SECTION 6.0 – HYDROGEOLOGY
TABLE OF CONTENTS

PAGE

6.0 HYDROGEOLOGY 6-1

6.1 Introduction 6-1
6.1.1 Key Issues 6-1

6.2 Methods 6-1
6.2.1 Study Areas 6-1
6.2.2 Public Domain Information 6-3
6.2.3 Field Methods 6-3
6.2.4 Model Methods 6-4
6.2.5 Assessment Criteria 6-4

6.3 Baseline Case 6-4
6.3.1 Physical Setting 6-4
6.3.2 Geology 6-7
6.3.3 Hydrogeology 6-19

6.4 Application Case 6-35
6.4.1 Pre-production 6-35
6.4.2 Operations 6-35
6.4.3 Closure 6-37
6.4.4 Mitigation and Monitoring 6-42

6.5 Planned Development Case 6-42

6.6 Summary 6-42

6.7 References 6-43

TABLE OF CONTENTS (cont)

PAGE

LIST OF TABLES

Table 6.4-1: MLX-W Simulated Flow Rates....6-36
Table 6.4-2: MLX-E Simulated Flow Rates....6-36
Table 6.4-3: Summary of Application Case Effects....6-41
Table 6.4-4: Summary of Proposed Mitigation and Monitoring....6-42

LIST OF FIGURES

Figure 6.2-1: Hydrogeological Study Areas Location Map....6-2
Figure 6.3-1: Physiography and Topography....6-5
Figure 6.3-2: Regional Stratigraphic Column....6-8
Figure 6.3-3: Bedrock Geology....6-9
Figure 6.3-4: Top of Devonian Bedrock....6-11
Figure 6.3-5: Top of McMurray Formation....6-12
Figure 6.3-6: McMurray Formation Isopach....6-13
Figure 6.3-7: Top of Clearwater Elevation....6-14
Figure 6.3-8: Clearwater Formation Isopach....6-15
Figure 6.3-9: Quaternary Sediments Isopach....6-17
Figure 6.3-10: Empress Formation Buried Channels....6-18
Figure 6.3-11: Hydrogeological Cross-section A-A'....6-20
Figure 6.3-12: Hydrogeological Cross-section B-B'....6-21
Figure 6.3-13: Hydrogeological Cross-section C-C'....6-22
Figure 6.3-14: Quaternary Groundwater Elevation MLX-W....6-23
Figure 6.3-15: Quaternary Groundwater Elevation MLX-E....6-24
Figure 6.3-16: Piper Diagram – MLX-W....6-26
Figure 6.3-17: Piper Diagram – MLX-E....6-27
Figure 6.3-18: Basal Aquifer Isopach....6-29
Figure 6.3-19: Reported Locations of Water Wells....6-31
Figure 6.3-20: Groundwater Users....6-32
Figure 6.4-1: Maximum Extent of 1 m Drawdown in Quaternary During Mining – MLX-W....6-38
Figure 6.4-2: Maximum Extent of 1 m Drawdown in Quaternary at End of Mining – MLX-E....6-39
Figure 6.4-3: Extent of 1 m Drawdown in Quaternary Post Closure – MLX-W....6-40

6.0 HYDROGEOLOGY

6.1 Introduction

This section describes hydrogeology at the Mildred Lake Extension Project (MLX Project). Baseline conditions are presented and changes to groundwater associated with the MLX Project are assessed. The changes to groundwater evaluated include changes to groundwater elevations, flow patterns and chemistry. The effects of these changes on other components, such as surface water, vegetation, etc., are also evaluated. Additionally, the cumulative effects on groundwater of existing approved and planned industrial activities in the region are examined.

The assessment of the effects to groundwater is based on the available hydrogeology data within the study areas, the planned mine progression and the closure plan.

6.1.1 Key Issues

The key groundwater issues during the pre-production and operations phases of the mines are the effects of the open pits and Basal Water Sands (Basal McMurray Aquifer) depressurization on groundwater levels and flow directions. The open pits will result in groundwater influx into the pits and lowering of the groundwater table surrounding the pits, which can affect rivers and creeks, as well as wetlands. The depressurization of Basal Water Sands will lower groundwater pressures within the Basal Water Sands and produce water that will be managed as part of the MLX Project water management plan.

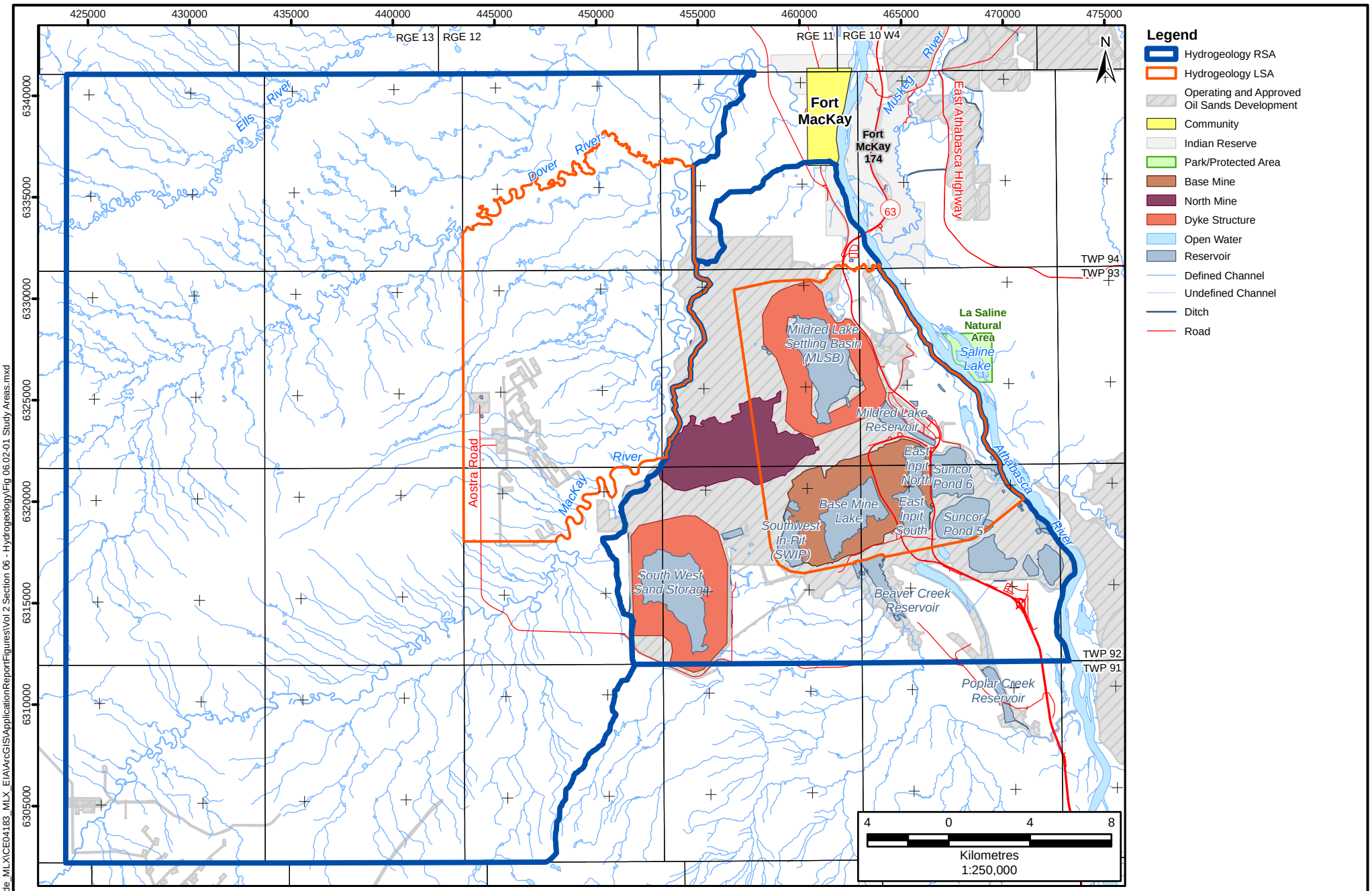
At closure, groundwater elevations and flow directions will have been altered from the pre-mining conditions. Process-affected groundwater, due to contact with tailings in the backfilled mine pits, can migrate to aquifers and surface waterbodies.

6.2 Methods

6.2.1 Study Areas

6.2.1.1 Local Study Areas

Two hydrogeology local study areas (HLSA) were defined to encompass the expected extent of potential effects of the MLX Project with respect to hydrogeology. The West HLSA is bounded to the east by the MacKay River, to the south by the MacKay River, to the north by the Dover River, and to the west by the western extent of Range (Rge) 12 (Figure 6.2-1). The East HLSA is bounded to the east by the Athabasca River, to the south by the north edge of Beaver Creek Reservoir and the south edge of Suncor Pond 5, to the north by Beaver Creek, and to the west by the approximate groundwater divide to the west of Mildred Lake Setting Basin (Figure 6.2-1).



S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.02-01 Study Areas.mxd

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Hydrogeological Study Areas Location Map

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Fig 06.02-01 Study Areas 14-10-01				**Figure 6.2-1**

6.2.1.2 Regional Study Areas

The two hydrogeology regional study areas (HRSA) for the MLX Project were defined to include areas large enough to allow for descriptions of the regional geology and hydrogeology (Figure 6.2-1). The MLX West (MLX-W) mine HRSA is bounded to the north by the northern extent of Township (Twp) 91, to the west by the western extent of Rge 14, to the south by southern extent of Rge 91, and to the east by the MacKay River in the northern half of the HRSA and by the edge of eastern extent of the MacKay River catchment area in the southern part of the HRSA. The MLX East (MLX-E) mine HRSA is bounded to the northeast by the Athabasca River, to the northwest by the MacKay River and to the south by the southern extent of Twp 92.

6.2.2 Public Domain Information

The key sources of public domain information were:

- 2012 Groundwater Monitoring Report, Mildred Lake Site (Syncrude 2013);
- reports on the regional hydrogeology in northeast Alberta (Bachu *et al*. 1993);
- a report describing the buried channels and glacial-drift aquifers in the Fort McMurray region (Andriashek and Atkinson 2007);
- a geological atlas of the western Canada sedimentary basin (Mossop and Shetsen 1994);
- Map 600 – Bedrock Geology of Alberta (Alberta Geological Survey 2013);
- Quaternary Stratigraphy of the Buried Birch and Willow Bedrock Channels, NE Alberta (Andriashek 2001);
- Amendment Application – MacKay River Expansion (Petro-Canada 2005);
- MacKay River Commercial Project Application (Athabasca Oil Sands Corporation 2009);
- GeoSCOUT, an on-line geologic database (geoLOGIC Systems 2013);
- Oilsands Groundwater Database (Golder 2013); and
- the Alberta Environment and Sustainable Resource Development (ESRD) Groundwater Information System database was searched for water well drilling reports and the ESRD Authorization/Approval database was searched for water diversion licence information.

6.2.3 Field Methods

Hydrogeological field data was collected in 2013. Data was collected through the drilling and installation of 50-mm diameter PVC groundwater monitoring wells installed in Quaternary aged sediments. There were eight drilling locations in each of MLX-W and MLX-E. Based on the geology and hydrogeology encountered at each location, eight wells were installed in MLX-W and five wells were installed at MLX-E. The drilling locations were spread out over the HLSAs, with two locations in MLX-W targeting the expected location of the Birch Channel. Data collected included geologic stratigraphy, groundwater elevations, groundwater chemistry, and hydraulic conductivity. The field program is summarized in Volume 3, Appendix C1.

6.2.4 Model Methods

To assist in evaluating the MLX Project effects on groundwater, 3D numerical groundwater flow models were developed for both MLX-W and MLX-E using finite element computer software Finite Element subsurface flow system (FEFLOW), Version 6.0 (DHI-WASY GmbH 2010). The models were used to simulate groundwater elevations and flow for the assessment scenarios. The modelling for MLX-W and MLX-E are described in detail in Volume 3, Appendices C2 and C3, respectively. The models were developed using available geological data and there is a high degree of confidence in the understanding of the 3D distribution of the hydrogeological units. The models were calibrated to field measured data. Interpolation and extrapolation of existing data was performed where data was not available. Data from public sources was used when site-specific data was not available, such as hydraulic properties of aquifers and aquitards. Where appropriate and required due to lack of data, professional judgment was used, but in such a way to conservatively assess negative effects.

6.2.5 Assessment Criteria

The potential hydrogeological effects were assessed in accordance with the assessment criteria presented in Volume 2, Section 3.4.

6.3 Baseline Case

The Baseline Case considers the existing environmental conditions in the study areas prior to development of the MLX Project, including disturbances associated with existing and approved projects.

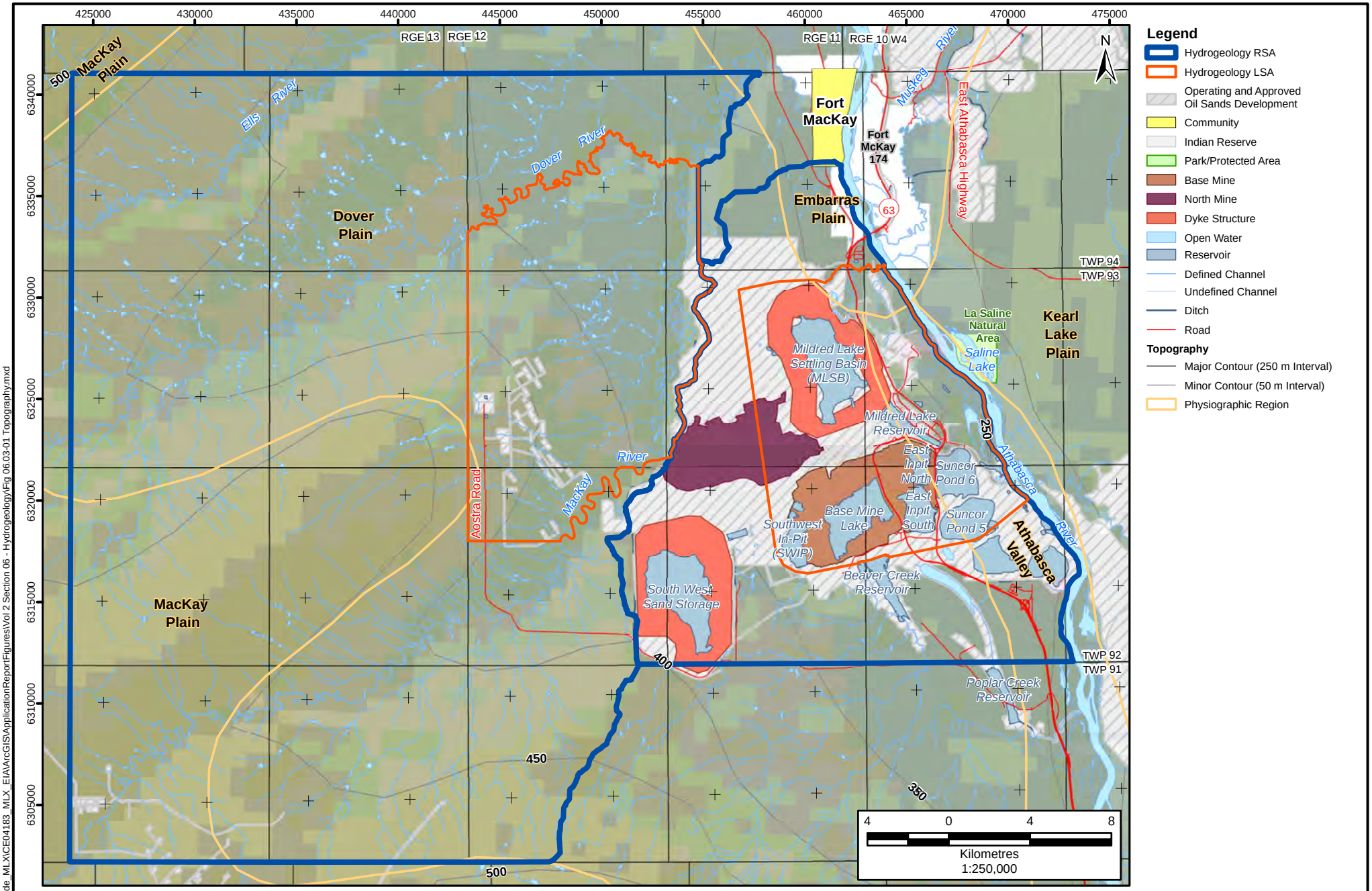
The baseline hydrogeological conditions in the vicinity of the MLX Project were characterized using information in the public domain, Syncrude hydrogeological and geological data, and information obtained from the 2013 hydrogeology field investigation undertaken within the HLSAs.

6.3.1 Physical Setting

The MLX-W and MLX-E HRSAs include portions of the following physiographic regions:

- the Dover Plain (the majority of the HRSAs);
- the MacKay Plains (southwest area of the MLX-W HRSA);
- the Embrass Plain; and
- the Athabasca Valley (Figure 6.3-1).

The Dover Plain is part of the broad Athabasca River lowland (Andriashek and Atkinson 2007). Ground elevation within the HRSAs ranges from approximately 235 metres above sea level (masl) on the west side of the Athabasca River up to approximately 500 masl to the western uplands. Topography drops off sharply along the escarpment of both the Athabasca River and MacKay River.



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Topography

- Major Contour (250 m Interval)
- Minor Contour (50 m Interval)
- Physiographic Region

Projection: UTM Zone 12 NAD83
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MLX Project

Physiography and Topography

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Fig 06.03-01 Topography 14-10-03	**Figure 6.3-1**

The HRSAs are within the Central Mixedwood subregion of the Boreal Forest natural region (Natural Regions Committee 2006). The Central Mixedwood subregion spans much of the northern two-thirds of Alberta. The forests within this subregion include aspen, mixedwood, white spruce, and jack pine. The subregion also includes wetlands. Mean daily minimum of the coldest month is -25.5°C and the mean daily maximum of the warmest month is 20.7°C, with an average annual temperature of 0.2°C. Annual precipitation is 478 mm on average.

The HRSAs are situated within the Athabasca River Basin. The major rivers in the vicinity include the Athabasca, MacKay, Ells, and Dover. Prior to mine development in the 1960s and 1970s, the topography within the east HRSA varied from flat to undulating relief with an abundance of small lakes, streams, marshes, and bogs between incised rivers and creeks (Syncrude 2006). Muskeg deposits, typically 1 to 2 m thick, covered approximately 30% of the area. The topography was poorly drained by a series of major north-easterly flowing, incised creeks and rivers that drained into the Athabasca River. Mildred Lake, Horseshoe Lake and Ruth Lake were the three lakes on the Mildred Lake leases prior to disturbance (Syncrude 2001). The main watercourses affected by development included Beaver Creek, MacKay River, Poplar Creek, and Athabasca River.

Beaver Creek and its tributaries originally drained north through the center of the Mildred Lake Operation to Lower Beaver Creek before discharging into the Athabasca River. Channels were considered well defined and incised in the headwaters, and less incised in the lower reaches (gradients ranged from 0.3% to 1%). The predevelopment drainage area of Beaver Creek was 471 km^2, of which 181 km^2 was diverted to Poplar Creek through a diversion and spillway (Syncrude 1998). The existing mine footprint is within 221 km^2 of the watershed, while the remaining 69 km^2 is located downstream of the mine development (Syncrude 1998). Poplar Creek continues to drain south towards the Athabasca River.

Since the construction of the Beaver Creek Dam, Poplar Creek and Poplar Creek Spillway in the 1970s, the majority of the Beaver Creek watershed has been diverted south through Poplar Creek before eventually discharging to the Athabasca River. In addition to these drainage networks, a number of small lakes and reservoirs are present, including Beaver Creek Reservoir, Poplar Creek Reservoir, Ruth Lake, Mildred Lake Reservoir, and Horseshoe Lake. Crane Lake, an additional man-made lake within the adjacent Suncor lease boundary, is present in a reclaimed area of Suncor's lease.

The Mildred Lake Settling Basin (MLSB) and the Southwest Sand Storage tailings storage areas now rise above original ground to elevations of 352 and 400 masl, respectively. A number of in-pit tailings and process water ponds are also present within the lease.

The southern half of the lease area consists of mature reclaimed landforms, such as South Hills (SW30 Dump) and Gateway Hill (S4 Dump), while the northern half is primarily actively managed operational areas. Overland drainage is diverted around the lease area through a series of clean water interception channels that eventually discharge to the Athabasca River. Process-affected water is collected through a series of mine dewatering ditches and returned to active tailings management areas for reuse within the bitumen production process (Syncrude 2011).

Saline Lake is located on the east side of the Athabasca River and northeast of MLX-E.

6.3.2 Geology

The MLX Project falls within the Western Canada Sedimentary Basin, with underlying bedrock representing the northeastern edge of a wedge of sedimentary rock extending from the Canadian Shield at the east, to the 6 km thick western edge at the Rocky Mountains.

Three major unconformities have removed stratigraphic units at the top of the Precambrian, Devonian and Cretaceous aged bedrock formations. Each erosional unconformity has altered the structure of the underlying unit, allowing basal permeable materials to infill low relief areas, including the La Loche 'granite wash' above the Precambrian granite, the Basal McMurray Aquifer (also known as 'water sands') above the Waterways Formation of the Upper Beaverhill Lake Group, and Quaternary sands and gravels, which have been deposited in valleys and channels incised into the Cretaceous aged Grand Rapids, Clearwater and McMurray formations.

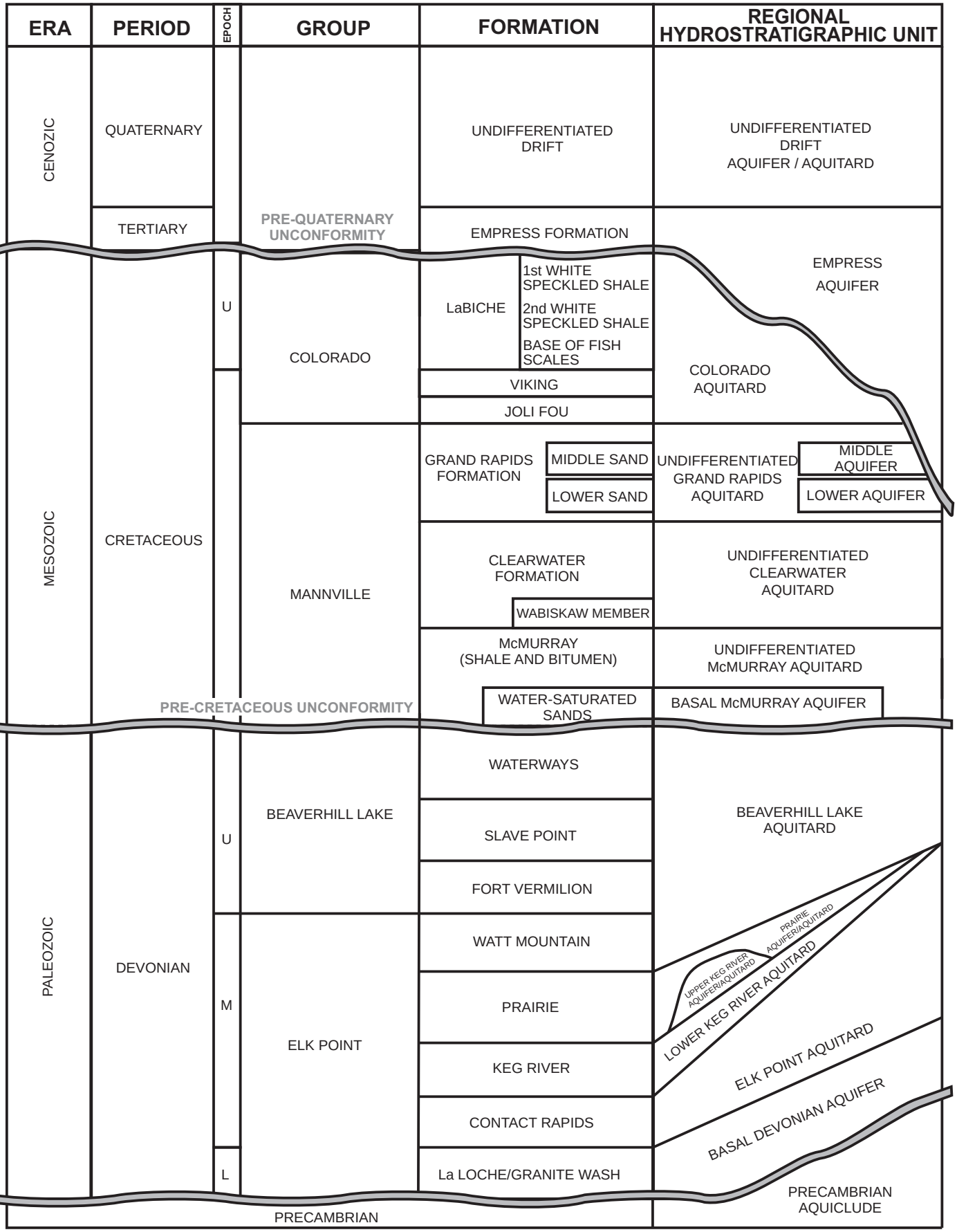
Subsidence due to dissolution of the Prairie Formation halites has altered the dip direction of the overlying Beaverhill Lake Group, from southwest trending to northeast, and returning to a southwesterly dip within the Cretaceous. Outside of buried channels and valleys, Quaternary sediments are unconsolidated glacial till, inter-till fluvial materials, and recent alluvium and organic muskeg. Figure 6.3-2 illustrates the regional stratigraphic column and Figure 6.3-3 shows a map of the uppermost bedrock geology.

6.3.2.1 Precambrian

The Precambrian basement consists of igneous and metamorphosed Achaean-age rocks, dipping to the southwest by 4 to 5 m/km. The basement rock has been locally incised by Phanerozoic deposits, with relief of up to 50 m (Bachu *et al*. 1993) and lies between 300 and 600 m below ground within the MLX HRSAs.

6.3.2.2 Devonian

The Elk Point Group of the Lower to Middle Devonian unconformably overlies and onlaps onto the Precambrian basement rock, following its dip and thickening to the southwest. The Elk Point Group is a clastic-carbonate-evaporite sequence that includes, in ascending order, basal clastic sediments of the La Loche Formation, interbedded argillaceous dolostone and shale of the Contact Rapids Formation (also known as the Methy Formation), carbonate platform and reef carbonate rocks of the Keg River Formation and the interbedded halites and shales of the Prairie Evaporite Formation and the Watt Mountain Formation, a shale marking the transition to the overlying Beaverhill Lake Group. The green shales and interbedded limestones of the Watt Mountain may be closer in age to the Beaverhill Lake Group, due to a major unconformity documented at its base (Mahood *et al.* 2012; Mossop and Shetsen 1994). Within the MLX HRSAs, the oldest basal Red Bed and Ernestina Lake successions are not present; the oldest continuous unit in the MLX Project is the Contact Rapids Formation.



S:\Gis\Projects\CES\Syncrude_MLX\CE04183_MLX_EIA\CorelDraw\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig06.03-02 Stratigraphic Column

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MLX Project

Regional Stratigraphic Column

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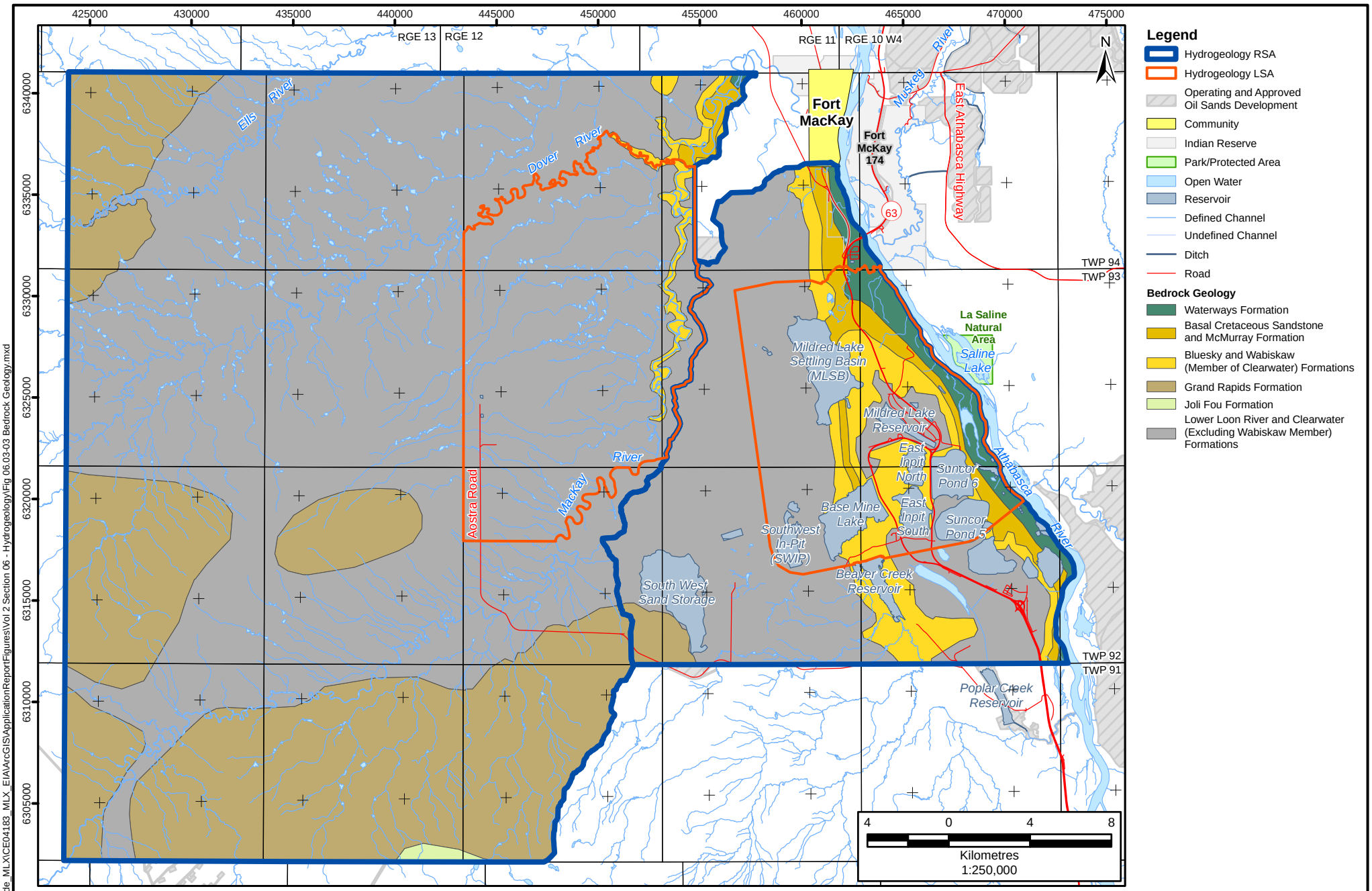
Fig 06.03-02 Stratigraphic Column 14-04-01	**Figure 6.3-2**



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Bedrock Geology

- Waterways Formation
- Basal Cretaceous Sandstone and McMurray Formation
- Bluesky and Wabiskaw (Member of Clearwater) Formations
- Grand Rapids Formation
- Joli Fou Formation
- Lower Loon River and Clearwater (Excluding Wabiskaw Member) Formations

Projection: UTM Zone 12 NAD83
Note:
Sources: AB TPR, Alberta Geological Survey
Bedrock Geology of Alberta- Map 600 (2013),
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S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.03-03 Bedrock Geology.mxd

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Bedrock Geology

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Fig 06.03-03 Bedrock Geology 14-10-10			**Figure 6.3-3**

West of the Athabasca River, the Prairie Evaporite Formation is a thick and extensive sequence. East of the Athabasca River, dissolution of the halites has resulted in collapse and rapid thinning of the unit, leaving a scarp of low porosity breccias.

The Beaverhill Lake Group overlies the Elk Point Group and consists of the lowermost anhydrite Fort Vermilion Formation, overlain by the crystalline limestone Slave Point Formation, which is in turn overlain by the calcareous shale and limestone members of the Waterways Formation. The Fort Vermillion, Slave Point and Waterways formations of the Beaverhill Lake Group show a southwest to northeast dip reversal similar to that of the Watt Mountain Formation, indicating collapse of the Prairie Evaporites occurred after deposition of the Beaverhill Lake Group.

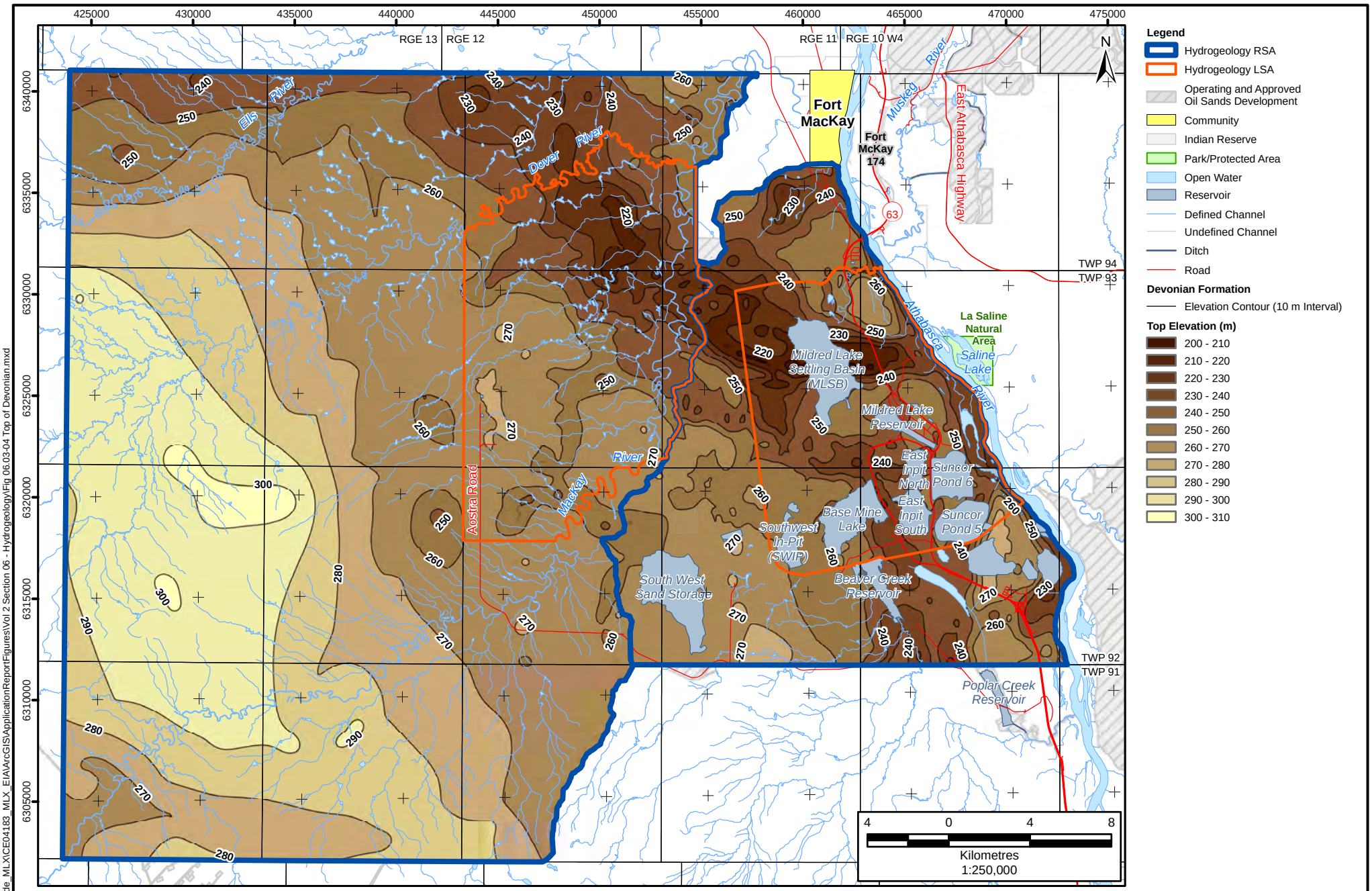
The Devonian surface (Figure 6.3-4) was extensively eroded and later modified by dissolution and collapse of the salt beds of the Prairie Evaporite Formation and the fluvial depositional environments in the Cretaceous period (Andriashek *et al.* 2007).

6.3.2.3 Cretaceous

Cretaceous formations present within the MLX HRSAs are classified as part of the Mannville Group of the Western Canada Sedimentary Basin. They were deposited between 114 and 66 million years ago and include important coal, oil and gas reserves in the province of Alberta. In the Athabasca Oil Sands region, the Mannville group consists of, from base to top, the McMurray, Clearwater and Grand Rapids formations.

The McMurray Formation (Km) was deposited during a widespread period of marine transgression. Sediments were deposited on the eroded Devonian surface in fluvial, estuarine and near-shore marine environments. Top elevations for the McMurray Formation range between 240 masl along the Athabasca River, to 310 masl in the southwest of the MLX Project. Figure 6.3-5 shows the elevations of the top of the McMurray Formation. The thickness of the McMurray Formation within the HRSA ranges to over 100 m (Figure 6.3-6). The McMurray units are divided into three informal members based on deposition and lithofacies. The Lower McMurray unconformably overlies the eroded Devonian surface. This is a discontinuous basal aquifer, consisting of fine to coarse bitumen- or water-bearing sand, with associated silt and clay interbeds deposited in a continental fluvial environment (Syncrude 2011). The basal water sands, defined by low bitumen content and high water content, are present only discontinuously, with localized thicknesses of less than 2 m within MLX-W and up to 8 m within MLX-E (see Figure 6.3.5). The Middle and Upper McMurray consist of bitumen deposits within a silty sandy matrix deposited in estuarine and near-shore marine environments and are the units with high bitumen content.

The Clearwater Formation (Kc) was deposited in a marine environment and consists of silty sandy shale. The Clearwater conformably overlies the McMurray Formation, and is distinguished by the lower Wabiskaw member (Kcw), a distinctive green glauconite sand and silt (Syncrude 2011). Overlying the Kcw unit are grey marine clay shales called Clearwater clays. In the MLX-W HRSA, the unit reaches thicknesses of over 100 m in the southwest and the west uplands, while within the MLX-E HRSA, the Clearwater is thin to completely eroded along the Athabasca River edge (the Clearwater Formation has been removed within existing mine pit boundaries within the MLX-E HLSA). Figure 6.3-7 shows the elevations of the top of the formation and Figure 6.3-8 shows the thicknesses.



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Devonian Formation

- Elevation Contour (10 m Interval)

Top Elevation (m)

- 200 - 210
- 210 - 220
- 220 - 230
- 230 - 240
- 240 - 250
- 250 - 260
- 260 - 270
- 270 - 280
- 280 - 290
- 290 - 300
- 300 - 310

Projection: UTM Zone 12 NAD83
Note:
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Top of Devonian Bedrock

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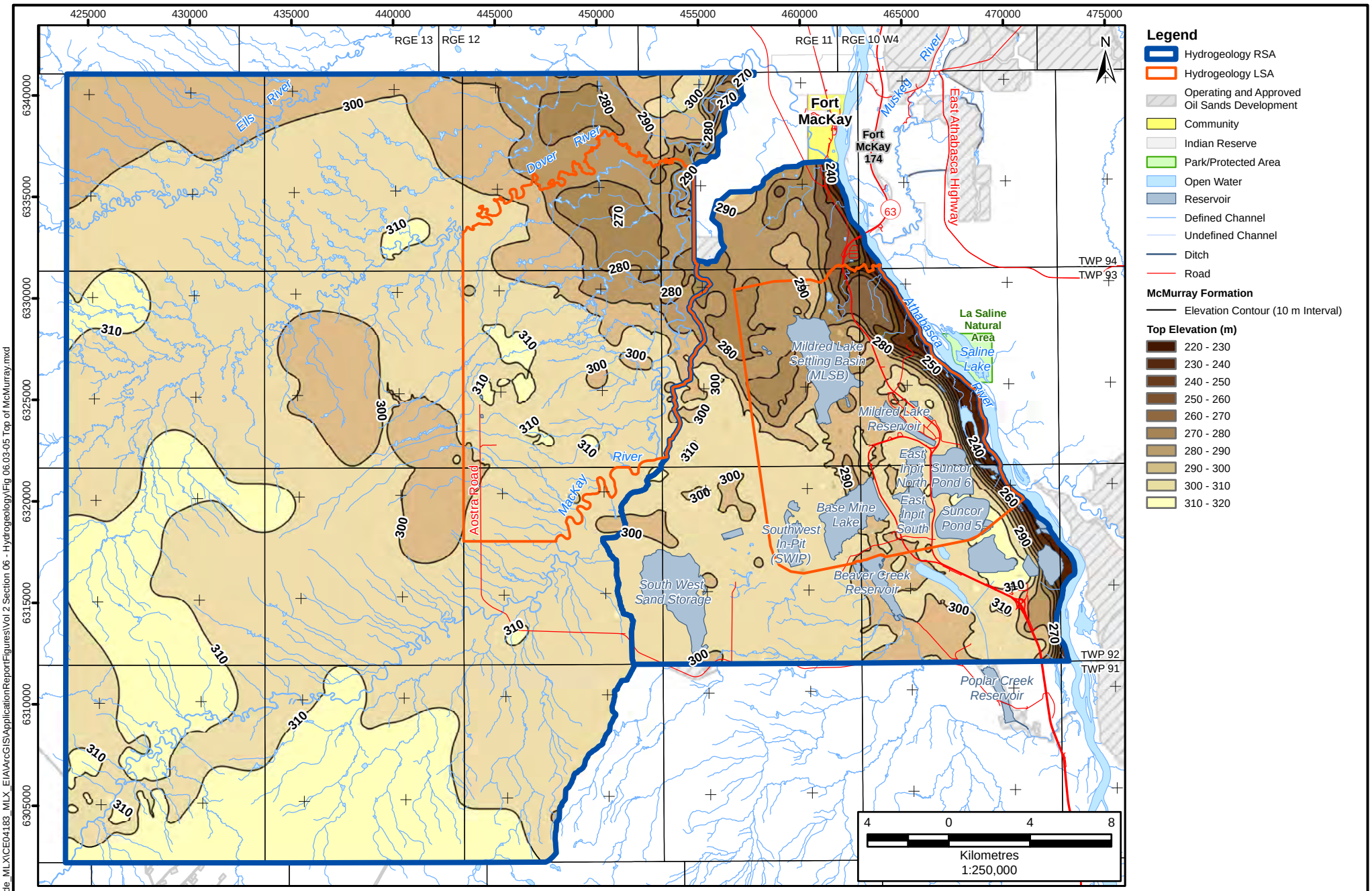
Fig 06.03-04 Top of Devonian 14-10-01	**Figure 6.3-4**



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

McMurray Formation

- Elevation Contour (10 m Interval)

Top Elevation (m)

- 220 - 230
- 230 - 240
- 240 - 250
- 250 - 260
- 260 - 270
- 270 - 280
- 280 - 290
- 290 - 300
- 300 - 310
- 310 - 320

Projection: UTM Zone 12 NAD83
Note:
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MLX Project

Top of McMurray Formation

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Fig 06.03-05 Top of McMurray 14-10-03	**Figure 6.3-5**

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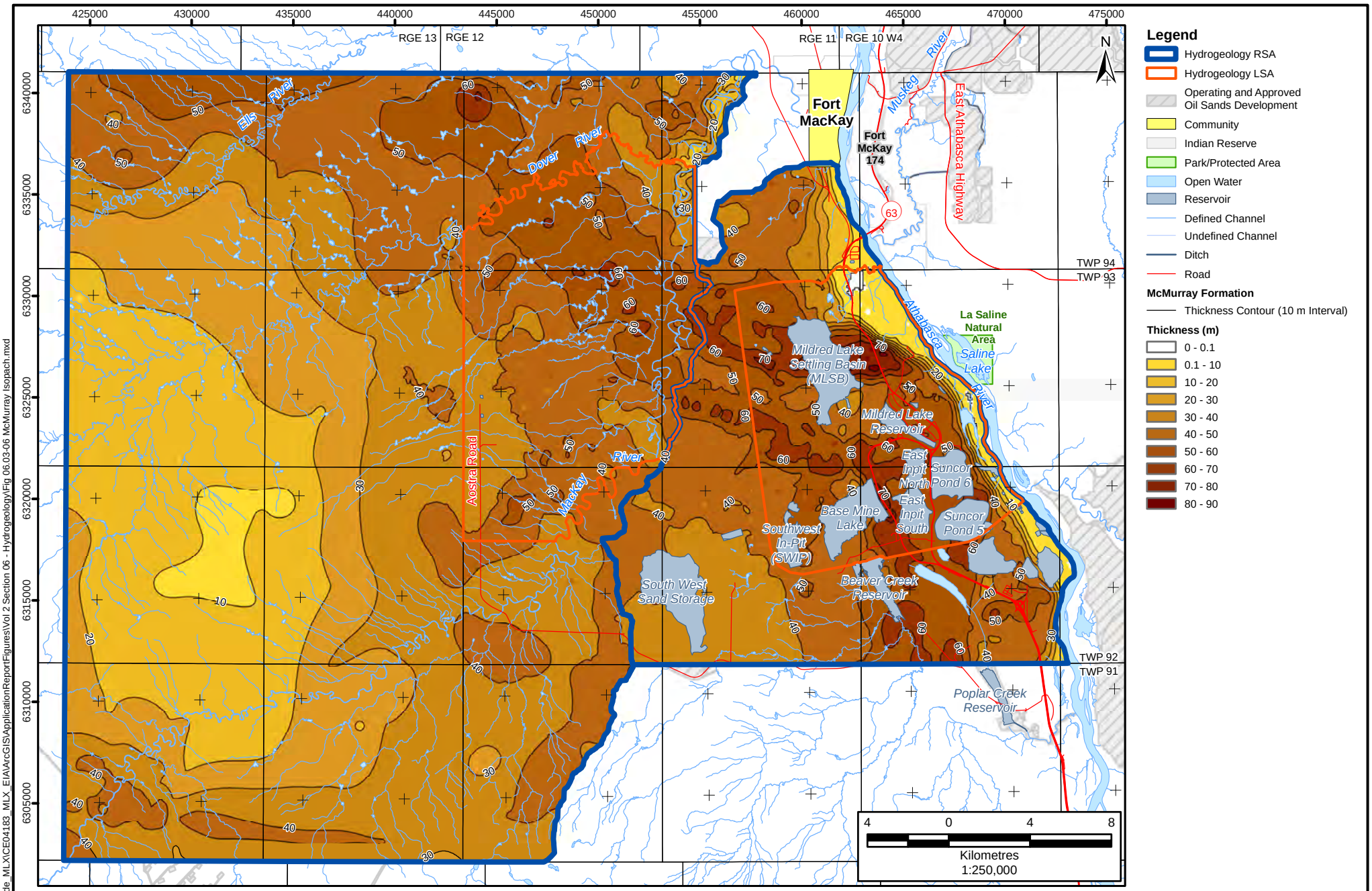

Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

McMurray Formation

- Thickness Contour (10 m Interval)

Thickness (m)

- 0 - 0.1
- 0.1 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90

Projection: UTM Zone 12 NAD83
Note:
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MLX Project

McMurray Formation Isopach

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October 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.03-06 McMurray Isopach 14-10-03	**Figure 6.3-6**

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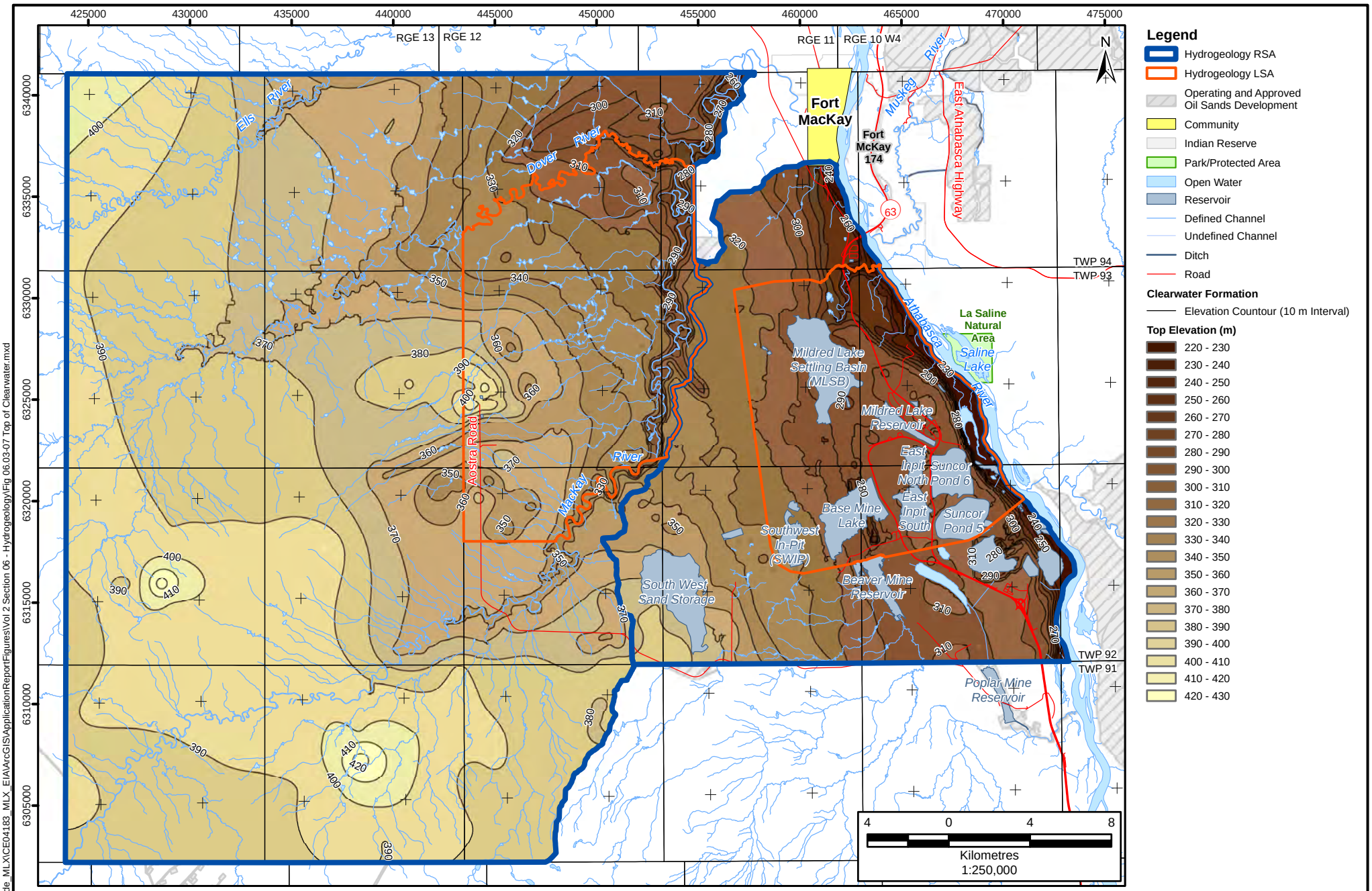

Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Clearwater Formation

- Elevation Countour (10 m Interval)

Top Elevation (m)

- 220 - 230
- 230 - 240
- 240 - 250
- 250 - 260
- 260 - 270
- 270 - 280
- 280 - 290
- 290 - 300
- 300 - 310
- 310 - 320
- 320 - 330
- 330 - 340
- 340 - 350
- 350 - 360
- 360 - 370
- 370 - 380
- 380 - 390
- 390 - 400
- 400 - 410
- 410 - 420
- 420 - 430

Projection: UTM Zone 12 NAD83
Note:
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Top of Clearwater Formation

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Fig 06.03-07 Top of Clearwater 14-10-03	**Figure 6.3-7**

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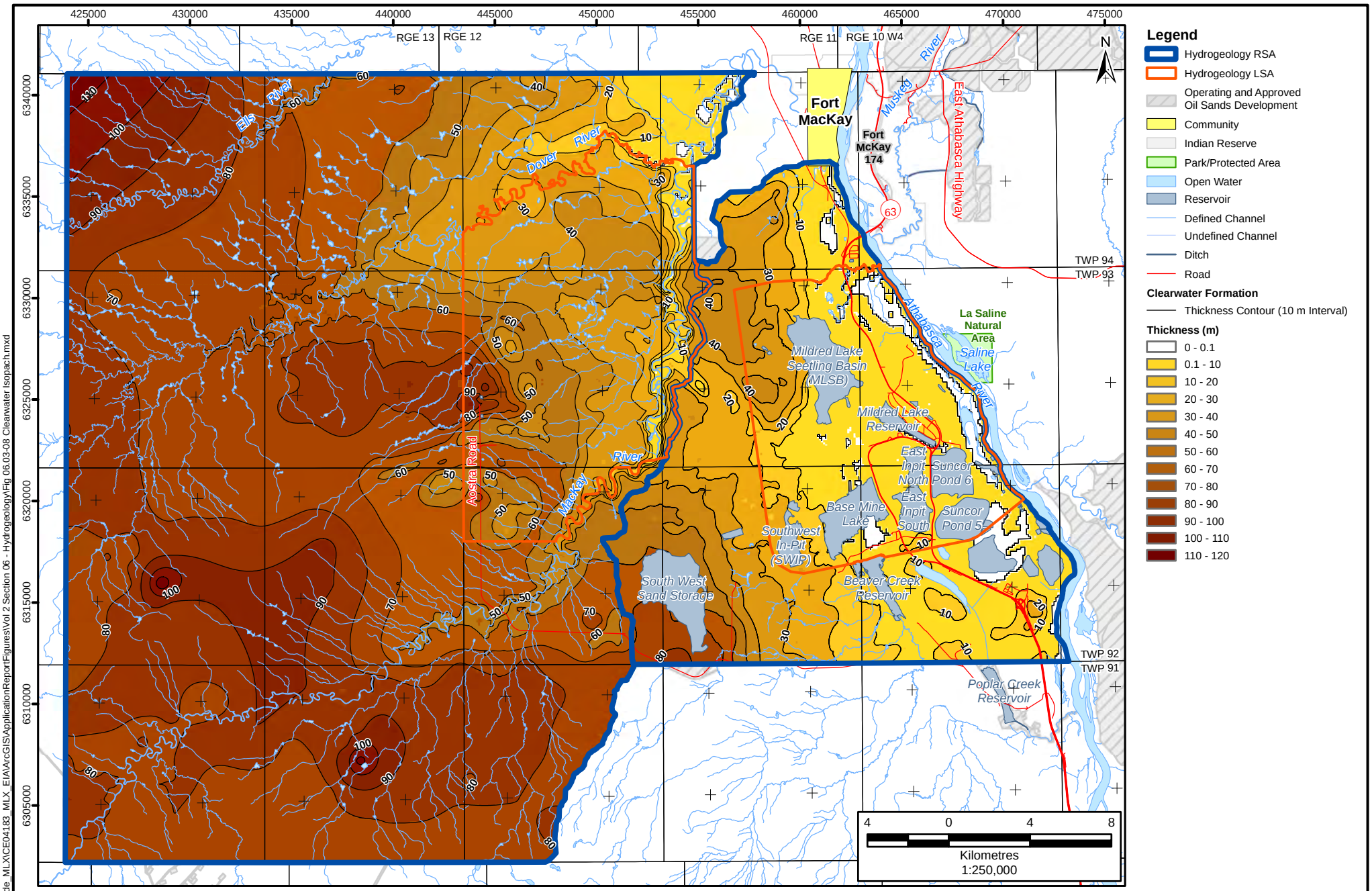

Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Clearwater Formation

- Thickness Contour (10 m Interval)

Thickness (m)

- 0 - 0.1
- 0.1 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120

Projection: UTM Zone 12 NAD83
Note:
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S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.03-08 Clearwater Isopach.mxd

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Clearwater Formation Isopach

DATE: October 2014			PROVIDED BY: AMEC
ANALYST: JH	QA/QC: KW DM EH		FINAL MAPPING BY: AMEC
Fig 06.03-08 Clearwater Isopach 14-10-03			**Figure 6.3-8**

The Grand Rapids Formation (Kg) was deposited in a marine environment and consists of uncemented fine- to coarse-grained “salt and pepper” sand (Syncrude 2011). The Grand Rapids Formation unit occurs on higher ground southwest of the MLX Project and in the uplands to the west of the MacKay River (Figure 6.3-3), but has otherwise been eroded throughout the area. Regionally, the Grand Rapids Formation is considered a good aquifer (Hackbarth *et al.* 1979); however, within the MLX HRSAs, it is a silty sand deposit and may be a poor aquifer.

6.3.2.4 Quaternary

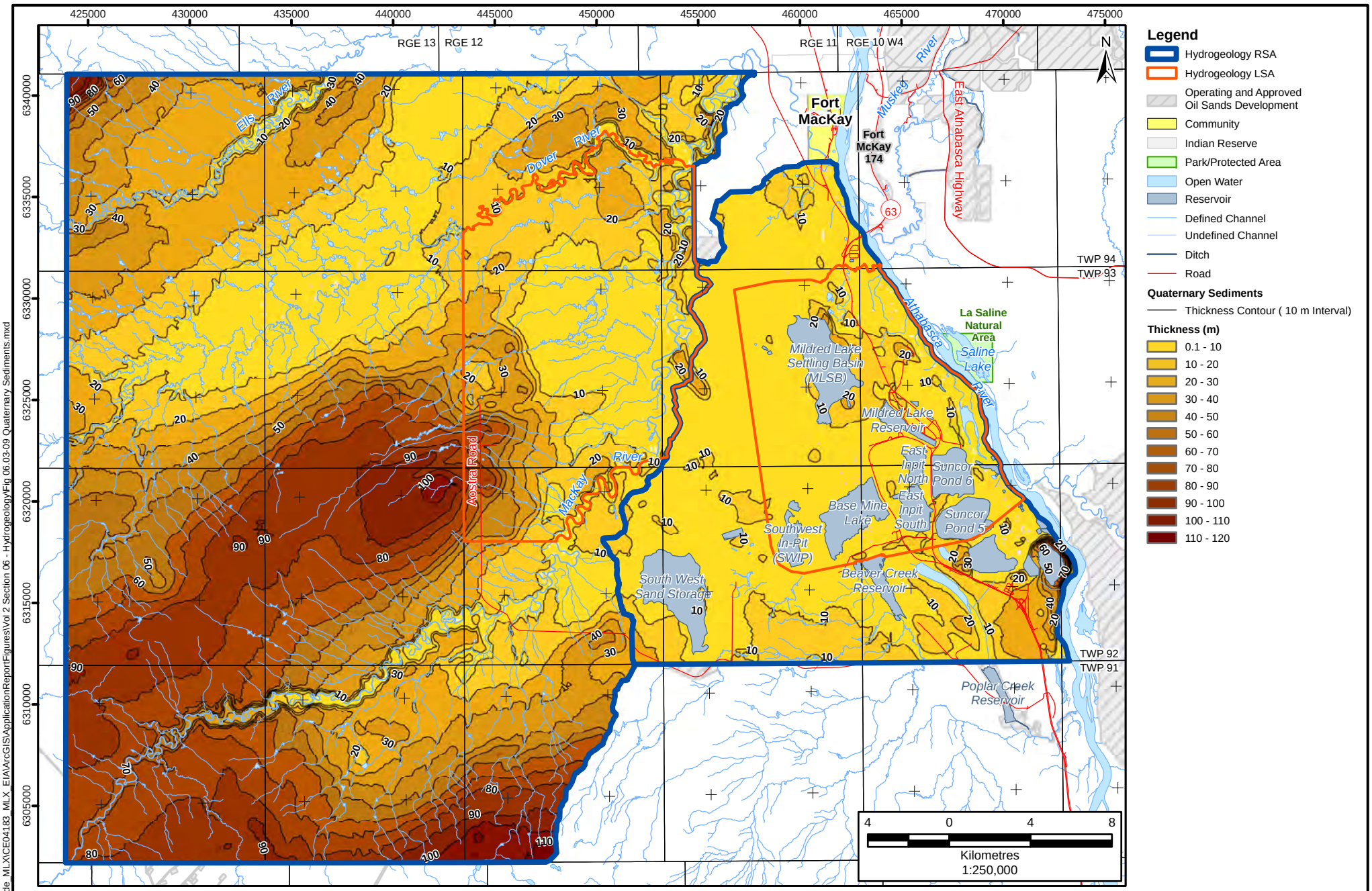
The Quaternary units in the Athabasca Oil Sands region consist of deposits from the Pleistocene and Holocene Periods, deposited by glacial and fluvial processes. Prior to the Quaternary glacial periods, the region was made up of broad, northeast to southwest trending valleys separated by low uplands. Stream deposits in the valleys consisted of quartz sand and gravel from older Tertiary or Cretaceous deposits (Fenton *et al.* 1994). The glacial advances and subsequent melting resulted in extensive erosion of the bedrock overlying the McMurray Formation, and the subsequent deposition of glacial and non-glacial units in a complex sequence of glacial, fluvial and lacustrine sediment of different ages and thicknesses. Figure 6.3-9 shows the thicknesses of the Quaternary age sediments within the HRSAs. The recent Holocene aged MacKay and Dover rivers incised valleys through these Quaternary sediments (Fenton *et al.* 1994) and into the underlying Clearwater and McMurray Formations.

Within the MLX HRSAs, Pleistocene units include fluvial sands and gravels, glaciolacustrine clays (Pl), tills (Pg), and may also include ice-rafted blocks of Clearwater and McMurray formations. Holocene units include aeolian sand and organic (peat and muskeg) deposits (Ho, Hf and Ha).

6.3.2.5 Empress Formation Buried Channels

Buried channels are characterized as narrow and deeply incised by glacial meltwater flowing under the base of an ice sheet, incising into bedrock of Cretaceous age and infilling with Tertiary-age Empress Formation sediments. These are stratified fluvial sands and gravels characteristic of a high energy depositional environment (Andriashek and Atkinson 2007), and are often masked at ground surface by overlying Quaternary glacial sediments.

Andriashek (2000 and 2007) mapped the buried channels of the region, including the Birch, MacKay, Willow, North Spruce, and South Spruce buried channels within the HRSAs (Figure 6.3-10). The Birch Channel has incised to the Clearwater Formation, with fluvial deposits up to approximately 90 m thick, extending for approximately 80 km westwards from the MacKay River (Andriashek 2000). The MacKay Channel has been mapped by Southern Pacific Resources Corp. (2011), extending from southwest of Twp 89, Rge 17 north-eastward to join the Birch Channel in the vicinity of the MLX-W study area. Thickness in the channel is up to 25 m thick. The Willow Channel lies north of and parallel to the Dover River, and has an approximate length of 20 km west of the MacKay River, and an average thickness of 30 m (Andriashek 2000). The North and South Spruce channels lie east of the MacKay River, where the North Spruce merges with the Birch Channel while the incised segments of the South Spruce are discontinuous (Andriashek and Atkinson 2007). These infilled sediments are 15 to 40 m thick (Syncrude 2011) overlain by till.



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Quaternary Sediments

- Thickness Contour (10 m Interval)

Thickness (m)

- 0.1 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 110
- 110 - 120

Projection: UTM Zone 12 NAD83
Note:
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Quaternary Sediments Isopach

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Fig 06.03-09 Quaternary Sediments 14-10-03			**Figure 6.3-9**

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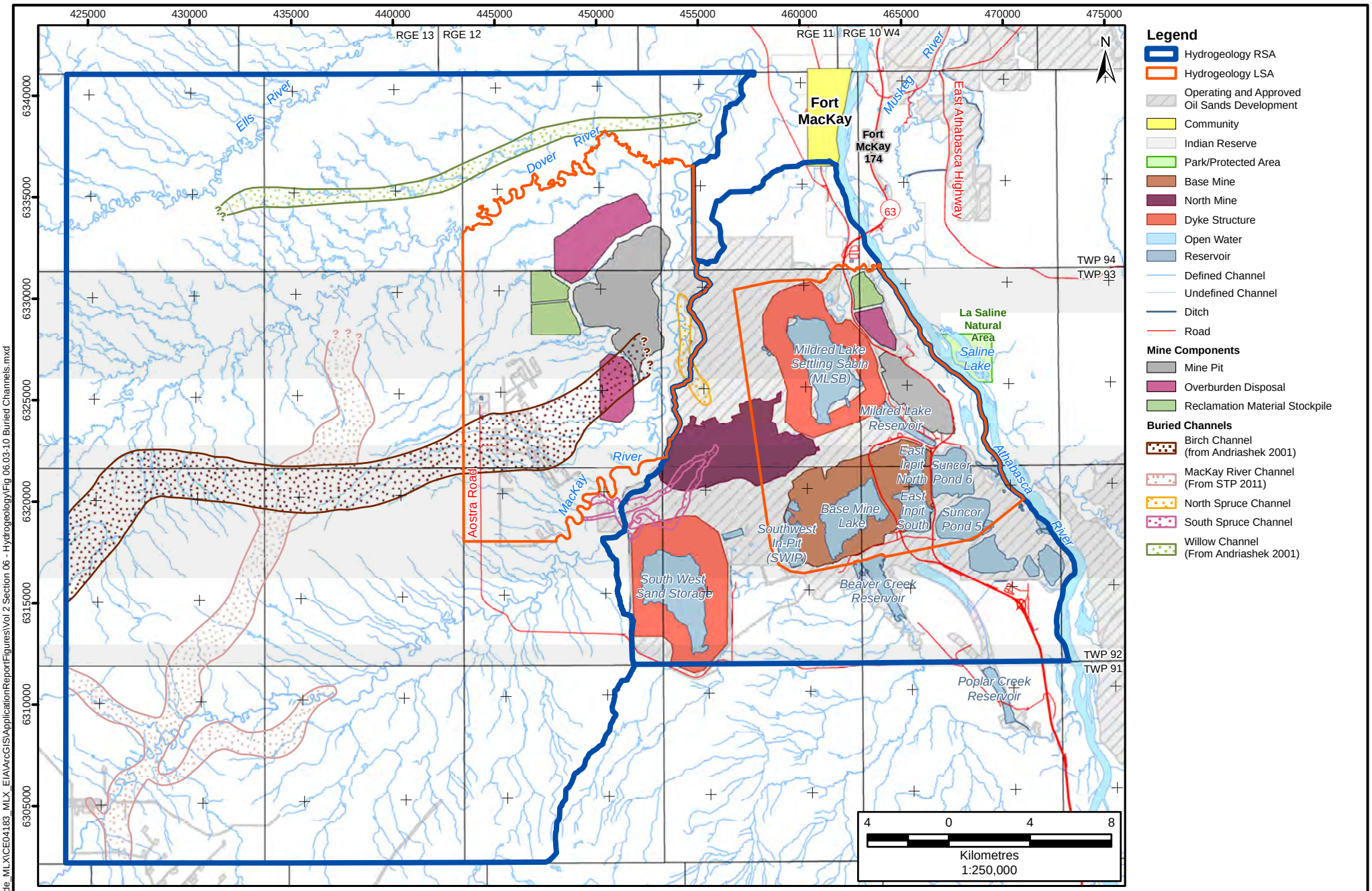

Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Mine Components

- Mine Pit
- Overburden Disposal
- Reclamation Material Stockpile

Buried Channels

- Birch Channel (from Andriashek 2001)
- MacKay River Channel (From STP 2011)
- North Spruce Channel
- South Spruce Channel
- Willow Channel (From Andriashek 2001)

Projection: UTM Zone 12 NAD83
Note:
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S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.03-10 Buried Channels.mxd

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Empress Formation Buried Channels

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Fig 06.03-10 Buried Channels 14-10-10				**Figure 6.3-10**

6.3.3 Hydrogeology

The hydrostratigraphic units shown on Figure 6.3-2 are classified as aquifers, aquitards or aquifer/aquitards on the basis of the definitions provided in Bachu *et al.* (1993). An aquifer is a laterally extensive geologic unit that is capable of transmitting formation water at the basin scale; however, it may not necessarily be capable of yielding a useful amount of water to water well. An aquitard is a geologic unit that stores groundwater, but transmits it very slowly due to its relatively low hydraulic conductivity. An aquifer/aquitard is a geologic unit that generally exhibits aquitard characteristics, but may be capable of transmitting water locally.

The hydrostratigraphic units relevant to the MLX Project include:

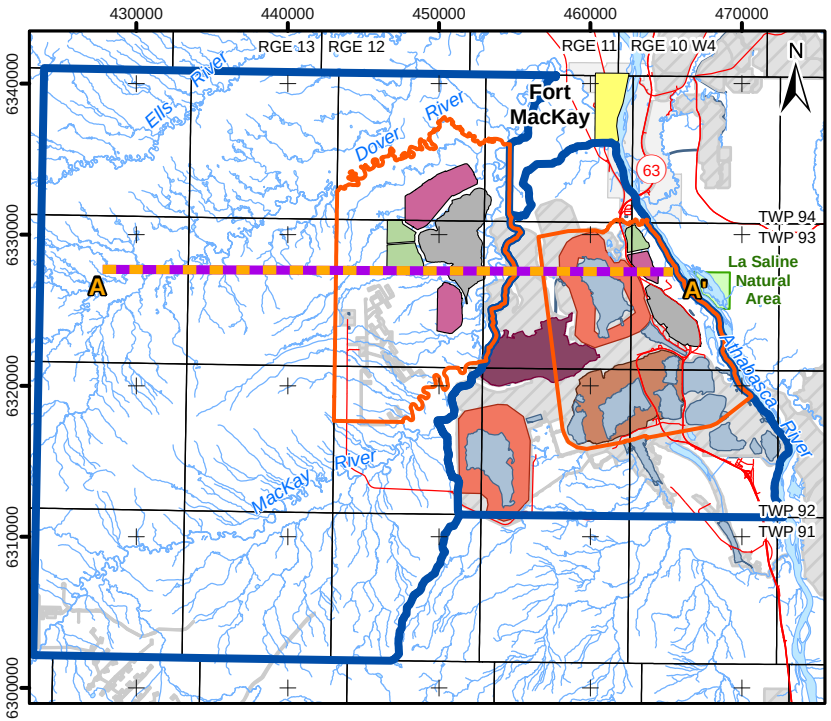
- Quaternary Aquifer/Aquitard;
- Empress Formation (Buried Channel Aquifers);
- Clearwater Aquitard;
- McMurray Aquitard;
- Basal McMurray Aquifer or Basal Water Sands; and
- Beaverhill Lake Aquitard.

The bedrock formations below the Beaverhill Lake Aquitard down to the Precambrian surface are aquitards and aquifer/aquitards. There are two aquifer/aquitards below the Beaverhill Lake Aquitard: the Methy (Keg River, Winnipegosis) Formation and the Prairie Evaporite Formation. The Precambrian surface is considered to be impermeable, and is the base for groundwater flow in the area (Bachu *et al.* 1993).

Figures 6.3-11 through 6.3-13 show the relevant hydrostratigraphic units within the HRSAs in cross-section.

6.3.3.1 Quaternary Aquifer/Aquitard

Within the MLX HRSAs, most of the Quaternary or overburden deposits are interpreted to be low permeability till deposits, with the exception of buried channels and small isolated pockets of sand or gravel (Andriashek and Atkinson 2007). Till deposits in the MLX-W area are reported to have hydraulic conductivities ranging from 3.5×10^{-8} to 2.4×10^{-5} m/s, with similar values reported by Hackbarth and Nastasa (1979), up to an order of magnitude higher in the sands and gravels. Syncrude (2012) and Sivarajan (pers. comm. 2014) reported a range of 3.7×10^{-9} to 1.4×10^{-4} m/s in the MLX-E HRSA. The main Quaternary age aquifer in the MLX-W HLSA is the Birch Channel Aquifer. The groundwater level in the overburden is generally at or near ground surface (240 to 450 masl) and the water table is generally controlled by the topography and surface waterbodies. Interpreted groundwater elevations, based on measured groundwater elevations and surface water elevations, for the undifferentiated Quaternary age sediments for MLX-W and MLX-E are shown on Figures 6.3-14 and 6.3-15, respectively.



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

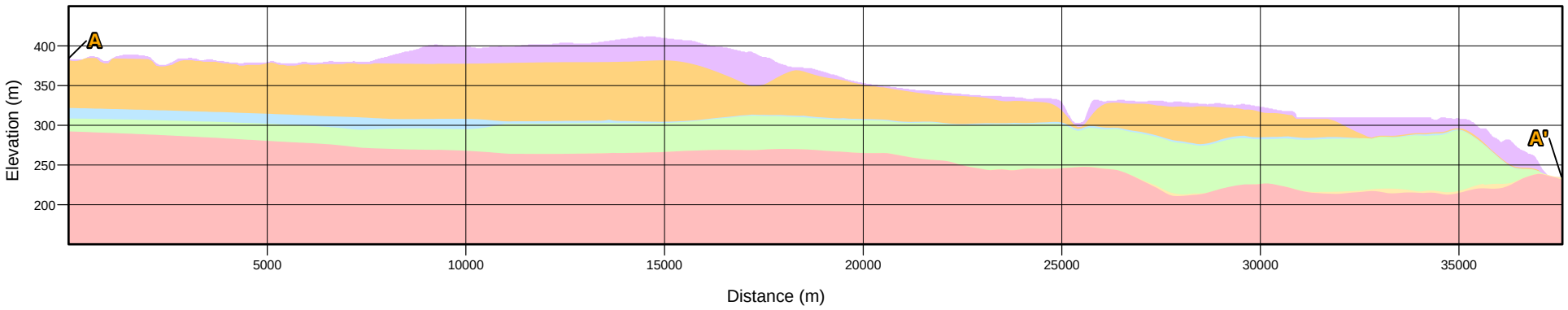
Mine Components

- Mine Pit
- Overburden Disposal
- Reclamation Material Stockpile

Cross-Section Data

- Cross-Section A-A'
- Devonian Beaverhill Lake Group
- McMurray Basal Water Sands
- McMurray Formation
- Clearwater Wabiskaw Member
- Clearwater Formation
- Quaternary Sediment

5 0 5 10
Kilometres
1:500,000



Projection: UTM Zone 12 NAD83
Note:
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Hydrogeological Cross-Section A-A'

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ANALYST: HB	QA/QC: KW	DM	EH	FINAL MAPPING BY: AMEC
Fig 06.03-11 Cross Section AA' 14-10-16				**Figure 6.3-11**

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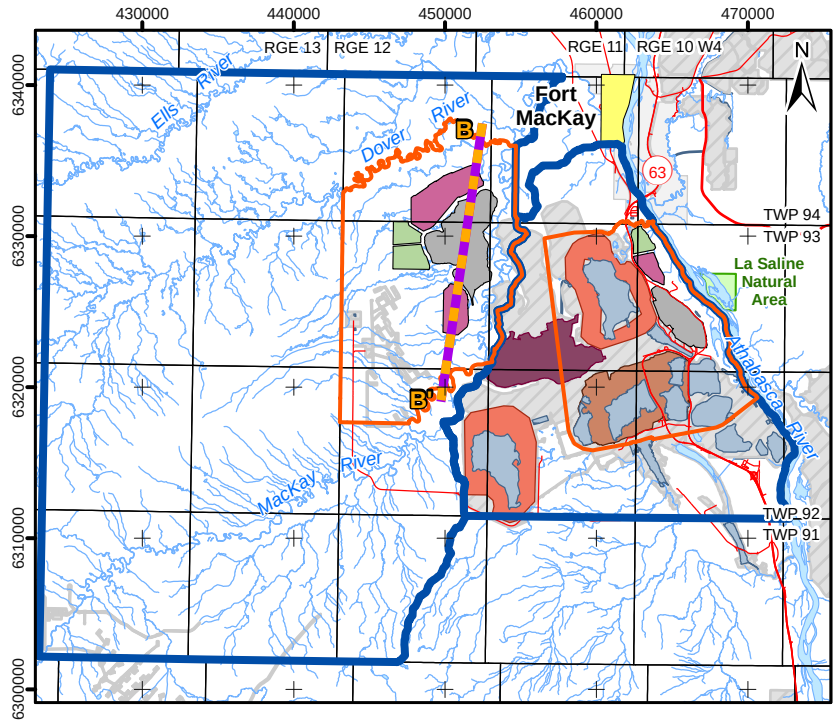


Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

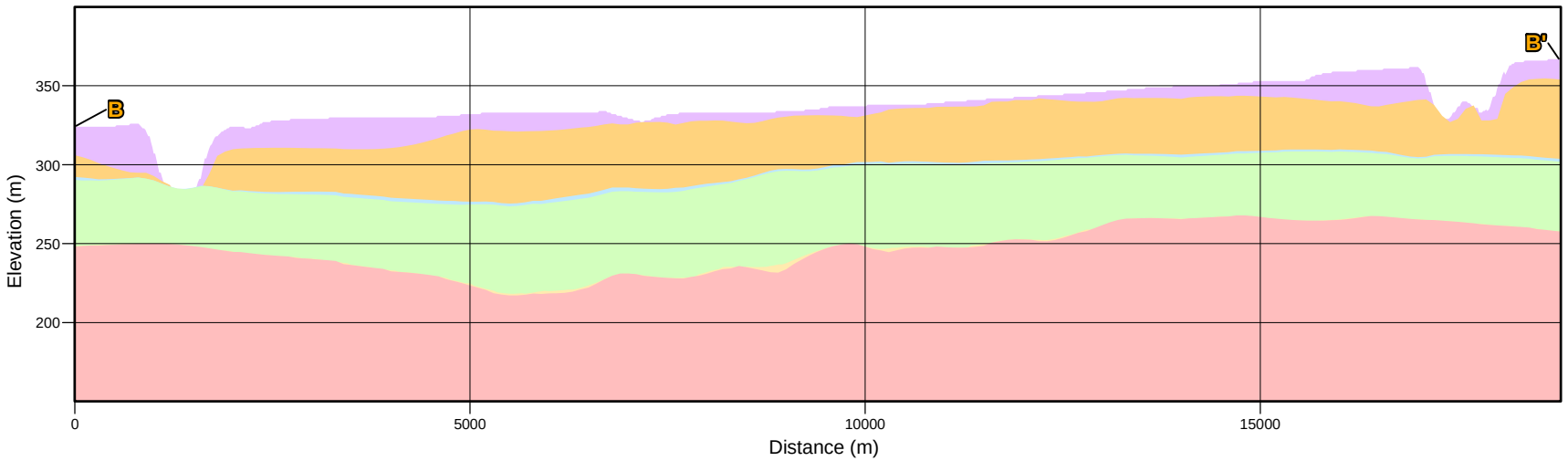
Mine Components

- Mine Pit
- Overburden Disposal
- Reclamation Material Stockpile

Cross-Section Data

- Cross-Section B-B'
- Devonian Beaverhill Lake Group
- McMurray Basal Water Sands
- McMurray Formation
- Clearwater Wabiskaw Member
- Clearwater Formation
- Quaternary Sediment

5 0 5 10
Kilometres
1:500,000



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Hydrogeological Cross-Section B-B'

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ANALYST: HB	QA/QC: KW	DM	EH	FINAL MAPPING BY: AMEC
Fig 06.03-12 Cross Section BB' 14-10-16				**Figure 6.3-12**

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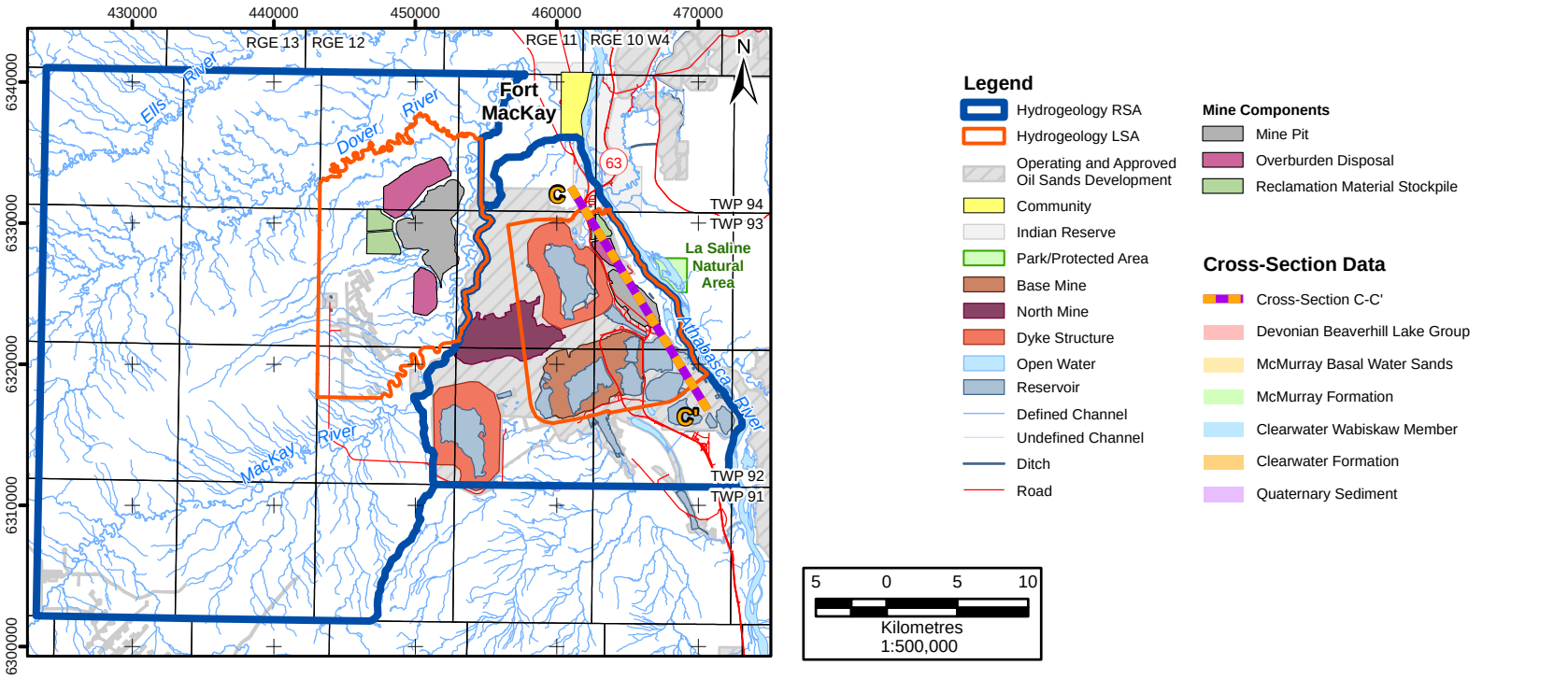


Legend

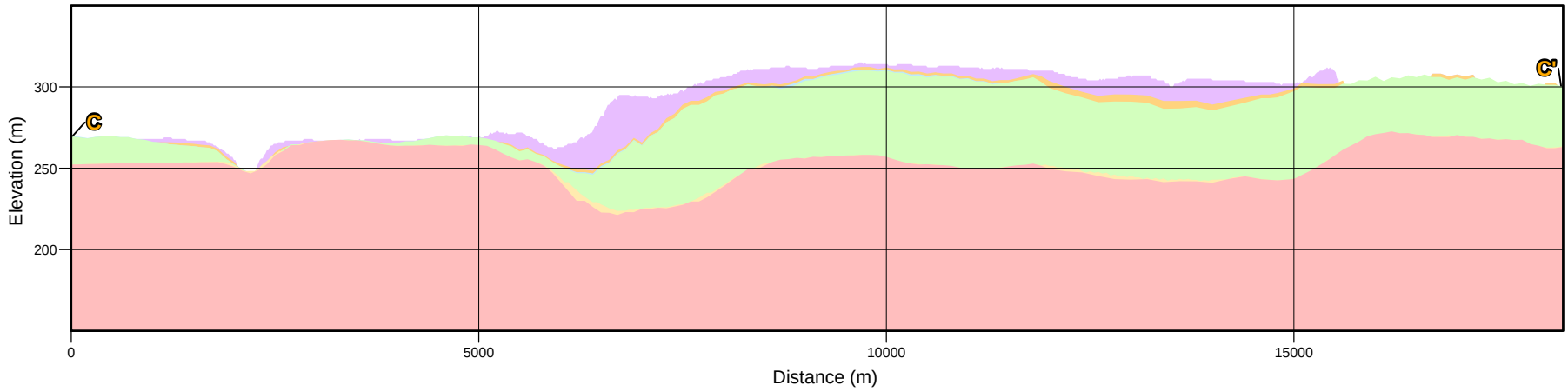
- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Mine Components

- Mine Pit
- Overburden Disposal
- Reclamation Material Stockpile

Cross-Section Data

- Cross-Section C-C'
- Devonian Beaverhill Lake Group
- McMurray Basal Water Sands
- McMurray Formation
- Clearwater Wabiskaw Member
- Clearwater Formation
- Quaternary Sediment



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MLX Project

Hydrogeological Cross-Section C-C'

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ANALYST: HB	QA/QC: KW	DM	EH	FINAL MAPPING BY: AMEC
Fig 06.03-13 Cross Section CC' 14-10-16				**Figure 6.3-13**

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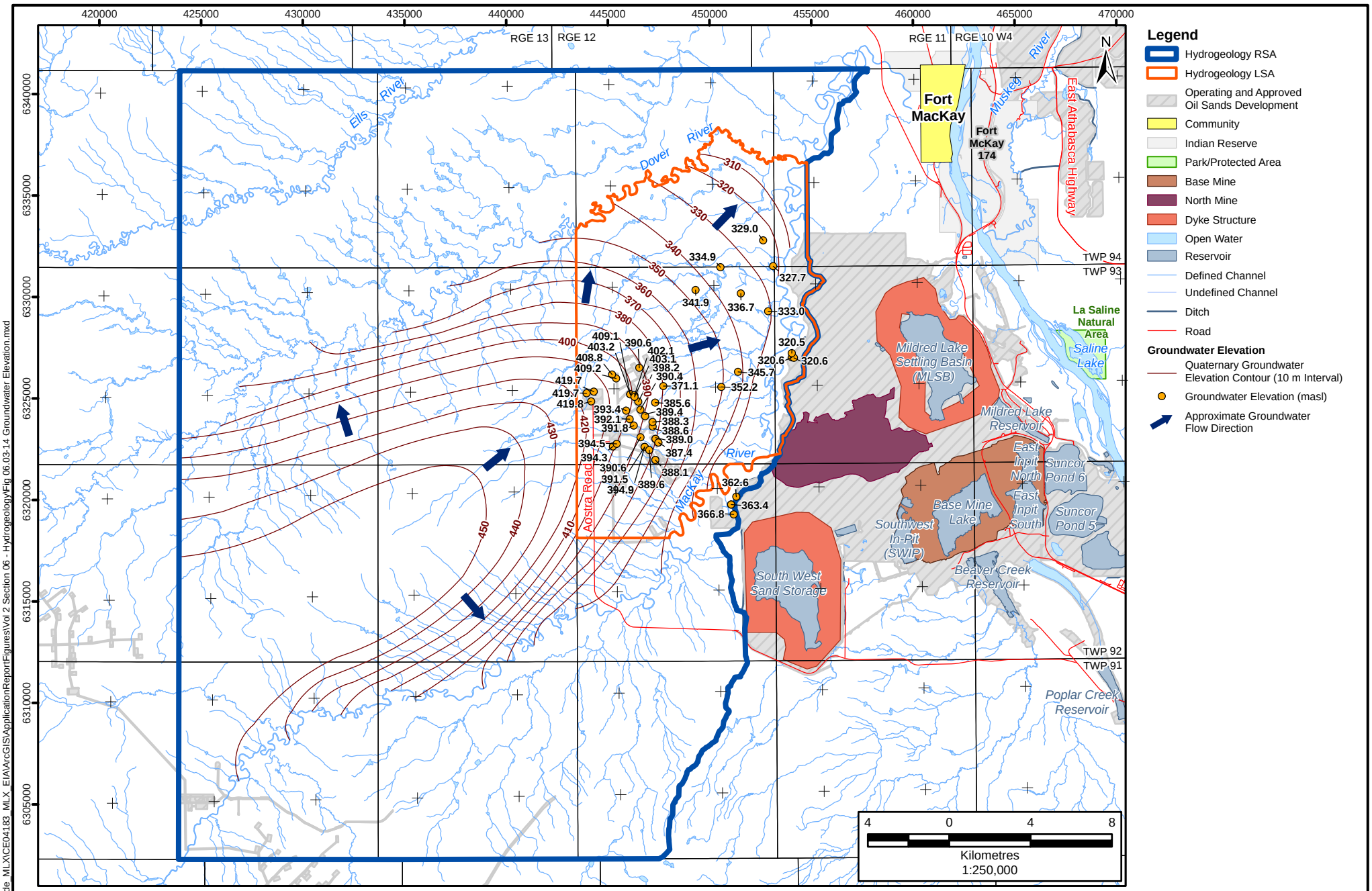

Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road

Groundwater Elevation

- Quaternary Groundwater Elevation Contour (10 m Interval)
- Groundwater Elevation (masl)
- Approximate Groundwater Flow Direction

Projection: UTM Zone 12 NAD83
Note: Groundwater elevation contours have been interpreted based on available measured groundwater and surface water elevations.
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Quaternary Groundwater Elevation MLX-W

DATE:	PROVIDED BY:
October 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.03-14 Groundwater Elevation 14-10-03	**Figure 6.3-14**

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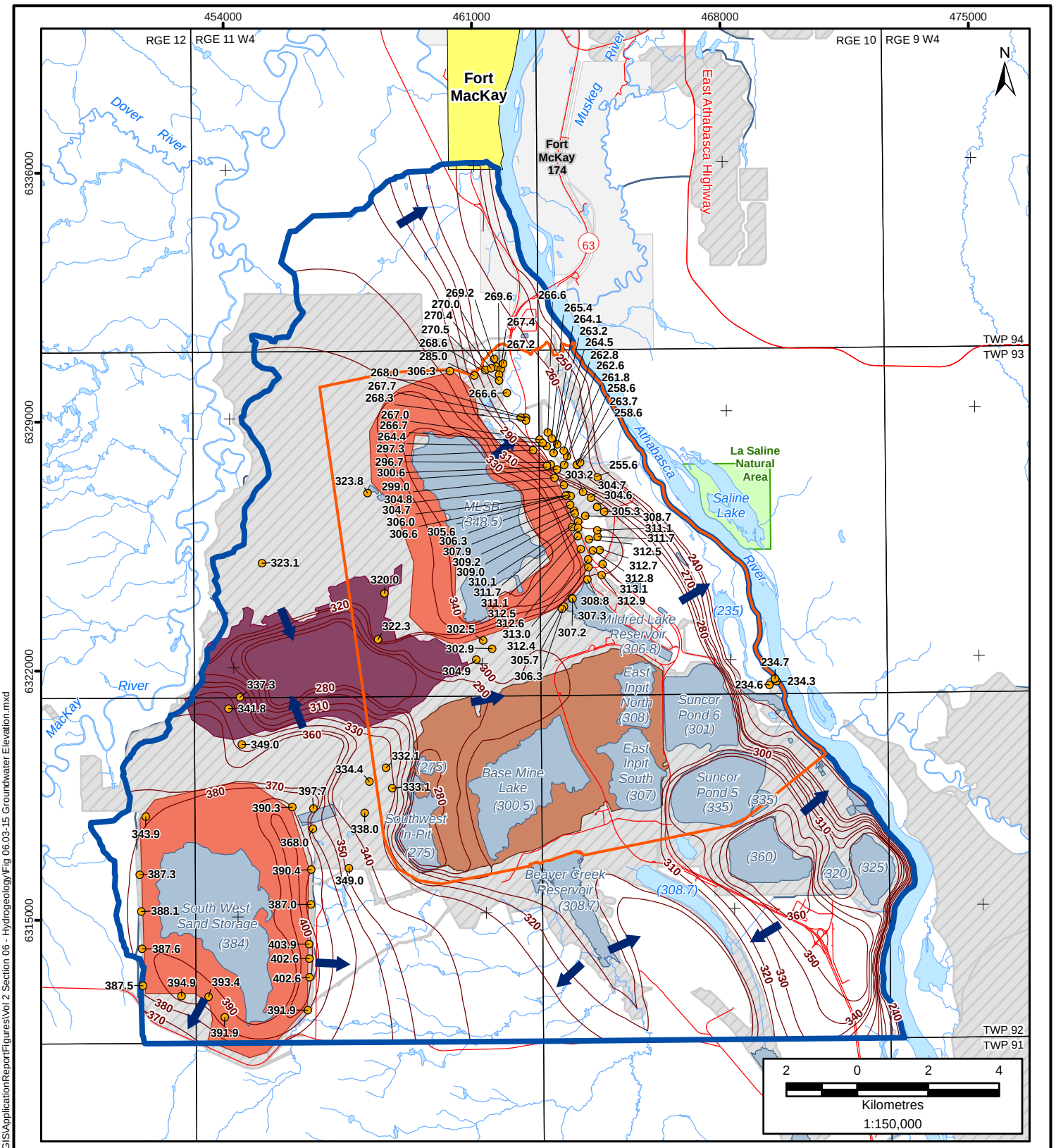

Legend

- Hydrogeology LSA
- Hydrogeology RSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- (384) Surface Water Level (masl)
- Defined Channel
- Undefined Channel
- Ditch
- Road

Groundwater Elevation

- Quaternary Groundwater Elevation Contour (10 m Interval)
- Groundwater Elevation (masl)
- Approximate Groundwater Flow Direction

Projection: UTM Zone 12 NAD83
Note: Groundwater elevation contours have been interpreted based on available measured groundwater and surface water elevations.
Sources: AB TPR, © Department of Natural Resources Canada. All rights reserved, GeoBase®, Spatial Data Warehouse Ltd., Syncrude.

Path: S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - HydrogeologyFig 06.03-15 Groundwater Elevation.mxd

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MLX Project

Quaternary Groundwater Elevation MLX-E

DATE:	PROVIDED BY:
October 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.03-15 Groundwater Elevation 14-10-03	**Figure 6.3-15**

In the MLX-W HRSA, the overburden acts as an aquitard and the groundwater flow is expected to be predominantly downwards, with a smaller horizontal component towards topographic lows. The topographic highs at the Birch Mountains to the northwest and the MacKay Plains Thickwood Hills plateau to the southwest, direct shallow groundwater flow towards the MacKay, Dover and Ells River. Volume 3, Tables C4-1 and C4-2 include well IDs, UTM coordinates, and groundwater elevations for wells screened within Quaternary age sediments in the HRSA.

Volume 3, Tables C4-3 to C4-6 include groundwater chemistry data from wells screened in the overburden, which are graphically shown on Piper Diagrams for MLX-W (Figure 6.3-16) and MLX-E (Figure 6.3-17). The overburden groundwater is generally non-saline with a variety of water types. Total dissolved solids (TDS) concentrations are generally below 2,000 mg/L, with an average of 1,230 mg/L.

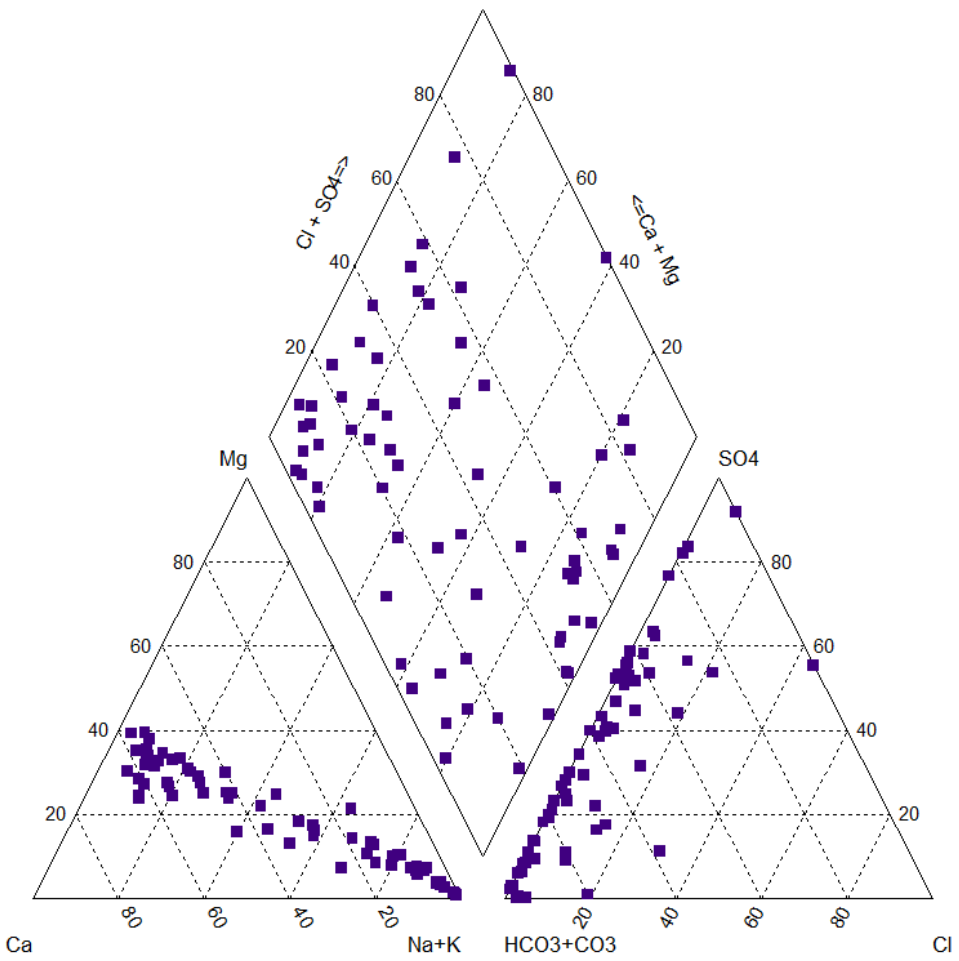
6.3.3.2 Empress Formation Buried Channel Aquifers

The Birch Channel is the major Empress Formation aquifer in the HRSA. Figure 6.3-10 shows the extent of this aquifer, as well as other Pleistocene buried channels, including the MacKay, Willow and North Spruce channels, as interpreted by Andriashek and Atkinson (2007) and Southern Pacific Resources Corp. (2011). The deepest parts of the channels incise into the Clearwater Formation. With the Basal Water Sands only locally present in the MLX-W area, there does not appear to be a significant vertical hydraulic connection between the Birch Channel and Basal Water Sands. The hydraulic conductivity of the Birch Channel was reported to be between 7.2×10^{-5} and 7.8×10^{-4} m/s (Petro-Canada 2005), compared to slightly higher conductivity of the MacKay Channel (5.0×10^{-4} to 4.8×10^{-5} m/s, various sources, Volume 3, Table C4-1). The confined groundwater piezometric elevations in the Birch Channel have been recorded at about 395 to 399 masl, sloping gently east, along the longitudinal axis of the channel.

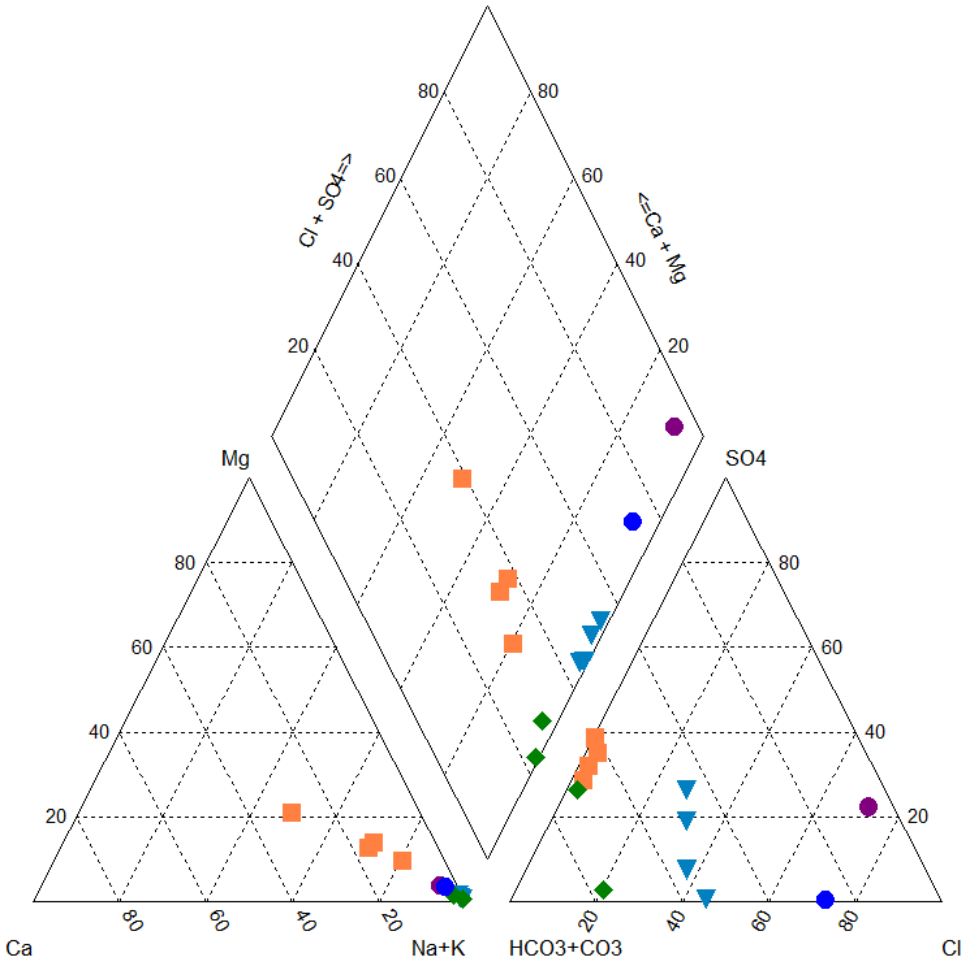
The Birch Channel has been mapped to cross a small part of the proposed mine pit at the mine pit at the southern end. However, two wells were drilled and installed in this area as part of the 2013 hydrogeology field program (Volume 3, Appendix C1) and channel sediments were not encountered. Based on this information, it is likely that the Birch Channel occurs further to the south or has been eroded in this area.

Because the buried channel aquifers are within channels incised through surficial Quaternary sediments, the channel aquifers are in direct connection with Quaternary sediments. The buried channel aquifers are not deep enough to be directly connected to Basal Water Sands and the two units are separated by aquitards material.

Both the Birch and MacKay channels are freshwater aquifers with similar chemical properties. TDS concentrations range from 790 to 1,160 mg/L, with an average of 980 mg/L where present in the HRSA. The groundwater is sodium-bicarbonate-sulfate type.



Quaternary



Non-Quaternary

- Wabiskaw / McMurray Aquitard
- Grand Rapids Aquifers
- Empress (Birch Channel) Aquifer
- Devonian Aquitard
- Clearwater Aquitard
- Undifferentiated Quaternary

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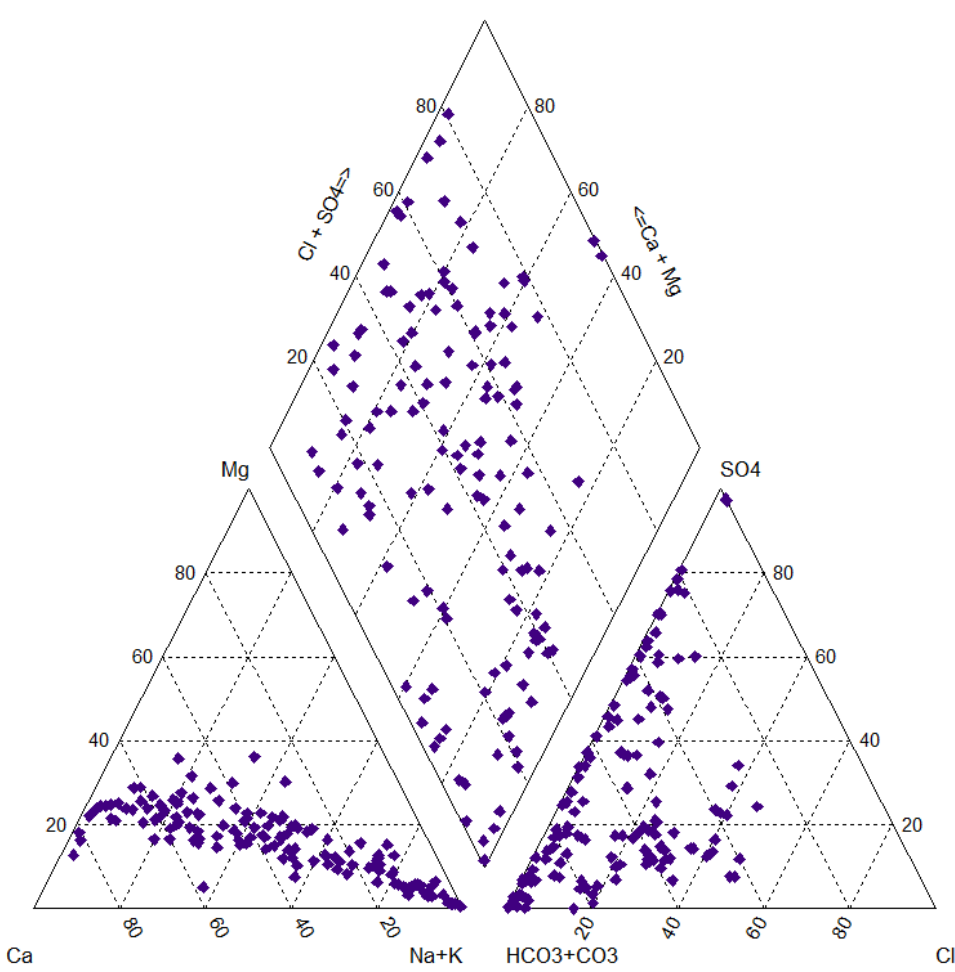
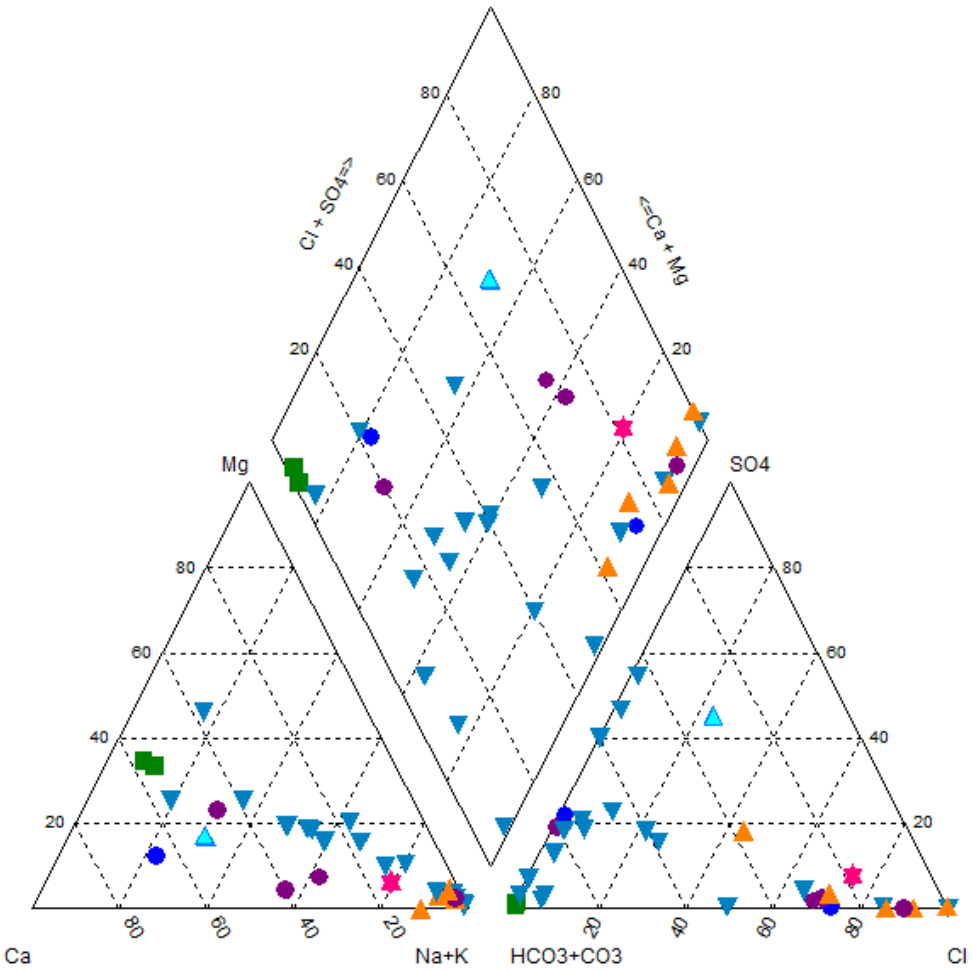
Piper Diagram - MLX-W

DATE: August 2014		PROVIDED BY: AMEC
ANALYST: JH	QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig06.03-16 Piper Diagram MLX-W 14-08-14		**Figure 6.3-16**

Path: S:\Gis\Projects\CEI\Syncrude_MLX\CE04183_MLX_EIA\CorelDraw\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig06.03-16 Piper Diagram - MLX-W.cdr



Quaternary



Non-Quaternary

- Wabiskaw / McMurray Aquitard
- Saline Spring
- Oxbow Lake
- Grand Rapids Aquifer
- Devonian Aquitard
- Clearwater Aquitard
- Basal McMurray Aquifer
- Undifferentiated Quaternary

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Piper Diagram - MLX-E

DATE:	PROVIDED BY:
August 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig06.03-17 Piper Diagram MLX-E 14-08-14	**Figure 6.3-17**

Path: S:\Gis\Projects\CEI\Syncrude_MLX\CE04183_MLX_EIA\CorelDraw\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig06.03-17 Piper Diagram - MLX-E.cdr

6.3.3.3 Clearwater Aquitard

The Clearwater Aquitard, comprised of shale and siltstone, overlies the McMurray Formation and underlies the Grand Rapids Formation (where present) and appears to be continuous across the HRSA except near major rivers. Hydraulic conductivity values for this unit range between 3.3 x 10^{-7} and 5 x 10^{-9} m/s (Petro-Canada 2005; Hackbarth and Nastasa 1981). Groundwater elevations in this unit are higher in the uplands, sloping east to the Athabasca River, from 320 to 410 masl. Groundwater is slightly alkaline, dominantly of Na-HCO_3 and Na-Cl-HCO_3 types. TDS ranges from 566 to 13,400 mg/L within the HRSA.

Within the HRSA, the Clearwater Formation has been set as the base of groundwater protection by the Alberta Energy Regulator (AER 2007).

This aquitard, along with the Wabiskaw/McMurray aquitard, acts as a significant hydraulic barrier between surficial Quaternary groundwater and the Basal Water Sands. However, groundwater slowly moves downward from the surficial sediments to the Basal Water Sands.

6.3.3.4 Wabiskaw/McMurray Aquitard

The Wabiskaw/McMurray Aquitard underlies the Clearwater Aquitard and includes bitumen-saturated sands of the McMurray Formation and low permeability marine sediments of the Wabiskaw Member. Groundwater elevations were on the order of 325 to 335 masl. TDS concentrations range from 573 to 10,420 mg/L and groundwater is primarily of Na-Cl-HCO_3 type.

Based on the calibrated models (Volume 3, Appendices C2 and C3), the Wabiskaw Member Aquitard has the following bulk hydraulic conductivities:

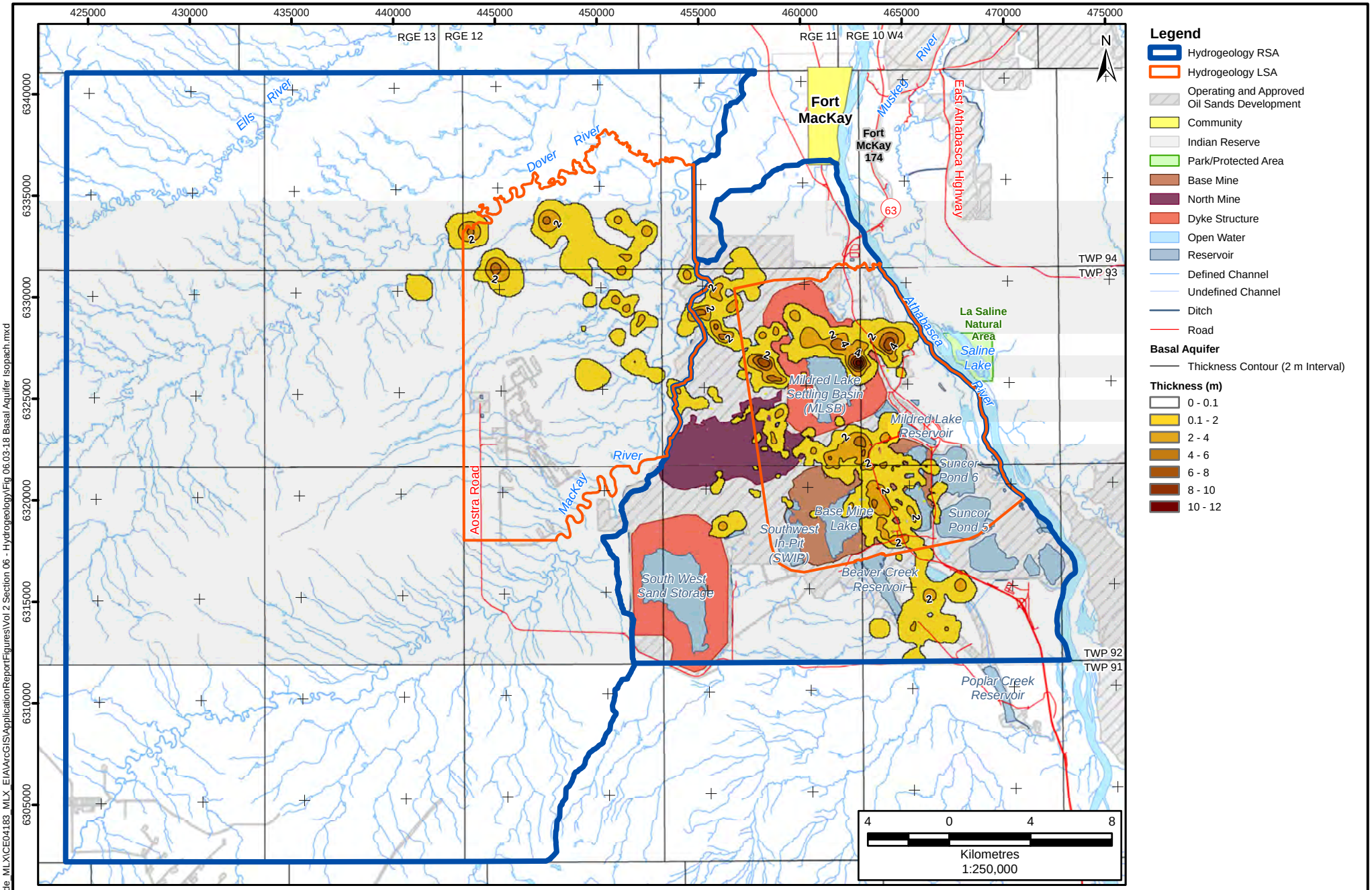
- $K_{x,y}$ = 2 x 10^{-7} to 5 x 10^{-7} m/s;
- K_z = 2 x 10^{-7} to 5 x 10^{-8} m/s; and
- specific storage = 4 x 10^{-5} m^{-1}.

Based on the calibrated models (Volume 3, Appendices C2 and C3), the McMurray Aquitard has the following bulk hydraulic conductivities:

- $K_{x,y}$ = 1 x 10^{-9} m/s;
- K_z = 1 x 10^{-10} m/s; and
- specific storage = 4 x 10^{-5} m^{-1}.

6.3.3.5 Basal McMurray Aquifer

The Basal McMurray Aquifer, also known as Basal Water Sands, generally occurs between bitumen saturated sediments of the McMurray Formation and the underlying Devonian bedrock in areas of bedrock topographic lows. Figure 6.3-18 shows the distribution and thickness of the Basal McMurray Aquifer within the HRSAs. The Basal McMurray Aquifer is not regionally continuous within the HRSAs.



S:\GIs\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.03-18 Basal Aquifer Isopach.mxd

Projection: UTM Zone 12 NAD83
Note:
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Basal Aquifer Isopach

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ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.03-18 Basal Aquifer Isopach 14-10-03	**Figure 6.3-18**

Based on the calibrated models (Volume 3, Appendices C2 and C3), the Basal Water Sands has the following bulk hydraulic conductivities:

- $K_{x,y}$ = 1 x 10^{-5} m/s;
- K_z = 1 x 10^{-6} m/s; and
- specific storage = 1 x 10^{-4} m^{-1}.

Groundwater in the basal aquifer is isolated from a direct connection with the ground surface. The basal aquifer is relatively deep (over 80 m below ground surface) and confined. Available groundwater elevations ranged between 230 and 290 masl. Groundwater in the basal aquifer is characterized as generally saline Na-Cl type, with elevated TDS of up to 35,000 mg/L (Sivarajan 2014; Syncrude 2012).

6.3.3.6 Beaverhill Lake Aquitard

Underlying the McMurray Formation is the Waterways Formation of the Beaverhill Lake Group. This unit acts as an aquitard and is referred herein as the Beaverhill Lake Aquitard. Within the HRSA, reported hydraulic conductivities were low, ranging from 1 x 10^{-7} to 4.5 x 10^{-9} m/s (Sivarajan 2014; Syncrude 2012; Hackbarth and Nastasa 1979). As with the other aquitards, groundwater flow is expected to be primarily downward. The groundwater type is Ca-Na-Mg-HCO_3 type, with TDS of 130 to 27,200 mg/L.

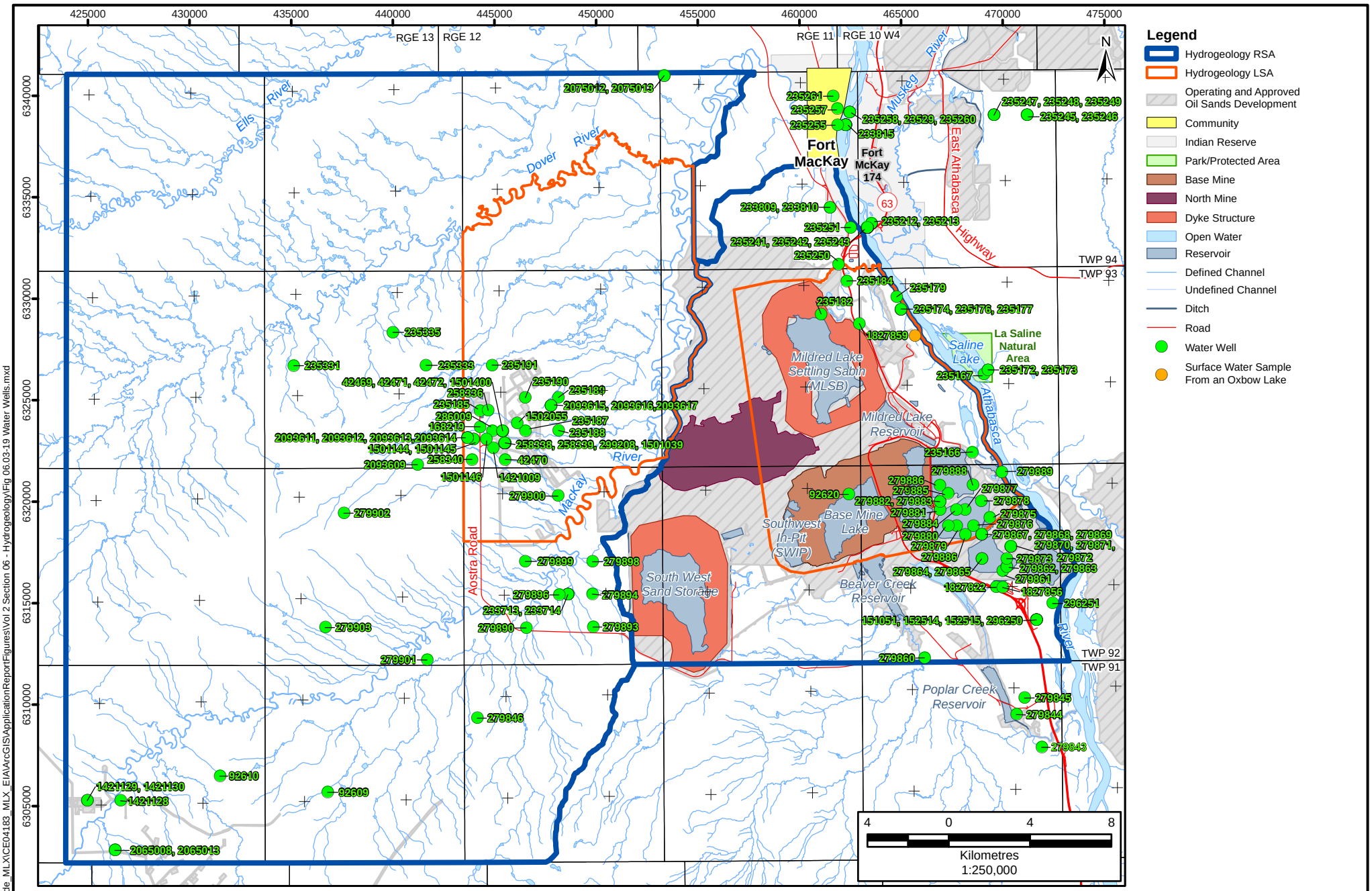
6.3.3.7 Water Wells

The Groundwater Information System database (ESRD 2014) was searched on 20 January 2014 to identify water wells within the MLX Project HRSAs. A total of 243 water well drilling reports were found, of which 183 wells were identified as: industrial (53), investigation (47), observation and monitoring (43), dewatering (14), or domestic/camp (10) water use. Sixteen wells had “other” or “unknown” uses, and 26 were used for chemistry sampling. Five springs were identified within the records.

Drilling records for abandoned or test holes were not included in Volume 3, Table C4-9, which summarizes the well record information. The records are listed in the database by legal land description, so some locations have more than one well. Figure 6.3-19 shows the locations of wells, labeled by the unique well identifier numbers.

6.3.3.8 Groundwater Use

Volume 3, Table C4-10 lists the *Water Act* approvals for groundwater diversion within the MLX HRSAs and their locations are shown on Figure 6.3-20. Most diversion sources are listed as surface water infiltration and groundwater seepage from shallow Quaternary sediments. Of the identified aquifer sources, the Birch Channel Aquifer is listed under five approvals owned by Suncor Energy Inc. within the HRSA. South of the MLX Project, one approval is listed sourcing groundwater from the MacKay Channel Empress Formation, owned by Southern Pacific Resource Corp., and one approval owned by MacKay Operating Corp. sources water from undifferentiated Empress Formation.



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road
- Water Well
- Surface Water Sample From an Oxbow Lake

Projection: UTM Zone 12 NAD83
Note:
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S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.03-19 Water Wells.mxd

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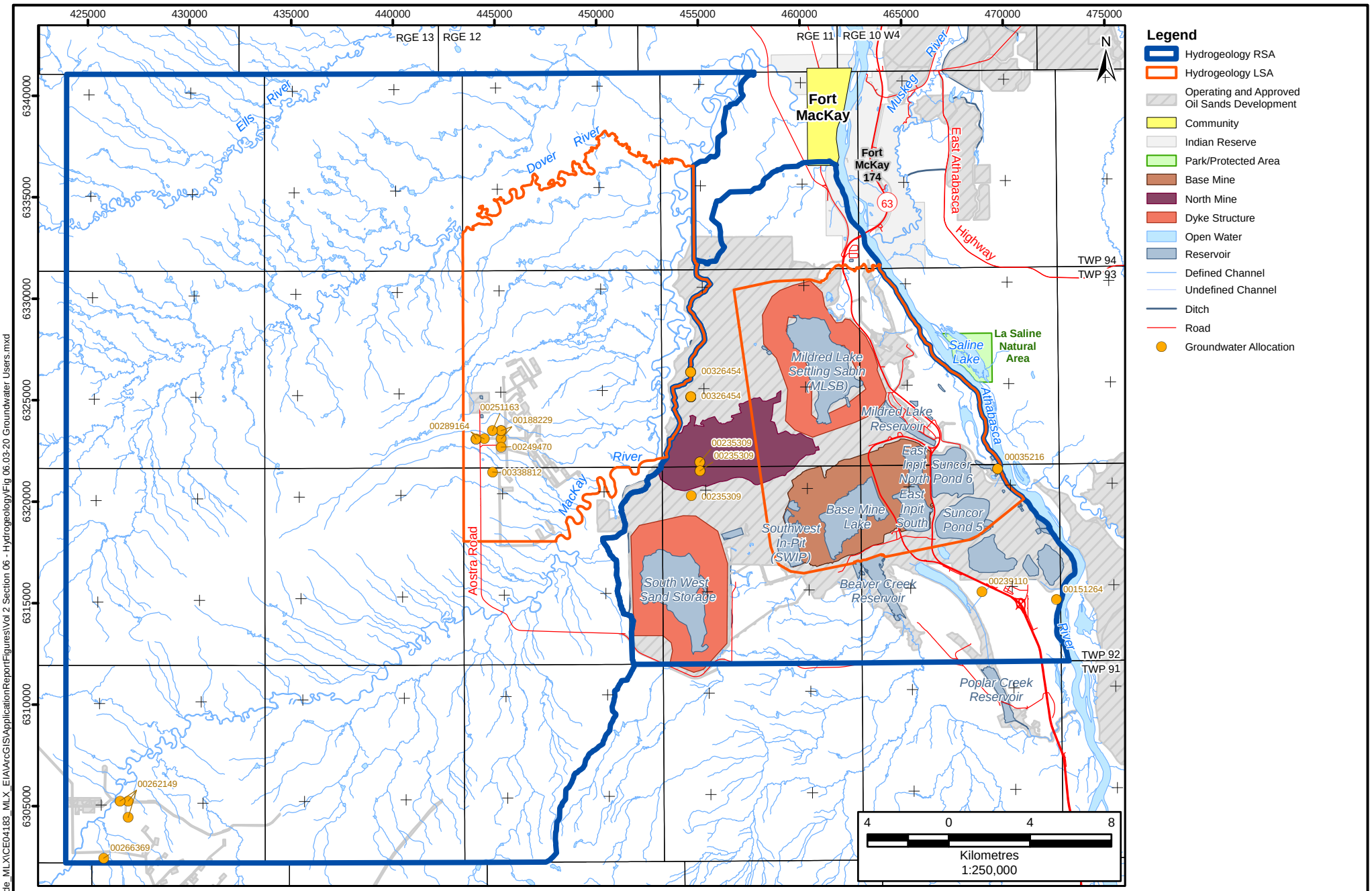
MLX Project

Reported Locations of Water Wells

DATE:	PROVIDED BY:
October 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.03-19 Water Wells 14-10-03	**Figure 6.3-19**



Legend

- Hydrogeology RSA
- Hydrogeology LSA
- Operating and Approved Oil Sands Development
- Community
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Undefined Channel
- Ditch
- Road
- Groundwater Allocation

Projection: UTM Zone 12 NAD83
Note:
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S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.03-20 Groundwater Users.mxd

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MLX Project

Groundwater Users

DATE:	PROVIDED BY:
October 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.03-20 Groundwater Users 14-10-03	**Figure 6.3-20**

There are no plans to withdraw groundwater specifically for MLX Project operations use, but groundwater will be pumped for the purpose of depressurizing the Basal Water Sands where required for safety reasons.

6.3.3.9 Domestic Use Aquifers

For the purpose of selecting and applying a groundwater guideline for human health protection by ingestion, a domestic use aquifer (DUA) is defined as a geologic unit (either of a single lithology or inter-bedded units) that is above the Base of Groundwater Protection having one or more of the following properties:

- a bulk hydraulic conductivity of 1 x 10^{-6} m/s or greater and sufficient thickness to support a sustained yield of 0.76 L/min or greater; or
- is currently being used for domestic purposes; or
- any aquifer determined by Alberta Environment to be a DUA.

Within the HRSAs, the geologic units above the Base of Groundwater Protection are the Grand Rapids Formation and Quaternary age sediments. The Grand Rapids is considered a DUA, although there are currently no production wells in this unit within the HRSAs. The Grand Rapids is not present within the HLSAs. The Empress Formation buried channel aquifers described in Section 6.3.2.5 are all considered to be DUAs. The saturated surficial Quaternary sediments within the MLX-W HLSA encountered during the field program were predominantly low permeability till and would likely not be considered to be a DUA, although one of the hydraulic conductivities measured in the field was greater than 1 x 10^{-6} m/s, this was likely due to the presence of a lens of higher permeability material and not reflective of the bulk hydraulic conductivity. The saturated surficial Quaternary sediments within the MLX-E HLSA are considered to be a DUA.

6.3.3.10 Wastewater Disposal

There are no wastewater injection wells within the HRSAs, based on available information (geoLOGIC 2014). There will not be any wastewater injection wells associated with the MLX Project.

6.3.3.11 Surface Water – Groundwater Interaction

Recharge of groundwater occurs primarily in higher elevation areas and flows towards major rivers, including the Dover, MacKay, Ells, and Athabasca River where it discharges. The shallow Quaternary sediments are predominately low permeability tills, especially in the MLX-W HRSA, and recharge is low, typically less than 1 to 3% of precipitation, based on the calibrated modelling results. However, within the MLX-E HRSA, recharge also occurs from natural and man-made lakes and ponds.

Five springs have been identified from ESRD Water Well Reports: one is located to the north of the MLX-E HLSA along the Athabasca River approximately 2 km north of the MacKay River; one is on the Beaver River tributary to the Athabasca River; and three were located at the edge of Saline Lake to the east of the MLX-E HLSA. Groundwater seepage also potentially occurs from recharge infiltration in the uplands in the southwest of the MLX Project, and along the escarpments of major watercourses, including the MacKay, Dover, Ells, Birchwood Creek, Beaver River, and other smaller tributaries. Fens, by definition, are areas of groundwater discharge and are discussed further in the Volume 2, Section 10.0.

During surface water field investigations, on 22 November 2013, a surface water sample was collected from a small Oxbow Lake at the location shown on Figure 6.3-19. The sample location is between the escarpment and the west bank of the Athabasca River, with the La Saline Natural Area to the east on the other side of the Athabasca River. The TDS concentration measured at approximately 1,800 mg/L was higher than expected for surface water in that area. The origin of the elevated salinity in this surface water could be groundwater discharge, possibly diluted by surface water runoff, or due to concentration of surface water by evaporation.

Three possibilities for the origin of the water from groundwater sources were considered: Devonian bedrock, Basal Water Sands (Cretaceous) and Quaternary sediments. Water from the Devonian bedrock reaching the surface at this location is possible as dissolution of the Prairie Evaporite Formation during the Pleistocene Era has caused localized connectivity between Devonian and Basal McMurray Formations with the overlying Quaternary sediments. Upwelling of saline groundwater from the deeper units has been documented along deeply-incised reaches of the Athabasca River (Gibson *et al.* 2013) and at Saline Lake, which is located on the eastern side of the Athabasca River directly across from the MLX-E HLSA. A spring of Devonian source water was identified at Saline Lake (ESRD 2014). The groundwater chemistry of the Basal Water Sands and Devonian units is typically higher in electrical conductivity, TDS, and chloride indicator parameters, compared to fresh surface water sources. Water type is typically Na-Cl or Na-Cl-HCO3 regionally, and within the MLX HRSAs. The chemistry of the surface water with elevated salinity could be groundwater from either Devonian bedrock or Basal water sands diluted with fresher surface runoff. The salinity level of the surface water is within the range of nearby groundwater within Quaternary sediments, so this could also be the source of the water. The MLSB was also considered as a possible source.

To evaluate the groundwater source of the water, routine parameters from the Oxbow Lake sample were compared with the chemistry of groundwater samples from Quaternary, Basal Water Sands and Devonian wells within the MLX HRSAs, as well as surface water from the MSLB and T-Pit Lakes (Syncrude 2012). Piper plots show the ratios of major ions for water from the various sources (Figure 6.3-16).

Devonian and McMurray formation waters were found to have elevated chloride and sodium (on the order of 3,000 to 20,000 mg/L) and low calcium and bicarbonate concentrations. The chemistry of water from the saline spring near Saline Lake correlated closely with the proportions of Na-Cl in Devonian and McMurray groundwater. By contrast, the Quaternary samples had higher proportions of calcium and bicarbonate, with little sodium or chloride.

Tailings pond water from MLSB had elevated sodium, comparable to Devonian and McMurray water, but a more moderate chloride concentration. Based on these results, the Oxbow Lake sample appears to correlate closely with the higher calcium and bicarbonate proportions present in Quaternary groundwater, with similarly low salinity indicators. It is unlikely to be directly influenced by upwelling of highly saline formation water from deeper units. Naphthenic acids are also much lower than results from the bitumen-bearing McMurray Formation, which suggests minimal anthropogenic influence to the lake from process-affected water.

6.4 Application Case

6.4.1 Pre-production

Prior to mining, it is assumed that the Basal Water Sands (Basal McMurray Aquifer) will need to be depressurized to allow safe mining. Pumping will likely begin approximately two years prior to mining and continue throughout the mining phase. Basal Water Sands depressurizing was assessed through groundwater modelling for both MLX-W (Volume 3, Appendix C2) and MLX-E (Volume 3, Appendix C3).

For both MLX-W and MLX-E, the lateral extents of the Basal Water Sands are limited and the effects of depressurization are essentially limited to the Basal Water Sands, namely lowering of the hydraulic head of the groundwater within the hydrogeological unit, which is the objective of the depressurization. The geologic units, which have low permeability, surrounding the Basal Water Sands will not be negatively affected by the depressurization pumping.

For MLX-E, there appears to be some connection between Basal Water Sands and the Athabasca River, based on their relative locations and the numerical modelling results. Prior to depressurization, it is estimated from the modelling that approximately 347 m^3/d of groundwater flows from the Basal Water Sands into the Athabasca River within the MLX-E HLSA. The simulated depressurization pumping shows reversal of the flow of Basal Water Sands groundwater to the Athabasca River and pull approximately 470 m^3/d from the river towards the pumping well. Compared to the flow in the Athabasca River, the amount of groundwater discharge reduction would not have a measurable effect. The expected changes in groundwater flow rates to the Athabasca River are summarized in Volume 3, Table C3-3.

For both MLX-W and MLX-E, once the depressurization pumping stops and the mine pit has been backfilled and the end pit lake filled (MLX-W only), the groundwater conditions will return to close to pre-pumping conditions within several years.

6.4.2 Operations

During mining operations, the presence of an open pit mine, along with continued depressurization of the Basal Water Sands, will act to lower the groundwater elevations in the area surrounding the mine and divert groundwater flow towards the mine. This will occur because, by necessity, the pit will be kept free of water and groundwater will flow into the pit through the pit walls due to the pressure gradient.

The diverting of groundwater flow to the mine pit will reduce the flow of groundwater to the MacKay and Dover rivers. Pre-mining groundwater discharge rates to the MacKay and Dover rivers were estimated to be 730 and 344 m^3/d, respectively, within the MLX-W HLSA. By the end of mining in 2036, the simulated subsurface water flow rate to the MacKay River reversed to be approximately 50 m^3/d being pulled from the river towards the mine and the groundwater discharge rate to the Dover River reduced to 185 m^3/d. The expected changes in groundwater flow rates to the MacKay and Dover rivers based on the computer modelling are summarized in Table 6.4-1. The effect of the changes to the groundwater discharge to the rivers on the total surface water flow in the rivers is expected to be below measurable levels (i.e., a neutral effect).

Table 6.4-1: MLX-W Simulated Flow Rates

Description	Pre-Mining (m^3/d)	End of 2026 (m^3/d)	End of 2029 (m^3/d)	End of 2036 (m^3/d)
Total flow rate into the mine (groundwater from all directions)	–	10,400	12,400	10,800
Flow rate into MacKay River	730	238	158	-57
Flow rate into Dover River	344	296	285	185

Note:
– = Not applicable.

Within the MLX-E HLSA, the diverting of groundwater flow to the mine pit and continued depressurization pumping of the Basal Water Sands will reduce the flow of groundwater to the Athabasca River. Prior to the start of depressurization, the discharge rate of groundwater to the Athabasca River within the MLX-E HLSA is estimated to be approximately 523 m^3/d. By the end of mining, the modelling indicates that the mining activities will result in river water being pulled towards the mine pit at a rate of approximately 371 m^3/d. The expected changes in groundwater flow rates to the Athabasca River based on the computer modelling are summarized in Table 6.4-2. The effect of the changes to the groundwater discharge to the Athabasca River on the total surface water flow in the river is expected to be below measurable levels (i.e., a neutral effect).

Table 6.4-2: MLX-E Simulated Flow Rates

	Pre-production	End of Operations (2035)	Closure (2235)
Water flow from model domain to Athabasca River	Q[1]: 176[2] BWS[3]: 347 Total: 523	Q: 99 BWS: -470 Total: -371	Q: 80 BWS: 490 Total: 570
MLX-E pit mine groundwater flow to Athabasca River	Q: 133 BWS: 43 Total: 176	Q: -757 BWS: -191 Total: -948	Q: 56 BWS: 127 Total: 183
Groundwater flow from MLSB-area toe of dyke (leaving MLSB area)	Q: 1,067 BWS: 375 Total: 1,442	Q: 1,312 BWS: 647 Total: 1,959	Q: 1,698 BWS: 364 Total: 2,062

Notes:
[1] Q = Quaternary aquifers.
[2] Flow in units of m^3/d.
[3] BWS = Basal Water Sands aquifer.

The lowered groundwater table can affect fens by reducing or eliminating the groundwater discharge that is sustaining them and is discussed in detail in Volume 2, Section 10.0. The lowered groundwater table can also reduce or eliminate baseflow to rivers, creeks and streams and is discussed in detail on Volume 2, Section 5.0. For both MLX-W and MLX-E, this could potentially affect a large part of the HLSAs and would continue for the duration of the mining. However, for much of the MLX-E HLSA is already disturbed and there are few streams or fens that could be affected. Figures 6.4-1 and 6.4-2 show the expected maximum extent of the 1 m drawdown during operations for MLX-W and MLX-E, respectively.

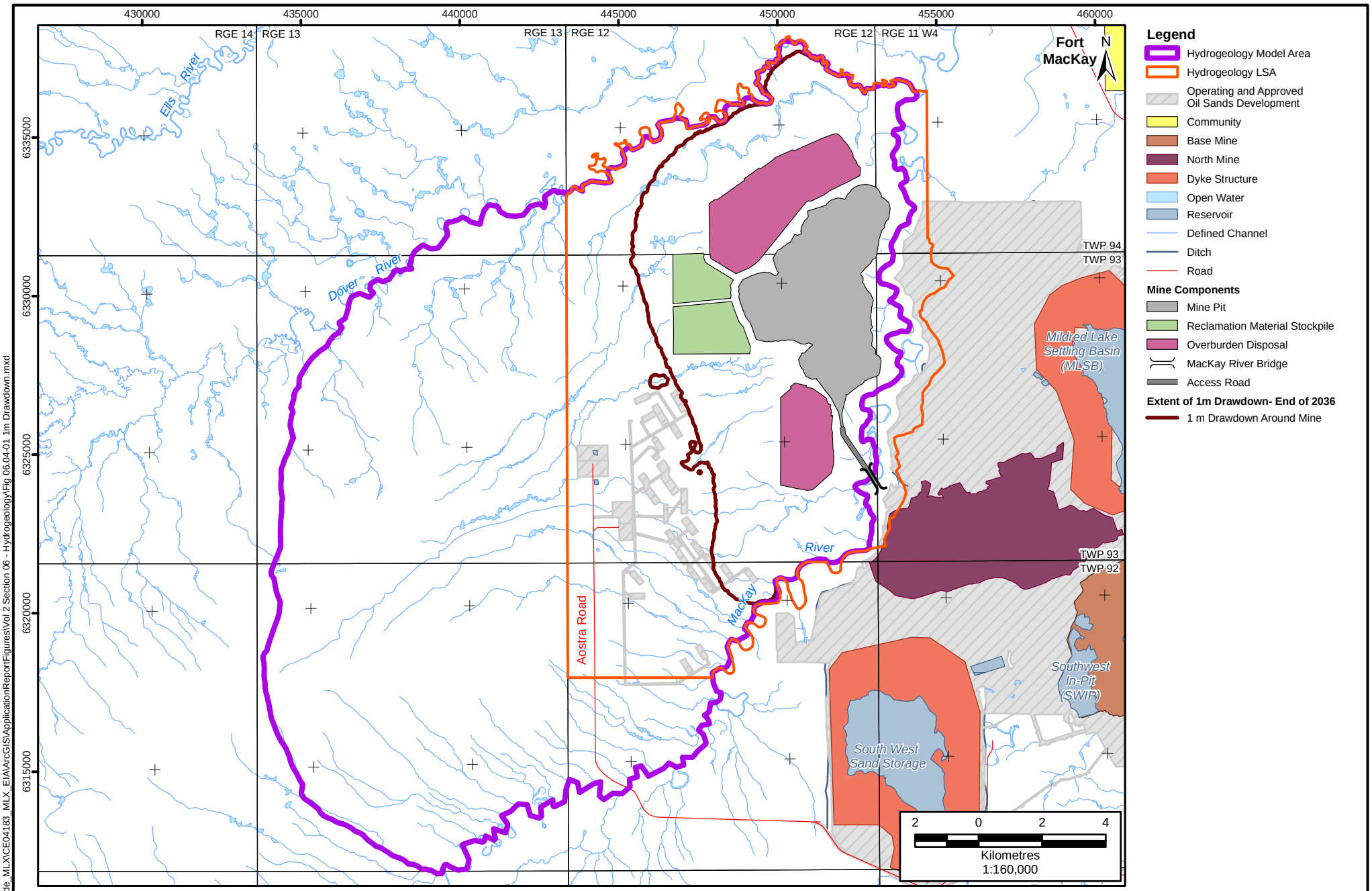
The removal of overburden and oil sands has the potential to cause a fracture or fractures to form in the Devonian bedrock such that deep saline water could flow into the open pit. There has been only one such occurrence due to mining activities in the Alberta oil sands area. The likelihood that it would happen at the MLX Project is considered very low, although the mechanism through which it occurred is poorly understood. Although rare in occurrence, the potential negative effects to surface water quality could be high. Additional information regarding caprock integrity within the MLX Project area can be found in Volume 1, Section 8.1.5.

6.4.3 Closure

For MLX-W, the presence of an end pit lake with a water elevation significantly lower than the original ground surface will affect groundwater elevations, flow directions and flow volumes. The groundwater table will be permanently lowered compared to pre-mining conditions, although to a smaller extent than at the end of mining. This will potentially affect fens, creeks and streams. Figure 6.4-3 shows the expected 1 m groundwater table drawdown contour in the far future after closure. Also, groundwater discharge rates to the MacKay and Dover rivers will be decreased to 583 and 140 m^3/d, respectively, within the MLX-W HLSA. Pre-mining groundwater discharge rates to the MacKay and Dover rivers were estimated to be 730 and 344 m^3/d, respectively, based on numerical modelling. The effect of the changes to the groundwater discharge to the rivers on the total surface water flow in the rivers is expected to be below measurable levels (i.e., a neutral effect). The expected changes in groundwater flow rates to the MacKay and Dover rivers are summarized in Table 6.4-1.

The north overburden dump area (ODA) and south ODA will be placed on Quaternary till adjacent to the MLX-W mine pit. Within the west pit, the backfill material (overburden and cake) will be in direct contact with Quaternary till and unmined McMurray Formation oil sands, all low permeability materials. The backfill material will have lower hydraulic conductivity that the Quaternary sediments, so the groundwater discharge rate from the former mine pit will be lower than pre-mining conditions (Volume 3, Table C2-4) and the groundwater quality is not expected to change (i.e., a neutral effect).

Due to the elevation of the end pit lake, groundwater that has been in contact with backfill material within the mine pit will not flow within the subsurface to potential surface water receptors except for the end pit lake.



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Projection: UTM Zone 12 NAD83
Note:
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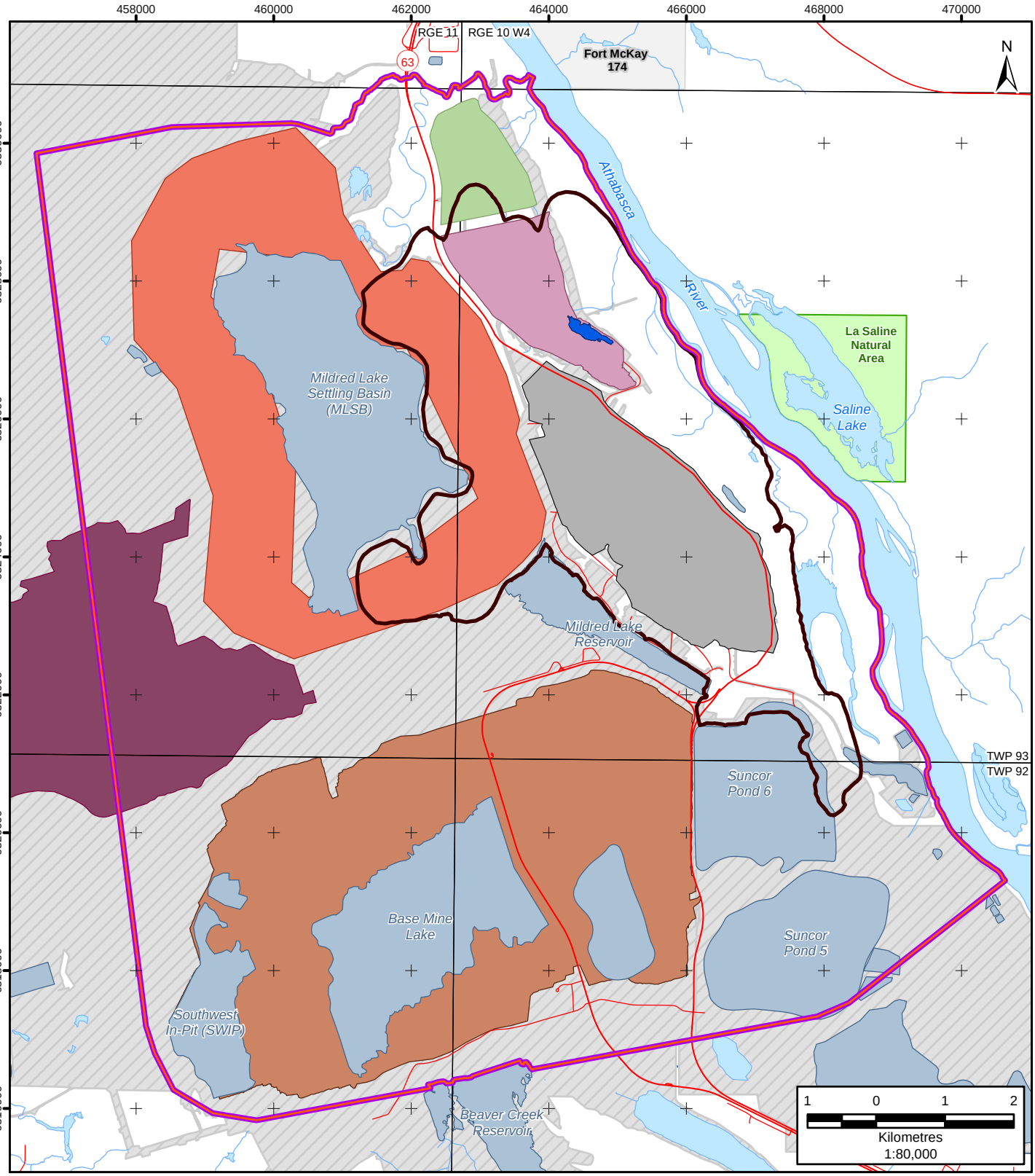
Maximum Extent of 1 m Drawdown in Quaternary During Mining MLX-W

DATE:	PROVIDED BY:
October 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.04-01 1m Drawdown 14-10-03	**Figure 6.4-1**



Legend

- Hydrogeology LSA
- Hydrogeology Model Area
- Operating and Approved Oil Sands Development
- Indian Reserve
- Park/Protected Area
- Base Mine
- North Mine
- T-Pit
- Dyke Structure
- Open Water
- Reservoir
- Defined Channel
- Ditch
- Road

Mine Components

- Mine Pit
- Overburden Disposal
- Reclamation Material Stockpile

Drawdown Around Mine

- 1 m Drawdown Around Mine

Projection: UTM Zone 12 NAD83
Note:
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Path: S:\Gis\Projects\CE\Syncrude_MLX\CE04183_MLX_EIA\ArcGIS\ApplicationReportFigures\Vol 2 Section 06 - Hydrogeology\Fig 06.04-02 MLXE 1m Drawdown.mxd

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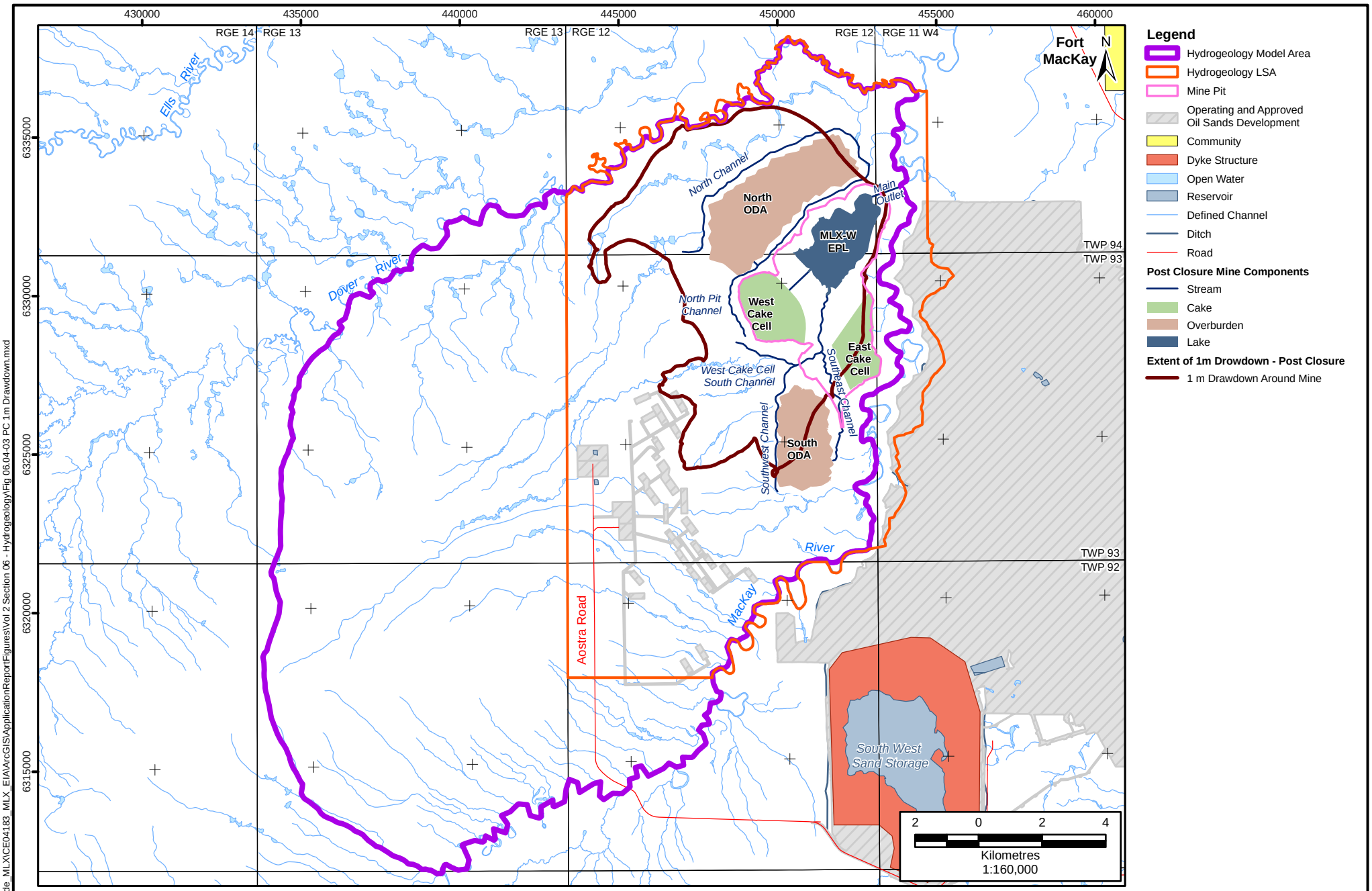
MLX Project

Maximum Extent of 1 m Drawdown in Quaternary at End of Mining MLX-E

DATE:	PROVIDED BY:
October 2014	AMEC
ANALYST: JH / QA/QC: KW DM EH	FINAL MAPPING BY: AMEC
Fig 06.04-02 MLXE 1m Drawdown 14-10-03	**Figure 6.4-2**



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Projection: UTM Zone 12 NAD83
Note:
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MLX Project

Extent of 1 m Drawdown in Quaternary Post Closure MLX-W

DATE: October 2014			PROVIDED BY: AMEC
ANALYST: JH	QA/QC: KW DM EH		FINAL MAPPING BY: AMEC
Fig 06.04-03 PC 1m Drawdown 14-10-03			**Figure 6.4-3**

At MLX-E, the mine pit will be backfilled and there will not be an end-pit lake. Therefore, groundwater elevations, flow directions and flow volumes at closure are expected to be similar to pre-mining conditions. The groundwater discharge rate from the backfilled mine pit to the Athabasca River is expected to be approximately 60 m^3/d. The quality of this water is expected to be similar to pre-mining conditions due to the nature of the backfill material. The MLX-E ODA and a soil dump will be placed just north of the MLX-E mine pit (Volume 3, Figure C3-19) directly on top of Quaternary aged sediments. The backfill material within the MLX-E mine pit will be coke, cake and overburden directly in contact with Quaternary sediments and unmined McMurray Formation oil sands. Groundwater is predicted to seep out of the former mine pit at a rate of 56 m^3/d through Quaternary sediments and 183 m^3/d through Basal Water Sands. This water will eventually reach the Athabasca River. The environmental effects on the Athabasca River are addressed in detail in Volume 2, Section 8.0.

A summary of the Application Case effects is presented in Table 6.4-3.

Table 6.4-3: Summary of Application Case Effects

Indicator	MLX Project Phase	Direction	Geographic Extent	Magnitude	Duration	Frequency	Confidence	Final Effects Rating
Groundwater discharge changes to Athabasca, MacKay and Dover Rivers	Pre-Production, Operations and Closure	Neutral	–	–	–	–	–	–
MLX-W – Groundwater Table Lowering	Operations and Closure	Negative	Local	Moderate	Long-term	Continuous	Good	Moderate
Changes to groundwater quality	Pre-Production, Operations and Closure	Neutral	–	–	–	–	–	–
MLX-E – Reduction of Groundwater Discharge Rates Due to Depressurization	Pre-Production and Operations	Neutral	-	–	–	–	–	–
MLX-E – Groundwater Table Lowering	Operations and Closure	Neutral	-	–	–	–	–	–
Devonian Geohazard	Operations	Negative	Regional	High	Long-term	Infrequent	Poor	Low

Note:
– = Not applicable.

6.4.4 Mitigation and Monitoring

Mitigation to prevent the lowering of the groundwater table resulting from the MLX Project is not practical. For MLX-W, a groundwater monitoring program (GMP) will be developed to monitor changes to groundwater elevations and quality. The GMP will be developed in accordance with the Lower Athabasca Region Groundwater Management Framework (ESRD 2012). The GMP will be prepared and submitted to ESRD following approval of the MLX Project. For the MLX-E HLSA, there is already a GMP in place and that is ongoing to monitor groundwater elevations and quality. This GMP will be updated to take into account the MLX-E portion of the Project. A summary of the proposed mitigation and monitoring is presented in Table 6.4-4.

Table 6.4-4: Summary of Proposed Mitigation and Monitoring

Effect	Mitigation	Monitoring	Final Effects Rating
MLX-W - Groundwater Table Lowering	It is not possible to prevent lowering of the groundwater table during the MLX Project phases.	Groundwater elevations will be monitored to provide data to assess the magnitude and extent of changes to groundwater elevations. The effects on fens, streams and creeks will be monitored to document the magnitude.	Moderate

6.5 Planned Development Case

There are no planned developments that would affect groundwater in addition to the Application Case.

6.6 Summary

Baseline conditions consist of a surficial Quaternary layer, primarily till with several Empress Formation buried channel aquifers, overlying the Cretaceous age Clearwater Formation (a shale aquitard), which overlies the Cretaceous age McMurray Formation. The McMurray Formation is predominantly oil sands, which has low permeability and is an aquitard, with a discontinuous water saturated zone, called Basal Water Sands or Basal McMurray Aquifer, occurring at the base of the formation and just above Devonian limestone bedrock, which has very low permeability. The Basal Water Sands subset of the McMurray Formation is an aquifer with elevated salinity that is below the base of groundwater protection. The main difference between MLX-W and MLX-E is that the Clearwater formation is much thinner to absent within the MLX-E HLSA. Groundwater elevation in the Quaternary sediments is close to ground surface. Groundwater recharge occurs in higher elevation areas and groundwater flows towards the MacKay, Ells and Dover rivers in the MLX-W HRSA and towards the MacKay and Athabasca rivers in the MLX-E HRSA. Groundwater from Quaternary sediments, primarily buried channel aquifers, is utilized within the HRSAs, but withdrawals are minor. There are no deep disposal wells within the HRSAs.

As part of construction, depressurization of the Basal Water Sands will likely be necessary. This will reduce groundwater hydraulic heads and reduce groundwater flow, as well as the salinity load, to the MacKay, Dover and Athabasca rivers. The effect of the changes to the groundwater discharge to the rivers on the total surface water flow in the rivers is expected to be below measurable levels.

During operations, groundwater flow will be re-directed to the mine pits. This will reduce groundwater flows to nearby creeks and rivers and lower the groundwater table. The amount of groundwater discharge reduction to the MacKay, Dover and Athabasca rivers will be very low compared to the surface water flow in the rivers. Lowering of the groundwater table has the potential to affect fens.

After closure, groundwater elevations will be permanently lowered compared to pre-mining conditions in the vicinity of the former MLX-W mine pit due to the final elevation of the end pit lake. This will affect fens and streams and reduce groundwater flow to the MacKay and Dover rivers. Since groundwater will not be flowing out of the former mine pit, groundwater quality will not be affected. After closure of MLX-E, the groundwater table will be similar to pre-mining conditions. Groundwater is predicted to seep out of the former mine pit Quaternary sediments and Basal Water Sands and will likely have non-oil sands related constituents. This water will eventually reach the Athabasca River. The environmental effects of this groundwater seepage on the Athabasca River are addressed in detail in Volume 2, Section 8.0.

The contribution of the MLX Project to cumulative regional effects (reduction in groundwater discharge to MacKay, Dover and Athabasca rivers) is expected to be minimal and likely below measurable levels outside the HLSAs.

6.7 References

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