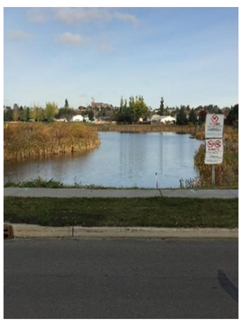
TECHNICAL MEMORANDUM NO. 3

Blackmud/Whitemud Creek Surface Water Management Group

Blackmud/Whitemud Creek Surface Water Management Study
Hydrology Assessment



October 2016

Executive Summary

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

Large portions of the Blackmud/Whitemud Creek watershed are expected to be intensively developed in the foreseeable future by the surrounding municipalities. This development will place additional stresses on Blackmud and Whitemud Creeks, which have already been impacted by previous development.

The objective of this technical memorandum was to provide a preliminary hydrology assessment for Whitemud and Blackmud Creeks. The information obtained from this assessment will be used to analyse flooding and erosion potential along the creeks and the impact of future development in the basins. This hydrology assessment included the following:

- Review of previous hydrology reports.
- Understanding the existing topography and hydrologic characteristics of the basins.
- Analyzing available hydrometric information to characterize the existing flow regime in the study area, including annual runoff and seasonal runoff patterns.
- Flood frequency analysis to estimate peak flows at different return periods.
- Assessment of peak runoff rates for the study area.

Below is a summary of the key conclusions from the study:

- Portions of the Blackmud and Whitemud basins are flat and poorly drained, and there are numerous wetlands especially in the upper basin. The upper basin creek channels are poorly defined and have limited capacities.
- The Blackmud Creek channel is relatively flat in its upper reaches (longitudinal slope = 0.05 m/km upstream of Highway 2) and steeper in the lower reaches, downstream of Highway 2.
- Whitemud Creek is relatively steep in the upstream and downstream reaches and flat in the middle. This profile suggests that the creek is still downcutting to its base level at the North Saskatchewan River which could partly explain the channel erosion that is occurring.
- Approximately 90-95% of the annual precipitation within the basin is lost to evaporation and evapotranspiration. The remaining 5-10% runs off. Runoff percentages are considerably higher in urban areas (typically 40-50% on an annual basis). This means that runoff volumes will increase by a factor of five even if peak flows are controlled, unless source controls (low impact development practices) are adopted.
- Groundwater recharge generally begins in March and peaks in early May; therefore, rainfall events in this period tend to produce relatively more surface runoff than the summer period due to the increased soil saturation in the active layer.

- Peak flows within the watercourses in the study area generally occur during the spring runoff period due to snowmelt or rain-on-snow events.
- The flood frequency analysis provides the most reliable estimates of peak discharges as it is based on actual creek discharge records from over 45 years.
- The table below provides the flood frequency estimates for key locations within the study area.

Table E-1: Flood Frequency Estimates for Key Study Area Locations

Return Period (Years)	Clearwater Creek at the mouth (m^3/s)	Irvine Creek at the Mouth (m^3/s)	Blackmud Creek at the Mouth (m^3/s)	Whitemud Creek above Blackmud Creek (m^3/s)
2	5.7	4.8	5.0	10.7
5	13.7	11.4	17.8	26.3
10	20.3	17.0	29.6	40.1
25	30.0	25.0	47.0	61.1
50	38.0	31.7	61.3	79.5
100	46.8	39.1	76.5	100.6

They indicate that the 1:100 year pre-development (existing conditions) runoff rate within the study area ranges from 1.8 to 3.0 L/s/ha based on the effective drainage area. These flood estimates are preliminary and are intended for basin planning and for comparison with modelling results, not for floodplain delineation. They will be reviewed when the modelling is completed.

- The various municipalities and the Edmonton International Airport (EIA) have different forms of SWM designed to provide varying levels of control and service level.
- The unit area runoff rates used for design of these facilities are somewhat higher than the pre-development runoff rates estimated herein and in previous studies; that is to say they are not conservative with respect to flooding and erosion potential.
- Creek channels in the project area are generally not expected to have capacity for the pre-development peak flows.

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1 Introduction

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

Large portions of the Blackmud /Whitemud Creek watershed are expected to be intensively developed in the foreseeable future by the surrounding municipalities. This development will place additional stresses on Blackmud and Whitemud Creeks, which have already been impacted by previous development.

The objective of this technical memorandum was to provide a preliminary hydrology assessment for Whitemud and Blackmud Creeks. The information obtained from this assessment will be used to analyse flooding and erosion potential along the creeks and the impact of future development in the basins. This hydrology assessment included the following:

- Review of previous hydrology reports.
- Understanding the existing topography and hydrologic characteristics of the basins.
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- Flood frequency analysis to estimate peak flows at different return periods.
- Assessment of peak runoff rates for the study area.

2 Study area

The study area is the Whitemud Creek watershed, which includes the Blackmud sub-basin as shown in **Figure 2.1**.

Blackmud Creek starts at the outlet of Saunders Lake, east of Nisku. It drains northwest through Nisku into the City of Edmonton before discharging into Whitemud Creek. Whitemud Creek originates in the farmland south of the Edmonton International Airport (EIA) and continues northwards to the North Saskatchewan River.

The study area includes a number of tributaries and creeks. Major watercourses within the study area are: Irvine Creek, Clearwater Creek, Deer Creek and the LeBlanc Canal. **Figure 2.2** presents the Whitemud/Blackmud Creek catchment boundaries and the major watercourses.

Irvine Creek is a tributary of Blackmud Creek located in the northeastern of Leduc County. The Irvine Creek basin includes lands within the Town of Beaumont, the City of Edmonton, City of Leduc, Leduc County, and Strathcona County. This area is mostly undeveloped with the exception of the Town of Beaumont. The Creek flows in a westerly direction from its upstream point at an unnamed lake east of Highway 21 into the Blackmud Creek just south of the intersection of 9th Street and 30th Avenue in Nisku.

Cawes Lake drains into Irvine Creek watershed in the Leduc County but does not have a defined outlet. The LeBlanc Canal drains into the Irvine Creek. It was originally constructed in 1910 to facilitate agricultural development in the lands south and west of the early Beaumont Village. The Canal flows in a northwesterly direction from a low area south of Beaumont into Irvine Creek. According to previous reports that we have reviewed, significant drainage modifications have been made to the Canal and its tributaries over time. This includes the addition of storm sewer outfalls, inline stormwater management ponds, and channel crossings. The Canal drains most of the Town of Beaumont, but runoff is controlled with a system of stormwater management ponds.

Clearwater Creek drains into Blackmud Creek north of Saunders Lake. The Clearwater Creek basin is mainly undeveloped with the exception of two small communities, New Sarepta and Rolly View.

Deer Creek runs in a westerly direction towards the Whitemud Creek. The Creek receives flow from the west half of the City of Leduc, the EIA, and stormwater management facilities in several developments (Deer Valley, Lakeside Estates, Bridgeport and West Haven). The eastern portion of the City of Leduc drains to Telford Lake and Blackmud Creek. The eastern portion of the EIA drains to the Blackmud Creek.

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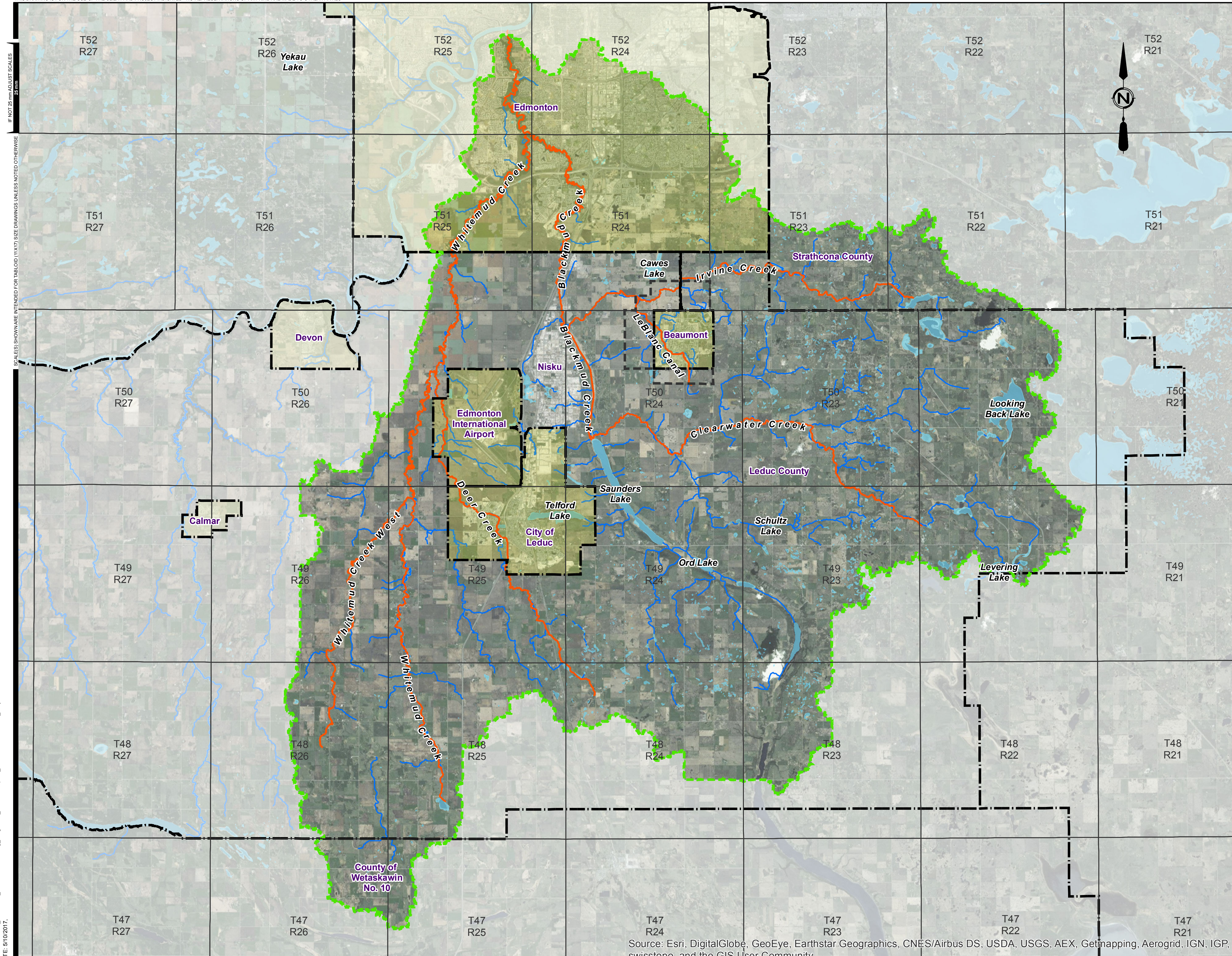

IF NOT 25 mm ADJUST SCALES 25 mm

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\2-1_ProjectArea.mxd
DATE: 5/10/2017,

Associated Engineering

Legend:
- Whitemud Watershed
- Creek of Interest
- Stream
- Municipal Boundary

FIGURE No. 2.1

BLACKMUD/WHITEMUD CREEK
WATERSHED MANAGEMENT STUDY

PROJECT AREA

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

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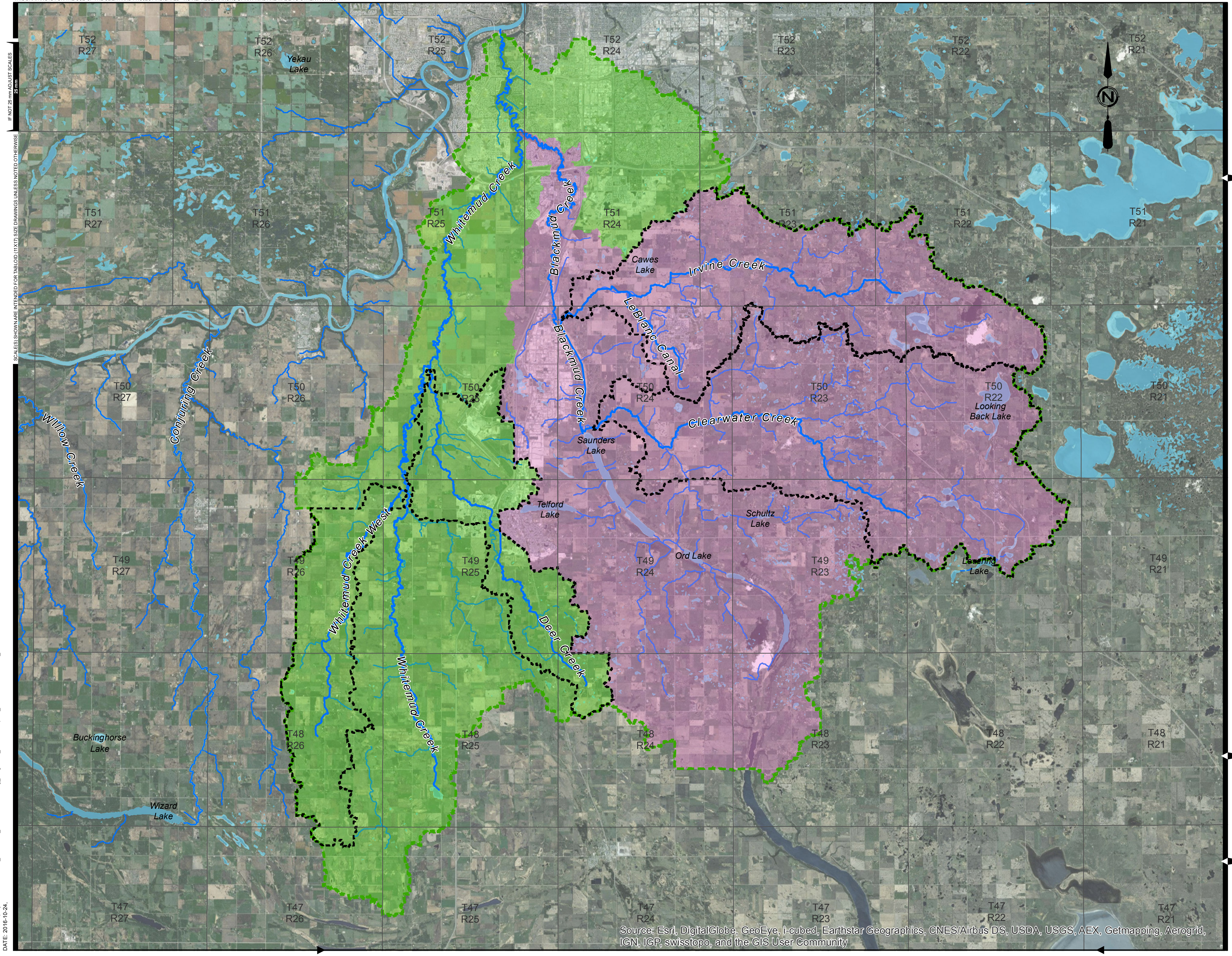


Associated Engineering

Legend:

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

FIGURE No. 2.2

BLACKMUD/WHITEMUD CREEK WATERSHED MANAGEMENT STUDY

CATCHMENT BOUNDARIES

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

2.1 EXISTING TOPOGRAPHY AND NATURAL FEATURES

AE used the bare-earth LIDAR data to generate a digital elevation model (DEM) and detailed ground elevation contours for the study area.

Figure 2.3 provides a view of the topography within the study area derived from the LIDAR data. The map is colour-coded to represent the relative elevations and the locations of the stream channels. The elevation contours have a resolution of 15 m. The DEM defines the stream channels and their physical dimensions. The LIDAR data was used to delineate boundaries for the study area as previously shown in **Figure 2.2**.

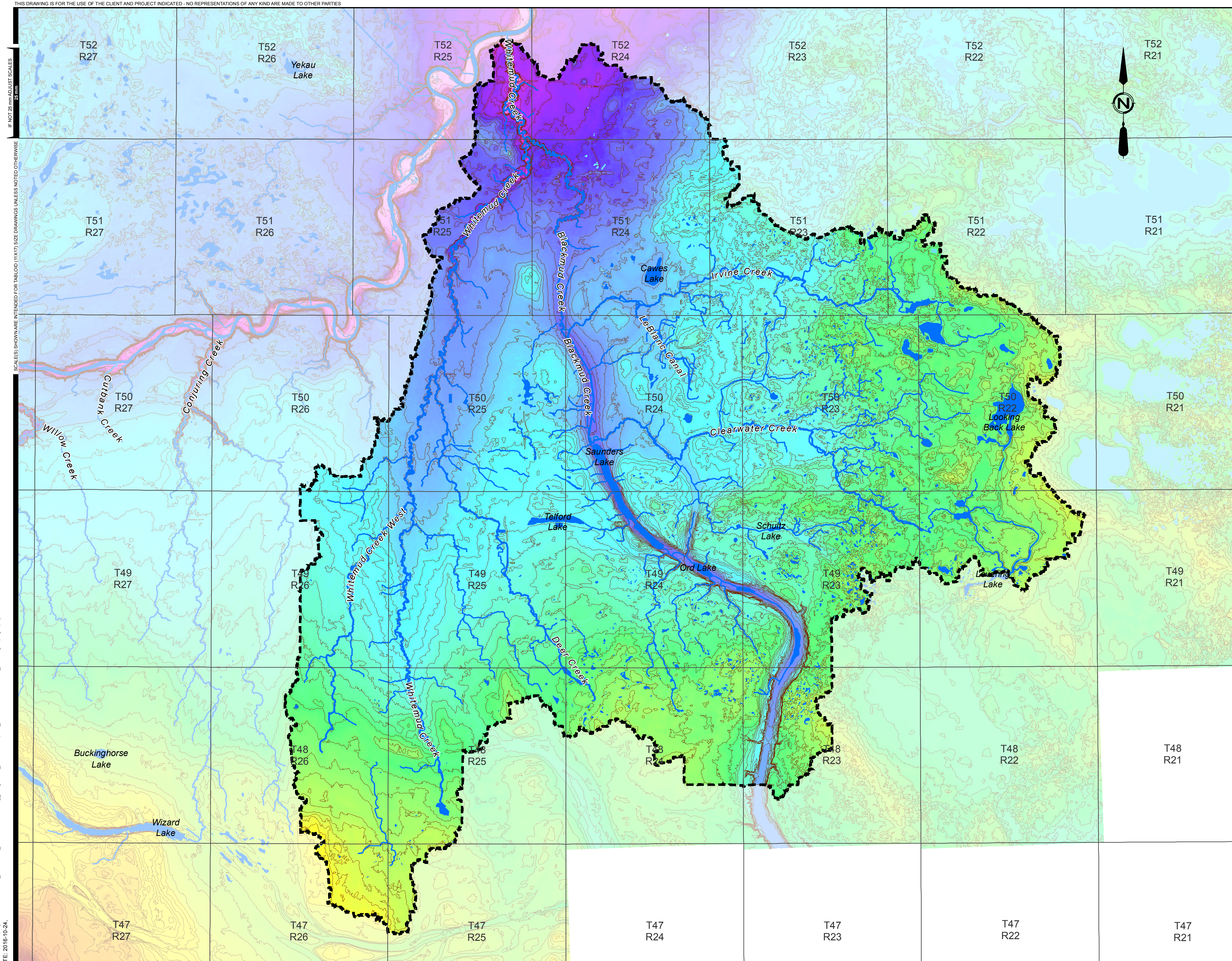
Based on the derived elevation contours, in general the Blackmud and Whitemud catchments both have gently sloping topography with average basin slopes of 1.7% for Blackmud and 1.5% for the Whitemud (at the mouth). Clearwater and Irvine Creek sub-basins have average slopes of 1.6%.

Portions of the Blackmud and Whitemud basins are flat and poorly drained. There are numerous wetlands especially in the upper basins.

Table 2.1 provides a summary of the Blackmud and Whitemud Creek watershed characteristics.

Table 2.1
Blackmud Creek and Whitemud Creek Watershed Characteristics

Basin	Drainage Area (km^2)	Average Basin Slope (%)	Sub-Basins
Clearwater Creek	208	1.6	-
Irvine Creek	158	1.6	-
Telford, Saunders and Ord Lake	237	2.1	-
Blackmud Creek	683	1.7	Clearwater Creek Irvine Creek
Deer Creek	74.5	0.8	-
West Whitemud Creek	64.8	0.7	-
Whitemud Creek at the mouth	1,168	1.5	Blackmud Creek West Whitemud Creek Deer Creek



Associated Engineering

Legend:

- Whitemud Watershed
- Creek Centreline
- 5 m Contour

Elevation

- 880 m
- 840 m
- 800 m
- 760 m
- 720 m
- 680 m
- 640 m

FIGURE No. 2.3

BLACKMUD/WHITEMUD CREEK WATERSHED MANAGEMENT STUDY

EXISTING TOPOGRAPHY

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

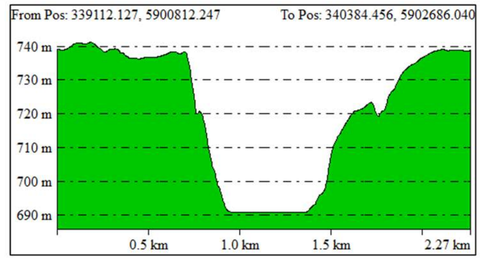
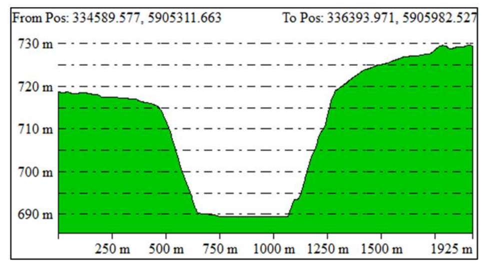
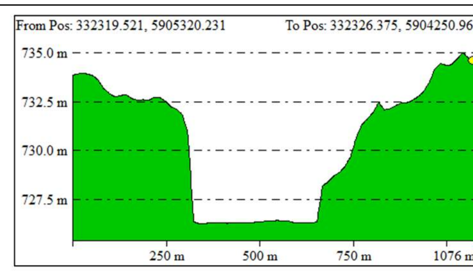
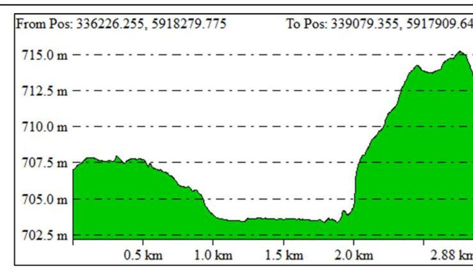
The upper catchment of Blackmud Creek contains several large lakes, namely: Saunders, Ord, Telford, Looking Back, and Cawes Lakes. It also contains vast areas of knob-and-kettle terrain that store runoff and reduce peak flows. The contributing drainage areas into these lakes is approximately 249 km^2.

Analysis of the topography of the study area indicates the following:

- The Blackmud/Whitemud Basin covers an area of approximately 1,168 km^2.
- Approximately 60% of the study area (683 km^2) is drained by Blackmud Creek and its tributaries.
- The major lakes in the Blackmud Basin cover an area of approximately 4.2 km^2 and drain an area of 249 km^2, thus providing significant streamflow routing potential and reducing peak flows.

Table 2.2 summarizes the lake characteristics based on the 15 m LIDAR data.

Table 2.2
Lake Characteristics within the Study Area

Lakes	Catchment Area (km2)	Water Level Elevation* (m)	Top of Bank Elevation (m)	Surface Area** (km2)	Typical Cross-section
Ord Lake	**99.9**	690.1	740	0.6	
Saunders Lake*	**237**	689.4	715	2.4	
Telford Lake	**11.9**	726.3	732.5	0.9	
Cawes Lake	**12**	703.6	707.5	0.5	

*Water level corresponds to the surface water elevation at the time of obtaining the 15 m LIDAR.

**Surface Area refers to the area at the surface of a lake. This is based on LIDAR data.

***Catchment area to Saunders Lake includes catchments of Ord Lake and Telford Lake.

Cross sections are taken from coordinates indicated.

2.2 CREEK CHARACTERISTICS

Blackmud and Whitemud Creeks are tributaries to the North Saskatchewan River.

Figure 2.4 and **Figure 2.5** illustrate the channel profiles for Blackmud and Whitemud Creeks, respectively. These profiles are based on the 15 m LIDAR data for the study area. The upper reaches of Blackmud Creek are relatively flat with the channel steepening down in the lower basin. In contrast, the upper and lower reaches of the Whitemud Creek are relatively steep. The channel flattens out as the creek drains through the central part of the basin. **Table 2.3** summarizes the estimated average slopes within the different sections of the creeks.

Table 2.3
Average Slopes for different Creek Reaches

Creek	Section	Slope (m/km)
Blackmud Creek	Upper Reach	0.05
	Middle Reach	1.3
	Lower Reach	3.4
Whitemud Creek	Upper Reach	2.8
	Middle Reach	0.7
	Lower Reach	2.4

AE conducted a bathymetric survey on both creeks in September 2016. The survey included approximately 6 channel cross-sections along the Blackmud and 65 along the Whitemud Creek. Typical channel cross-sections and channel dimensions are presented in **Table 2.4**.

The bathymetric survey shows that the upper basin creek channels are poorly defined and have limited hydraulic capacities. Flooding and erosion have been experienced in various areas of the basin, specifically along Irvine Creek, Blackmud Creek and Whitemud Creek. In some locations these channels are too shallow to drain run off from urban development.

Portions of the LeBlanc Canal, Irvine Creek, and the Blackmud Creek (upstream of 41st Avenue) have been extensively channelized in the past. Our assumption is that, this was undertaken to improve drainage and reduce flooding. Other channelized stream courses exist in some parts of the basin. These are likely a result of farming drainage practices. These practices tend to increase peak flow rates, erosion, and sedimentation downstream.

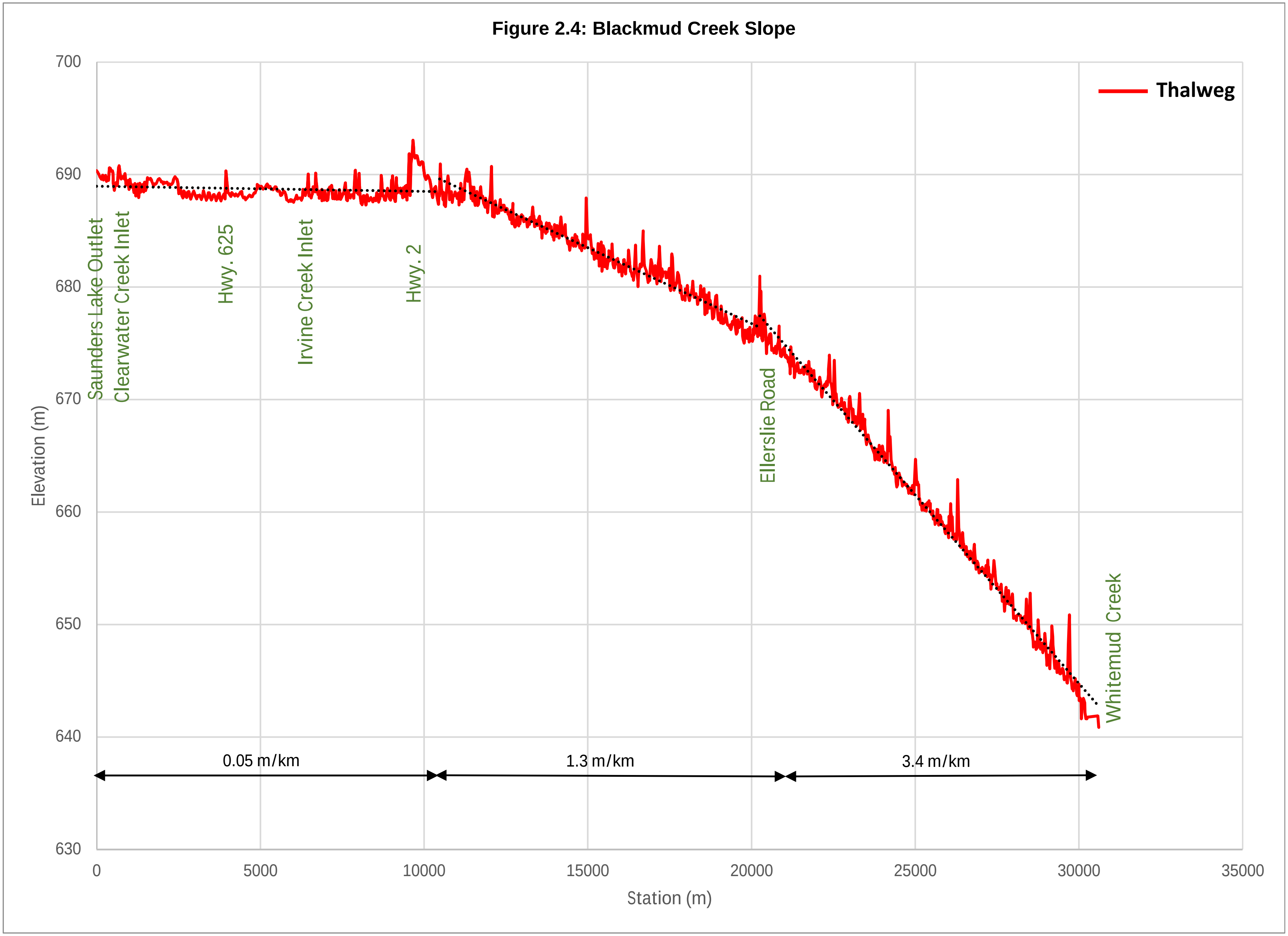


Figure 2.4: Blackmud Creek Slope
Thalweg
Elevation (m)
Station (m)
700
690
680
670
660
650
640
630
0
5000
10000
15000
20000
25000
30000
35000
Saunders Lake Outlet
Clearwater Creek Inlet
Hwy. 625
Irvine Creek Inlet
Hwy. 2
Ellerslie Road
Whitemud Creek
0.05 m/km
1.3 m/km
3.4 m/km

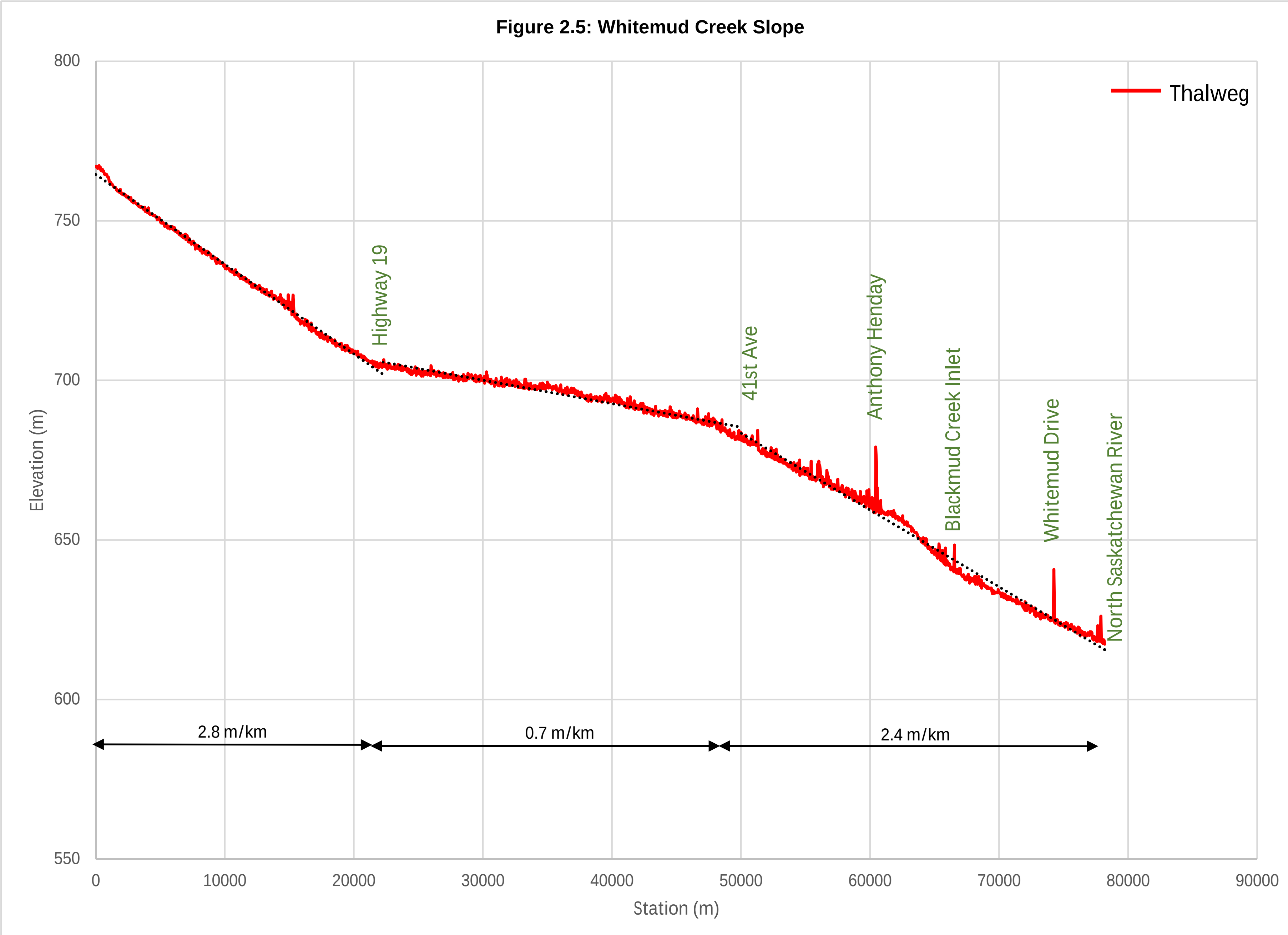
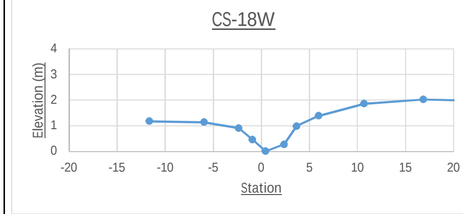
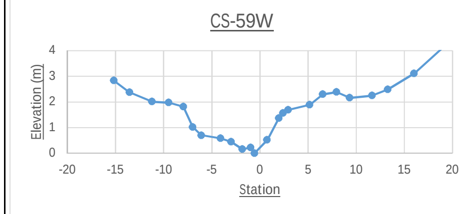
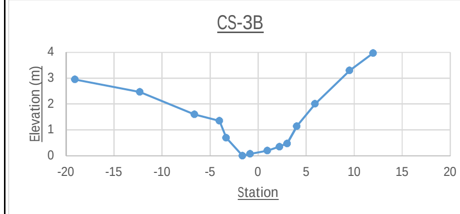
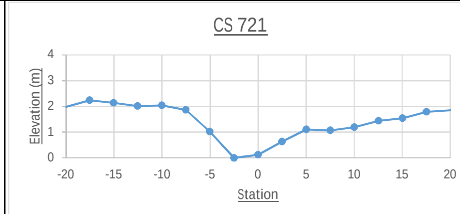
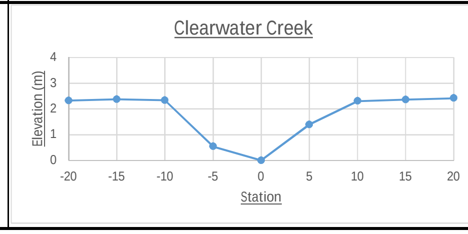


Figure 2.5: Whitemud Creek Slope
Thalweg
Highway 19
41st Ave
Anthony Henday
Blackmud Creek Inlet
Whitemud Drive
North Saskatchewan River
2.8 m/km
0.7 m/km
2.4 m/km
Elevation (m)
Station (m)
800
750
700
650
600
550
0
10000
20000
30000
40000
50000
60000
70000
80000
90000

Table 2.4: Typical Creek Cross-sections

Creek	Reach	Top Width (m)	Depth (m)	Bottom Width (m)	Typical Cross-section
WHITEMUD CREEK	**Within Leduc County (Upstream of 41 ave)**	7.4	0.9	3.0	
	Within the City of Edmonton Limits	10.4	1.4	3.9	
BLACKMUD CREEK	**Within the City of Edmonton Limits**	8.0	1.1	6.1	
IRVINE CREEK*	Upstream of the mouth	10.0	1.0	1.0	
CLEARWATER CREEK**	Upstream of the mouth	20.0	2.3	5.0	

*Cross Section obtained from Irvine Creek Stantec MIKE 11 model
**Cross Section obtained from 1 m resolution LiDAR surface
CS-3B represents survey x-sec location

2.3 EXISTING DEVELOPMENT

The Blackmud and Whitemud basins are being developed and this trend is envisioned to continue in the future. The following are developed areas that are currently discharging into the Whitemud and Blackmud Creeks:

- City of Edmonton extending south to 41st Avenue SW;
- City of Leduc;
- Leduc County's Nisku Industrial Park;
- Town of Beaumont; and
- Edmonton International Airport.

Our review of the available data shows that existing subdivisions within the study area have been developed following different standards and criteria. Based on the background review (TM1), **Table 2.5** presents the discharge release rates that have been adopted or proposed for development by each municipality. Older areas within the City of Leduc currently drain without stormwater management (SWM) or controls. These areas drain to the east towards the Telford Lake and to the northwest towards a tributary of the Whitemud Creek.

Table 2.5
Summary of SWM Discharge Release Rate

Municipality	SWM Discharge Release Rate (l/s/ha)
City of Edmonton	5
City of Leduc	2 – 8.8**
Leduc County	3.1 - 3.8*
Town of Beaumont	1.8 – 6.7

* Obtained from Planning studies

** Estimated based on outlet pipe and drainage catchment

It should be noted that the contributing drainage areas within Strathcona County are not developed.

Older developments within the City of Edmonton drain directly to Whitemud Creek without SWM or controls. The newer developments drain into Whitemud Creek and Blackmud Creek with SWM, in accordance with the Whitemud Creek Watershed Plan (1982 and 1999 Update). SWM facilities within the newer development areas of the City of Edmonton are currently designed for a release rate of 5 l/s/ha.

The Town of Beaumont, City of Leduc, Leduc County's Nisku Industrial Park, and the Edmonton International Airport all have various forms of SWM facilities designed to provide different levels of control and service levels.

The majority of runoff from the Town of Beaumont discharges into the Leblanc Canal which drains into Irvine Creek. The Town has approximately 20 SWM facilities with discharge release rates ranging from 1.8 to 6.7 l/s/ha as identified in the Irvine Creek and Cawes Lake Watershed Study (STANTEC 2014). The higher release rates correspond to areas that were built before standards were developed and adopted in the Town. However, new developments are currently being designed for a 1.8 l/s/ha release rate, as noted in the Town's design standards.

The City of Leduc also has over 25 SWM facilities for runoff control and water treatment. The release rates from these facilities range from 2 l/s/ha to 8.8 l/s/ha. The City of Leduc's design standards indicate an allowable release rate of 7.5 l/s/ha.

In general, runoff from most developments is being controlled with SWM facilities, but not always to the same standard. Drainage standards have also become more restrictive over time. In addition, significant drainage changes and channelization have occurred due to agricultural drainage practices throughout much of the basin.

These changes, plus historic land clearing to create farmland, have undoubtedly increased the flows in the study area streams in the past. As development continues in the Blackmud and Whitemud basins, the runoff rates and volumes will increase. As a result, flooding and erosion issues will likely increase unless stormwater releases are mitigated in the future.

3 Previous Hydrology Studies Summary

A number of background reports were provided by the Group during the background review stage. The most recent reports that were relevant to the hydrology of Blackmud and Whitemud Creeks are summarized in the following sections.

3.1 NISKU FLOOD HAZARD STUDY - BLACKMUD CREEK

Northwest Hydraulic Consultants (NHC) (2014) conducted a flood hazard study for Blackmud Creek within Leduc County. The study was part of the continuing flood hazard mapping efforts by the Government of Alberta to identify, map, and document flood hazard areas in communities throughout Alberta. The study area included 12 km of Blackmud Creek, from Saunders Lake to the north boundary of Leduc County.

The following is a summary of the results of the Nisku Flood Hazard Study:

- Two main tributaries discharge to Blackmud Creek.
- Upper Blackmud Creek catchment contains several large lakes, including Saunders Lake, Ord Lake, and Telford Lake and drains an area of 237 km^2.
- A Water Survey of Canada (WSC) hydrometric station, reflecting an effective drainage area of 643 km^2 (current study estimate is 683 km^2) is located on Blackmud Creek at 111th Street SW (WSC 05DF003, Blackmud Creek near Ellerslie).
- Alberta Environment (1981) provided an estimate of the Blackmud Creek 1974 hydrograph from April 11 to May 1, with a peak occurring on April 24. Maximum daily discharge was estimated by Alberta Environment to be 87.8 m^3/s. The corresponding instantaneous peak of 97.5 m^3/s was estimated by applying the Blackmud Creek peak to mean discharge ratio of 1.110 to the maximum daily discharge.
- The 1974 peak (greater than the 100-year flood event) is estimated to have an instantaneous peak of 97.35 m^3/s at the Blackmud Creek near Ellerslie WSC station.
- The next highest flood on record occurred in 1983, with a maximum instantaneous discharge of 19.4 m^3/s being recorded on July 7 at the Blackmud Creek near Ellerslie WSC station. This flood is estimated to be less than a 5-year event.
- The majority of the Blackmud Creek flood peaks have occurred in spring with the earliest peak recorded on March.
- Based on the report, the distributed runoff on a unit basis is the same everywhere in the basin – both upstream and downstream of Saunders Lake. Based on the analysis, there is a little difference in runoff depth between the catchment downstream of Saunders Lake and the entire Blackmud catchment. The storage in the Saunders Lake does not play a significant role over and above the distributed storage elsewhere in the catchment, in reducing runoff volumes, however, this will be reviewed in further project stages.

- Flow frequency analysis was completed by including the 1974 flood event. Pearson III distributions were selected for the flood peaks. The peaks at the outlet of Saunders Lake were assumed to scale with the peak for the entire catchment area downstream of Saunders Lake.
- Flood discharges on Blackmud Creek for 2-year to 1000-year return periods were estimated using peak discharge recorded by WSC at the following gauges: Blackmud Creek near Ellerslie (1974 - 2011), Whitemud Creek near Ellerslie (1969 – 2011), West Whitemud Creek near Ireton (1976 – 2000), Whitemud Creek near Nisku (1960 – 1968) and Pipestone Creek near Wetaskiwin (1972 – 2011).
- Flood frequencies for each of the salient reaches along Blackmud Creek are summarized in **Table 3.1**.

Table 3.1
Flow Frequency Estimates for Blackmud Creek

Return Period (years)	Probability of Exceedance (%)	Peak Instantaneous Discharge (m^3/s)		
		Saunders Lake to Clearwater Creek	Clearwater Creek to Irvine Creek	Irvine Creek to WSC Gauge at Ellerslie
1000	0.1	25.7	76.8	124
500	0.2	22.7	68.02	110
200	0.5	18.9	56.6	91.5
100	1	16.1	48.2	78.0
50	2	13.4	40.0	64.8
20	5	9.89	29.6	47.9
10	10	7.37	22.1	35.7
5	20	4.94	14.8	23.9

Source: Nisku Flood Hazard Study – Blackmud Creek 2014

3.2 IRVINE CREEK AND CAWES LAKE WATERSHED STUDY

The Irvine Creek and Cawes Lake Watershed Study delineated the Irvine Creek floodplain and provided options to reduce flooding and erosional impacts.

The following is a summary of the Irvine Creek and Cawes Lake watershed study (STANTEC, 2014):

- A water balance was completed based on data from nearby basins:
  - Blackmud Creek (gross area 643 km^2, effective area 374.2 km^2, flow recorded 1977-2011),
  - West Whitemud Creek (gross area 65.4 km^2, effective area 53.2 km^2, flow record 1969-2011),
  - Whitemud Creek (gross area 330.4 km^2, effective area 300.5 km^2, flow record 1969-2011).
- According to the study, a simplified water balance equation (P = Q + L) was used in the analysis, where P represents precipitation, Q represents flow, and L represents losses (combining evapotranspiration and groundwater infiltration). Calculations were performed on three different time scales: on a daily, monthly, and yearly basis. Water balance results indicated a runoff range from 6-10% of total precipitation (losses to evaporation of 90-94% on an annual basis). This contrasts with annual runoff of 40-50% of precipitation from an urban area.
- The 1:100-year peak flow for Irvine Creek at the mouth was calculated as 17.5 m^3/s. This peak flow is equivalent to a unit discharge rate of 1.1 L/s/ha (based on effective area).
- The study provided a summary of an erosion study completed by Golder (2006). Golder completed a brief hydrological assessment and flood frequency analysis of three hydrometric stations on Blackmud and Whitemud Creeks. Golder (2006) reported that high flows in Blackmud and Whitemud Creeks typically occur during the snowmelt period (mid-March and mid-April).
- The maximum recorded flow for the Whitemud Creek occurred on 23 April 1974, with a maximum instantaneous discharge of 114 m^3/s and a maximum daily discharge of 95.1 m^3/s.
- Various methods were used to generate flood flow estimates (Single-Station transfer, Regional Flood Frequency Analysis, Alberta Transportation method, Hydrological Modeling). The HEC-SSP software package was used to compute flood frequencies and to fit a 3-parameter log Pearson statistical distribution to the data. Using computed flows for the 2, 5, and 100 year return periods for each station, a power function line-of-best-fit was applied to the data to determine regression equations.
- Irving Creek Peak flows estimates are shown in **Table 3.2**.
- Expressed on a unit area basis, the 100-year return period unit discharge peak flows estimated in the report range from 0.9 l/s/ha – 2.7 l/s/ha, with the median estimate being 1.3 l/s/ha. The median value is lower than the unit release rate adopted by any of the municipalities in the basin.

Table 3.2
Irvine Creek Maximum Instantaneous Flows Estimates

Peak Flow Calculation Method	2 Year		5 Year		100 Year	
	Flow (cms)	L/s per Ha	Flow (cms)	L/s per Ha	Flow (cms)	L/s per Ha
Single Station Transfer (Blackmud)	1.7	0.1	3.5	0.2	15.6	0.9
Single Station Transfer (Whitemud)	6.2	0.4	13.5	0.8	44.6	2.7
Single Station Transfer (West Whitemud)	5.8	0.4	11.2	0.7	23.1	1.4
Regional Flood Frequency Analysis (Gross)	3.0	0.2	6.9	0.4	22.2	1.3
Regional Flood Frequency Analysis (Effective)	2.4	0.1	5.3	0.3	15.5	0.9
Alberta Transportation Method	-	-	-	-	18.1	1.1
Hydrological Modelling	-	-	-	-	17.5	1.1

Source: Irvine Creek and Cawes Lake Watershed Study 2014

4 Hydrometeorological Review

The following sections provide an overview of the hydrometeorological conditions in the study area and the general runoff mechanisms.

4.1 CLIMATE

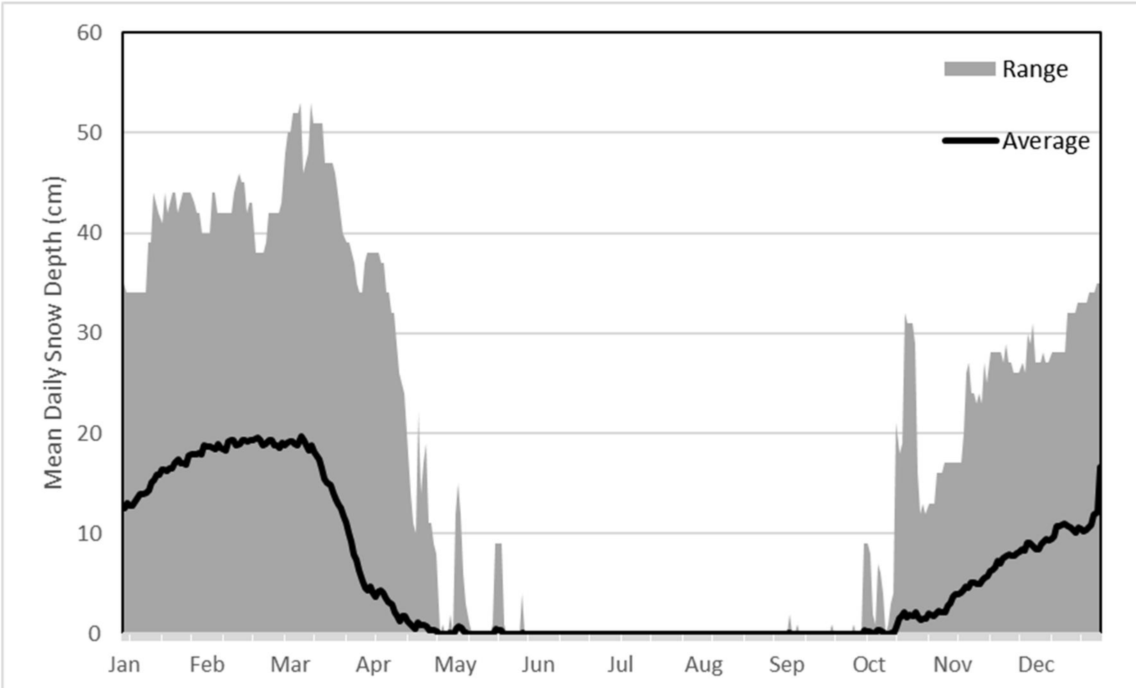
The climate of the study area is characterized by warm summers and cold winters, with a relatively even distribution of precipitation throughout the year. Based on 1981-2010 averages (i.e., climate “normal”) from Edmonton International Airport (Meteorological Service of Canada Station No. 3012205; Elevation = 703.1 m), the mean monthly air temperatures of the study area ranges from -12.1°C in January to 16.2°C in July. Air temperatures are, on average, below zero from November to March. Approximately 25% of the total annual precipitation of 446 mm falls as snow. Rainfall in June and July (combined) provides almost 40% of the total annual precipitation. **Table 4.1** presents a summary of climate information for the Edmonton International Airport.

Table 4.1
Climate Summary for Edmonton International Airport (Station No. 3012250), 1981-2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Air Temp (°C)	-12.1	-9.9	-4.4	4.2	10.2	14.1	16.2	15.2	10.2	3.8	-5.4	-11	2.6
Rain (mm)	1.4	0.5	0.9	14.9	42.9	72.7	95.6	54.9	40.3	12.6	1.6	0.8	339
Snow (cm)	21.7	13.4	17.5	14.4	6.5	0	0	0.1	1.1	10.4	17.3	15.9	118.1
Total Precip. (mm)	20.8	11.9	16.5	28.7	49.4	72.7	95.6	54.9	41.3	22.6	17.3	14.5	446.1

Based on snow depth records collected at the Edmonton International Airport, the snowpack in the study area begins to develop in October and generally persists until April. Maximum snowpacks occur in mid-February / early March and melting occurs from mid-March to April. The trend of snowpack development and melt is illustrated in **Figure 4.1**.

Figure 4.1: Summary of Snowpack Development and Melt at the Edmonton International Airport (Station No. 3012250), 1981-2010



4.2 GROUNDWATER

The study area is located in the Eastern Alberta Plains physiographic region, within the Lake Edmonton Plain district (Agriculture Canada 1986). The Lake Edmonton Plain district is an undulating area of low relief, with soils comprised of glaciolacustrine and glaciofluvial deposits.

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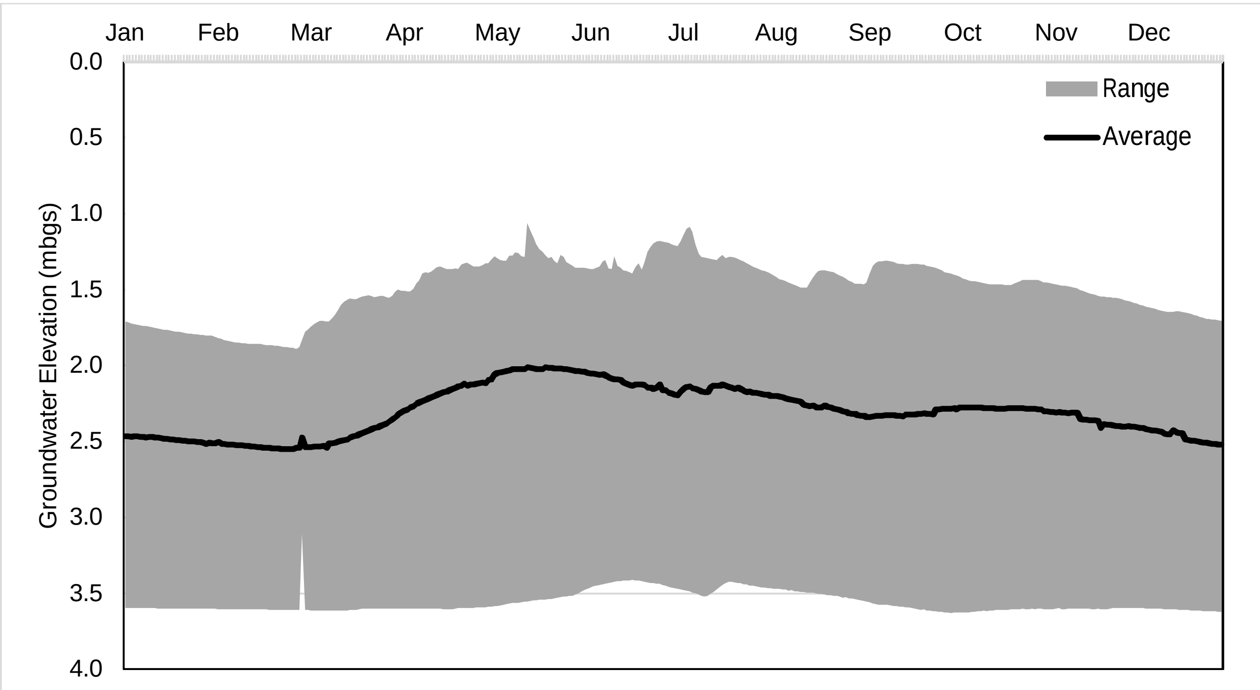
Research Council of Alberta (1979) reported that groundwater movement for the study area was from the southwest to the north towards the North Saskatchewan River. No specific surficial aquifer mapping is available for the study area, but the Research Council of Alberta (1979) noted that the surficial aquifer materials consisted of sands and clayey tills. Recharge of the surficial aquifer within the study area is dependent on the surficial materials present and is generally low in clayey materials (Research Council of Alberta 1979). ECOS Engineering Services Ltd. (1982) also reported that the surficial aquifer materials are directly connected to the creeks within the study area and impact baseflows.

There are numerous water wells within the study area, but no groundwater level monitoring is available. An Alberta Environment and Parks observation well (No. 05DFG007) is located approximately 8 km southwest of the study area north of the North Saskatchewan River opposite the Town of Devon. Figure 4.2 presents a summary of groundwater levels recorded at this well site. The seasonal trend is one of peak levels occurring in late April or early May and lowest levels generally occurring in February.

Well No. 05DFG007 is located within an unconfined aquifer and is comprised of sands. Although the well is located on the opposite side of the North Saskatchewan River to the study area, the recorded seasonal variability of groundwater levels is likely consistent with groundwater levels within the study area.

Figure 4.2: Summary of groundwater levels measured by Well No. 05DF007 (Devon), 1981-2010



4.3 HYDROLOGIC REGIME

According to NHC (2014), high flows in the study area are generally the result of spring snowmelt runoff. Figure 4.3 shows a summary of the flow data recorded by Water Survey of Canada (WSC) in Whitemud Creek near Ellerslie (WSC Gauge 05DF006). The graph shows the minimum and maximum flow recorded for each day of the calendar year along with the daily flow measurements for 2014, the most recent year of published data. As noted by NHC, the creek flow is generally highest in the spring and early summer due to snowmelt and spring rains. Peak events are relatively isolated and typically lower during the summer months June to October.

Figure 4.3: Historic Flow Data for Whitemud Creek near Ellerslie (WSC 05DF006)

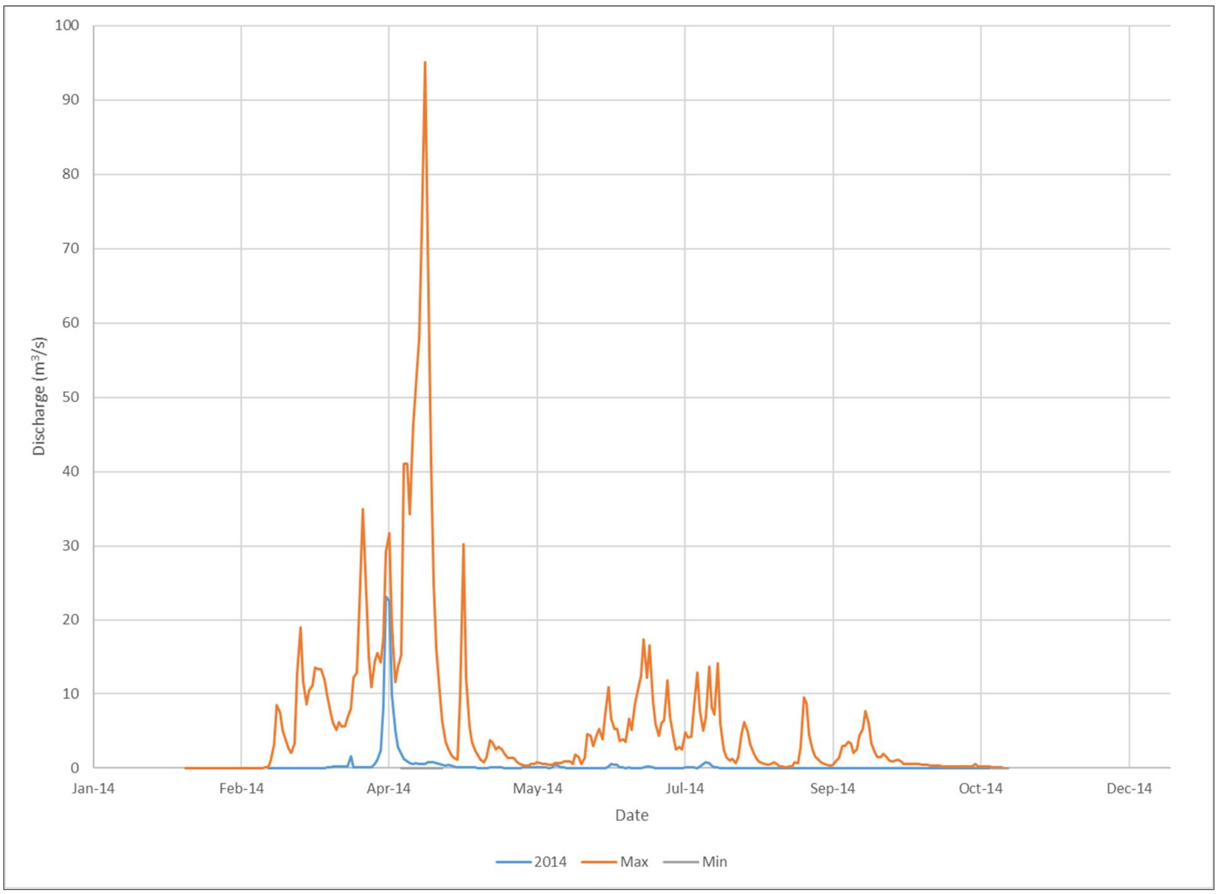


Figure 4.4 shows the historic (since 1977) and 2014 flow data for Blackmud Creek. A comparison of **Figure 4.3** to **4.4** show that summer runoff events are more significant in the Blackmud Creek than in the Whitemud Creek. The record for Blackmud Creek does not include the high snowmelt year of 1974 which dominates the flood hydrology of the region.

Figure 4.4: Historic Flow Data for Blackmud Creek near Ellerslie (WSC 05DF003)

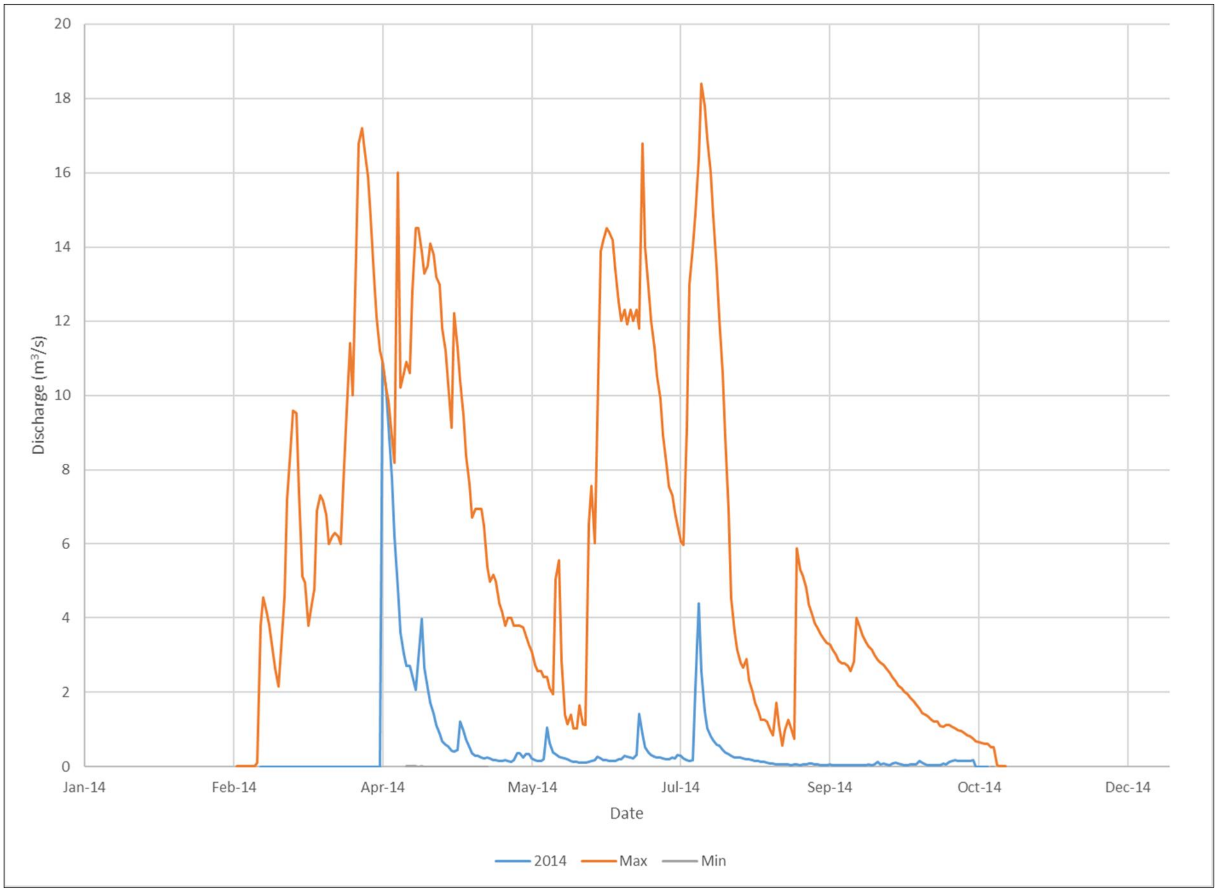


Figure 4.5 shows a direct comparison between the Whitemud and Blackmud Creks at the same scale.

Figure 4.5: Historic Flow Data for Whtiemud and Blackmud Creeks near Ellerslie

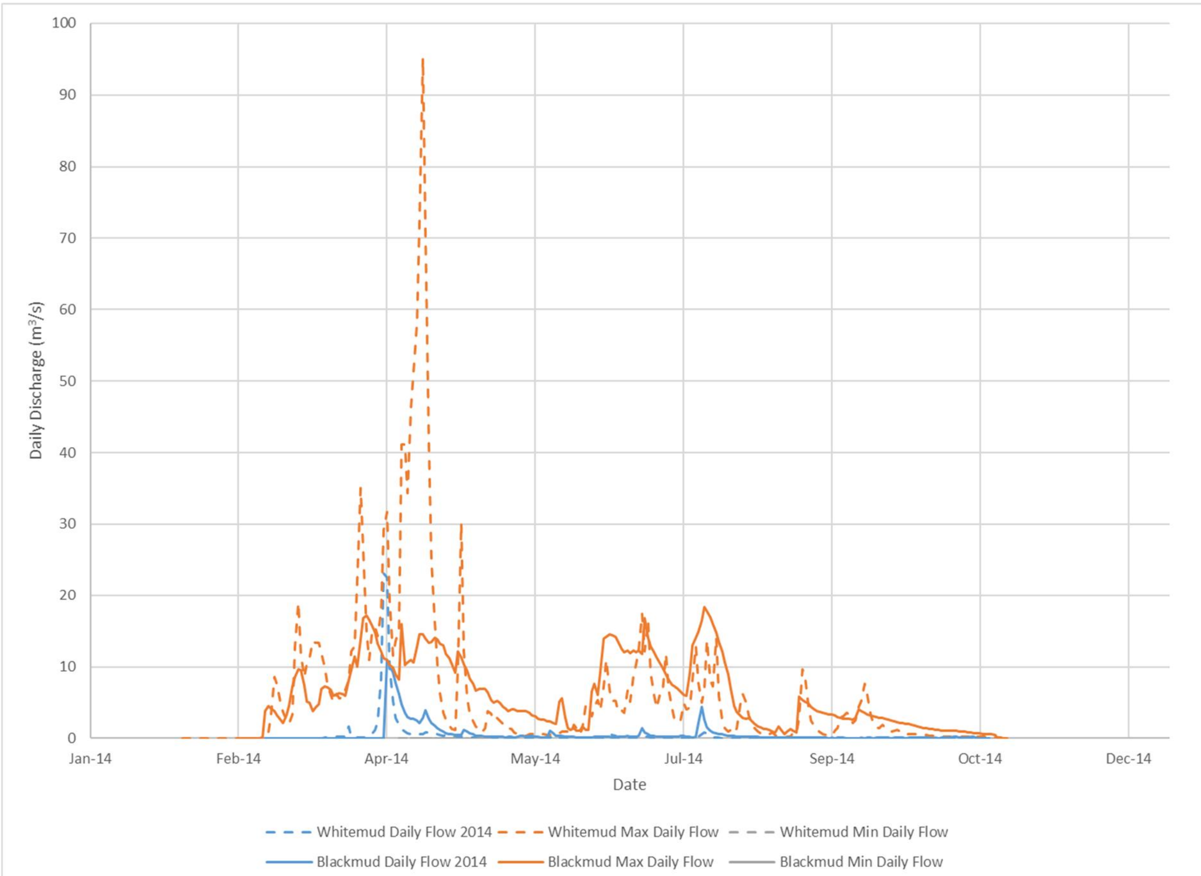


Figure 4.6 presents an overview of the annual peak flows recorded in Whitemud Creek near Ellerslie based on WSC flow records since 1969. As shown on this graph, the highest flow occurred in 1974. This was due to heavy snowpack during the previous winter months and rapid melt in April. Generally, flood peaks have been somewhat lower since 1985.

Figure 4.6: Annual Peak Flows in Whitemud Creek near Ellerslie (WSC 05DF006)

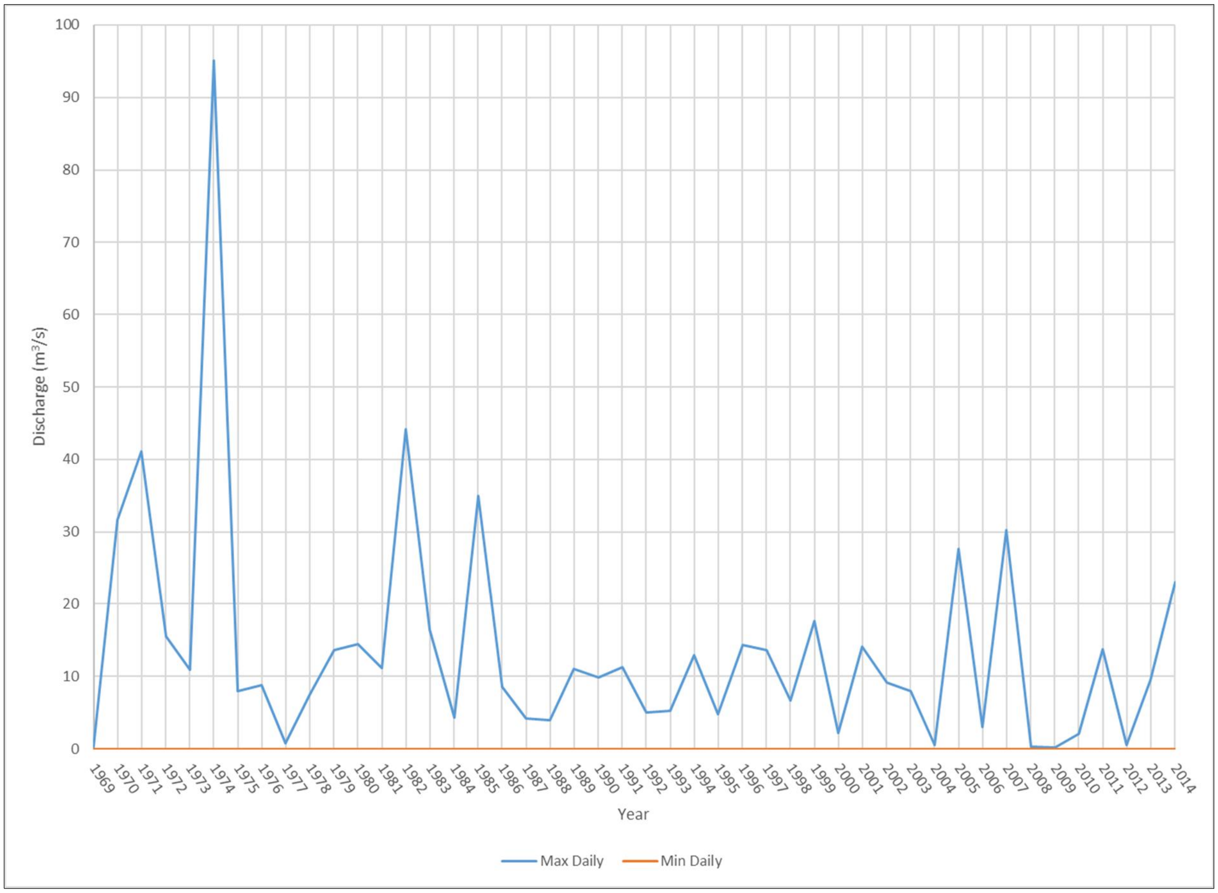
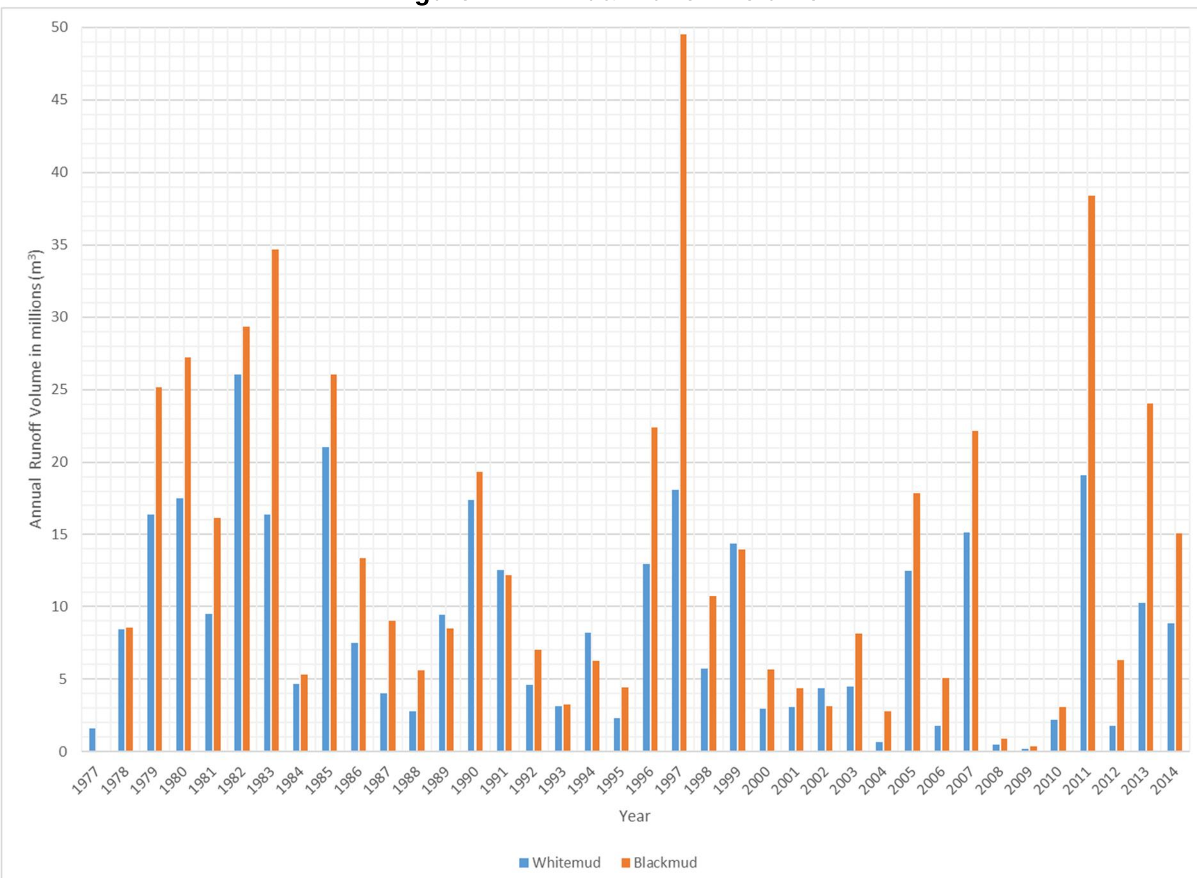


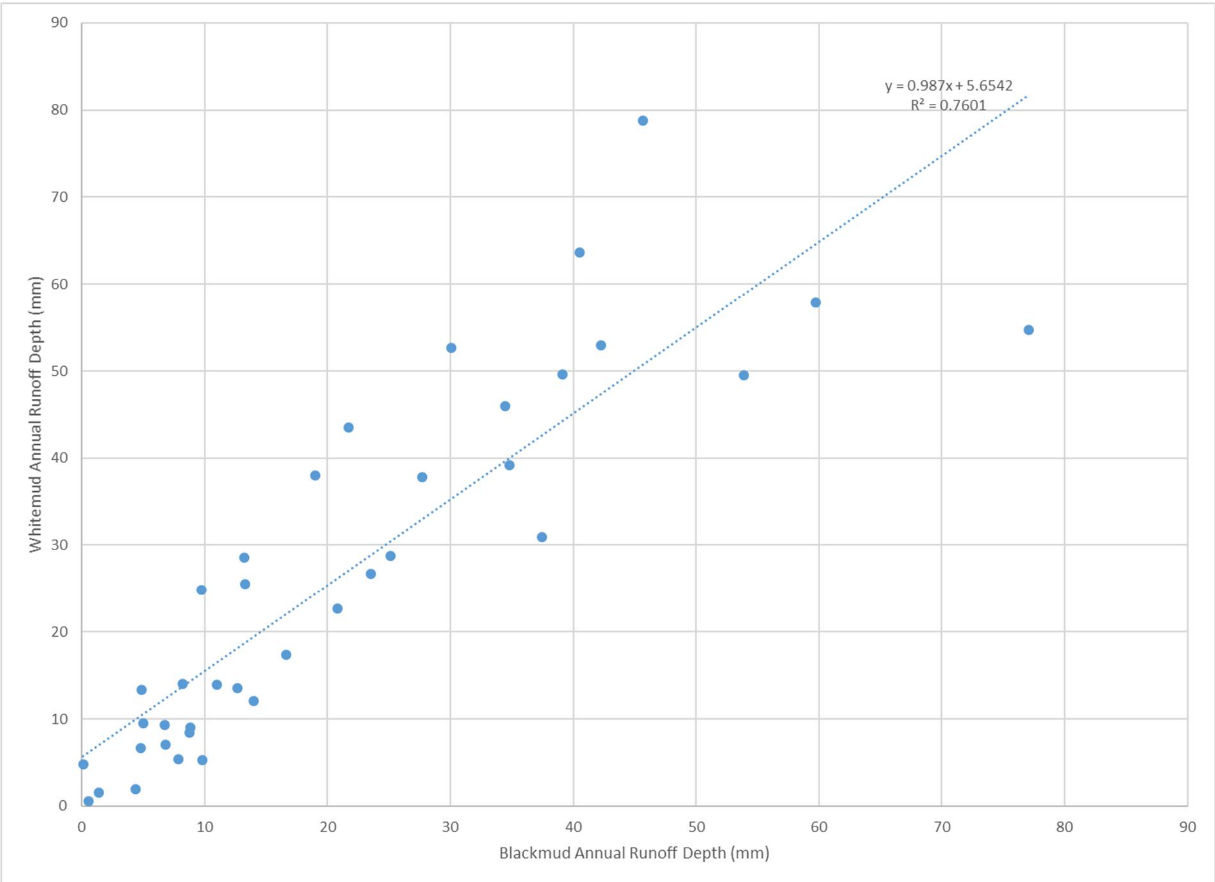
Figure 4.7 shows the annual runoff volume inBlackmud and Whitemud Creeks for the period of record. On an average annual basis the runoff volume (average flow) in Blackmud creek near Ellerslie is 50% higher than that of the Whitemud Creek near Ellerslie.

Figure 4.7: Annual Runoff Volume



A relationship was established between the annual runoff depth (volume/gross drainage area) for the Blackmud and Whitemud Creeks near Ellerslie. The analysis showed an R^2 value 0.76 which indicates a relatively good data correlation. **Figure 4.8** presents the annual run off depth correlation. This Figure shows that on a unit area basis the Blackmud and Whitemud basins generate relatively similar runoff depths although the temporal variation of this runoff, as reflected in peak flow, is affected by lake and upland storage routing which is somewhat more significant in the Blackmud basin.

Figure 4.8: Annual Runoff Depth Correlation



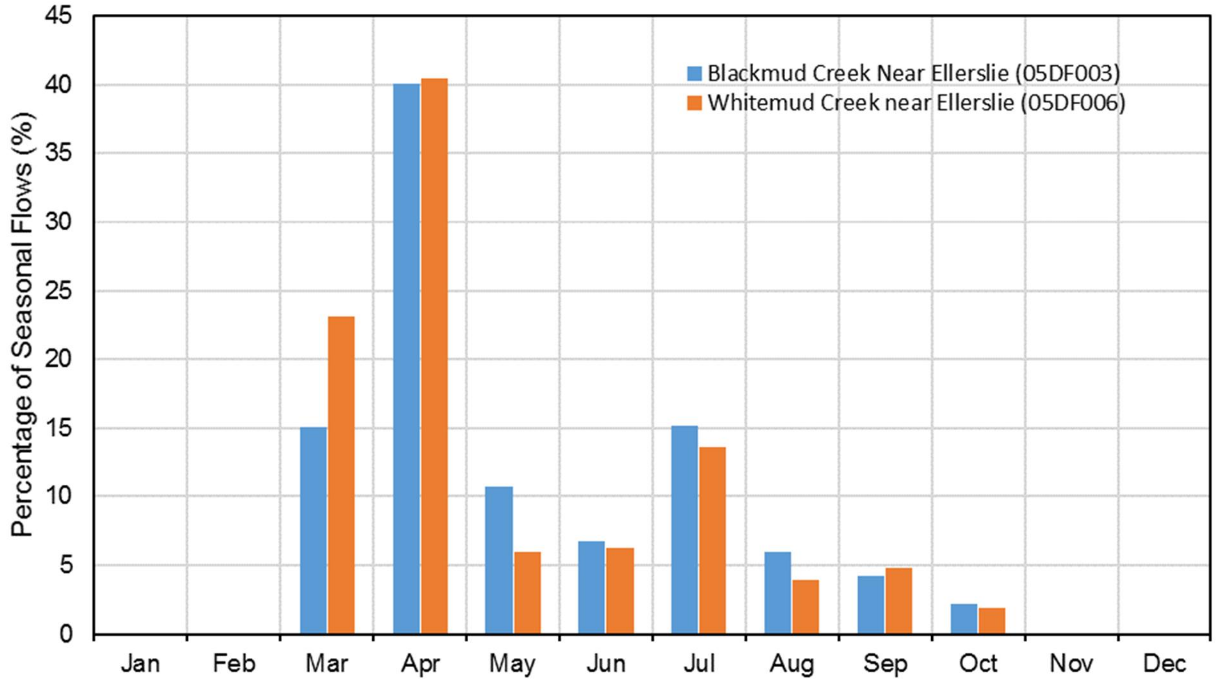
The general hydrologic regime of the study area, based on streamflow records from WSC 05DF003 and WSC 05DF006, is as follows:

- During the late summer, fall, and winter, discharge is very low or zero.
- Mid-summer and late fall rainstorms are common, recharging soil moisture and producing short-duration peak flows.

- The majority of peak flows occur in March to April (10 out of 24 years of record for WSC 05DF003 and 17 out of 26 years of record for WSC 05DF006) and are associated with snowmelt runoff events. The WSC also reports that some of the peak flows in March to April are backwater influenced, indicating the presence and influence of ice within creek channels during flood peaks.
- Other maximum instantaneous peak flows occur in June to July (10 out of 24 years of record for WSC 05DF003 and 7 out of 26 years of record for WSC 05DF006) and are associated to convectional rainfall or regional storm events.

Due to the low monthly streamflows recorded in October it is assumed that there is very low or zero flow within most watercourses within the study area from November to February when stream flows are not measured. However, during the open water season, monthly streamflows are highly variable. The highest monthly streamflows occur during March and April, with a secondary streamflow increase in July. **Figure 4.9** shows the study area monthly streamflow distribution.

Figure 4.9: Study area Monthly Streamflow Distribution based on Available Seasonal Records



The mean monthly streamflow distribution for the study area recorded by WSC 05DF003 and WSC 05DF006 was averaged. The mean monthly distribution is assumed to be representative of the natural distribution within the study area. **Table 4.2** presents the estimated natural monthly stream flow distribution, however, there can be natural variability within each month (as observed in **Figure 4.3**). As stated earlier, it is assumed that there is very low or zero streamflow within the watercourses in the study area from November to February.

Table 4.2
Estimated Monthly Streamflow Distribution within the Study area

Month	Monthly Flow Distribution (%)	Month	Monthly Flow Distribution (%)
January	0.0	July	14.4
February	0.0	August	4.9
March	19.1	September	4.5
April	40.2	October	2.0
May	8.3	November	0.0
June	6.5	December	0.0

Table 4.2 indicates that most of the natural streamflow in the study area is typically generated by snowmelt, which accounts for about 60% of the annual streamflow runoff. However, the monthly distribution is highly variable and can be significantly different from year to year.

5 Peak Flow Analysis

AE updated the flood frequency analysis using the most recent flow data (up to 2014) to estimate the peak streamflows at various locations in the study area. The following sections summarizes the analysis completed for both Blackmud and Whitemud Creeks.

5.1 FLOW FREQUENCY ANALYSIS

The available Water Survey of Canada (WSC) gauge data showed that there is one (1) gauge located on Blackmud Creek and three (3) gauges located on Whitemud Creek. **Figure 5.1** shows the gauge locations and the outlines of their catchment areas. **Table 5.1** presents key information about the gauges located within the study area.

Table 5.1
WSC Gauges

Gauge	Description	Gross Drainage Area (km^2)	Effective Drainage Area (km^2) *	Years of Available Data
05DF003	Blackmud Creek near Ellerslie	643	375	1935 + 1977 - 2016
05DF006	Whitemud Creek near Ellerslie	330.4	300	1969 - 2016
05DF007	West Whitemud Creek near Ireton	65.4	53	1976 - 2016
05DF009	Whitemud Creek at Edmonton	1107.8	800	2013 - 2016

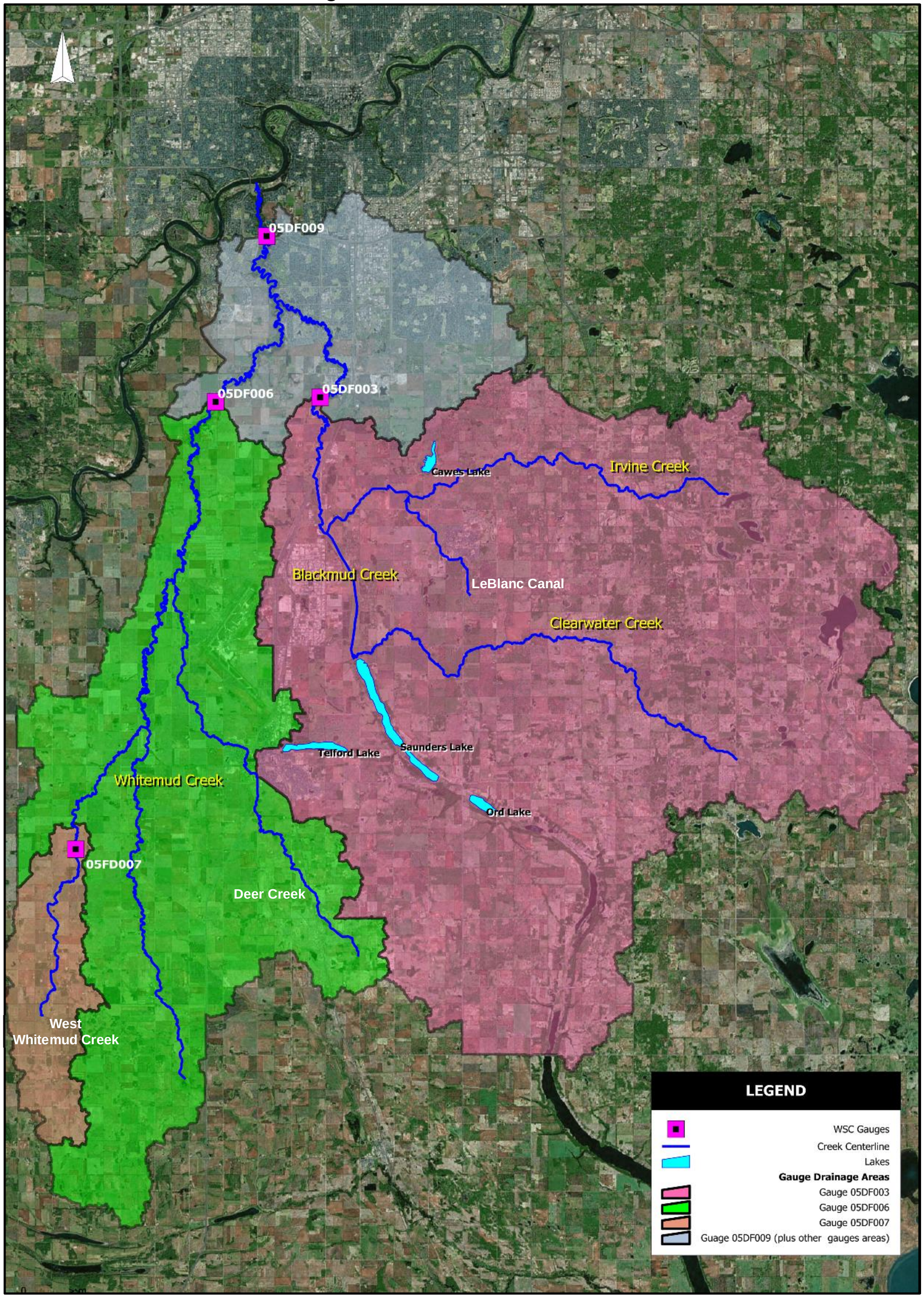
*To be modified if necessary

Table 5.2 presents below the available data for annual peak flows provided by Water Survey of Canada for the study area flow gauges.

Alberta Environment estimated the maximum daily discharge for the 1974 event to be 87.8 m^3/s for Blackmud Creek. The corresponding instantaneous peak was estimated to be 97.5 m^3/s. This value was included in the flood frequency analysis for the Blackmud Creek.

Flood frequency analysis was conducted using the available data for maximum instantaneous values up to 2014. Where maximum instantaneous values were not available, they were estimated based on a linear relationship between maximum daily values and maximum instantaneous values, as shown in **Figure 5.2** and **Figure 5.3**. The average ratio of instantaneous to daily maximum flow is 1.10 for Blackmud Creek and 1.18 for Whitemud Creek. Missing years (1969-1976 for Blackmud Creek and West Whitemud Creek) were estimated by correlating annual maximum daily peak flows for Blackmud and Whitemud Creeks. The 1974 flood peak was estimated previously by Alberta Environment.

Figure 5.1
WSC Gauge Locations and Catchment Areas



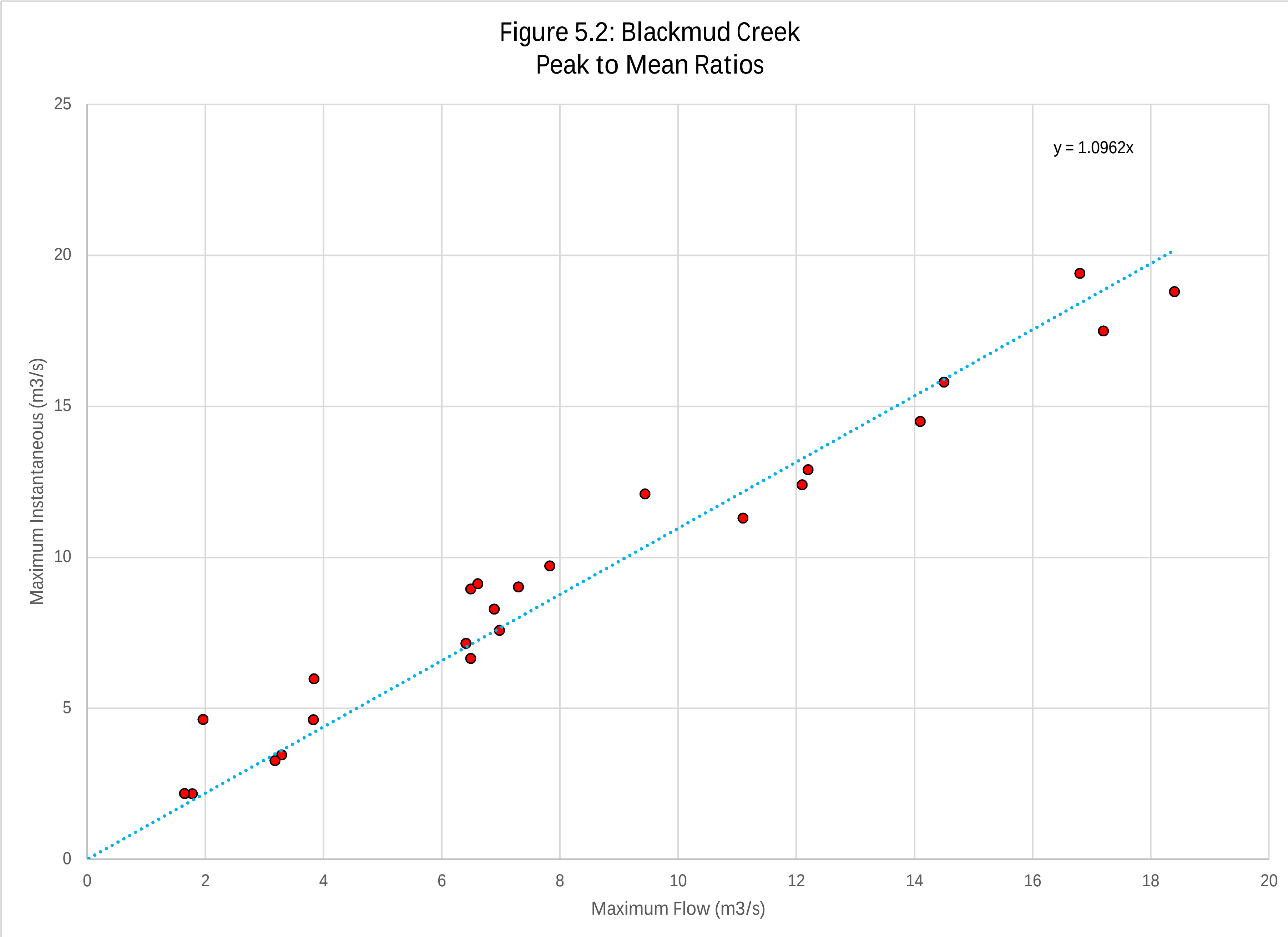


Figure 5.2: Blackmud Creek
Peak to Mean Ratios
y = 1.0962x
Maximum Instantaneous (m3/s)
Maximum Flow (m3/s)
0
5
10
15
20
25
0
2
4
6
8
10
12
14
16
18
20

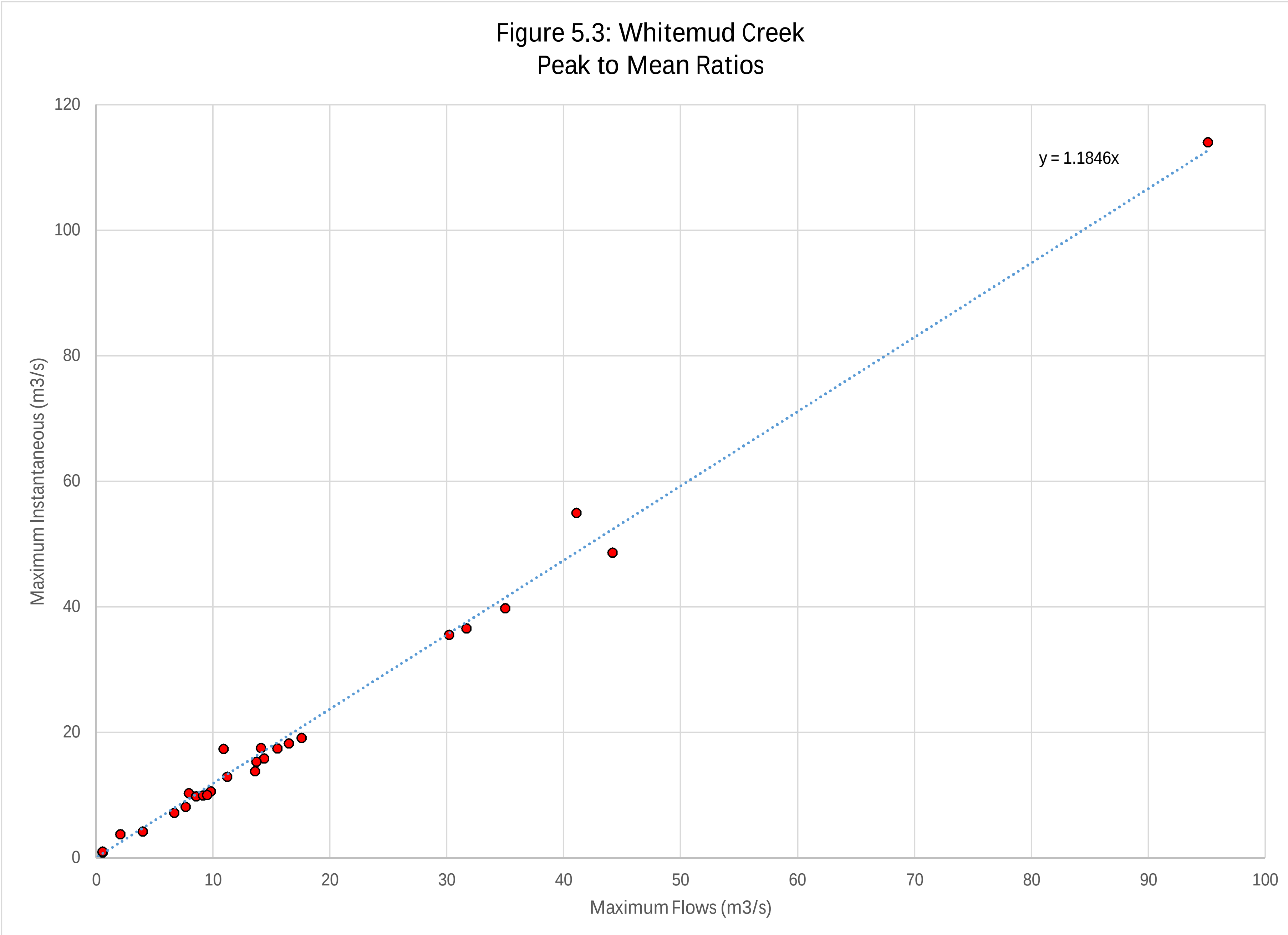


Figure 5.3: Whitemud Creek
Peak to Mean Ratios
y = 1.1846x
Maximum Instantaneous (m3/s)
Maximum Flows (m3/s)
0
20
40
60
80
100
120
0
10
20
30
40
50
60
70
80
90
100

Table 5-2
Maximum Instantaneous and Mean Discharges

Year	Blackmud Creek		Whitemud Creek		West Whitemud Creek		Whitemud Creek COE	
	Maximum Instantaneous Values (m^3/s)	Maximum Mean Values (m^3/s)	Maximum Instantaneous Values (m^3/s)	Maximum Mean Values (m^3/s)	Maximum Instantaneous Values (m^3/s)	Maximum Mean Values(m^3/s)	Maximum Instantaneous Values (m^3/s)	Maximum Mean Values (m^3/s)
1969	0.17	0.15	0.4	0.303	0.06	0.05	-	-
1970	17.48	15.95	36.5	31.7	6.63	5.28	-	-
1971	22.66	20.67	54.9	41.1	8.59	6.85	-	-
1972	8.55	7.80	17.4	15.5	3.24	2.58	-	-
1973	6.01	5.48	17.3	10.9	2.28	1.82	-	-
1974	97.5**	87.8**	114	95.1	19.88	15.85	-	-
1975	4.37	3.99	10.3	7.93	1.66	1.32	-	-
1976	4.84	4.42	10.4	8.78	1.84	1.46	-	-
1977	0.034	0.031	0.9	0.776	3.14	1.59	-	-
1978	2.17	1.78	8.07	7.65	3.77	3.23	-	-
1979	9.02	7.3	13.8	13.6	3.6	2.9	-	-
1980	7.58	6.98	15.8	14.4	3.3	2.35	-	-
1981	6.906	6.3	12.9	11.2	1.72	1	-	-
1982	14.5	14.1	48.6	44.2	6.21	5.52	-	-
1983	19.4	16.8	18.2	16.5	3.64	2.72	-	-
1984	4.056	3.7	5.1	4.27	0.871	0.818	-	-
1985	17.5	17.2	39.7	35	5.75	5.2	-	-
1986	8.29	6.89	9.75	8.56	1.13	1.1	-	-
1987	5.98	3.84	4.9	4.14	3.48	1.76	-	-
1988	12.1	9.44	4.15	3.98	0.49	0.337	-	-
1989	4.62	3.83	13.0	11	6.16	3.14	-	-
1990	12.497	11.4	10.6	9.82	4.05	3.81	-	-
1991	8.95	6.49	13.4	11.3	4.02	2.82	-	-
1992	3.881	3.54	5.9	5	0.78	0.62	-	-
1993	2.751	2.51	6.2	5.21	1.59	1.27	-	-
1994	4.472	4.08	15.3	12.9	1.63	1.3	-	-
1995	3.201	2.92	5.6	4.75	0.71	0.565	-	-
1996	8.846	8.07	16.9	14.3	3.45	2.75	-	-
1997	15.8	14.5	16.1	13.6	5.02	4	-	-
1998	9.72	7.83	7.14	6.68	4.18	2.95	-	-
1999	6.65	6.49	19.1	17.6	4.01	2.63	-	-
2000	3.46	3.29	2.6	2.19	0.28	0.227	-	-
2001	9.13	6.61	17.5	14.1	1.99	1.41	-	-
2002	3.047	2.78	9.91	9.16	1.12	0.972	-	-
2003	10.140	9.25	9.5	8	3.18	2.54	-	-
2004	1.206	1.1	0.789	0.564	0.013	0.01	-	-
2005	10.513	9.59	32.8	27.7	3.67	2.93	-	-
2006	3.27	3.18	3.5	2.98	1.05	0.955	-	-
2007	12.9	12.2	35.5	30.2	7.1	6.11	-	-
2008	2.18	1.65	0.3	0.293	0.061	0.049	-	-
2009	0.409	0.373	0.2	0.168	0.035	0.028	-	-
2010	4.63	1.96	3.73	2.07	2.02	1.44	-	-
2011	18.8	18.4	15.3	13.7	5.4	4.63	-	-
2012	7.15	6.41	0.982	0.549	0.208	0.075	-	-
2013	12.4	12.1	10	9.52	1.01	0.796	21.1	31.8
2014	11.3	11.1	27.4	23.1	5.46	4.45	41.1	48.3

Estimated Values Highlighted in red

**Estimated by AEP

Calculations were based on the analysis and comparison of Pearson Type III, Log Pearson Type III, Log Normal and Gumbel frequency distribution systems. **Figure 5.4a-c** shows the adopted flood frequency curves. **Table 5.3** provides a summary of the flood frequency estimates for the three gauge sites along with the gross and effective drainage area and the unit discharge rates per hectare calculated from the peak flow estimate and the gross drainage area.

Based on the above data, the estimated 1:100 year return period discharge is 71.5 m^3/s for Blackmud Creek and 95 m^3/s for Whitemud Creek at the WSC gauge sites. The unit discharge rates range from 1.1 to 2.9 L/s/ha for the 1:100 year return period when calculated using the gross drainage area. Note that this analysis includes the 2013 and 2014 peak flows from the WSC gauge stations and therefore yields slightly different values than the previous analyses.

Figure 5.4a: Blackmud Creek near Ellerslie Flow Frequency Curve

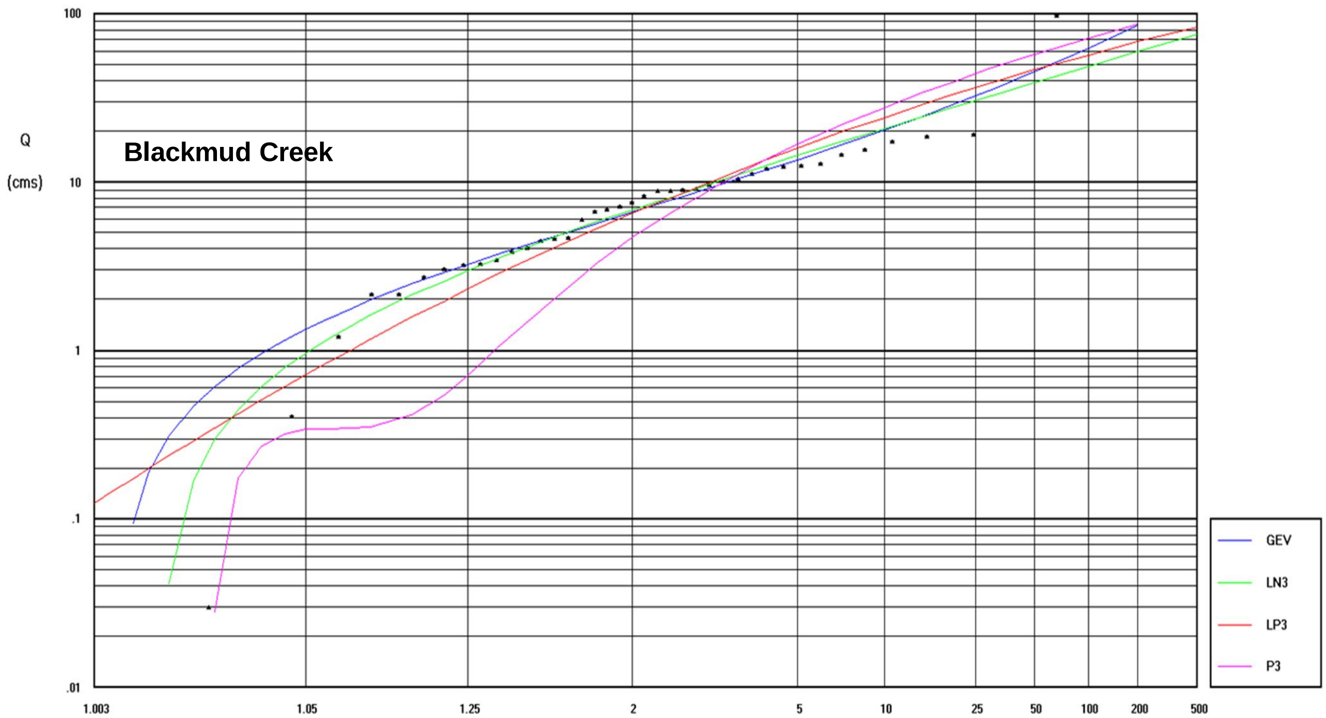


Figure 5.4b: Whitemud Creek near Ellerslie Flow Frequency Curve

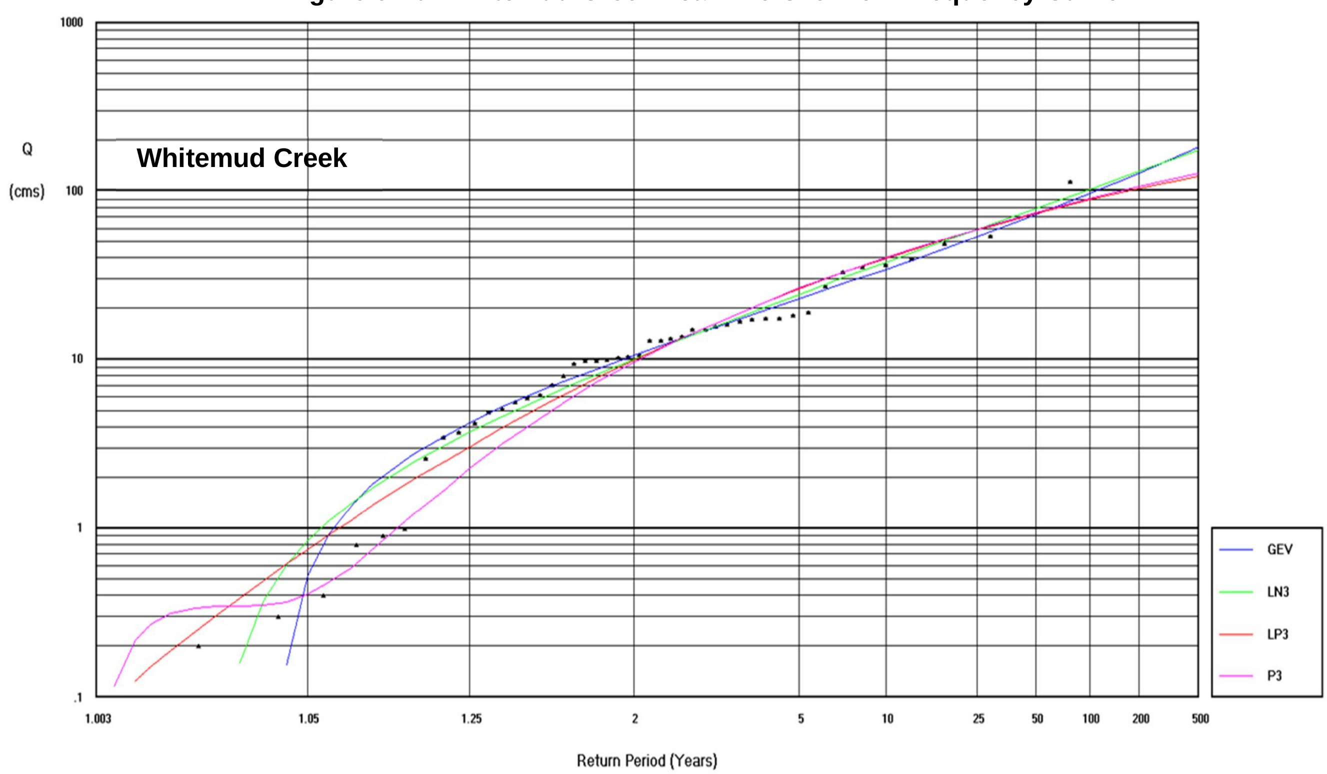


Figure 5.4c: West Whitemud Creek near Ireton Flow Frequency Curve

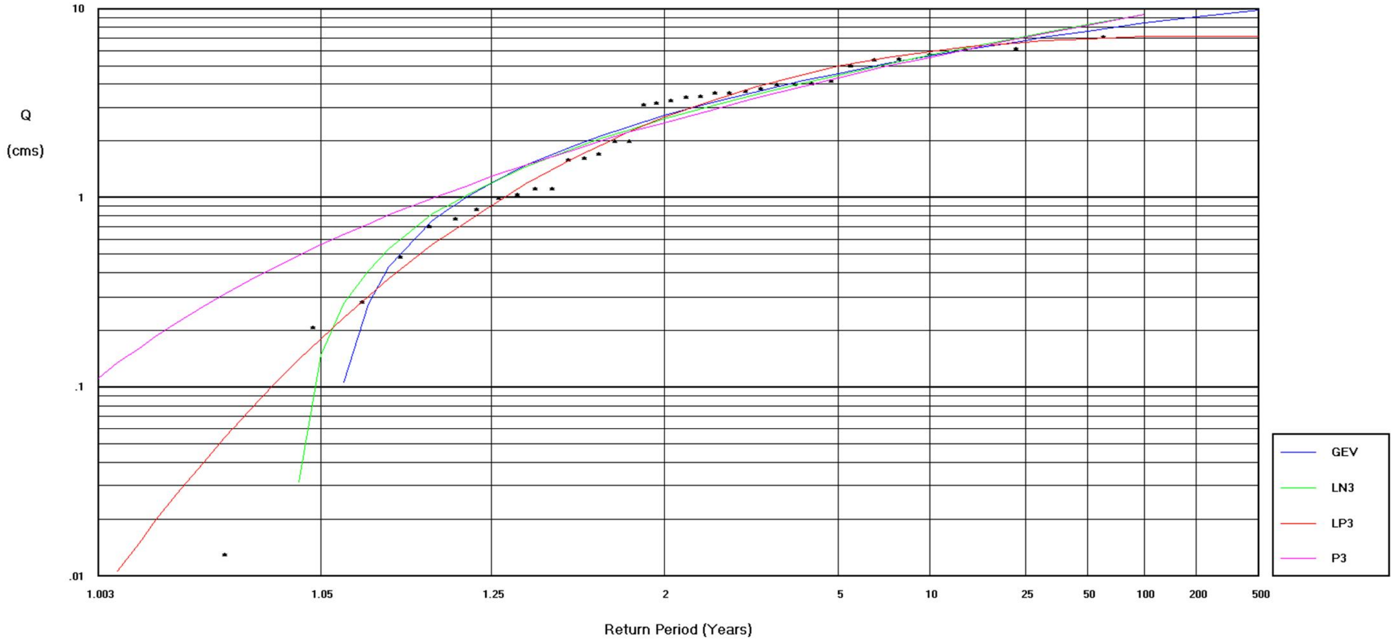


Table 5.3
Flood Frequency Estimates at WSC Gauge Sites

	Blackmud Creek WSC 05DF003	Whitemud Creek WSC 05DF006	West Whitemud Creek WSC 05DF007
Gross Drainage Area (km^2)	643	330.4	65.4
Effective Drainage Area (km^2)	375	300	53
Return Period (years)	**Maximum Instantaneous Flood Estimates (m^3 /s)**		
2	4.6	10.1	2.6
5	16.6	24.9	4.6
10	27.6	37.9	5.7
25	43.9	57.7	6.9
50	57.3	75.1	7.8
100	71.5	95	8.5
Return Period (years)	**Unit Discharge Rates (L/s/ha) Based on Gross Drainage Area**		
2	0.1	0.3	0.4
5	0.3	0.8	0.7
10	0.4	1.1	0.9
25	0.7	1.7	1.1
50	0.9	2.3	1.2
100	1.1	2.9	1.3

5.2 REGIONAL ANALYSIS

AE conducted a regional analysis using Water Survey of Canada (WSC) gauge data for nearby streams such as Sturgeon River, Battle River, Beaverhill Creek, Amisk Creek, Vermillion River, Redwater River, Pipestone Creek, Pointe-Aux-Pins Creek, Atim Creek, Maskwa Creek, and Muskeg Creek based on flow data up to 1997. The advantage of the regional analysis method is that it is based on flow data for a number of streams within the area of interest. Therefore, it is less sensitive to limitations of data and statistical analysis for any individual stream. Although the data on which it is based is somewhat dated the form of the regional relationship is still valid.

Figure 5.5 shows the regional results. The analysis showed an R^2 value of 0.73 which indicates a relatively good data correlation between the effective drainage area and the flood discharge. The scatter around the best-fit regional line may be due to differences in record length and differences in topography between the individual basins.

The correlation equation indicates that the peak flow can be estimated as a function of effective drainage area raised to the power of 0.67. Using this regional exponent and the results of the updated flood frequency analysis, peak flows can be estimated for the various catchments in the Whitemud/Blackmud Basin as indicated in **Table 5.4**. Estimates are based on The Irvine Creek and Cawes Lake Watershed Study (2014) estimate of effective drainage area for each of the sub-basins.

Figure 5.5: Blackmud and Whitemud Creek Regional Analysis

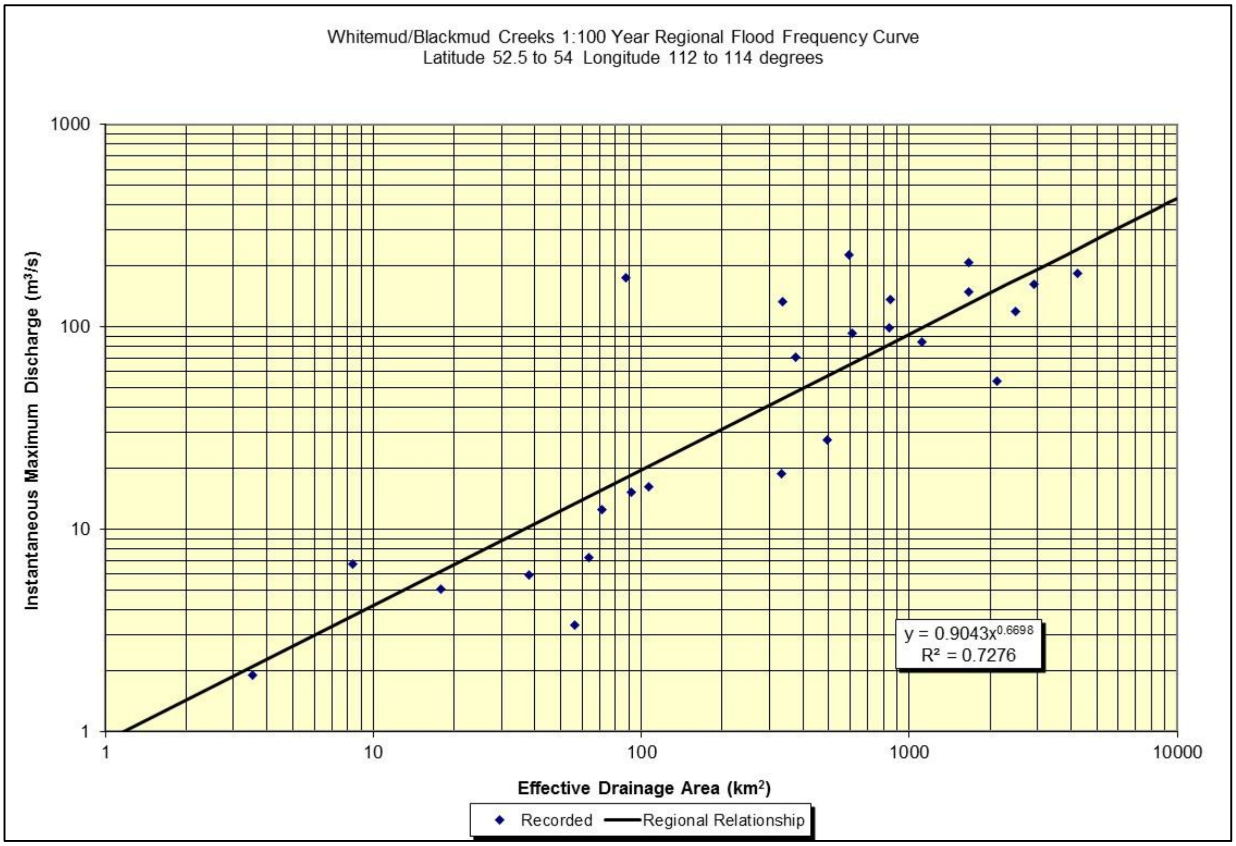


Table 5.4:
Flood Frequency Estimates for Key Study Area Locations

Return Period (Years)	Clearwater Creek at the mouth	Irvine Creek at the Mouth	Blackmud Creek at the Mouth	Whitemud Creek above Blackmud Creek
Gross Drainage Area (km²)	208	158	683	385.9
Effective Drainage Area (km²)	200.92	153.28	415	326.67
Return Period (years)	Maximum Instantaneous Flood Estimates (m^3/s)			
2	5.7	4.8	5.0	10.7
5	13.7	11.4	17.8	26.3
10	20.3	17.0	29.6	40.1
25	30.0	25.0	47.0	61.1
50	38.0	31.7	61.3	79.5
100	46.8	39.1	76.5	100.6

Note that these flood estimates are preliminary and are intended for basin planning and for comparison with modelling results, not for floodplain delineation. They will be reviewed when the modelling is completed.

5.3 CHANNEL CAPACITY

As noted in Section 2.2, AE completed channel survey for the Blackmud and Whitemud Creeks in September 2016. Based on the average channel cross-sections and a Manning's n of 0.03, the estimated channel capacity at bankfull stage for Whitemud Creek, upstream of the City of Edmonton was estimated to be 4.4 m^3/s upstream, and 16.1 m^3/s within the City limits. The Blackmud Creek channel capacity was estimated to be 12 m^3/s at bankfull stage and 26 m^3/s at floodplain level.

The channel capacity in an alluvial stream typically corresponds to the median (1:2 year) annual peak discharge. For the study area, the Blackmud Creek channel capacity corresponds to the 1:5 year storm. The Whitemud Creek channel capacity corresponds to the 1:2 year (upstream of the City limits) and 1:5 year storm (downstream of the City limits). These results also show that the 1:100 year peak flow is approximately 3-5 times larger than the channel capacity in the study area. This suggests that the study area channels generally do not have capacity for the pre-development peak flows.

6 Conclusions

Based on the hydrologic assessment of the Blackmud Creek and Whitemud Creek, the following conclusions are made:

- Development will place additional stresses on Blackmud and Whitemud Creeks, which have already been impacted by both agricultural and urban development. Potential impacts include increased peak flows, runoff volumes and increased channel erosion.

- Portions of the Blackmud and Whitemud basins are flat and poorly drained. There are numerous wetlands especially in the upper basin. The upper basin creek channels are poorly defined and have limited capacities.

- The Blackmud Creek channel is relatively flat in its upper reaches (longitudinal slope = 0.05 m/km upstream of Highway 2) and steeper in the lower reaches downstream of Highway 2. The flatter headwater slope is the result of the creek's glacial origin as an outflow channel from glacial Lake Edmonton, which originally flowed to the southeast.

- Whitemud Creek is relatively steep in the upstream and downstream reaches and flat in the middle. This profile suggests that the creek is still downcutting to its base level at the North Saskatchewan River, which could partly explain the channel erosion that is occurring.

- On an annual basis about 90-95% of the precipitation is lost to evaporation and evapotranspiration in the basin. Five to ten percent of the annual precipitation runs off. Runoff percentages are considerably higher in urban areas (typically 40-50% on an annual basis) which means that runoff volumes will increase by a factor of five (5) even if peak flows are controlled, unless source controls (low impact development practices) are adopted.

- Groundwater recharge generally begins in March and peaks in early May. Therefore, rainfall events in this period tend to produce relatively more surface runoff than the summer period due to the increased soil saturation in the active layer.

- Peak flows within the study area watercourses generally occur during the spring runoff period due to snowmelt or rain-on-snow events.

- Early summer peak events do occur due to convectional rainfall or regional storm events, but are typically smaller than the early-season snowmelt events.

- Different methods (regional analysis, channel capacity and flood frequency analysis) have been used to estimate peak flows for different return periods within the creeks. The flood frequency analysis provides the most reliable estimates of peak discharges as it is based on actual creek discharge records from over 45 years. It does not account for the possible impacts of climate change that are likely to be relatively small compared to other sources of uncertainty in the flood discharge estimates.

- As noted in the NHC report, 1974 was the year of greatest flow recorded in the Edmonton region. For this reason, the estimated 1974 peak flow was included in the flood frequency analysis where actual measurements were not available.

- Including the more recent 2013 and 2014 peak flows from the WSC gauge stations results in the following estimates: 1:100 year return period discharge of 71.5 m^3/s and 95 m^3/s for Blackmud and Whitemud Creeks.

- The 1:100 year pre-development (existing conditions) runoff rate is in the range of 1.8 to 3 L/s/ha in the study area. This is based on the effective drainage area. Pre-development runoff rates are somewhat lower if they are based on gross drainage area which includes some areas that drain at a reduced rate.

- The various municipalities and the Edmonton International Airport have different forms of SWM designed to provide varying levels of control and service level. The unit area runoff rates used for design of these facilities are somewhat higher than the pre-development runoff rates estimated herein and in previous studies; that is to say they are not conservative with respect to flooding and erosion potential.

- Creek channels in the project area are generally not expected to have capacity for the pre-development peak flows.

TECHNICAL MEMORANDUM NO. 3

Closure

This report was prepared for the Blackmud/Whitemud Creek Surface Water Management Group to summarize the hydrology assessment results for the Blackmud and Whitemud Creeks.

The services provided by Associated Engineering Alberta Ltd. in the preparation of this report were conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions. No other warranty expressed or implied is made.

Respectfully submitted,
Associated Engineering Alberta Ltd.

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ASSOCIATED ENGINEERING
QUALITY MANAGEMENT SIGN-OFF
Signature:
Date: Oct 25, 2016

APEGA Permit to Practice P 3979

References

1. Stantec, 2014. Irvine Creek and Cawes Lake Watershed Study.

2. Northwest Hydraulic Consultants, 2014. Nisku Flood Hazard Study – Blackmud Creek.