0.31	0.75	2.88	12.83	31.05	119.23	0.013	0.03	0.12	0.13	0.30	1.16
		362.7	UD	0.31	0.75	2.88	112.44	272.03	1044.58	0.112	0.27	1.04			
	P7_WC	1644.35	UD	0.31	0.75	2.88	509.75	1233.26	4735.73	0.510	1.23	4.74	0.51	1.23	4.74
	P8_WC	927.81	UD	0.31	0.75	2.88	287.62	695.86	2672.09	0.288	0.696	2.672	0.31	0.74	2.84
		58.57	UD	0.31	0.75	2.88	18.16	43.93	168.68	0.018	0.044	0.169			
	P9_WC	575.3	UD	0.31	0.75	2.88	178.34	431.48	1656.86	0.178	0.43	1.66	0.18	0.43	1.66
	P10_WC	1510.47	UD	0.31	0.75	2.88	468.25	1132.85	4350.15	0.468	1.13	4.35	0.47	1.13	4.35
	P11_WC	1674.47	UD	0.31	0.75	2.88	519.09	1255.85	4822.47	0.519	1.26	4.82	0.52	1.26	4.82
	P12_WC	503.73	UD	0.31	0.75	2.88	156.16	377.80	1450.74	0.156	0.38	1.45	0.16	0.38	1.45
	P13_WC	351.57	UD	0.31	0.75	2.88	108.99	263.68	1012.52	0.109	0.26	1.01	0.22	0.43	1.87
		172.41	DC	0.63	0.95	5.00	108.62	163.79	862.05	0.109	0.16	0.86			
	P14_WC	461.16	DC	0.63	0.95	5.00	290.53	438.10	2305.80	0.291	0.44	2.31	0.29	0.44	2.31
	P15_WC	313.29	DC	0.63	0.95	5.00	197.37	297.63	1566.45	0.20	0.30	1.57	0.29	0.52	2.44
		302.64	UD	0.31	0.75	2.88	93.82	226.98	871.60	0.09	0.23	0.87			
	P16_WC	1505.65	DC	0.63	0.95	5.00	948.56	1430.37	7528.25	0.95	1.43	7.53	0.96	1.46	7.63
		34.78	UD	0.31	0.75	2.88	10.78	26.09	100.17	0.01	0.03	0.10			
	P17_WC	37.96	UD	0.31	0.75	2.88	11.77	28.47	109.32	0.01	0.03	0.11	2.76	3.63	7.73
		1283.04	Duc	2.14	2.81	5.94	2745.71	3605.34	7621.26	2.75	3.61	7.62			
	P18_WC	335.15	Duc	2.14	2.81	5.94	717.22	941.77	1990.79	0.72	0.94	1.99	0.72	0.94	1.99
CLEARWATER CREEK	P1_CW	9600.08	UD	0.07	0.26	1.11	672.01	2496.02	10656.09	0.67	2.50	10.66	0.67	2.50	10.66
	P2_CW	3327.89	UD	0.07	0.26	1.11	232.95	865.25	3693.96	0.23	0.87	3.69	0.23	0.87	3.69
	P3_CW	997.4	UD	0.07	0.26	1.11	69.82	259.32	1107.11	0.07	0.26	1.11	0.07	0.26	1.11
	P4_CW	707.24	UD	0.07	0.26	1.11	49.51	183.88	785.04	0.05	0.18	0.79	0.05	0.18	0.79
	P5_CW	2624.42	UD	0.07	0.26	1.11	183.71	682.35	2913.11	0.18	0.68	2.91	0.18	0.68	2.91
	P6_CW	489.4	UD	0.07	0.26	1.11	34.26	127.24	543.23	0.03	0.13	0.54	0.03	0.13	0.54
	P7_CW	1806.77	UD	0.07	0.26	1.11	126.47	469.76	2005.51	0.13	0.47	2.01	0.13	0.47	2.01
	P8_CW	654.48	UD	0.07	0.26	1.11	45.81	170.16	726.47	0.05	0.17	0.73	0.05	0.17	0.73
LEBLANC CANAL	P1_LC	213.62	UD	0.07	0.26	1.11	0.40	55.54	237.12	0.00	0.06	0.24	0.40	0.64	3.82
		N/A	Town of Beaumont	0.38	0.57	3.00	402.00	580.00	3580.00	0.40	0.58	3.58			
IRVINE CREEK	P1_IC	6060.83	UD	0.07	0.26	1.11	424.26	1575.82	6727.52	0.42	1.58	6.73	0.42	1.58	6.73
	P2_IC	1361.4	UD	0.07	0.26	1.11	95.30	353.96	1511.15	0.10	0.35	1.51	0.10	0.35	1.51
	P3_IC	1019.34	UD	0.07	0.26	1.11	71.35	265.03	1131.47	0.07	0.27	1.13	0.07	0.27	1.13
	P4_IC	1078.97	UD	0.07	0.26	1.11	75.53	280.53	1197.66	0.08	0.28	1.20	0.08	0.28	1.20
	P5_IC	378.92	UD	0.07	0.26	1.11	26.52	98.52	420.60	0.03	0.10	0.42	0.03	0.10	0.42
	P6_IC	647.39	UD	0.07	0.26	1.11	45.32	168.32	718.60	0.05	0.17	0.72	0.05	0.17	0.72
	P7_IC	1053.63	UD	0.07	0.26	1.11	73.75	273.94	1169.53	0.0738	0.2739	1.1695	0.35	0.72	2.99
		N/A	Town of Beaumont	0.38	0.57	3.00	280.00	450.00	1820.00	0.2800	0.4500	1.8200			
	P8_IC	348.97	UD	0.07	0.26	1.11	24.43	90.73	387.36	0.0244	0.0907	0.3874	0.02	0.09	0.39
	P9_IC	1354.37	UD	0.07	0.26	1.11	94.81	352.14	1503.35	0.0948	0.3521	1.5034	0.09	0.35	1.50
BLACKMUD CREEK	P1_BC	15300	UD	0.13	0.32	1.05	1930.00	4940.00	16100.00	1.93	4.94	16.1	2.00	5.05	16.66
		116.21	DC	0.61	0.91	4.8	70.89	105.75	557.81	0.07	0.11	0.56			
	P2_BC	539.75	UD	0.07	0.26	1.11	37.78	140.34	599.12	0.04	0.14	0.60	0.04	0.14	0.60
	P3_BC	327.04	UD	0.07	0.26	1.11	22.89	85.03	363.01	0.02	0.09	0.36	1.39	1.91	4.88
		432.58	Duc	2.85	3.75	7.92	1232.85	1622.18	3426.03	1.23	1.62	3.43			
		107.68	DC	0.61	0.91	4.8	65.68	97.99	516.86	0.07	0.10	0.52			
		120.21	DC	0.61	0.91	4.8	73.33	109.39	577.01	0.07	0.11	0.58			
	P4_BC	446.04	UD	0.07	0.26	1.11	31.22	115.97	495.10	0.03	0.12	0.50	0.17	0.30	0.98
		39.17	Duc	2.85	3.75	7.92	111.63	146.89	310.23	0.11	0.15	0.31			
		36.38	DC	0.61	0.91	4.8	22.19	33.11	174.62	0.02	0.03	0.17			
	P5_BC	1218.17	UD	0.07	0.26	1.11	85.27	316.72	1352.17	0.09	0.32	1.35	0.43	0.77	2.32
		121.57	Duc	2.85	3.75	7.92	346.47	455.89	962.83	0.35	0.46	0.96			
	P6_BC	485.23	UD	0.07	0.26	1.11	33.97	126.16	538.61	0.03	0.13	0.54	0.57	0.87	2.29
		214.11	UD	0.07	0.26	1.11	14.99	55.67	237.66	0.01	0.06	0.24			
		178.78	Duc	2.85	3.75	7.92	509.52	670.43	1415.94	0.51	0.67	1.42			
		21.2	DC	0.61	0.91	4.8	12.93	19.29	101.76	0.01	0.02	0.10			
	P7_BC	59.48	UD	0.07	0.26	1.11	4.16	15.46	66.02	0.00	0.02	0.07	3.27	4.36	10.53
		1048.61	Duc	2.85	3.75	7.92	2988.54	3932.29	8304.99	2.99	3.93	8.30			
		450.33	DC	0.61	0.91	4.8	274.70	409.80	2161.58	0.27	0.41	2.16			
	P8_BC	143.32	UD	0.07	0.26	1.11	10.03	37.26	159.09	0.01	0.04	0.16	0.36	0.55	2.56
		25.82	Duc	2.85	3.75	7.92	73.59	96.83	204.49	0.07	0.10	0.20			
		456.8	DC	0.61	0.91	4.8	278.65	415.69	2192.64	0.28	0.42	2.19			
	P9_BC	1304.27	UD	0.07	0.26	1.11	91.30	339.11	1447.74	0.09	0.34	1.45	0.12	0.38	1.68
		48.24	DC	0.61	0.91	4.8	29.43	43.90	231.55	0.03	0.04	0.23			
	P10_BC	71.58	UD	0.07	0.26	1.11	5.01	18.61	79.45	0.01	0.02	0.08	0.12	0.19	0.97
		185.67	DC	0.61	0.91	4.8	113.26	168.96	891.22	0.11	0.17	0.89			
	P11_BC	216.03	DC	0.63	0.95	5.00	136.82	205.23	1080.17	0.14	0.21	1.08	0.14	0.21	1.08
	P12_BC	1885.39	DC	0.63	0.95	5.00	1194.10	1791.16	9427.14	1.19	1.79	9.43	1.35	2.17	10.86
		498.83	UD	0.31	0.75	2.88	154.64	374.12	1436.63	0.15	0.37	1.44			
	P13_BC	293.64	DC	0.63	0.95	5.00	185.98	278.96	1468.23	0.19	0.28	1.47	0.19	0.28	1.47

3 1D Model Results

The maximum flows, water depths, and velocities for existing conditions were simulated for the 1:2, 1:5, and 1:100 year design events. Inflows were applied to the 1D model from developed and undeveloped portions of the basin as described above. Flood maps depicting the maximum extent of flooding were developed by overlaying the simulated water surface on the 1m ground LiDAR surface within the MIKE 11 software.

3.1 FLOOD DEPTHS AND EXTENT

Figure 3-1 provides the flood map and the water depths for the entire basin for the simulated 1:100 year design event. The results of the model simulation show significant flooding along Irvine Creek, Leblanc Canal, Blackmud Creek upstream of Highway 2, and more localized flooding along Whitemud and Clearwater Creeks.

Figures 3-2 to **3-5** show the flood extent and water depths for the simulated 1:100 year design event at critical locations along Blackmud Creek, Irvine Creek, Deer Creek, and Whitemud Creek, respectively. In addition, **Appendix A** provides maps showing flood extents and water depths during the 1:2, 1:5 and 1:100 year design events. The following observations were made from the modelling results:

- Generally, flows generated by the existing conditions were confined within the channel banks during the 1:2 year design event. Localized flooding occurred along the creeks during the 1:5 year design event. Overland flooding occurred during the 1:100 year design event.

- The majority of the creeks within the basin had limited hydraulic capacity to convey runoff generated from existing and any future development. However, in the lower reaches of Blackmud and Whitemud Creeks erosion is a significant concern.

- The upper reaches of the Blackmud Creek experienced flooding over a wide floodplain that geologically formed the outlet from glacial Lake Edmonton. Flooding was mostly confined to the valley. Flows were mostly confined to the Blackmud Creek channel as they approached the City of Edmonton.

- The upper reaches of the Whitemud Creek experienced flooding within the valley. Flows in the lower reaches were mostly confined to the creek channel.

- Portions of the Irvine Creek and LeBlanc Canal near Beaumont experienced significant overland flooding due to limited channel capacity. These areas had been channelized in the past to provide drainage but do not have the capacity to prevent flooding in a major runoff event. The lower reaches of the LeBlanc Canal also experienced backwater effects from Irvine Creek.

- Deer Creek had limited channel capacity to convey runoff and this resulted in overland flooding along the creek.

Figure 3-6 provides the longitudinal profile of Blackmud Creek showing the creek bed and 1:100 year water surface. **Figures 3-7A** and **B** provide typical cross-sections upstream and downstream of Nisku. From the profile, it can be observed that the longitudinal slope of the Blackmud Creek steepens downstream of Nisku, as the valley becomes deeper and flows increase. Extensive flooding occurred in the glacial valley upstream of Nisku (**Figure 3-7A**) and became confined to the creek channel at Highway 2 (**Figure 3-7B**) and downstream.

Figure 3-8 shows the longitudinal profile of Irvine Creek and **Figures 3-9C** and **D** provide typical cross-sections between Beaumont and Nisku. The channel is flat and shallow near Beaumont, which is a factor in the extensive flooding that occurs there (**Figure 3-9C**). The natural (un-modified) reaches were somewhat steeper and the channel is larger and better defined (**Figure 3-9D**).

Figure 3-10 presents the longitudinal profile of Deer Creek and **Figures 3-11E** and **F** show typical cross-sections between Leduc and the Edmonton International Airport. The longitudinal channel slope is relatively uniform, other than the backwater from the Leduc Reservoir outlet. The channel changes substantially from a fairly confined and well-defined channel upstream (**Figure 3-11E**) to a shallow and poorly-defined channel downstream (**Figure 3-11F**). Portions of this creek downstream of Range Road 254 have been channelized in the past. The results of the model showed that the channel had capacity for the 1:5 year return period peak flow which is typically used for channel design.

Figure 3-12 shows the longitudinal profile of the Whitemud Creek and **Figures 3-13G** and **H** provide typical cross-sections near Highway 19 and Anthony Henday Drive. The channel becomes steeper and the valley deeper near the WSC gauge and downstream of Anthony Henday Drive (**Figure 3-13H**). Flood flows are mostly confined to the valley of Whitemud Creek and to the vegetated floodplain in the upper reaches.

Appendix B presents longitudinal profiles showing the channel bottom and the maximum water surface for the 1:2, 1:5 and 1:100 year design events. **Appendix C** presents typical cross sections within the various reaches along with the simulated maximum water surface for the 1:2, 1:5 and 1:100 year design events. **Appendix D** presents longitudinal profiles showing the maximum velocity for the 1:2, 1:5 and 1:100 year design events.

3.2 CHANNEL VELOCITY ALONG THE BLACKMUD AND WHITEMUD CREEKS

The channel morphology is a function of the hydrologic regime, bed and bank materials, and longitudinal channel slope. Bed and bank erosion are, in turn, an expression of the channel morphology.

Bank erosion was found to be common throughout the lower reaches of Whitemud and Blackmud Creeks. It is the result of various natural and human influences. The City of Edmonton has conducted several studies to understand the nature and cause of the bank erosion and to develop a mitigation plan. This City of Edmonton currently collects levies from area developers which is used to fund channel upgrade and protection projects.

Figures 3-14 and 3-15 present the simulated channel average velocities along the Blackmud and Whitemud Creeks, respectively, for the 1:2, 1:5, and 1:100 peak design flows. These velocities represent the averages taken across the channel cross section at intervals along the creek.

The average velocities for both creeks was found to increase from upstream to the downstream, corresponding to the overall increase in flow and longitudinal channel slope. In general, velocities higher than 1.0 m/s occur in channels that are geologically more active such as the lower reaches of Whitemud and Blackmud Creeks. Upper reaches where the velocities are generally lower than 1 m/s are typically stable and show little sign of active channel erosion.

Streambank erosion is very sensitive to increases in velocity and flow and could potentially be impacted by development upstream. These potential impacts will be further evaluated in the next phase of this project.

3.3 DEVELOPMENT ISSUES AND CONSTRAINTS

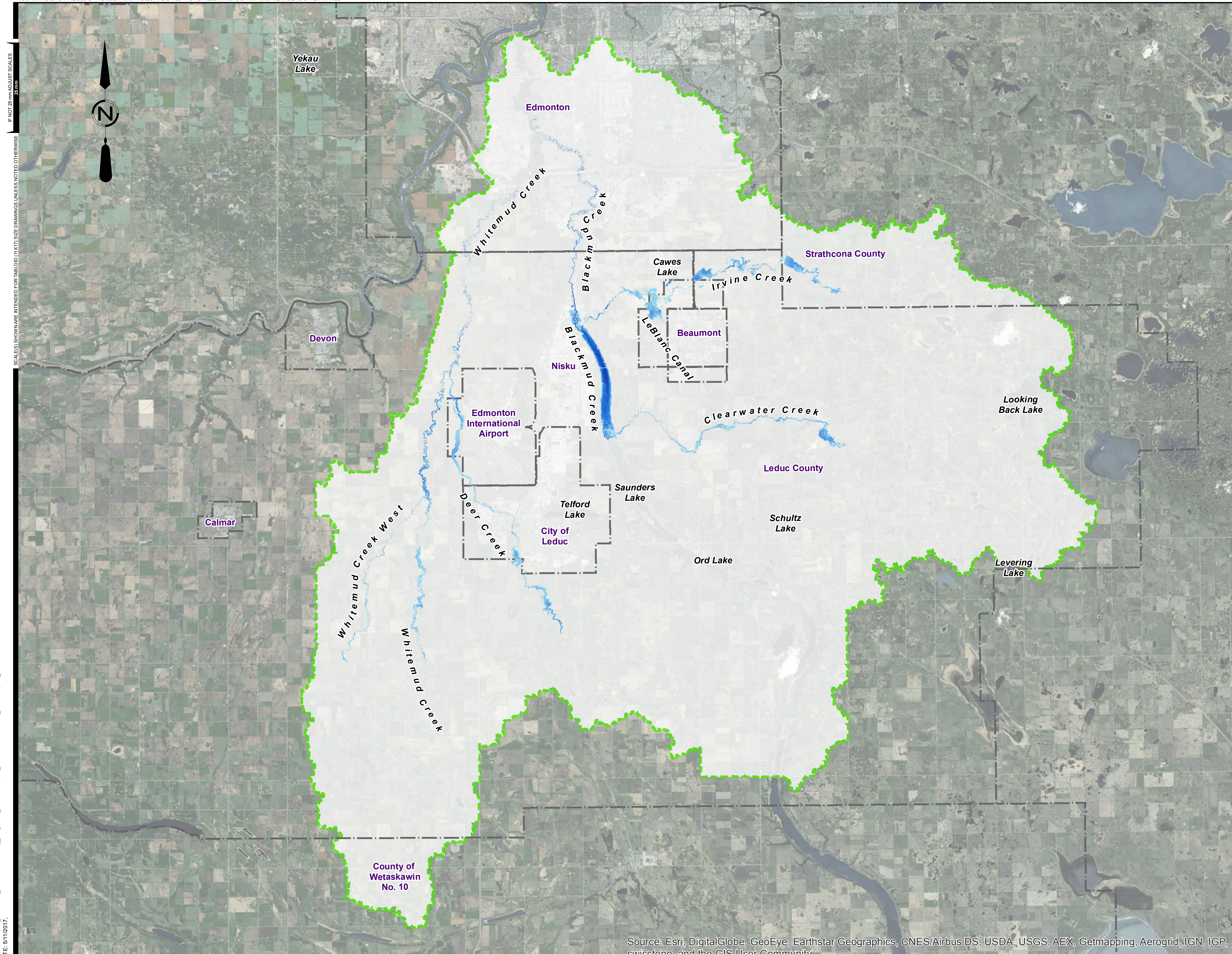
The analysis of existing conditions has identified several issues and constraints that will need to be addressed in subsequent tasks of the Surface Water Management Study. The following issues will need to be addressed:

- The extent of flooding will constrain development. In some locations along the Blackmud Creek, Irvine Creek, Deer Creek and Leblanc Canal, the flood-risk areas are extensive. The Municipal Government Act empowers municipalities to preserve floodplain areas as Environmental Reserve (land subject to flooding) at the time of development, however, these powers are not always applied consistently. Where extensive overland flooding is found to occur, it is not always practical to sterilize large areas from development, and these locations should be considered as possible sites for stormwater management ponds or wetlands. A policy for protecting floodplains that recognizes the flood risk and the environmental value that floodplains create should be developed.

- Along with the extensive flooding, some of the creek channels, in the same locations as above, are too shallow to permit drainage of adjacent development using a conventional underground pipe system. Typically, a depth of 4 m from adjacent land areas to channel bottom is required and in many places this does not exist. Alternatives need to be considered such as:

    - a surface drainage system
    - channel deepening and widening to provide the required capacity (a drainage parkway)
    - a trunk storm sewer system to carry outflows from stormwater management facilities to a safe and reliable discharge point
    - Low-Impact Development standards to reduce the volume and peak runoff rates to pre-development levels

- Erosion issues in Whitemud and Blackmud Creek are understood in only a general way and could be aggravated by increasing runoff volumes and flood peak discharges resulting from further development in the basin. There are no reliable models of the erosion process to give ***quantitative*** estimates of the erosion rates and the impacts of the changing flow regime that will occur with development, but a ***qualitative*** estimate is possible from the model-simulated velocities and shear stresses and morphological principles that relate these hydraulic parameters to the rate of sediment transport.



Associated Engineering

Legend:
Water Depth
High
Low
Whitemud Watershed
Municipal Boundary

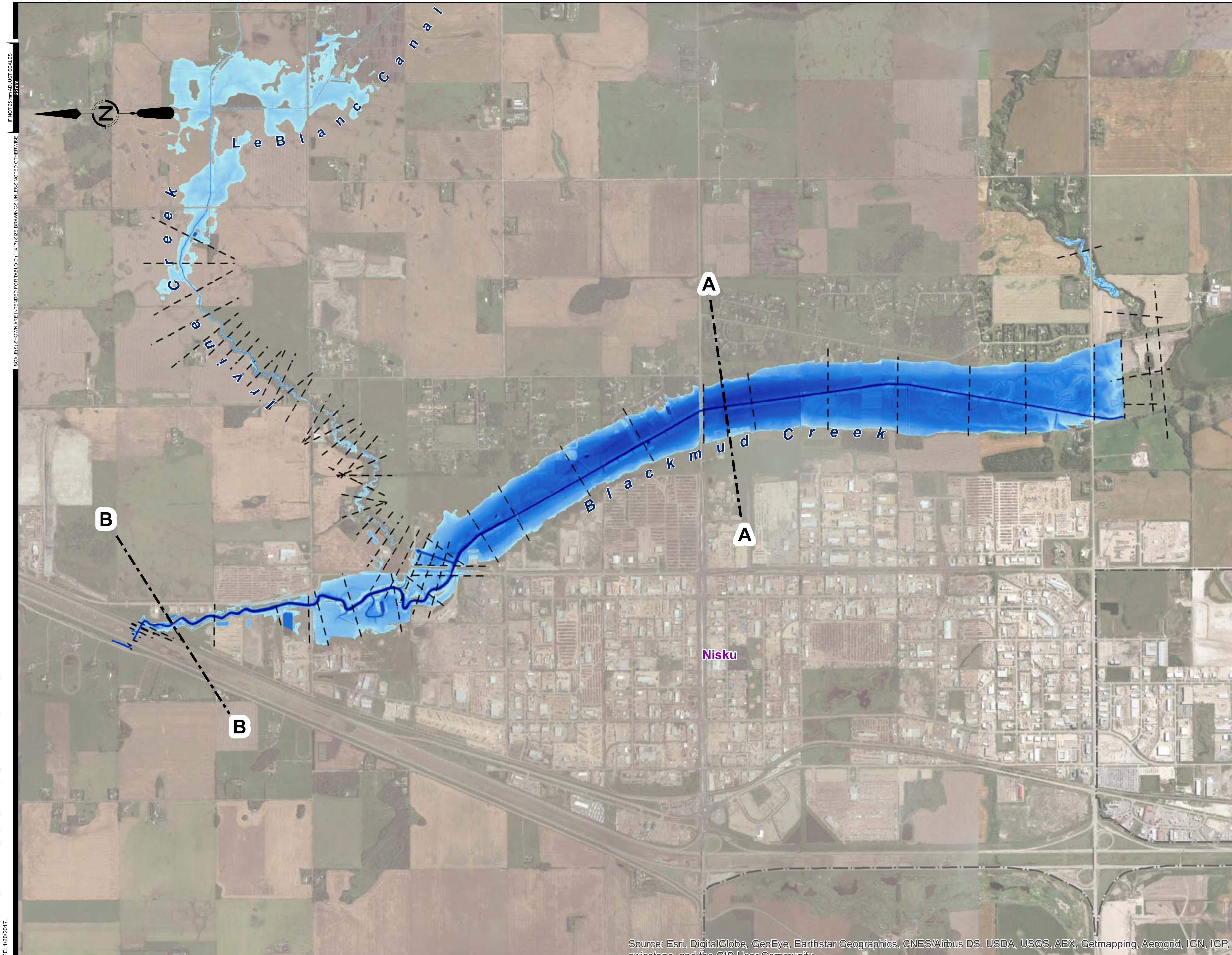
FIGURE No. 3-1

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

PROJECT AREA

AE PROJECT No.	2016-3785
SCALE	1:200,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

THIS DRAWING IS FOR THE USE OF THE CLIENT AND PROJECT INDICATED - NO REPRESENTATIONS OF ANY KIND ARE MADE TO OTHER PARTIES



IF NOT 25 mm ADJUST SCALES

SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

P:\20163785\00_Blackmud_Whitemud\Working_Dwgs\010_GIS\ArcMap\02_WaterResources\xxx_CreekDepths_v2.mxd
DATE: 1/20/2017,

Associated Engineering

Legend:

Water Depth (100 Year)
High (4.1 m)
Low (0 m)

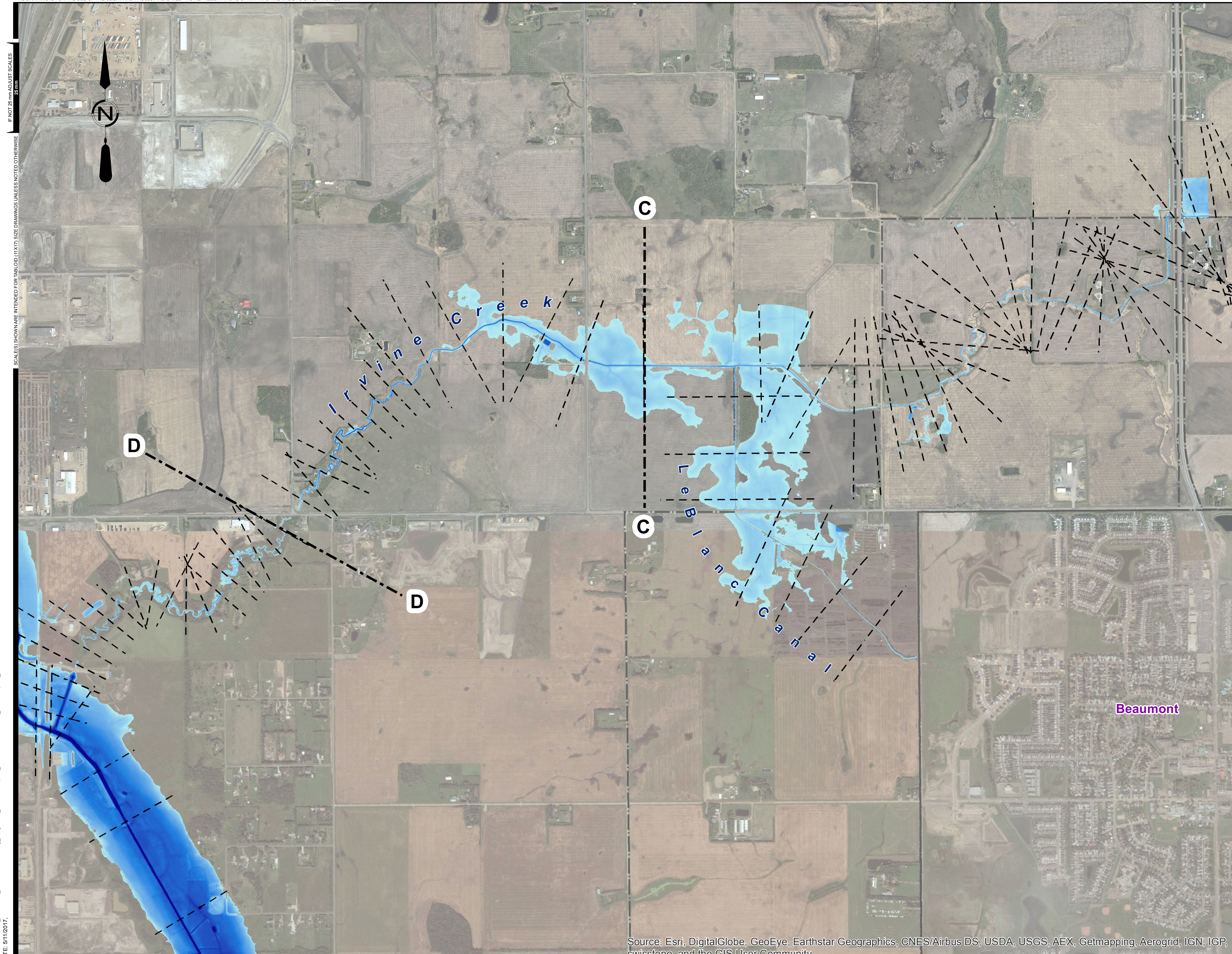
Cross Section
Municipal Boundary

FIGURE No. 3-2

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

Blackmud Creek 1:100 Year

AE PROJECT No.	2016-3785
SCALE	1:30,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT



Associated Engineering

Legend:

Water Depth (100 Year)
High (3.7 m)
Low (0 m)

Cross Section
Municipal Boundary

FIGURE No. 3-3

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

IRVINE CREEK 1:100 YEAR

AE PROJECT No.	2016-3785
SCALE	1:20,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

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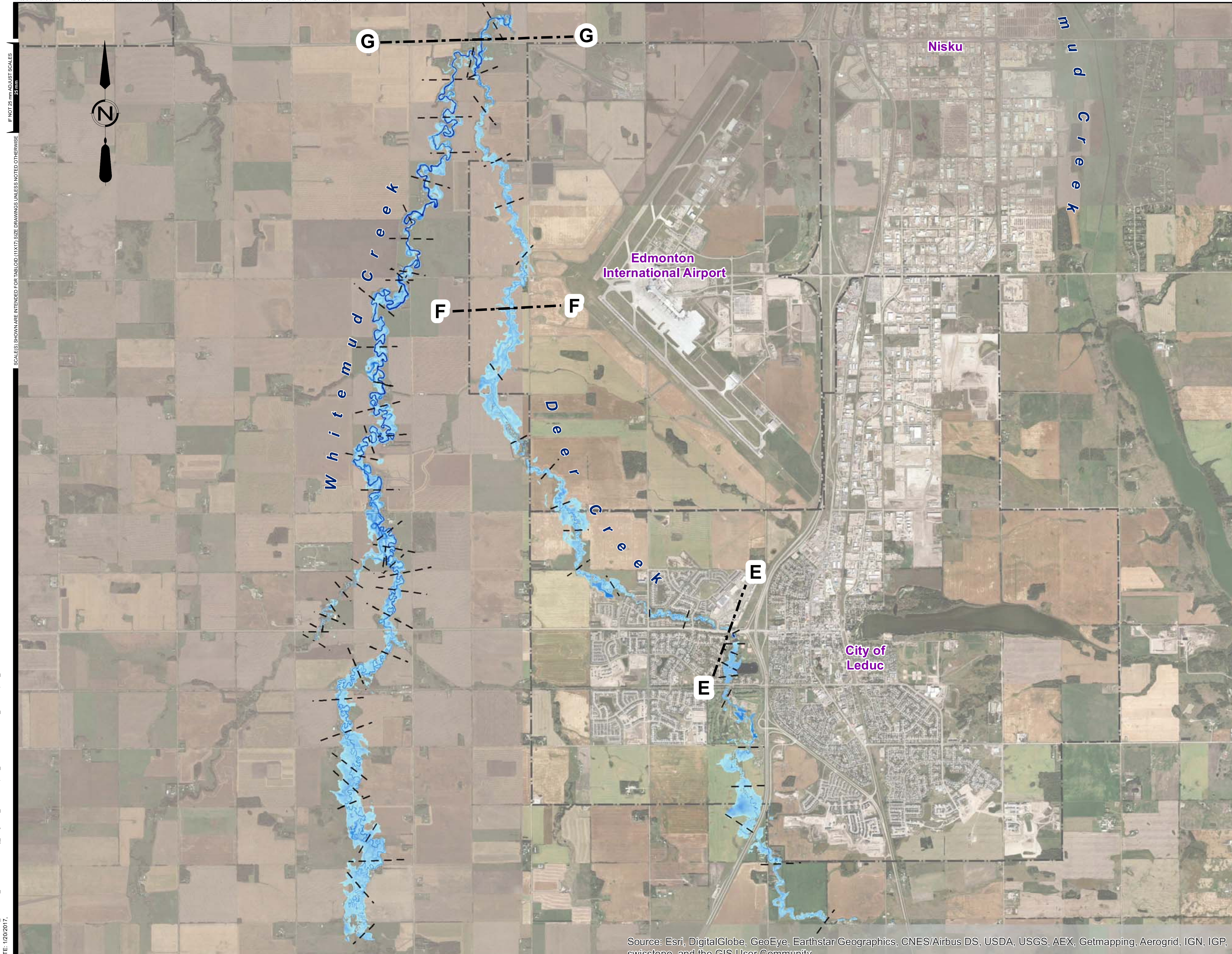
DATE: 5/11/2017,

THIS DRAWING IS FOR THE USE OF THE CLIENT AND PROJECT INDICATED - NO REPRESENTATIONS OF ANY KIND ARE MADE TO OTHER PARTIES



Associated Engineering

Legend:

Water Depth (100 Year)

High (4.1 m)

Low (0 m)

Cross Section

Municipal Boundary

FIGURE No. 3-4

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

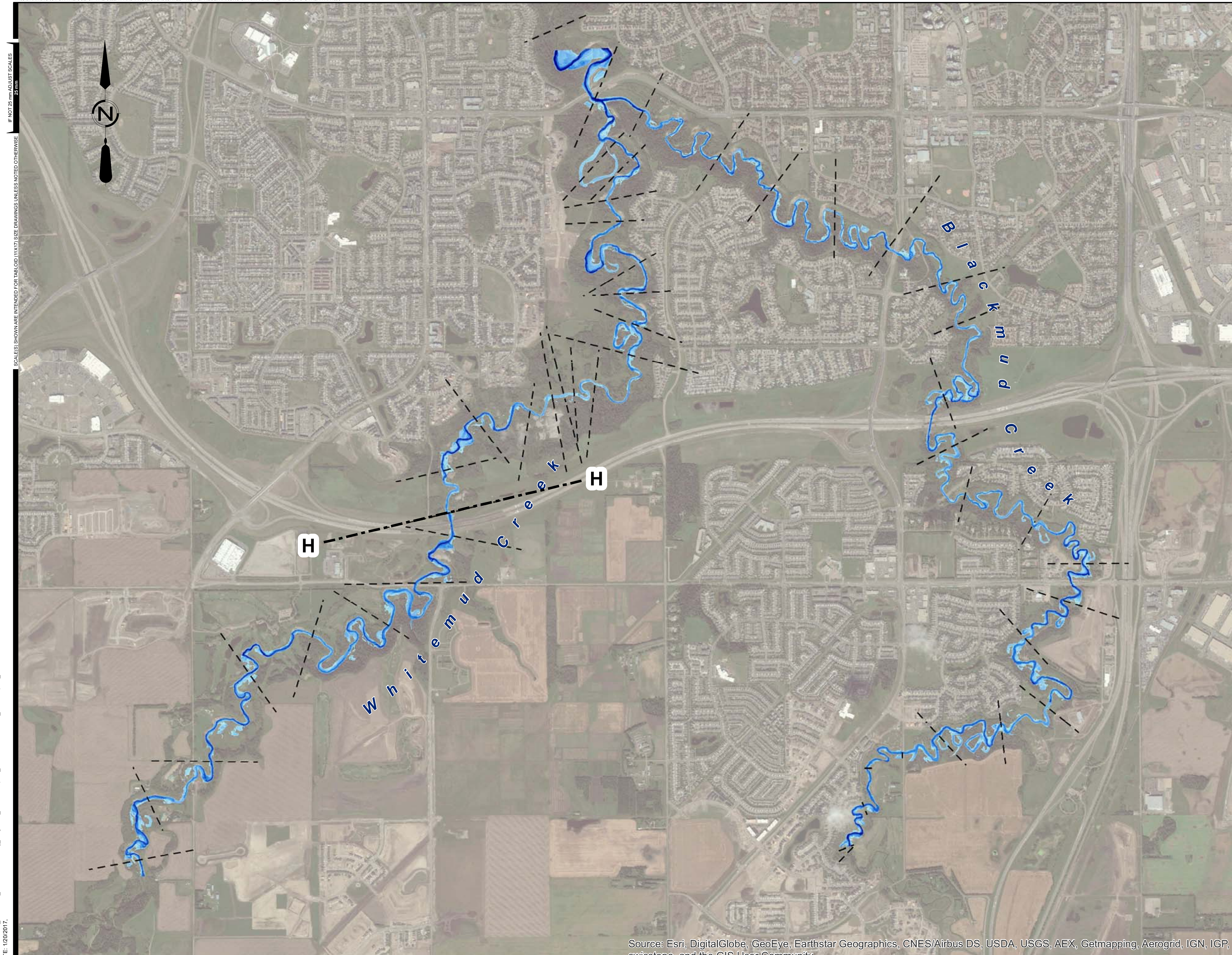
Deer Creek 1:100 Year

AE PROJECT No.	2016-3785
SCALE	1:50,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

IF NOT 25 mm ADJUST SCALES

SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

P:\20163785\00_Blackmud_Whitemud\Working_Dwgs\010_GIS\ArcMap\02_WaterResources\xxx_CreekDepths_v2.mxd
DATE: 1/20/2017,



Associated Engineering

Legend:

Water Depth (100 Year)

High (4.1 m)

Low (0 m)

Cross Section

Municipal Boundary

FIGURE No. 3-5

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

Whitemud Creek 1:100 Year

AE PROJECT No.	2016-3785
SCALE	1:25,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

IF NOT 25 mm ADJUST SCALES

SCALE(S) SHOWN ARE INTENDED FOR TABLOID (11X17) SIZE DRAWINGS UNLESS NOTED OTHERWISE

P:\20163785\00_Blackmud_Whitemud\Working_Dwgs\010_GIS\ArcMap\02_WaterResources\xxx_CreekDepths_v2.mxd
DATE: 1/20/2017,

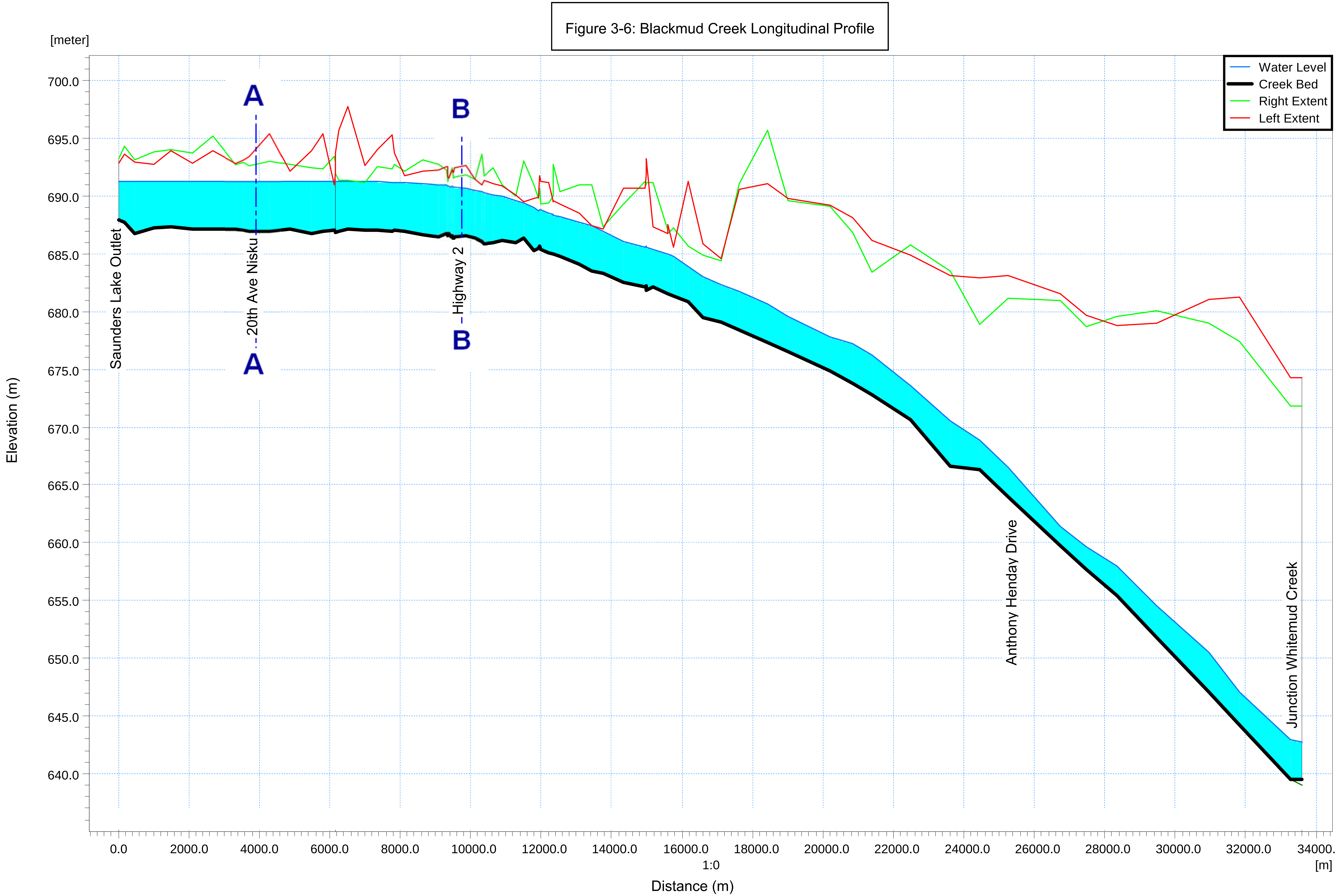


Figure 3-6: Blackmud Creek Longitudinal Profile
[meter]
Water Level
Creek Bed
Right Extent
Left Extent
A
A
B
B
Saunders Lake Outlet
20th Ave Nisku
Highway 2
Anthony Henday Drive
Junction Whitemud Creek
700.0
695.0
690.0
685.0
680.0
675.0
670.0
665.0
660.0
655.0
650.0
645.0
640.0
Elevation (m)
0.0
2000.0
4000.0
6000.0
8000.0
10000.0
12000.0
14000.0
16000.0
18000.0
20000.0
22000.0
24000.0
26000.0
28000.0
30000.0
32000.0
34000.0
[m]
1:0
Distance (m)

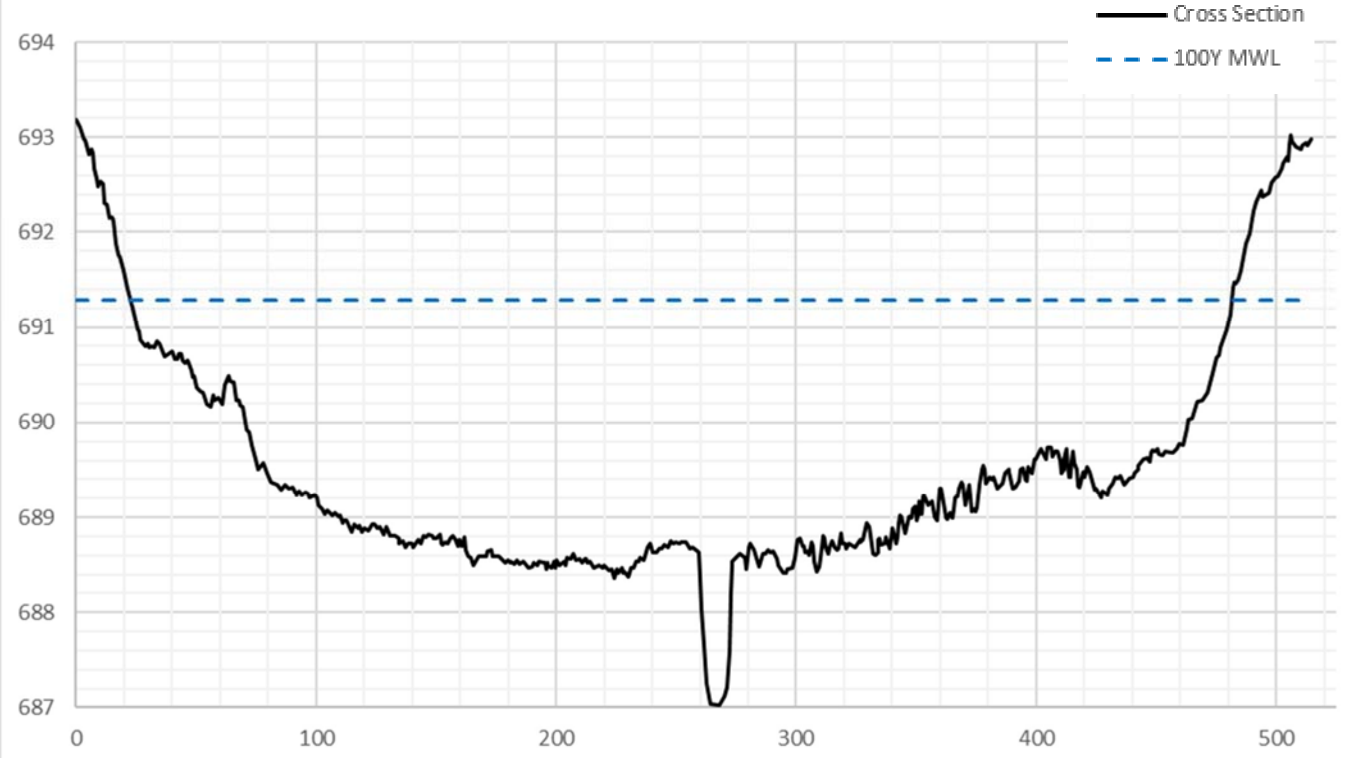


Figure 3-7 A: Blackmud Creek Section A-A

Figure 3-7 B: Blackmud Creek Section B-B

Figure 3-8: Irvine Creek Longitudinal Profile

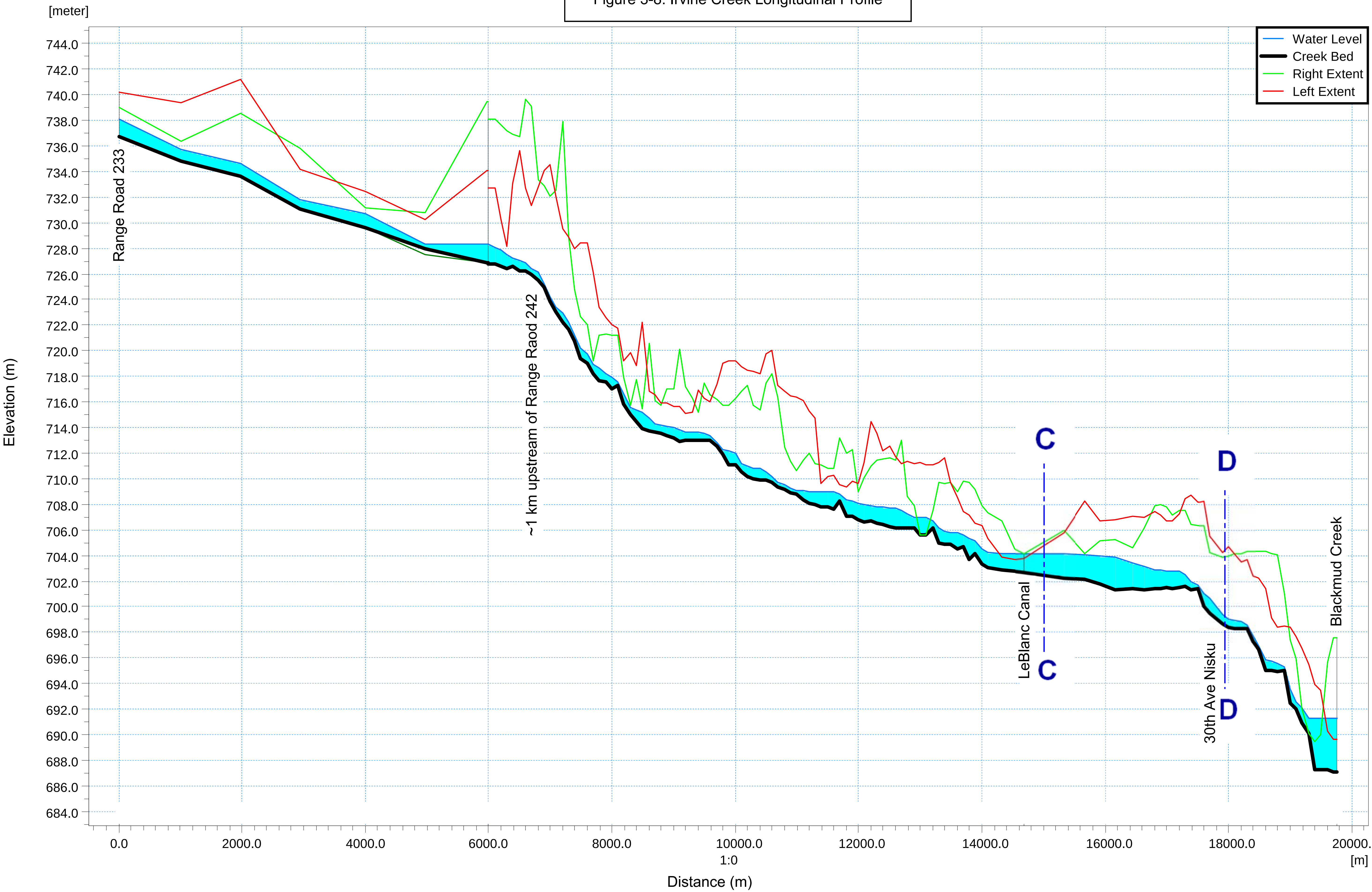


Figure 3-9 C: Irvine Creek Section C-C

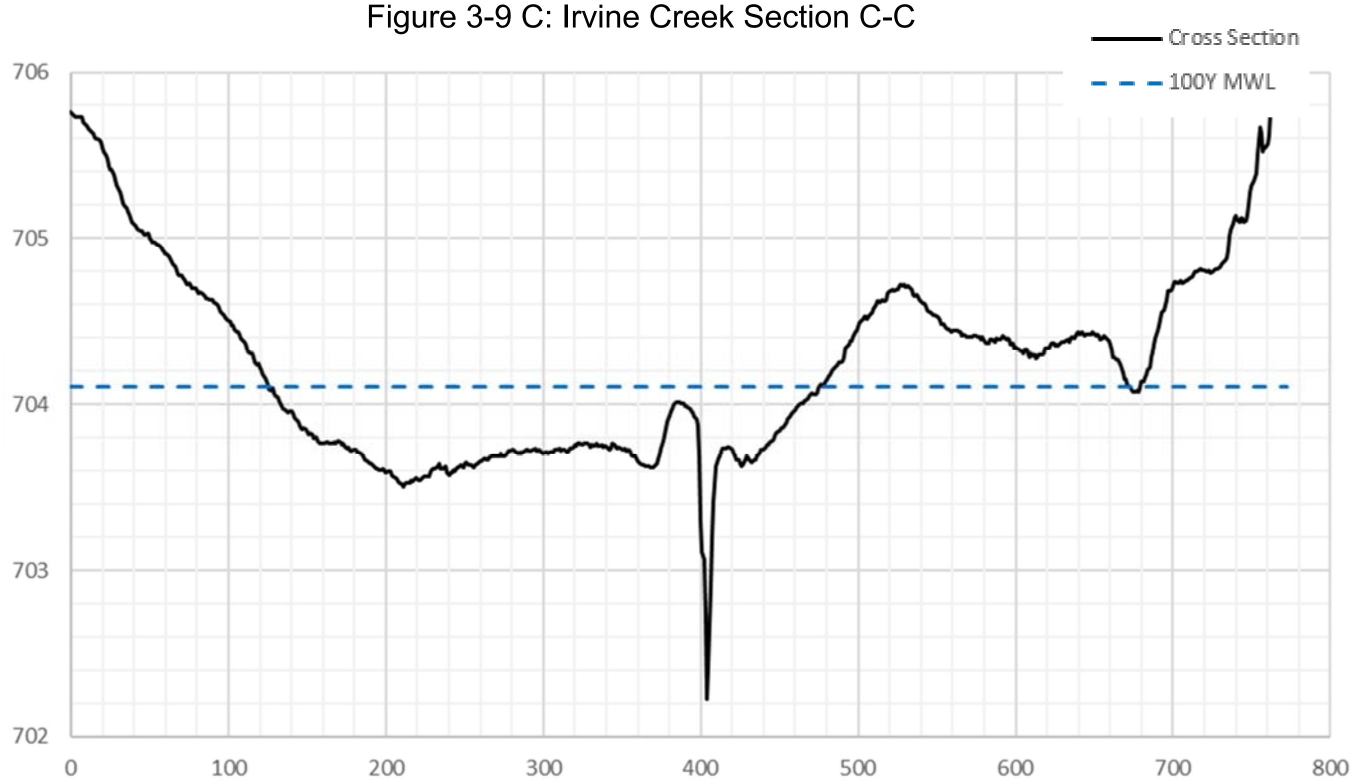
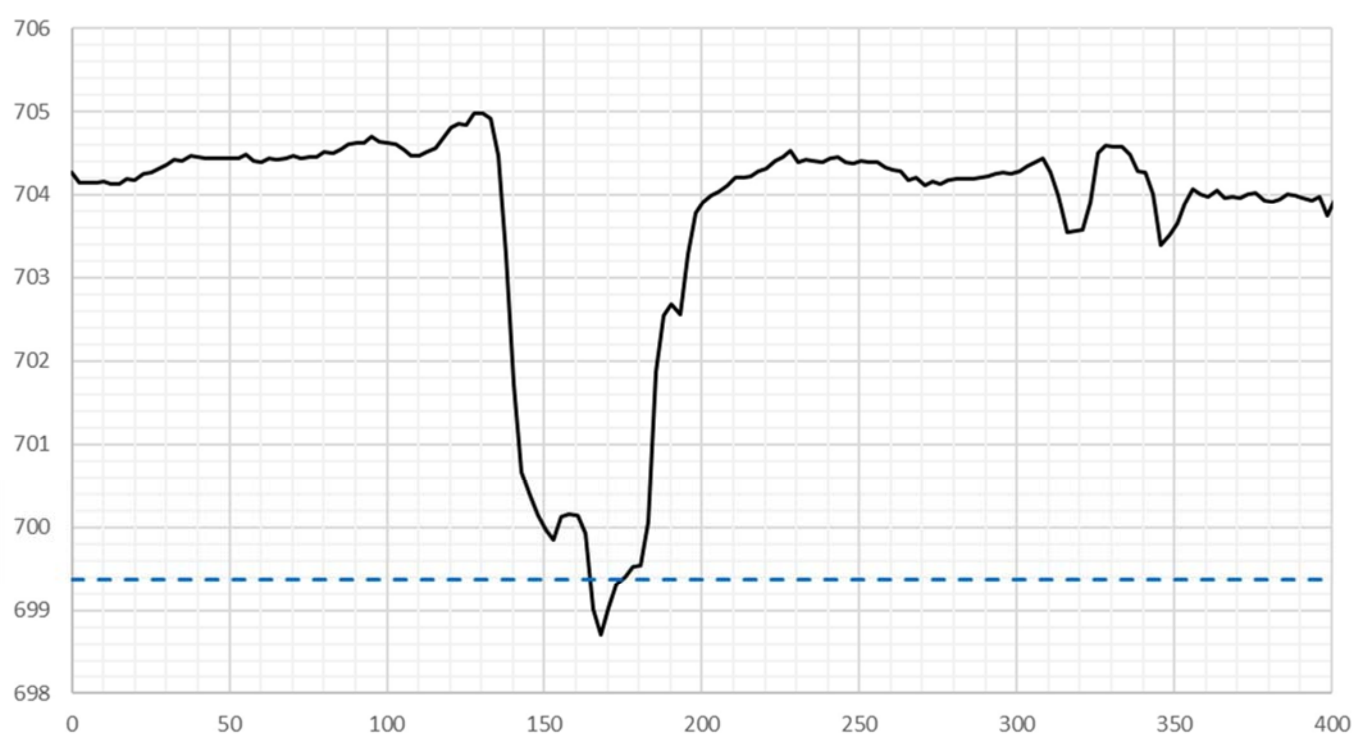


Figure 3-9 D: Irvine Creek Section D-D



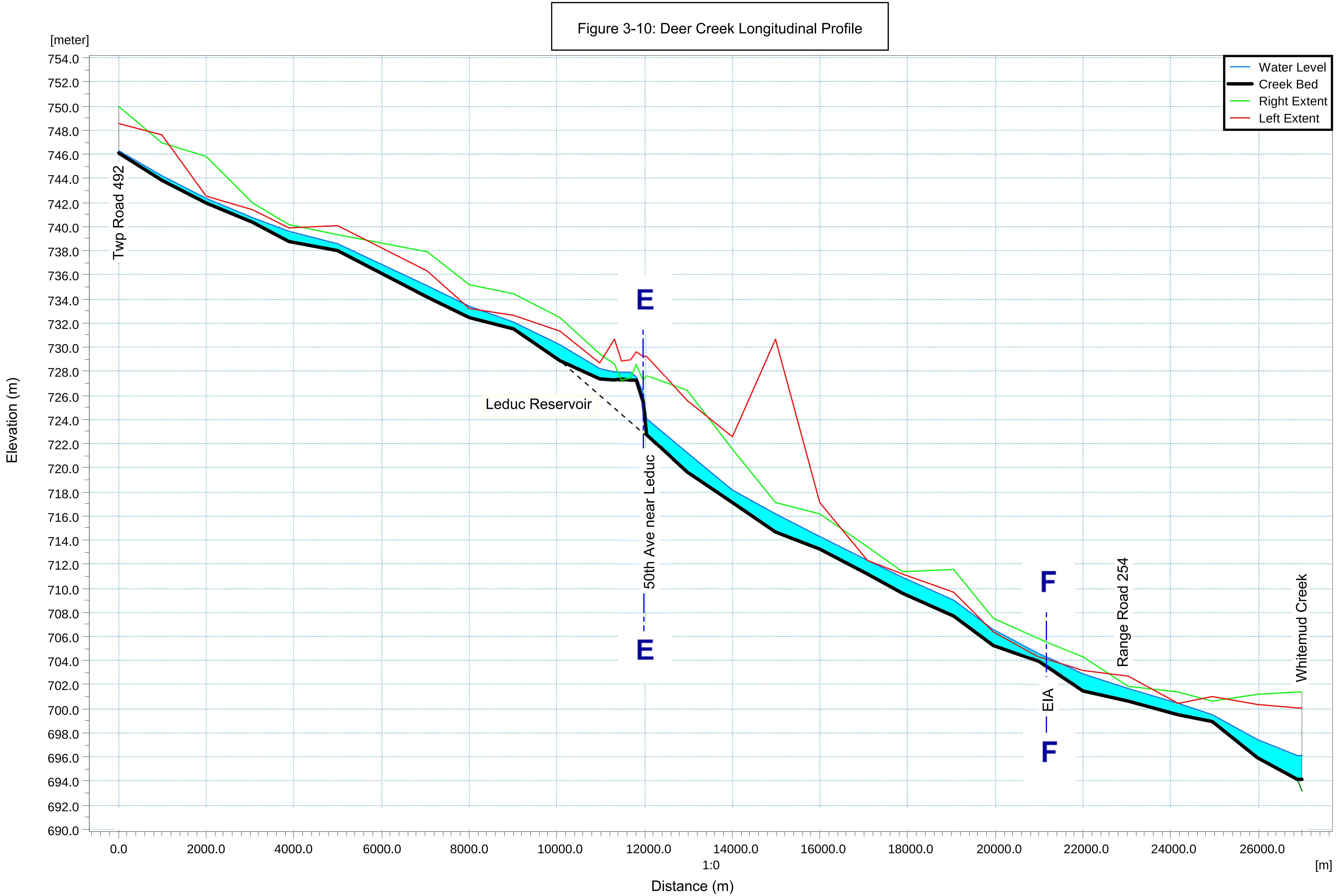


Figure 3-10: Deer Creek Longitudinal Profile
[meter]
754.0
752.0
750.0
748.0
746.0
744.0
742.0
740.0
738.0
736.0
734.0
732.0
730.0
728.0
726.0
724.0
722.0
720.0
718.0
716.0
714.0
712.0
710.0
708.0
706.0
704.0
702.0
700.0
698.0
696.0
694.0
692.0
690.0
Elevation (m)
Water Level
Creek Bed
Right Extent
Left Extent
Twp Road 492
E
E
Leduc Reservoir
50th Ave near Leduc
F
F
EIA
Range Road 254
Whitemud Creek
0.0
2000.0
4000.0
6000.0
8000.0
10000.0
12000.0
14000.0
16000.0
18000.0
20000.0
22000.0
24000.0
26000.0
1:0
[m]
Distance (m)

Figure 3-11 E: Deer Creek Section E-E

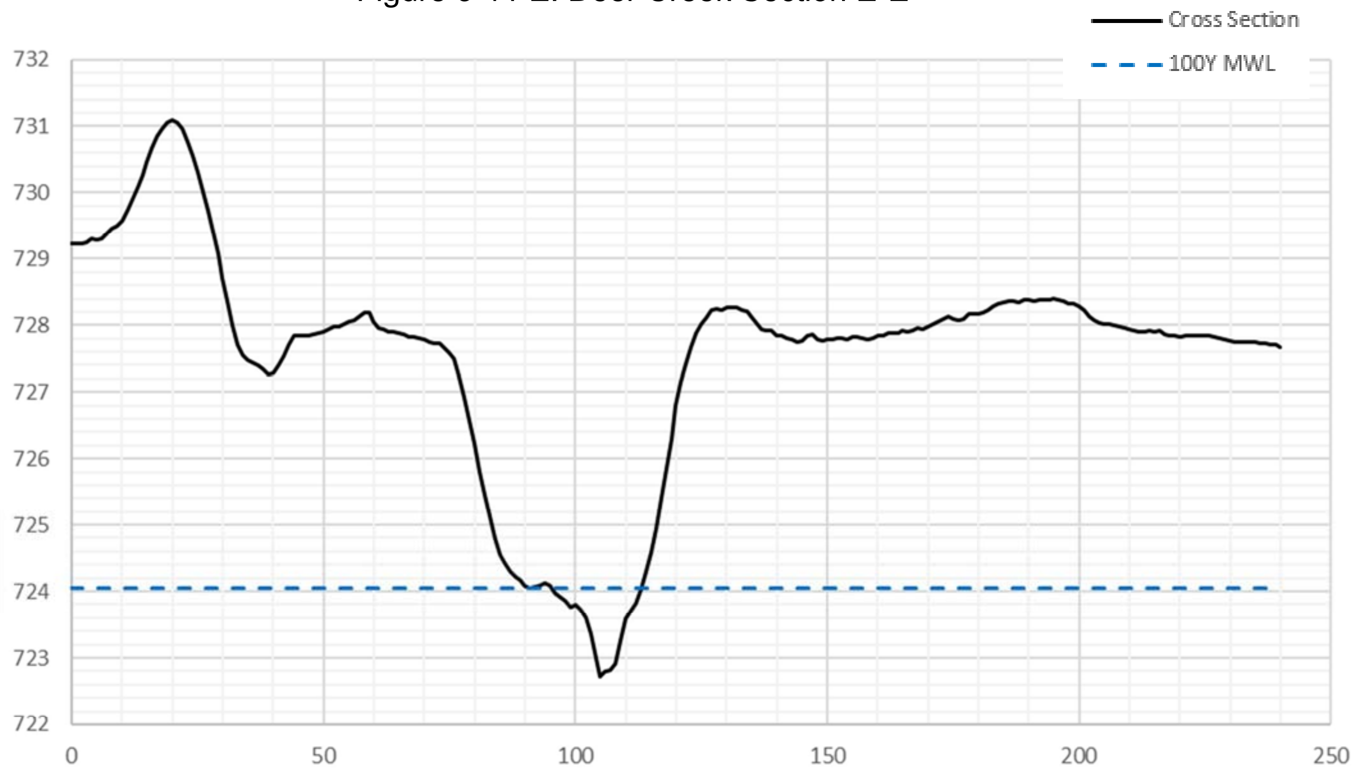
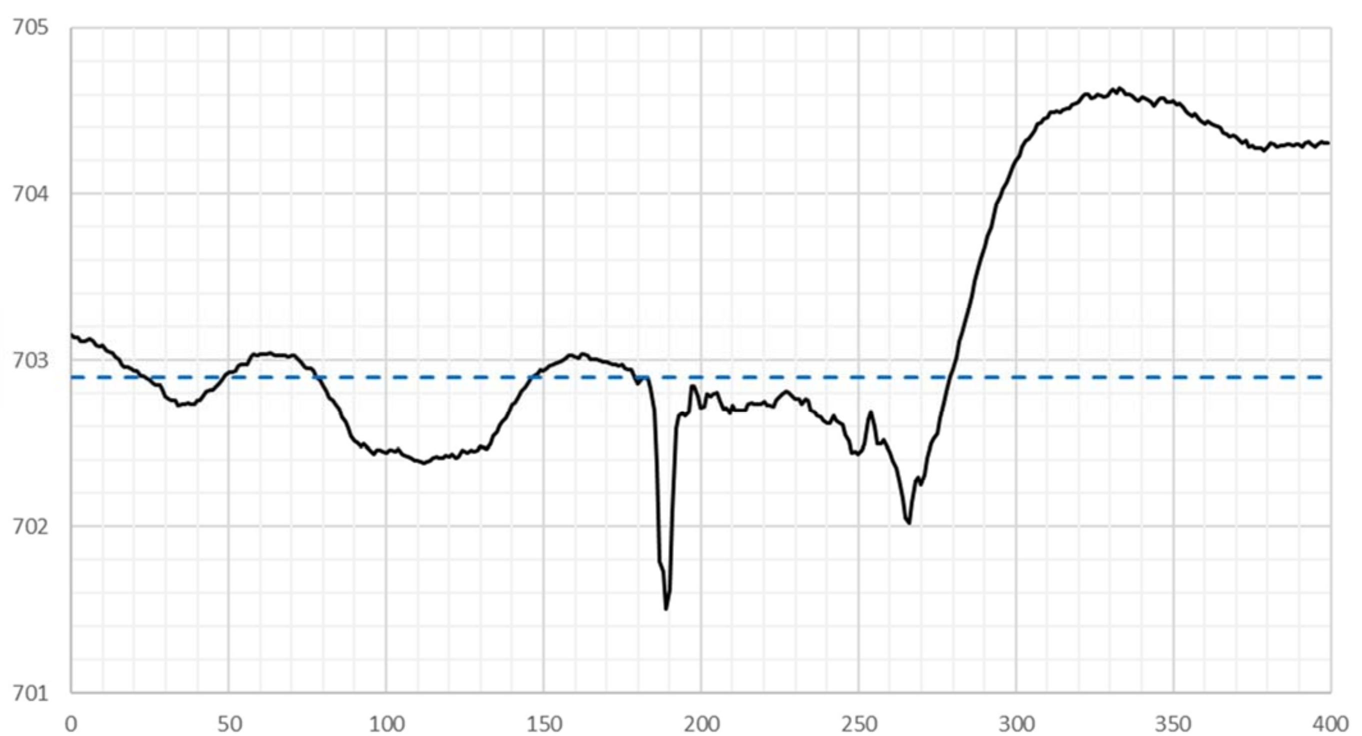


Figure 3-11 F: Deer Creek Section F-F



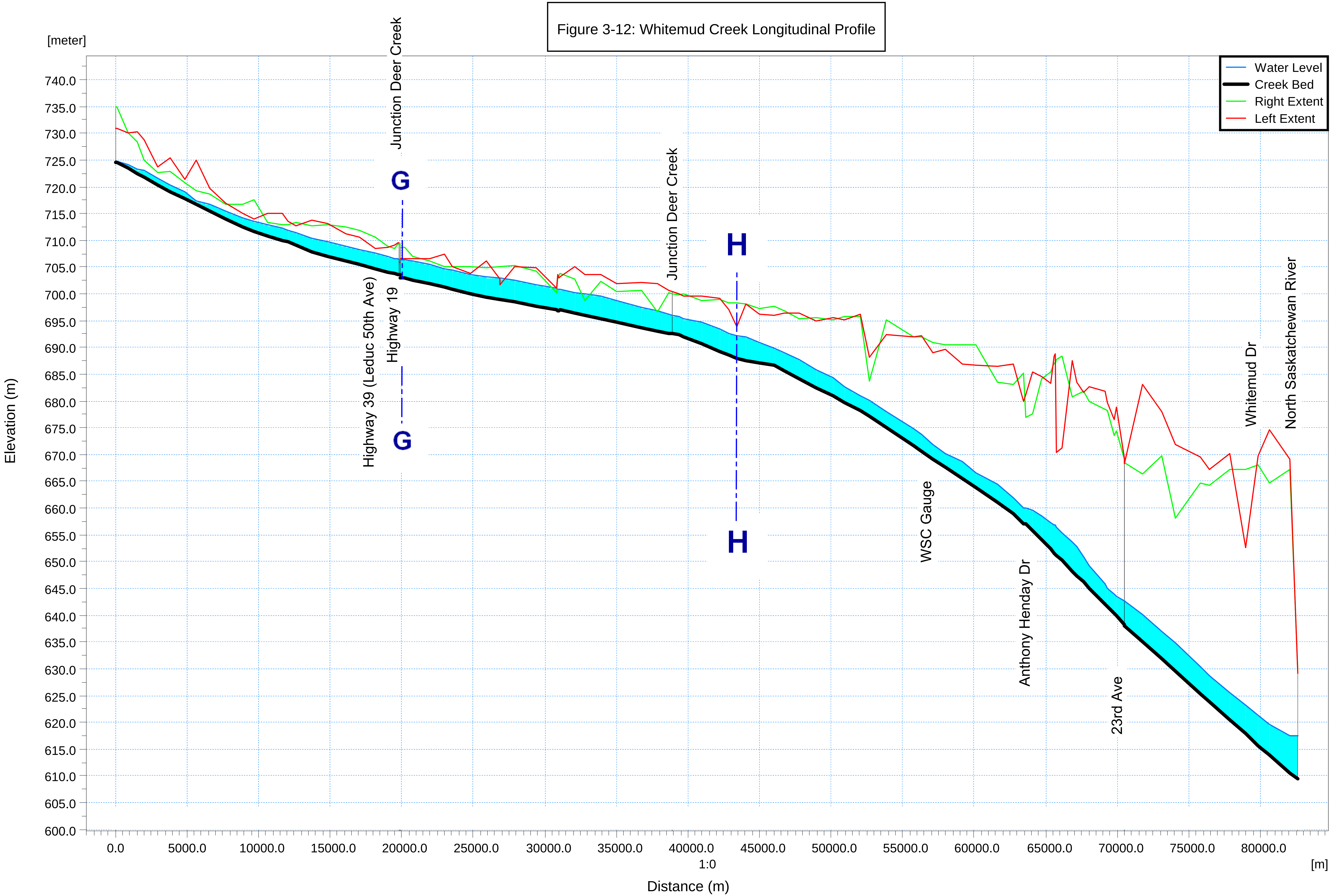


Figure 3-12: Whitemud Creek Longitudinal Profile
[meter]
Elevation (m)
Distance (m)
1:0
[m]
Water Level
Creek Bed
Right Extent
Left Extent
Junction Deer Creek
Highway 39 (Leduc 50th Ave)
Highway 19
Junction Deer Creek
WSC Gauge
Anthony Henday Dr
23rd Ave
Whitemud Dr
North Saskatchewan River
G
G
H
H
740.0
735.0
730.0
725.0
720.0
715.0
710.0
705.0
700.0
695.0
690.0
685.0
680.0
675.0
670.0
665.0
660.0
655.0
650.0
645.0
640.0
635.0
630.0
625.0
620.0
615.0
610.0
605.0
600.0
0.0
5000.0
10000.0
15000.0
20000.0
25000.0
30000.0
35000.0
40000.0
45000.0
50000.0
55000.0
60000.0
65000.0
70000.0
75000.0
80000.0

Figure 3-13 G: Whitemud Creek Section G-G

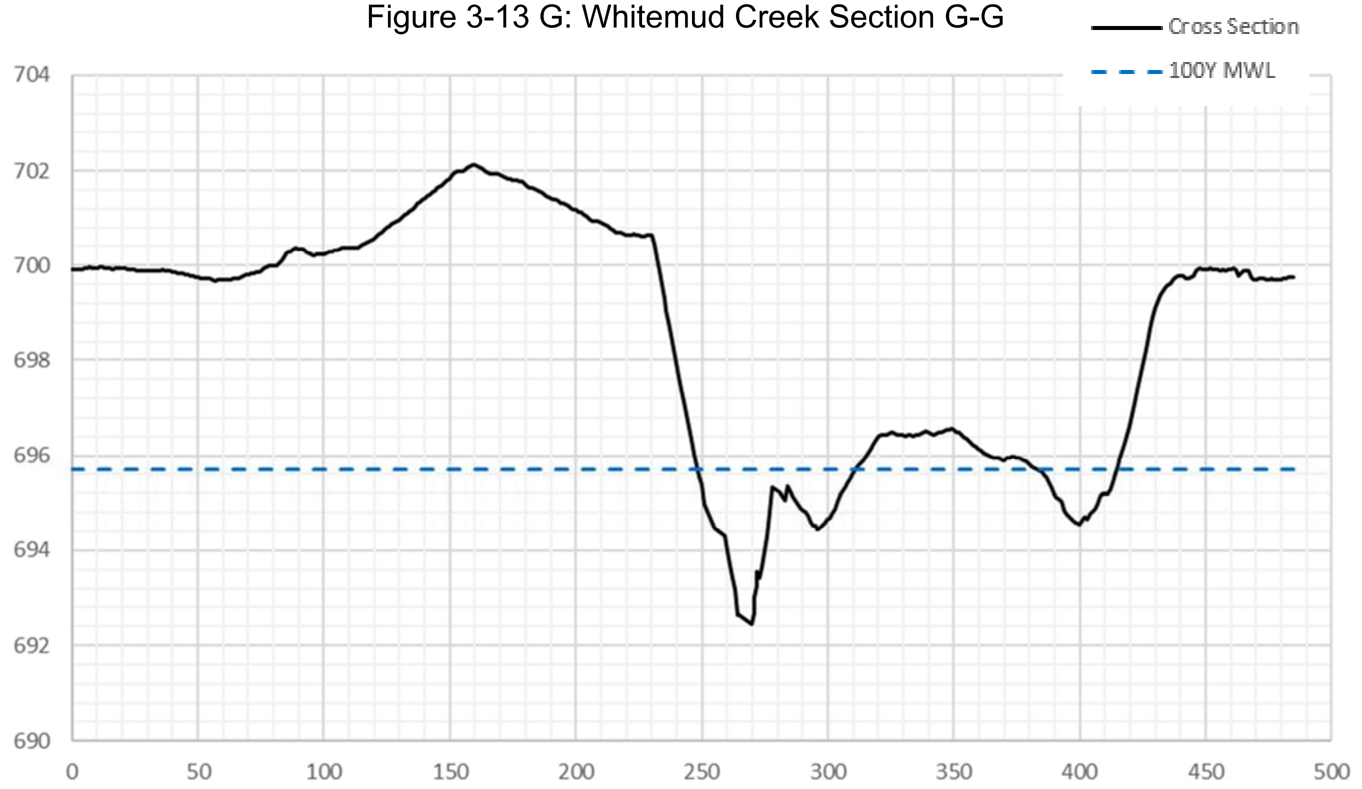
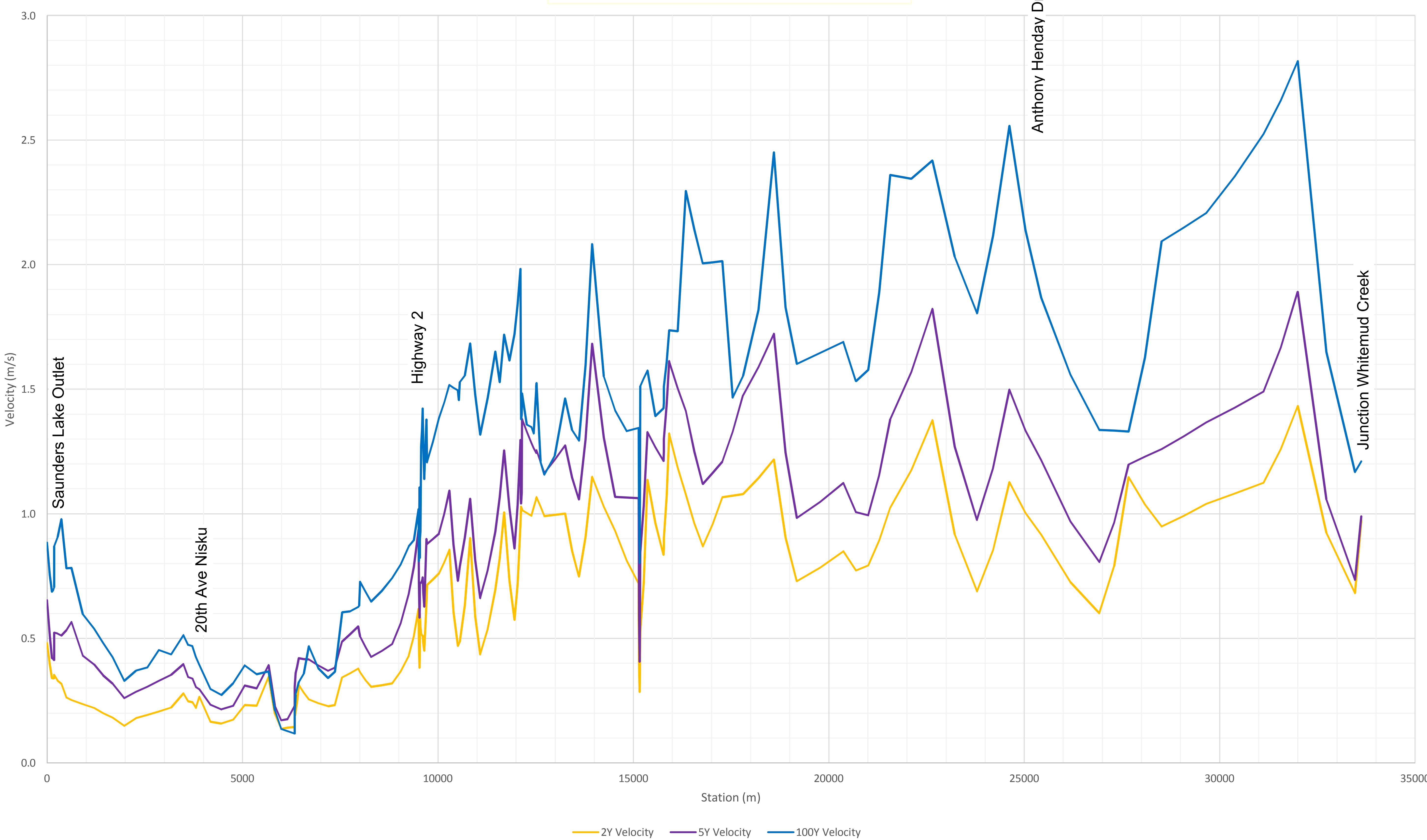


Figure 3-13 H: Whitemud Creek Section H-H

Figure 3-14: Blackmud Creek Average Velocities



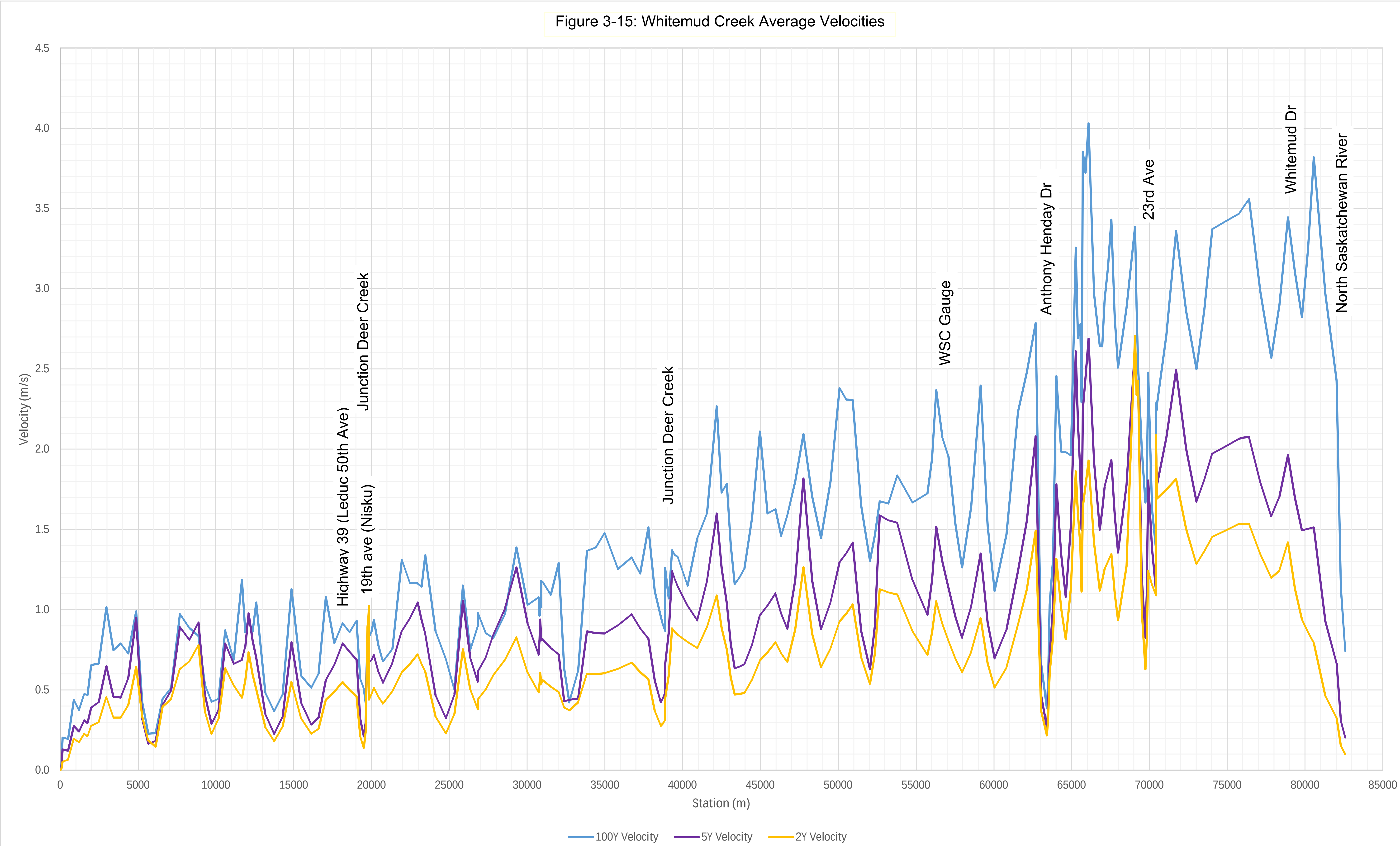


Figure 3-15: Whitemud Creek Average Velocities
Velocity (m/s)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000
60000
65000
70000
75000
80000
85000
Station (m)
Highway 39 (Leduc 50th Ave)
Junction Deer Creek
19th ave (Nisku)
Junction Deer Creek
WSC Gauge
Anthony Henday Dr
23rd Ave
Whitemud Dr
North Saskatchewan River
100Y Velocity
5Y Velocity
2Y Velocity

4 2D Model

To better understand the rate and extent of erosion in Whitemud and Blackmud Creeks, a detailed 2D model was developed. This model was used to determine velocity distribution and bed shear stresses along the Blackmud and Whitemud Creeks within the City of Edmonton and will form the baseline against which to measure changes due to development in subsequent phases of this project.

4.1 MODEL DEVELOPMENT

The 2D model extends from the gauge stations on Whitemud and Blackmud Creeks (05DF006 and 05DF003) to the North Saskatchewan River (**Figure 1-2**). The creek topography and floodplain were represented by using LIDAR data and a flexible mesh routine. The flexible mesh routine in MIKE21-FM develops a triangular mesh configuration in which the individual cell spacing is varied to better represent key elements of the topography such as the channel alignment than does a rectangular grid. The mesh sizes and arrangement affect the resolution of the final results and require a compromise between mesh resolution and run times. A 5 m mesh size was used within the creek and a range between 10 m and 100 m sizes were used for the floodplain.

Inflow boundary conditions were consistent with those adopted in the 1D model. However, the downstream boundary was represented as a negative discharge to avoid instabilities in the model. Roughness coefficients (Manning's n) of 0.035 within the creeks and 0.1 along the floodplain were used, consistent with the values used in the 1D model.

4.2 2D MODEL RESULTS

The maximum flows, water depths and velocities for existing conditions were simulated for the 1:2, 1:5, and 1:100 year design events. **Appendix E** presents the maximum velocity distribution along the creeks for the 1:2, 1:5 and 1:100 year design events. These results will be summarized below.

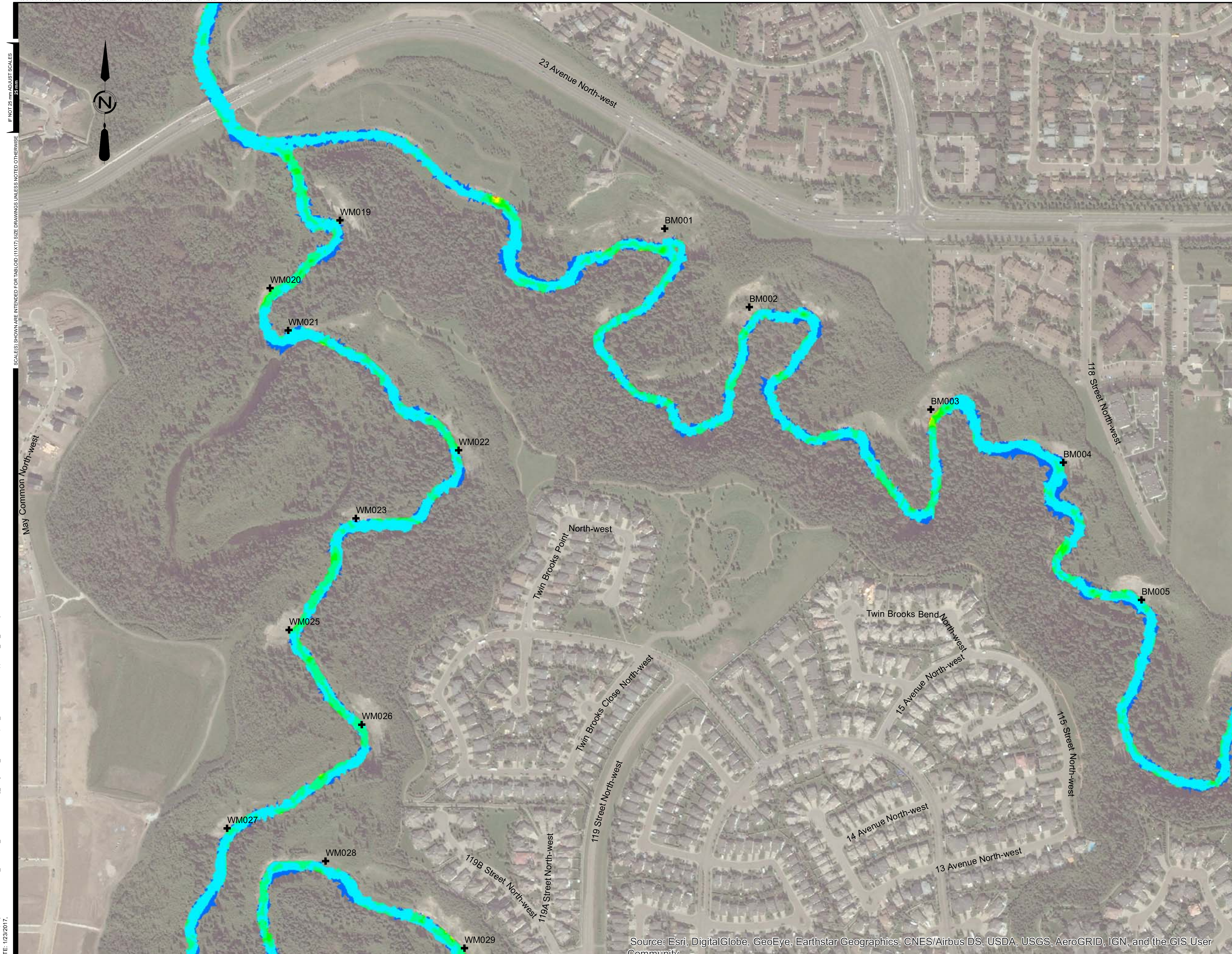
4.2.1 Channel Velocity and Bed Shear Stress

Figures 4-1 to **4-3** show a sample of the simulated velocities for the 1:2, 1:5 and 1:100 year design flow conditions, respectively, for a representative site located at the junction of Whitemud and Blackmud Creeks upstream of 23 Avenue. These maps show that the flow is mostly confined to the channel in the 1:2 year flood and some overbank flow occurs in the 1:5 year and 1:100 year floods as would be expected. These maps clearly show that the velocities are higher in the channel than in the floodplain, as would be expected, and that they increase with increasing flow. Typically, the highest velocities occur at the outside of the meander bends, as expected.

As stated in the previous section, bank erosion is common throughout the lower reaches of Blackmud and Whitemud Creeks. In general, the rate of bed and bank erosion is related to the velocity of water flowing in the channel. Vertical changes in these velocities produce shear forces that are parallel to the bed. These shear forces acting on the bed of a channel generate shear stress, which causes bedload transport or erosion, and the rate of erosion is generally higher where the velocities are higher.

Instream erosion is actively occurring at many meander bends throughout the lower reaches of Blackmud and Whitemud Creeks. In part measure this is due to the higher velocities at these locations and in part due to other processes that govern the lateral migration that occurs naturally at bends.

The erosion process is complicated and depends on a number of factors such as bed and bank materials and local hydraulic effects. Hydraulic theory indicates that the rate of sediment transport is proportional to the 3rd power of velocity or, alternatively, the shear stress raised to a power of 1.5, which means that erosion rates are very sensitive to changes in velocity. It is clear that increasing the creek flow would increase the local velocities and therefore the rate of erosion and sediment transport. These issues will be explored in the next phase of this project, for which the simulated velocities will form a baseline against which those changes resulting from future development can be measured.



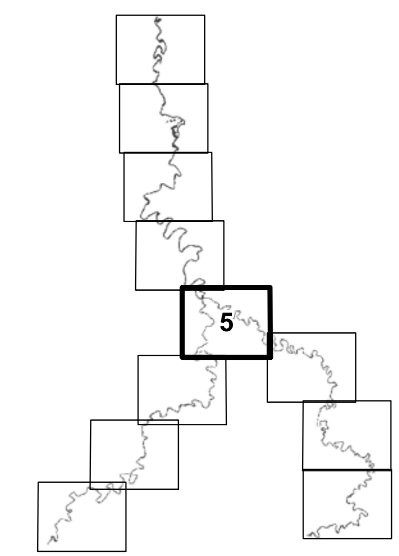
Associated Engineering

Legend:

- ✚ Erosion Site

Velocity (m/s)

- >3.5 - 4.0
- >3.0 - 3.5
- >2.5 - 3.0
- >2.0 - 2.5
- >1.5 - 2.0
- >1.0 - 1.5
- >0.5 - 1.0
- >0.0 - 0.5



Note: Maps are preliminary and subject to change.

FIGURE No. 4-1

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

2 YEAR
VELOCITY

AE PROJECT No.	2016-3785
SCALE	1:5,000
APPROVED	
DATE	2017 JANUARY
REV	
DESCRIPTION	ISSUED FOR REPORT

DATE: 1/23/2017.