Project Millennium
Taking Suncor into the 21st Century

SUNCOR
ENERGY

HYDROGEOLOGY BASELINE FOR PROJECT MILLENNIUM

REPORT

PA 2839.02

Klohn-Crippen

EXECUTIVE SUMMARY

This report is one of a series that provides input to the environmental impact analysis of Suncor's Project Millennium. Project Millennium consists of an extension towards the south and east of the current Steepbank Mine on the east side of the Athabasca River. The new proposed mine will be called the east bank mine. The impact analysis assesses the four main stages of mine development:

- baseline conditions (1997):
- construction (2000 to 2002):
- operational phase (2002 to 2033); and
- closure and reclamation (far future).

This report describes the current (or baseline) conditions of the groundwater system in the Local Study Area (LSA).

The main surface water bodies in the LSA are the Athabasca River, the Steepbank River, Shipyard Lake, Wood Creek, and McLean Creek. Shipyard Lake is a large wetlands located in the Athabasca River valley.

RESOURCE INVENTORY

The baseline study included both a review of regional geologic and hydrogeologic information, and a detailed investigation of the LSA. The baseline conditions in the LSA are summarized below.

Geology

The site's landforms are divided into uplands, organic plain, valley slopes and floodplain. The organic plain slopes gently toward the Athabasca River. The organic plain is poorly drained, and is covered with peat. The organic plain is cut by the steep valley slopes of the Steepbank and Athabasca Rivers. The stratigraphy of the LSA consists of:

- Drift Deposits
- Clearwater Formation
- McMurray Oil Sands
- Basal Aquifer
- Upper Devonian limestone

Major Aquifers

Three major aquifers have been identified including sand and gravel within the drift, the Basal Aquifer and the Upper Devonian limestone. In the organic plain, there is an extensive but discontinuous sand and gravel deposit within the drift overlying the Clearwater Formation. This sand and gravel ranges in thickness from 1 m to 10 m over most of the LSA with localized accumulations of 16 to 32 meters. In the Athabasca River valley, there is a thick (up to 40 m) sand and gravel deposit, that is in contact with the Athabasca River. In the bedrock the Basal Aquifer is a discontinuous zone of lean oil sands in the McMurray Formation, that generally rests upon the Upper Devonian surface. The Upper Devonian rock is limestone of the Waterways Formation. The Upper Devonian Surface is highly irregular, consisting of numerous depressions and rises with a total relief of 35 m at some locations.

Direction of Groundwater Flow

Groundwater is recharged in the organic plain, and discharges in lowlands. All groundwater flow is directed to the major rivers, including the Athabasca River and the Steepbank River. A shallow flow system exists in the drift deposits in which groundwater flows horizontally through the more permeable sediment. This groundwater discharges to the surface flow system along deeply incised valleys of the Steepbank River, Leggett Creek, Wood Creek, McLean Creek and in the area of Shipyard Lake. Groundwater flowing horizontally through the Basal Aquifer and the Upper Devonian discharges to the Athabasca River, the Steepbank River and to Shipyard Lake.

Groundwater as a Resource

There are no groundwater users in the LSA other than Suncor. The sand and gravel aquifer in the Athabasca River valley has the potential to be used for water supply purposes. Due to its proximity to the river, wells completed in the aquifer are expected to induce recharge from the Athabasca River.

The sand and gravel aquifer in the drift deposits in the organic plain is locally a viable resource for water supply based on Alberta Environmental Protection guidelines for groundwater quantity and quality for domestic supply. The bedrock aquifers may not be useable for water supply purposes. Although they meet and exceed the minimum required yield for a domestic supply, the water quality in the bedrock is poor. The bedrock groundwater is brackish, and contains organic compounds, including PAHs and napthenic acids.

Groundwater Discharge to Surface Waters

The total rate of groundwater discharge from all aquifers to the Athabasca River, Shipyard Creek, Leggett Creek, Wood Creek and McLean Creek has been calculated to be 32 L/s. In comparison, the estimated annual runoff for basins in the LSA are:

- Athabasca River 71 L/s
- Leggett Creek 66 L/s
- Wood Creek 197 L/s
- McLean Creek 130 L/s
- Shipyard Creek 190 L/s

Therefore, the total surface flow originating in the LSA (not including the Steepbank River) is 656 L/s. The groundwater discharge is therefore less than 5% of the minimum recorded surface water flow in the LSA. The groundwater discharge to McLean Creek is approximately 14 % of the total flow. This groundwater originates from an area south of the LSA.

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APPENDICES

1. INTRODUCTION

Suncor's Project Millennium comprises an extension of the Steepbank Mine presently being developed on the east side of the Athabasca River. The Steepbank Mine and Project Millennium collectively comprise the east bank mine. Both projects are located opposite Suncor's existing facilities, as shown on Figure 1.

This report evaluates the environmental baseline conditions relating to the geology and hydrogeology of the Regional Study Area (RSA) shown in Figure 2, and the Local Study Area (LSA) shown in Figure 3. The area directly affected by Steepbank Mine and Project Millennium includes portions of Lease 19 and 25 as well as Fee Lots 3 and 4. Lease 97 and Fee Lot 1 will be affected by the approved Steepbank Mine but not by the proposed Project Millennium. Figure 3 shows the Leases and Fee Lots affected as well as an outline of the east bank mine footprint.

The baseline presented in this report is that before the current development of the Steepbank Mine commenced.

2. METHODOLOGY

The hydrogeologic baseline study was conducted in two stages:

- a literature review of regional data; and
- a detailed investigation of the LSA.

Regional geologic and hydrogeologic information was compiled from sources such as Suncor's Lease 86 and Steepbank Mine, Alsands, OSLO, and Alberta Research Council. In addition, the Muskeg River Mine Project EIA (Shell Canada Ltd., 1998) was reviewed along with the Aurora Mine Project. This information was used to characterize the regional setting of the mine area. A summary of the regional information is provided in Section 4.

The detailed hydrogeologic investigation of the LSA comprised the following:

- Aerial reconnaissance by helicopter;
- Interpretation of geologic logs from 740 boreholes (Figure 4);
- Geophysical survey (transient electromagnetic) (Figure 5);
- Installation of eight standpipe piezometers and five pneumatic piezometers to supplement the existing monitoring network (Figure 5);
- Analysis of groundwater samples for major ions, dissolved metals, organic compounds, and toxicity, and
- Analysis of groundwater flow directions and rates and groundwater discharge rates to surface water bodies.

Two field reconnaissance trips were made to the LSA by Klohn-Crippen staff, in the spring and fall of 1997. The objective of the first trip was to familiarize the EIA team with the general conditions at the site, and to ground-truth interpretations of the site geology and hydrogeology made from desktop studies. The objective of the second trip was to assess the accessibility of the site for a drilling program. Observations made during the trips have been incorporated in the discussions of results presented in Sections 5 and 6.

Site specific geology data was compiled from 740 borehole logs located in Leases 19, 25 and 97, Fee Lots 1 and 3 (Figure 4). Of these, 60 boreholes were drilled and cored in the area of the Steepbank Mine during the 1996 winter overburden evaluation program. An additional 24 boreholes were drilled and the overburden was logged as part of the Mine Handling Facilities investigation. The balance of the boreholes were drilled and logged as part of the Suncor exploration program throughout the LSA. The information was used to create geologic cross sections (Figures 10 to 15), and structure and isopach maps of geologic units (Figures 17 to 29). The results of the geologic interpretation are discussed in Section 5.

A transient electromagnetic (TEM) survey was conducted on the site in 1997 (Figure 16) to assess areas where the drift deposits could consist of sand and gravel. The results of this survey are presented in Section 5.

Standpipe piezometers were installed in eight locations throughout the LSA (Figure 5). The piezometers were installed in surficial drift deposits to assess hydraulic gradients, hydraulic conductivities and groundwater chemistry.

Five pneumatic piezometers were installed in the bedrock in three locations in the LSA (Figure 5). The piezometers were installed to assess hydraulic head and gradients in the Basal Aquifer and the Upper Devonian.

Groundwater samples were obtained from the standpipe piezometers and analyzed for general chemical parameters, dissolved metals, toxicity, PAH and alkylated PAH, PANH and Alkylated PANH, nutrients and naphthenic acid. The results of these analyses were not available at the time of writing this report, however, groundwater chemistry was compiled from Suncor's annual groundwater monitoring program and is presented in Section 6.

Calculations were made to determine aquifer productivity and the rates of groundwater flow. The productivity of the aquifers in surficial deposits and bedrock was assessed using estimates of their 20-year yield. The rates of groundwater discharge to the Athabsca River, Steepbank River, Shipyard Lake, Leggett Creek, Wood Creek and Unnamed Creek in the LSA were estimated, using hydraulic gradients and values of hydraulic conductivity determined on-site. The results of these calculations are presented in Sections 6.4.

3. BACKGROUND INFORMATION

3.1 Local Study Area (LSA)

The Local Study Area (LSA) is approximately triangular in shape. It is bounded by the Athabasca River to the west and Steepbank River to the northeast. Watercourses within the LSA include those draining to Shipyard Lake (the largest of which are Unnamed Creek and Creek 2), Leggett Creek, Wood Creek, and McLean Creek. The McLean Creek watershed forms the south boundary of the LSA (Figure 3).

The topography of most of the LSA is flat to gently rolling. Relief across the LSA is about 190 m; ranging from elevation 235 to 240 mASL in the Athabasca River floodplain to about elevation 425 mASL in the east part of the site (Figure 6). The physiography of the LSA, shown on Figure 6, is divided into four main units: the Athabasca floodplain; Athabasca and Steepbank escarpments; Steepbank organic plain; and Steepbank uplands. The average slope of the Athabasca escarpment is approximately 8%: locally, the slopes are as high as 20% to 40%. In contrast, the Steepbank organic plain has an average gradient of approximately 0.7%.

The Athabasca River has eroded through the surficial soils and bedrock (Crestaceous and Devonian) to form a valley that is approximately 80 m to 100 m deep. The escarpment slopes and floodplain are moderately forested. The river has irregular meanders with occasional islands and bars.

Relatively steep slopes in the lower 35 km long reach of the Steepbank River that bounds the LSA have resulted in a moderately to well defined entrenched valley approximately 80 m deep. At the downstream end of Steepbank River, its valley cuts through the surficial deposits and, close to its confluence with the Athabasca River, the Cretaceous (McMurray Formation) and underlying Devonian bedrock are exposed. The Steepbank escarpment slopes are steep for a distance of approximately 6 km upstream of its confluence with the Athabasca River. Along this reach, gradients are locally in excess of 60%. Further upstream, the escarpment slopes become flatter and the average gradient is about 18%.

Within the LSA Unnamed Creek, Creek 2, Leggett Creek, Wood Creek and McLean Creek are deeply incised into the Athabasca escarpment and tend to flow year-round. The other creeks tend to be ephemeral and the entrenched channel systems are generally limited to the immediate vicinity of the Athabasca escarpment. On the organic plain and uplands, all watercourses are generally poorly drained and covered with muskeg fens and bogs. Here the creeks are not well defined and tend to comprise muskeg channels up to about 100 m to 150 m wide.

There is one large wetland complex on the Athabasca River floodplain within the study area known as Shipyard Lake. It is located approximately 6 km upstream (south-east) of the confluence between the Athabasca and Steepbank Rivers as shown on Figure 3.

3.2 Drainage

The regional drainage is shown on Figure 1 while Figure 6 shows the drainage basins in the LSA. The principle drainage is via the Athabasca River, which forms the western boundary of the LSA. It flows northward past the proposed mine site and eventually discharges through a delta complex into Lake Athabasca. Secondary drainage is by the Steepbank River system which discharges into the Athabasca River opposite the existing Suncor mine, as shown on Figure 1. Within the LSA, a strip of land averaging less than a kilometre wide drains into the Steepbank River. The remainder of the LSA drains directly to the Athabasca River.

Of the Athabasca tributaries, Unnamed Creek, Creek 2 (both of which flow into Shipyard Lake), Leggett Creek and Wood Creek have most or all of their drainage basins entirely within the east bank mine footprint. McLean Creek, in contrast, has a substantial portion of its drainage outside the proposed mine limit. There are also several small drainage basins that drain to the Athabasca River that do not contain any well-defined watercourses or the creeks are ephemeral: these are named Athabasca A through D on Figure 6.

The drainage basin areas for watercourses in the LSA are presented on Table 1.

Table 1 Drainage Basins in LSA

Basins	Leases and Lots Affected	Total Drainage Area (km^2)
Athabasca River		133 000
Steepbank River	Leases 19, 25 and 97; Fee Lot 1	1 320
Shipyard Creek	Leases 19, 25 and 97; Fee Lots 1 and 3	48.4
Unnamed Creek	Leases 25 and 97; Fee Lot 3	8.7
Creek 2	Leases 19 and 25; Fee Lot 3	9.5
Leggett Creek	Lease 19	23.0
Wood Creek	Lease 19: Fee Lot 4	56.5
McLean Creek	Lease 19: Fee Lot 4	43.4
Athabasca A	Leases 25 and 97; Fee Lot 1	6.6
Athabasca B	Leases 19, 25 and 97, Fee Lot 3	6.0
Athabasca C	Lease 19	5.7
Athabasca D	Lease 19	1.0

Muskeg fens and bogs with an average thickness of between 0.8 and 1.5 m cover approximately 60% of the LSA. These soils represent one of the most dominant features controlling surface runoff.

Muskeg is defined (Radforth and Brawner, 1977) as a soil substrate consisting largely of organic residues formed in a water-saturated condition as a result of an incomplete decomposition of plant constituents. The incomplete decomposition is a direct result of an anaerobic conditions. In muskeg, most of the moisture exchange takes place within an "active layer" at the surface. Literature (Radforth and Brawner, 1977) suggests that this layer is approximately 200 mm to 450 mm thick. Although, significant interflow can occur within the active layer, vertical permeability rapidly reduces with depth. At the lower boundary, decomposed and compressed organic material produces a relatively impervious zone. Ivanov (1953) and Boelter (1965, 1972) cite values of hydraulic conductivity of 1×10^{-7} m/s, 0.75×10^{-7} m/s and 2.2×10^{-7} m/s for the highly decomposed peat typically found at the lower boundary of an active layer.

When the muskeg is saturated, lateral flow through the more permeable upper strata will predominate. This flow will be fed by precipitation and by the upward flows of groundwater from any underlying fluvial deposits. During dryer periods, vertical flow through the less permeable lower strata will predominate.

Hydrologically, the initial abstraction (absorption to satisfy soil moisture deficit) of rainfall during storm events to these soils will be significant and highly variable. Once saturated, infiltration to lower surficial materials will be low and a large proportion of the rainfall will run off.

3.3 Climate

The climate in the oil sands area is characterized by long cold winters and short cool summers. Mean daily temperatures at Fort McMurray in January, average about -20°C while July temperatures average 17°C. The mean annual temperature at this location is 0.2°C. There are usually less than 120 frost-free days per year (Atmospheric Environment Service, 1993).

The average annual precipitation at Fort McMurray Airport, approximately 30 km south of the LSA, is about 444 mm, of which almost three-quarters falls as rain during the summer and fall.

4. REGIONAL GEOLOGY AND HYDROGEOLOGY

4.1 Surficial Geology

The surficial geology of the oil sands region has been mapped by L.A. Bayrock (1971), L.A. Bayrock and T.H.F. Reimchen of the Alberta Research Council (1973) and by R.A. McPherson and C.P. Kathol (1977). The work by R.A. McPherson and C.P. Kathol, because it is the most recent, is accepted here as the most accurate. An excerpt of the surficial geology map from R.A. McPherson and C.P. Kathol is shown in Figure 7. This map shows the type of surficial material that is expected to occur in the shallow subsurface. A summary of the stratigraphic succession of surficial deposits in the region is provided in Table 2. The distribution of surficial sediments in the region can be characterized into three physiographic settings; organic plain, valley slopes and floodplain.

4.1.1 Organic Plain

The majority of the region on the east side of the Athabasca River is an organic plain, with an elevation of 315 mASL or greater. The topography of the organic plain is gently sloped toward the river. Much of the ground in the region is covered with peat. Thin, discontinuous deposits of aeolian sand are also common in the region, particularly where glaciofluvial sand is near the ground surface. The surficial stratigraphy is the result of the advance and retreat of at least three periods of glaciation. With each glacial advance, till was deposited. The till is an assorted mix of clay, silt, sand and cobbles. The three tills that have been identified in the region from the oldest to youngest are known as the unnamed till, the Firebag till and the Fort Hills till. The unnamed and Firebag tills are present in most of the region. The Fort Hills till is not believed to extend south of the Muskeg River (McPherson and Kathol, 1977).

Table 2 Succession of Surficial Geologic Deposits in the Oil Sands Region

PERIOD	PHYSIOGRAPHIC SETTINGS	DESCRIPTION OF UNITS	
Quaternary	Organic plain	Recent Sediments	Peat; generally less than 3 m thick aeolian deposits; fine to medium grained sand, in dis-continuous thin sheets and dunes outwash deposits; commonly very fine to fine grained sand, with minor coarse sand.
		Upper Sediments	Stratified sand and gravel layers, till fragments, pebbles and boulders; mixed glacio-lacustrine deposits; stratified clay, silt and sand, with pebbles and till-like layers.
		Fort Hills Till	Low relief till; composed of sand silt and clay (68% silt), commonly with thin lenses of lacustrine clay and/or glaciofluvial sand.
		Lower Sediments (?)	Stratified glacio-lacustrine deposits; stratified clay, silt and sand.
			Outwash deposits; commonly very fine to fine grained sand, with minor coarse sand and gravel layers, till fragments, pebbles and boulders.
			Kames and kame moraine; composed primarily of stratified sand and silt, with minor gravel, clay and till lenses.
		Firebag Till	Low relief till, composed of sand, silt and clay, with gravel and boulders, usually in contact with bedrock.
		Unnamed Till	
		Undifferentiated till and stratified sediments	The existence of these deposits is inferred, based on the presence of very thick drift sequences, and complex geophysical responses in boreholes in areas of thick drift.
	Valley Slopes	Recent Sediments	Eroded slope and gully; discontinuous colluvial cover on slopes.
	Floodplains	Recent Sediments	Stream valley; discontinuous alluvial gravel, sand, silt and clay along streams.
			Alluvial sand; with minor silt and clay, confined mainly to the floodplain of the Athabasca River.
			Alluvial silt and clay; with minor sand and gravel, common along most streams usually discontinuous and less than 3 m thick.
		Stratified Sediments	Meltwater channel sediment; fine to coarse-grained sand, with minor silt and clay, overlying thin sand and gravel and lag gravel with boulders, possibly early Athabasca river alluvium.
Cretaceous		Sandstone, silt-stone and shale	

(Modified from McPherson and Kathol, 1977)

As the glaciers retreated, stratified fluvial and lacustrine sediments were deposited. These deposits included glaciofluvial sands and gravels, and glaciolacustrine sands, silts and clays, which overly the till.

4.1.2 Uplands

The uplands area occupies the eastern edge of the LSA. It is characterized by inorganic soils with pockets of muskeg fens and bogs. The uplands relief is higher and more hummocky than the organic plain (Figure 6).

4.1.3 Athabasca and Steepbank Escarpment

Colluvial slope wash material, discontinuously overlies McMurray formation bedrock along the escarpment valley slopes east of the Athabasca River and along the slopes of the Steepbank River and some of the smaller tributaries. At the downstream end (lower 15 km) of the Steepbank River and at locations along the Athabasca River (where some of the smaller creeks in the LSA have eroded deep channels through the escarpment and where the Athabasca River abuts the escarpment), surficial materials are completely eroded and the bedrock is exposed.

4.1.4 Floodplains

The valley floor of the lower downcut reaches of the local tributaries consists of discontinuous alluvial gravel, sand, silt and clay. Where the McMurray oil sands are exposed the gravels are bitumen covered and bitumen rich sand bars and banks are common. Within the LSA the Athabasca floodplain is covered with an alluvial deposit of fine sand. Meltwater channel sediments, composed primarily of fine to coarse grained sand, are found below the alluvial deposits. The meltwater sediments are more or less continuous throughout the Athabasca River valley. The meltwater channel sediments are in contact with the Upper Devonian limestone.

4.1.5 Drift Thickness

An excerpt of McPherson and Kathol's (1977) map of the thickness of surficial deposits is shown in Figure 8. In the organic plain, the surficial deposits are commonly 7.5 m to 30 m thick. McPherson and Kathol identified an area south of the Steepbank River, near the middle of Lease 19, (Figure 8) where the surficial deposits are up to 45 m thick.

In the Athabasca River valley, the surficial materials are generally less than 6 m thick with localized deposits of greater than 40 m (McPherson and Kathol, 1977). Outcrops of Upper Devonian and Cretaceous rock are visible in numerous places along the river valley. However, near Suncor's Tar Island Dike, over 40 m of surficial sand and gravel has been logged beneath the floodplain.

4.2 Regional Bedrock Geology

4.2.1 Regional Bedrock Topography

The bedrock surface in the region has been shaped by three main processes:

- glaciation
- fluvial erosion
- collapse of karst features

Beneath the organic plain, the bedrock surface slopes gently toward the Athabasca River. On the east side of the Athabasca River, the elevation of the bedrock beneath the organic plain ranges from approximately 460 mASL 20 km from the river, to 315 mASL at the edge of the escarpment. This surface has been incised by both preglacial and postglacial fluvial processes. The most obvious of these incisions are the courses of present-day rivers, including the Athabasca and Steepbank Rivers. In other investigations

(McPherson and Kathol, 1977), channels in the bedrock surface commonly contain drift sand and gravel. The elevation of the bedrock surface beneath the Athabasca River is approximately 220 mASL.

Throughout the region, depressions in the bedrock surface have been observed, that have been interpreted to reflect collapse structures in the underlying Upper Devonian surface (McPherson and Kathol, 1977; Carrigy, 1973).

The present-day ground surface topography masks all but the most pronounced structural features of the bedrock surface. The bedrock outcrops only in river valleys, where slopes are very steep.

4.2.2 Regional Bedrock Stratigraphy

The Cretaceous and Devonian geology in the oil sands region has been described by Cotterill and Hamilton (1995), Crickmay (1957), Carrigy (1959, 1973) and Norris (1963). Table 3 shows the regional stratigraphy as it applies to the LSA. A simplified geologic cross section of the regional bedrock stratigraphy is shown in Figure 9. The thickness of the Cretaceous and Devonian section decreases toward the east. The depth to the underlying Precambrian surface also decreases to the east.

The Cretaceous deposits in the oil sands area consist of a succession of sandstones and shales that rest upon the eroded surface of the Devonian. Over most of the region, the Cretaceous strata are comprised of the Grand Rapids, Clearwater and McMurray Formations. The Grand Rapids Formation is an un-cemented feldspathic sandstone. It is present only in areas where the bedrock elevation exceeds approximately 410 mASL (Carrigy, 1973). The Clearwater Formation is a glauconitic shale of marine origin. A glauconitic sandstone deposit at the base of the shale is known as the Wabiskaw Member.

Commonly, the Wabiskaw sandstone contains heavy oil. It is therefore frequently considered part of the oil sands. In the Athabasca River valley, the bottom of the Clearwater Formation occurs at approximately 305 mASL elevation.

Table 3 Subsurface Stratigraphy of the Northern Part of the Athabasca Oil Sands Area, After Carrigy (1973), McPherson and Kathol (1975) and Cotterill and Hamilton (1995)

System or Series	Formation	Member	Lithology
Pleistocene and Recent			Clay, silt, sand, silt and gravel
	Erosional unconformity		
Cretaceous	Smoky Group		Shale
	LaBiche		Shale
	Dunvegan		Sandstone, siltstone and shale
	Shaftesbury		Shale, with sandstone and siltstone
	Manville Group		Sandstone
	Grand Rapids		Shale
	Clearwater	Wabiskaw	Glauconitic Sandstone
	McMurray	Upper	Sand, very fine, silt
		Middle	Sand, medium cross-bedded
		Lower	Sand, coarse, gravel, silt
	Erosional Unconformity		
Upper Devonian	Beaverhill Lake Group		
	Waterways	Mildred	Argillaceous Limestone
		Mobertly	Limestone
		Christina	Calcareous Shale
		Calumet	Clastic Limestone
		Firebag	Argillaceous Limestone
	Disconformity		
	Slave Point		Wackestone, mudstone and shale
	Fort Vermillion		Anhydrite, dolostone, minor mudstone
Middle Devonian	Elk Point Group		
	Watt Mountain		Dolomitic shale
	Prairie Evaporite		Salt, anhydride, gypsum, silty shale
	Winnipegosis (Methy)		Dolomite, in part reefal
	Contact Rapids		Dolomite, dolomitic siltstone, shale with minor anhydride and gypsum
Lower Devonian	Granite Wash (La Loche)		Arkosic Sandstone
	Erosional Unconformity		
Precambrian	Metasedimentary Rocks and Granite		

The McMurray Formation, commonly referred to as the oil sands, is a series of quartz sandstone units, impregnated with heavy oil. As shown in the cross section in Figure 9, the McMurray Formation is thickest where it has been deposited in depressions and channels in the surface of the underlying Devonian. In Suncor's active lease area, the McMurray Formation typically ranges in thickness from 45 m to 80 m. To the north, in the former Alsands area, the oil sands deposit is as great as 100 m thick.

In the lower portion of the McMurray Formation is a widespread, relatively continuous occurrence of sandstone which contains little or no heavy oil. This is known as the basal water sand, or commonly, the Basal Aquifer.

The Devonian strata form a wedge of westward dipping rock that sits directly on the Precambrian. The Upper Devonian strata consist of the Waterways, Slave Point and Fort Vermillion Formations. The Waterways Formation is also referred to as the Beaverhill Lake Group by some authors (Carrigy, 1973; Hackbarth and Nastasa, 1979). As shown in Table 3, the Waterways Formation has been subdivided into five limestone members. In the Athabasca River valley, the upper-most unit is the Moberly Member, which is a clastic limestone with beds of clastic lime mudstone, skeletal wackestone and shale (Cotterill and Hamilton, 1995). The rock outcrops along the Athabasca River and major tributaries between the Clearwater River and Fort MacKay. Exposures of the rock are described as rubbly and weathered (Carrigy, 1973). The subcrop of the Upper Devonian strata has been eroded, and exhibits a highly irregular surface. Relief on the Upper Devonian is as great as 100 m over distances as short as 1000 m (Hackbarth and Nastasa, 1979).

Below the Waterways Formation is the Slave Point Formation, which consists of wackestone and argillaceous lime mudstone. The Fort Vermillion Formation is made up of anhydrite, dolostone, and mudstone. Below this, the Middle Devonian deposits are present. As shown in Table 3, the Middle Devonian in the oil sands area is the Elk Point Group, which is comprised of the Watt Mountain, Prairie Evaporite, Methy and Contact Rapids Formations. The Watt Mountain Formation is a thin (10 m) layer of dolomitic shale. The Prairie Evaporite Formation is predominantly an anhydrite deposit. As shown in Figure 9, it is believed to be discontinuous or absent on the east side of the Athabasca River. The Methy Formation is a reefal dolomite. The Contact Rapids Formation consists of dolomite, dolomitic siltstone, shale, anhydride and gypsum.

4.3 Regional Hydrogeology

4.3.1 Regional Hydraulic Conductivity Data

Hydraulic conductivity data from the oil sands region has been collected from published sources such as Hackbarth and Nastasa (1979), as well as from Alsands (1978b) and OSLO projects and Suncor's Lease 86. Hydraulic conductivity data from the oil sands region has been collected from the following published sources:

- Hackbarth and Nastasa (1979)
- Alsands Project Group (1978)
- OSLO
- Suncor Lease 86
- Shell Muskeg River Mine (Komex International Ltd., 1997)
- Syncrude Aurora Mine (Bovar, 1996)

4.3.1.1 Surficial Materials

Table 4 provides a summary of hydraulic conductivity values measured in surficial materials in the region. The hydraulic conductivity of till ranges from 5.3×10^{-8} m/s to 6.8×10^{-7} m/s, with a mean of 1.4×10^{-7} m/s.

Table 4 Summary of Regional Hydraulic Conductivity Data from Surficial Deposits

Hydrogeologic Unit	Minimum Hydraulic Conductivity (m/s)	Maximum Hydraulic Conductivity (m/s)	Mean Hydraulic Conductivity (m/s)
TILL	5.3×10^{-8}	6.8×10^{-7}	1.4×10^{-7}
SAND	1.1×10^{-8}	1.0×10^{-4}	5.0×10^{-5}
SAND AND GRAVEL	7.0×10^{-6}	1.0×10^{-3}	3.8×10^{-4}

The hydraulic conductivity of sand deposits range from 1.1×10^{-8} m/s to 1.0×10^{-4} m/s, with a mean of 5.0×10^{-5} m/s. The hydraulic conductivity of surficial sand measured by Golder (Shell Canada Ltd, 1997) at the Muskeg River Mine is 1.0×10^{-4} m/s and Bovar (1996) recorded hydraulic conductivities for the sand and gravel up to 1×10^{-3} m/s. The sand and gravel in the area of the Aurora Mine South is distributed along a well defined, meandering pleistocene channel deposit..

The hydraulic conductivity of sand and gravel deposits, measured in the Athabasca floodplain at Suncor, ranges from 7.0×10^{-6} m/s to 1.0×10^{-3} m/s, with a mean of 3.8×10^{-4} m/s.

4.3.1.2 Bedrock Materials

The hydraulic conductivity of bedrock units measured in the oil sands region is summarized in Table 5. Hackbarth and Nastasa (1979) determined the hydraulic conductivity of the Clearwater Formation ranges from 1×10^{-9} m/s to 1×10^{-5} m/s, with a mean of approximately 1×10^{-7} m/s.

Tests conducted in the oil sands indicate that the hydraulic conductivity ranges between 3.5 x 10^{-9} m/s and 3.2 x 10^{-7} m/s, with a mean of 1.5 x 10^{-7}.

Extensive pumping tests have been conducted in the Basal Aquifer by Alberta Research Council (Hackbarth 1977) and others at the Alsands site, north of the Millennium Mine area. The results of these tests are listed in Table 5. The hydraulic conductivity of the Basal Aquifer ranges from 1.5 x 10^{-7} m/s to 2.4 x 10^{-4} m/s, with a mean of 4.2 x 10^{-5} m/s. This value is similar to the value of 3.0 x 10^{-5} m/s determined at the Muskeg River Mine (Komex International Ltd., 1997). Bovar (1996) measured hydraulic conductivities for the Aurora Mine of between 2 x 10^{-5} m/s and 2 x 10^{-4} m/s.

Table 5 Summary of Regional Hydraulic Conductivity Data from Bedrock

Hydrogeologic Unit	Minimum Hydraulic Conductivity (m/s)	Maximum Hydraulic Conductivity (m/s)	Mean Hydraulic Conductivity (m/s)
Clearwater Formation	1 x 10^{-9}	1 x 10^{-5}	1 x 10^{-7}
Oil Sands	3.5 x 10^{-9}	3.2 x 10^{-7}	1.5 x 10^{-7}
Basal Aquifer	1.5 x 10^{-7}	2.4 x 10^{-4}	4.2 x 10^{-5}
Upper Devonian (Waterways Formation)	4.0 x 10^{-11}	3.0 x 10^{-5}	5.1 x 10^{-7}
Prairie Evaporite Formation	-	-	3.0 x 10^{-9}
Methy Formation	2.6 x 10^{-10}	1.6 x 10^{-7}	1.8 x 10^{-8}

The hydraulic conductivity of the Upper Devonian limestone ranges from 4.0 x 10^{-11}m/s to 3.0 x 10^{-5}m/s, with a mean of 5.1 x 10^{-7} m/s. Such a wide range of hydraulic conductivity in a limestone indicates that the rock is probably fractured. Descriptions of the Upper Devonian Strata in Carrigy (1973) and Cotterill and Hamilton (1995) support this interpretation. In some areas of the region, the Upper Devonian limestone may therefore be nearly as permeable an aquifer as the Basal Aquifer.

Below the Upper Devonian strata, the hydraulic conductivity of the underlying formations is generally very low. The hydraulic conductivity of the salt in the Prairie Evaporite Formation is in the order of 3.0×10^{-9} m/s. The hydraulic conductivity of the Methy Formation has been found to range from 2.6×10^{-10} m/s to 1.6×10^{-7} m/s, with a mean of 1.8×10^{-8} m/s.

4.3.2 Regional Groundwater Flow Directions

The groundwater flow systems conform to the classic principles of regional groundwater flow. Groundwater is recharged in the uplands, and discharges in lowlands. All groundwater flow is directed to the Athabasca and Clearwater Rivers, as well as smaller rivers that have incised into the Upper Devonian strata, such as the Steepbank, Muskeg and MacKay Rivers.

In the surficial deposits in the organic plain, the direction of groundwater flow is controlled by the hydraulic conductivity, and ground surface topography and to a lesser extent to the bedrock topography. A shallow flow system exists in the surficial material, in which groundwater flows more or less horizontally toward the major surface water bodies. Groundwater discharges from the surficial deposits through the colluvium to the river valleys.

In the floodplain of the Athabasca River, the groundwater flow in the surficial deposits is horizontal. The groundwater generally flows toward the river, with a slight downstream component to its direction.

In the Clearwater Formation and oil sands, the direction of groundwater flow is predominantly downward (Hackbarth and Nastasa, 1979). The cause of these gradients is probably due to the fact that these deposits have very low hydraulic conductivity, in comparison to the underlying Basal Aquifer.

The direction of groundwater flow in the Basal Aquifer is toward the Athabasca River, and into any stream valleys and depressions where the aquifer outcrops.

In the upper-most portion of the Upper Devonian rock, the flow is horizontal toward the Athabasca River and deeply incised valleys. This is because the Upper Devonian limestone has a relatively high hydraulic conductivity in comparison to the oil sands above it, and the deeper limestone below it.

There is some evidence that the Upper Devonian Limestone and Basal Aquifer may act as a hydraulically connected unit. During pumping tests conducted by Alberta Research Council, the hydraulic head in the Upper Devonian Strata responded to pumping from the Basal Aquifer (Hackbarth and Nastasa, 1979). This implies that there may be some degree of groundwater flow between the two units.

4.3.3 Regional Groundwater Chemistry

Regional groundwater chemistry has been published by Schwartz (1979, 1980) and Hackbarth (1977). In addition, Suncor collects groundwater samples from its network of monitoring piezometers at its active mine. Table 6 shows a summary of groundwater chemistry data from peat and surficial deposits. Table 7 summarizes groundwater chemistry from bedrock units. The descriptions of the water quality include the terms fresh, brackish and saline. These descriptions are based on the concentration of total dissolved solids (TDS) found in the water. The descriptions are based on the following ranges of TDS:

	TDS (mg/L)		
Fresh	0	-	1000
Brackish	1000	-	20 000
Saline	20 000	-	35 000

The chemistry data presented in Table 6 was collected by Schwartz (1979) from the Muskeg River basin, which is several miles north of the LSA. The table shows that the chemistry of water found in peat is generally very fresh, with an electric conductivity (EC) ranging from 50 µmhos/cm to over 800 µmhos/cm. The mean EC was found to be 137 µmhos/cm. The major ions in the peat water tend to be calcium, magnesium and bicarbonate. Peat water that has high levels of EC or sodium concentration probably has been influenced by groundwater discharge from bedrock (Schwartz, 1980).

The groundwater chemistry data has been collected from a variety of surficial deposits, including sand units, and till. The groundwater in the surficial units tends to be fresh. The total dissolved solids (TDS) ranges from 144 mg/L to 754 mg/L, with a mean of 520 mg/L based on the data presented in Table 6. More recent data collected for the Shell Canada Muskeg River Mine Project by Komex International Inc. (1997) shows that the groundwater in the surficial deposits is fresh to brackish, within a range of TDS concentrations from 239 mg/L to 1729 mg/L. Bovar (1996) measured concentrations of TDS at less than 500 mg/L for the Aurora Mine. The major ions are predominantly calcium, magnesium and bicarbonate. Areas in which the groundwater in peat and surficial deposits has high levels of sodium and chloride are probably receiving water from bedrock units.

Data from chemical analyses of bedrock groundwater are shown in Table 7. Water in the Clearwater Formation is slightly brackish. The concentration of TDS reported in Schwartz (1979) ranged from 971 mg/L to 2762 mg/L, with a mean of 1794 mg/L. The major cations are sodium and potassium. Bicarbonate is the major anion. The sulphate and chloride concentrations in the Clearwater Formation appear to be higher than in the overlying surficial material.

Table 6 Regional Chemistry of Groundwater in Surficial Deposits

Well ID	Unit	Date	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	TDS[1] mg/L	EC µmhos/cm	Total ALK mg/L	Reference
Peat	Minimum		0.7	0.5	1.3	0	0	3.2	1.3		50	0	Schwartz 1980
	Maximum		33.6	9.9	212	2.4	566	15.6	9.1		84		
	Mean		17	4.9	4.1	0.6	80.7	5.9	2.4		137.0		
Surficial Deposits													
HC1	Clay, sandy	77/08/09	74.0	25.0	6.1	2.5	358.0	21.0	10.0	496.6	437.0	293.6	Schwartz 1979
HC2	Sand, clayey	77/08/08	35.5	10.0	3.9	1.3	156.0	7.7	0.3	214.7	256.0	127.9	Schwartz 1979
HC4	Clay	77/08/07	110.0	15.0	8.9	2.7	437.0	0.5	4.0	578.1	600.0	358.3	Schwartz 1979
HC6	Clay, silty	77/08/07	130.0	29.0	5.6	2.1	583.0	0.5	4.0	754.2	680.0	478.1	Schwartz 1979
HC7	Clay, silty	77/08/07	98.0	22.0	4.2	1.0	371.0	0.5	2.0	498.7	570.0	304.2	Schwartz 1979
HC8	Sand	77/08/07	38.7	22.0	12.4	2.7	250.0	0.5	4.0	330.3	363.0	205.0	Schwartz 1979
HC9	Sand	77/08/07	20.0	7.6	5.2	0.6	98.0	9.2	4.0	144.6	165.0	80.4	Schwartz 1979
HC10	Clay	77/08/07	117.0	25.0	7.3	2.0	484.0	3.5	4.0	642.8	695.0	396.9	Schwartz 1979
HC12	Clay	77/08/07	110.0	25.0	7.0	1.9	503.0	0.5	4.0	649.4	670.0	412.5	Schwartz 1979
HC13	Clay	77/08/08	110.0	30.0	16.0	2.2	534.0	9.5	4.0	705.7	690.0	437.9	Schwartz 1979
HC15	Clay	77/08/08	90.0	28.0	15.1	3.2	500.0	0.5	4.0	640.8	665.0	410.0	Schwartz 1979
HC16	Clay	77/08/08	73.4	21.3	7.6	2.0	368.0	0.5	4.0	476.8	508.0	301.8	Schwartz 1979
HC18	Clay, silty	77/08/08	82.0	33.0	14.6	8.9	499.0	0.5	4.0	642.0	650.0	409.2	Schwartz 1979
HC21	Silt and clay	77/08/06	66.0	35.0	7.0	2.1	428.0	0.5	10.0	548.6	550.0	351.0	Schwartz 1979
HC23	Silt	77/08/06	73.4	18.0	41.0	1.4	350.0	0.5	76.0	560.3	650.0	287.0	Schwartz 1979
HC25	Sand	77/08/11	27.0	11.01	36.0	5.8	236.0	15.8	4.0	335.7	375.0	193.5	Schwartz 1979
HC26	Sand	77/08/11	63.1	10.8	7.9	3.2	280.0	0.5	4.0	369.5	392.0	229.6	Schwartz 1979
HC27	Clay	77/08/07	110.0	26.0	10.4	1.1	430.0	10.0	4.0	591.5	625.0	352.6	Schwartz 1979
HC29	Clay	77/08/11	98.0	20.0	38.0	5.0	550.0	0.5	4.0	715.5	720.0	451.0	Schwartz 1979
	Minimum		20.0	7.6	3.9	0.6	98.0	0.5	0.3	144.6	165.0	80.4	
	Maximum		130.0	35.0	41.0	8.9	583.0	21.0	76.0	754.2	720.0	478.1	
	Mean		80.3	21.8	13.4	2.7	390.3	4.4	8.0	520.8	539.5	320.0	

Table 7 Regional Bedrock Groundwater Chemistry

Well ID	Unit	Date	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/l	SO4 mg/L	Cl mg/L	TDS[1] mg/L	EC µmhos/cm	Total ALK mg/L	Reference
Clearwater Formation													
8-114	Clay	75/02/22	19.6	6.6	239.0	13.3	541.8	97.0	54.0	971	1100	444	Schwartz 1979
8-220	Clay	75/03/06	34.0	3.2	700.0	117.0	1898.0	5.7	4.0	2762	1800	1556	Schwartz 1979
8-370	Clay	75/03/23	17.9	7.0	409.0	15.4	1054.0	117.0	27.0	1647	1710	864	Schwartz 1979
	Minimum		17.9	3.2	239.0	13.3	541.8189	5.7	4.0	971	1100	444	
	Maximum		34.0	7.0	700.0	117.0	8.0	117.0	54.0	2762	1800	1556	
	Mean		23.8	5.6	449.3	48.6	1164.6	73.2	28.3	1794	1537	955	
McMurray Formation													
6-21	Oil Sands	75/09/11	31.0	5.2	17.5	1.7	4.6	2.5	12.0	208	280	4	Hackbarth 1977
6-220	Oil Sands	75/09/11	6.9	21.1	1400.0	1017.0	2165.0	14.0	1600.0	37181	6500	1775	Hackbarth 1977
7-135	Oil Sands	75/09/10	9.6	15.0	34520.8	768.9	768.9	6.6	756.7	13922	3390	630	Hackbarth 1977
	Minimum		6.9	5.2	17.5	1.7	4.6	2.5	12.0	208	280		
	Maximum		31.0	21.1	34520.8	1017.0	2165.0	14.0	1600.0	37171	6500	1665	
	Mean		15.8	13.8	11979.4	381.2	768.9	6.6	756.7	13922	3389	630	
BP-2WA	Basal Aquifer	80/07/02	74.0	167.0	6281.0	63.0	3304.0	4.0	8550.0	16928	27400	2709	Hackbarth 1977
BP-4WA	Basal Aquifer	80/07/02	3.2	2.2	331.0	19.0	401.0	7.5	176.0	1032	1500	329	Hackbarth 1977
Fina 73-6	Basal Aquifer	80/07/02	8.5	20.0	625.0	15.0	1051.0	10.0	446.0	1652	2850	862	Hackbarth 1977
Fina 73-2	Basal Aquifer	80/07/02	11.0	21.0	203.0	11.3	647.0	6.0	49.0	643	1180	531	Hackbarth 1977
Tenneco	Basal Aquifer	79/07/07	9.0	0.6	118.0	6.7	361.0	6.7	2.0	366	525	296	Hackbarth 1977
Tenneco	Basal Aquifer	74/02/27	128.0	84.0	190.0	-	602.0	528.0	-	1532	-	494	Schwartz 1979
Tenneco	Basal Aquifer	74/02/18	42.0	62.0	161.0	-	431.0	344.0	-	1040	-	353	Schwartz 1979
7-337	Basal Aquifer	75/09/10	14.7	28.0	575.0	22.1	1239.0	2.7	218.0	2100	3200	1016	Schwartz 1979
	Minimum		3.2	0.6	118.0	6.7	361.0	2.7	2.0	366	525	353	
	Maximum		128.0	167.0	6281.0	63.0	304.0	528.0	8550.0	16928	27400	1016	
	Mean		36.3	48.1	1060.5	22.9	1004.5	113.6	1573.5	3162	6109	621	
Upper Devonian													
BP-1W	Limestone	80/07/01	106.0	451.0	10281.0	101.0	1515.0	1.0	16750.0	29024	45000	1242	Hackbarth 1977
BP-2W	Limestone	80/07/02	39.0	152.0	7312.0	66.0	1659.0	1700.0	10250.0	19684	31300	1360	Hackbarth 1977
BP-3W	Limestone	80/07/02	13.0	12.0	975.0	9.0	464.0	36.0	1290.0	2576	4550	380	Hackbarth 1977
Env91-2A	Limestone	94/10/27	73.0	58.0	3579.0	19.6	2038.0	1.4	4910.0	9660	16013	1672	KCCL 1995
Env91-5	Limestone	94/11/09	21.9	22.5	2555.0	12.1	2607.0	2.1	2540.0	6458	10752	2138	KCCL 1995
Env92-6	Limestone	94/10/26	110.0	150.0	10626.0	52.4	2731.8	7.0	15480.0	27791	42508	2241	KCCL 1995
Env94-10A	Limestone	94/10/31	190.0	35.5	2086.0	7.8	782.6	48.2	3240.0	5999	10340	642	KCCL 1995
Env94-7	Limestone	94/11/03	336.0	105.0	1180.0	12.1	982.5	918.0	1710.0	4753	7670	806	KCCL 1995
Env94-8A	Limestone	94/10/31	171.0	28.0	207.0	6.3	597.3	58.6	338.0	1108	2011	490	KCCL 1995
Env94-9A	Limestone	94/10/31	113.0	25.2	1460.5	2.7	719.0	61.4	1940.0	3962	7183	590	KCCL 1995
	Minimum		13.0	12.0	207.0	2.7	464.0	1.0	338.0	1108	2011	380	
	Maximum		336.0	451.0	10626.0	101.0	2731.8	1700.0	16750.0	29024	45000	2241	
	Mean		117.3	103.9	4026.0	28.9	1409.6	283.4	5844.8	11807	17733	1156	
Prairie Evaporite													
7-594	gypsum	75/02/19	380	346	1688	67	422	2500	2875	8278	8000+	346	Schwartz 1979
Precambrian													
7-933	Granite	75/03/11	25.4	1.5	251	76	158	134	300	946	1480	130	Schwartz 1979

[1] Approximate

Groundwater in the oil sands ranges from being quite fresh to saline. The value of TDS, as shown in Table 7, ranges from 208 mg/L to 37 181 mg/L. The mean concentration of TDS was 13 922 mg/L. Sodium, chloride and bicarbonate are the major ions in groundwater from the oil sands. Data collected by Komex International Ltd. (1997) falls within this range.

The Basal Aquifer yields water that ranges from fresh to very brackish. The TDS reported by Schwartz (1979) and Hackbarth (1977) ranged from 366 mg/L to 16 928 mg/L. The mean concentration of TDS in the Basal Aquifer was 3162 mg/L. Data collected by Komex International Ltd. (1997) falls within this range. Concentrations of TDS ranged from 1430 mg/L to 7407 mg/L. The TDS concentrations for the Aurora Mine were measured at less than 2000 mg/L. The major ions in the aquifer are sodium, bicarbonate and chloride. The sulphate level was also found to be quite high in two wells in the Alsands area (greater than 300 mg/L). In general, the groundwater in the oil sands and the Basal Aquifer appear to be quite similar. The concentration of dissolved compounds in both units varies by two orders of magnitude. They both have the same major ion chemistry. In one important characteristic, however, they are quite different; the oil sands contains a higher concentration of hydrocarbons.

The chemistry of groundwater in the Upper Devonian formations shown in Table 8 is from sites at Alsands and Suncor's active mine. The groundwater in the Upper Devonian strata is slightly brackish to saline. The concentration of TDS in the limestone ranged from 1108 mg/L to 29 024 mg/L, with a mean of 11 807 mg/L. Sodium, chloride and bicarbonate are the major ions in water in the Upper Devonian strata. In general, the data in Table 7 indicates that the groundwater in the Upper Devonian strata is more brackish than in the Basal Aquifer. Chloride is also more predominant in the Upper Devonian strata than in the Basal Aquifer.

Table 7 also provides chemistry data for groundwater from the Middle Devonian and Precambrian rock. Water from the Prairie Evaporite and Methy Formations is saline, with major ions being sodium, sulphate and chloride. Komex International Ltd. (1997) measured a range of concentrations of TDS from 9824 mg/L to 78 666 mg/L for groundwater from the Methy Formation.

5. GEOLOGY OF THE EAST BANK MINE AREA

5.1 Surficial Geology

An examination of the borehole logs confirms, in general, the interpretation of the surficial geology by McPherson and Kathol (1977). The following discussion describes the surficial deposits found in the organic plain, valley slopes and floodplain in the Project Millennium LSA.

5.1.1 Organic plain

On the organic plain, the simplified stratigraphic column is as follows:

Peat
Stratified Sediments
Till
Deep Undifferentiated Till and Stratifed Sediments
Bedrock

Cross sections through the surficial drift deposits in the organic plain have been prepared (Figures 10 to 15).

5.1.1.1 Peat

Peatland consists of an organic soil substrate consisting largely of organic residues formed in a water saturated condition as the result of incomplete decomposition of the plant constituents due to the prevailing anaerobic conditions (Radforth and Brawner, 1977). During a helicopter flight over the site, it was observed that the majority of the organic plain area is covered with peat. This observation was later confirmed by terrestrial mapping presented in Golder (1998). The drift has been logged in a sufficient number of boreholes to indicate that the peat is 0.8 to 1.5 m thick in the LSA.

5.1.1.2 Stratified Sediments

Stratified sediments include sand and gravel interbedded with discontinuous layers of siltier material and glacial till. This sediment was probably deposited through the fluvial reworking of the underlying till deposits.

Below the peat, sand was encountered in over half of the boreholes in which surficial materials were logged. From descriptions on the logs, these sediments are interpreted to be either glaciofluvial outwash or mixed glaciolacustrine sediments. Where they are present, the thickness of the sand units ranges from 1 m to 10 m with local accumulations of up to 36 m as shown in the cross sections (Figures 10 to 15).

The trends of sand and gravel occurrence observed in the borehole logs are reflected by the resistivity profiles determined through the TEM survey (Figure 16). The resistivity contrasts are indicative of changes in the sediment type. Generally, the higher resistivities correspond to the more clay deficient deposits (the sand and gravel deposits). The TEM response is also a function of the electrical properties of the fluid filling the pore spaces. Locally, extremely fresh water such as water found in the peat may cause a high resistivity response that is unrelated to the presence of sand and gravel in the subsurface.

The elevation of the base of the stratified sediments is shown in Figure 17. The net thickness of the sand and gravel above this surface is shown in Figure 18. Both of these maps are based on the borehole data. Resistivity profiles A-A and C-C in Figure 16 show two layers of higher resistivity material within a depth interval of ground surface to about 30 m below ground. These two layers have been identified locally in boreholes and summed as one hydrogeologic unit to account for the thickness represented in the isopach map (Figure 18). The meandering appearance and continuity of sand and gravel in Figure 18 may have resulted from fluvial reworking of the sediments. The north-westerly trend is parallel to that of the Mildred Lake Aquifer which has been mapped in an area northwest of the LSA.

5.1.1.3 Till

Till has been deposited over nearly the entire organic plain. The descriptions of till in the logs provided by Suncor resemble the Firebag till, as described by McPherson and Kathol (1977). The till is predominantly a sandy loam, increasing in clay content with depth. The composition of the Firebag till bears a resemblance to the bedrock beneath it. In the centre and east portions of the LSA, the till overlies shale of the Clearwater Formation. In these locations, the lower till horizons are clayey, and appear to contain rafted or re-worked Clearwater shale. On the west side of the LSA, where the Clearwater Formation has been eroded, the till is in contact with oil sands. Correspondingly, the borehole logs describe the till as being more sandy, with bitumen odour. Figure 17 represents the elevation of the top of the till (base of stratified sediments). The total thickness of the till ranges from zero to 36 m in the boreholes that have been logged.

Generally, the distribution of the till recorded in the borehole logs agrees with the surficial geology map prepared by McPherson and Kathol (1977) shown in Figure 7, with a few exceptions. In the western portion of the LSA and proximal to the Athabasca River, till is absent locally and the fluvial outwash deposits, lacustrine clay, fill material and peat directly overlies the bedrock. These locations correspond to areas where the fluvial outwash deposits tend to be thick implying that the till has been eroded and reworked locally. This reworking was focused along trends that correspond to the bedrock topographic lows as will be discussed in Section 6.1.6.

5.1.1.4 Deep Undifferentiated Till and Stratified Sediments

McPherson and Kathol (1977) suggested that undifferentiated deposits of till and stratified sediments may exist in areas where surficial deposits are very thick. Their investigation indicates that the drift in portions of Lease 19 may be up to 45 m thick. This was confirmed by the 1996 and 1997 drilling programs for the LSA. The drift ranges in thickness to a maximum of 44 metres in the eastern half of the LSA. Where the drift is thick, deep stratified sand and gravel has been observed beneath the till overlying the bedrock (for example borehole location AA09269109W4-L19). Till was encountered overlying deep sand and gravel in twenty locations distributed through the LSA (Figure 19).

To date the borehole information has not been comprehensive enough to determine whether this deep sand and gravel constitutes a major aquifer in the LSA.

5.1.2 Valley Slopes

The valley slopes along the Steepbank River and the east side of the Athabasca River are covered with colluvium. The colluvium consists mainly of sandy and silty material, with some bituminous sand. The thickness of these deposits is not known. However, it probably ranges from zero to several 10's of metres, where the slopes are less steep. The bedrock is exposed on slopes that are particularly steep.

5.1.3 Floodplain

The Athabasca River valley has been eroded into the Upper Devonian limestone. Valley sediments consist of discontinuous alluvial gravel, sand silt and clay that contact the Upper Devonian surface. The floodplain on the east bank of the Athabasca River is comprised of organic material and alluvial sand silt and clay, with some sand and gravel deposits. The results from geotechnical drilling in the fall of 1995 indicate that the sand and gravel is very clean, with no silt or clay sized material.

5.1.4 Thickness of Surficial Deposits

A map showing the total thickness of surficial drift deposits is shown in Figure 20. On the organic plain, the thickness of surficial material ranges from 1 m to 45 m. The surficial deposits are thin along the edge of the scarp of the river valleys. The thickest surficial deposits are located in the southeast part of Lease 25, and in Lease 19. The drift thickness map by McPherson and Kathol (1977), shown in Figure 8, is generally consistent with the map prepared for this study.

On the valley slopes, the surficial deposits are generally less than 1 m thick. Along the Steepbank River, in Lease 97 and Fee Lot 1, the valley walls are very steep, and the bedrock outcrops. Beneath the river near Tar Island Dyke, the surficial material has been found to be over 40 m thick.

5.1.5 Bedrock Geology

From the results of the compilation of borehole data, the simplified bedrock stratigraphy of the east bank mine area is as follows:

- Clearwater Formation;
- McMurray Formation;
- Basal Aquifer; and
- Upper Devonian Limestone.

The bedrock stratigraphy is presented in six cross sections in Figures 10 to 15. Maps showing structure contours and outcrop areas of each stratigraphic unit are illustrated in Figures 21 to 29.

5.1.6 Local Bedrock Topography

The bedrock surface beneath most of the organic plain in the LSA consists of the Clearwater Formation (Figure 21). The bedrock generally slopes toward the Athabasca River. The bedrock elevation ranges from 260 mASL to greater than 400 mASL.

Superimposed on the westerly sloping surface are local depressions in the bedrock surface. Three such depressions are clearly visible on the structure map in Figure 21. They are located northeast of Leggett Creek, east of the eastern limit of Unnamed Creek, and to the south of Wood Creek. The locations of the depressions correspond with depressions in the surface of the Upper Devonian (Figure 28). A comparison of the site topography (Figure 6), thickness of surficial deposits (Figure 20) and the bedrock structure (Figure 21) reveals that these depressions are filled with thick deposits of surficial material. In addition, from the sand and gravel isopach (Figure 18) it is evident that fluvial reworking of the till occurred in areas where the bedrock surface is deep. This implies that the ground surface during the time of glacial-fluvial outwash reflected the bedrock surface to some extent.

5.1.7 Clearwater Formation

The Clearwater Formation subcrops beneath the drift deposits over most of the area of the organic plain (Figure 21). The zero edge of the formation is locally an erosional edge, where the bedrock has been incised by the river valleys. The Clearwater Formation outcrops along the Athabasca River valley, the Steepbank River valley, and at the mouths of Leggett, Wood and McLean Creeks (Figure 22).

As shown in the geologic cross sections in Figures 10 to 15, the deposit forms a wedge of material that thickens from west to east. The thickness of the Clearwater Formation ranges from 0 to 80 m.

5.1.8 McMurray Formation Oil Sands

The thickness of the McMurray Formation (excluding the Basal Aquifer) ranges from 50 m to 85 m. The structure map of the McMurray Formation is shown in Figure 23. The McMurray outcrops below the Athabasca River valley escarpment along the entire LSA (Figure 24). The McMurray also outcrops along the Steepbank River valley up to a point about 12 km from the outflow of the Steepbank to the Athabasca River.

Borehole data indicate that interburden deposits occur sporadically in the McMurray Formation. Borehole logs did not provide enough detail to characterize the interburden deposits.

The oil sands is underlain by the Basal Aquifer in most of the LSA. In some depressions in the Devonian surface, there is oil sands below the Basal Aquifer. This is shown clearly in cross section B, (Figure 11), in which there is nearly 20 m of oil sands between the Basal Aquifer and the underlying limestone.

5.1.9 Basal Aquifer

The distribution and thickness of the Basal Aquifer in the LSA is shown in the isopach map in Figure 25. There are large portions of Leases 97, 19 and 25 where the aquifer is less than 1 meter thick.

The thickness of the Basal Aquifer ranges from zero to 50 m. There are three trends in the LSA along which the Basal Aquifer is thick. The Basal Aquifer is thickest at the northern end of the LSA, immediately south of Unnamed Creek and between Leggett Creek and Wood Creek. As shown in the cross sections (Figures 10 to 15), the Basal Aquifer is thickest where it overlies depressions in the Devonian surface.

Figure 26 is a structure contour map of the top of the Basal Aquifer. Where the aquifer is present, the elevation of its upper surface ranges from 216 mASL to 282 mASL. Where the aquifer is thin, (less than 15 m), the structure of the aquifer reflects the structure of the underlying Devonian.

The Basal Aquifer outcrop areas are localized (Figure 27). Along the Athabasca River valley, mapping indicates possible outcropping or near surface subcropping Basal Aquifer in the vicinity of Shipyard Lake and near Leggett Creek. The Basal Aquifer also outcrops sporadically along the Steepbank River valley from the Athabasca River to a point about 4.5 km upstream along the Steepbank River.

5.1.10 Upper Devonian

A structure contour map of the Upper Devonian surface is presented in Figure 28. The map illustrates the surface of the Devonian is an undulating erosional unconformity, ranging in elevation from 190 mASL to 290 mASL. Several closed depressions are present on the Devonian surface, which suggest that some subsidence due to karstification and collapse have taken place. Topographic highs are also apparent, at numerous locations on the surface. As shown in the cross sections in Figures 10 to 15, the surface of the Upper Devonian subcrops along the Athabasca River and the lower portion of the Steepbank River (Figure 29). In places, outcrops of limestone stand up to 10 m above river level. Observations made on core samples and outcrops revealed that the Upper Devonian limestone is highly fractured and weathered. Some of the fractures contain clay.

6. HYDROGEOLOGY OF THE EAST BANK MINE AREA

6.1 Surficial Materials

6.1.1 Organic Plain

The main water bearing materials included in the surficial materials are peat and underlying sands and gravels.

Thirteen standpipe piezometers have been constructed in surficial deposits in the organic plain of the LSA. The locations of the piezometers are shown in Figures 5 and 30. Rising head tests have been conducted in ten of the piezometers to determine the hydraulic conductivity of the drift. Piezometer L97-P95-OBS#4 was not tested, because the electrical conductivity of its water was too low to activate a depth sounder. In addition, L19-P98-OB7 was dry at the time of testing and L19-P98-OB8 was frozen. Table 8 presents the hydraulic conductivity of the drift.

6.1.1.1 Hydraulic Conductivity of Surficial Material in Organic Plain

The hydraulic conductivity of the surficial sand ranges from 2.9×10^{-7} m/s to 2.0×10^{-5} m/s, with a mean of 3.1×10^{-6} m/s. This is within the range calculated from piezometer tests elsewhere in the region (shown in Table 4).

The hydraulic conductivity of the till in the LSA was measured in four locations (Table 8). The geometric mean of the hydraulic conductivity is 2.8×10^{-7} m/s. The hydraulic conductivity of the till in the region ranges from 5.3×10^{-8} m/s to 6.8×10^{-7} m/s, with a mean of 1.4×10^{-7} m/s

Table 8 Hydraulic Conductivity of Surficial Deposits in the LSA

Monitoring Location	Suncor 1998 Drilling Program Location	Geology	Hydraulic Conductivity (m/sec)	Analytical Method
Sand and Gravel Deposits				
L97-P95-OBS#1	NA	Sand	4.00E-05	Hvorslev (1951)
L97-P95-OBS#2	NA	Silty sand	6.00E-07	Hvorslev (1951)
L97-P95-OBS#3	NA	Sand	2.00E-05	Hvorslev (1951)
L97-P95-OBS#5	NA	Sand	4.00E-07	Hvorslev (1951)
L25-P98-OB1	98-103	Fine to medium grain sand and cobbles	2.90E-07	Hvorslev (1951)
L25-P98-OB2	98-080	Medium to coarse sand	9.10E-05	Hvorslev (1951)
L19-P98-OB4	98-117	Medium to coarse sand	6.10E-07	Hvorslev (1951)
L19-P98-OB7	98-125	Medium to coarse sand	Dry	Hvorslev (1951)
		Geometric Mean	3.15E-06	
Till Deposits				
L25-P98-OB3	98-083	Clay till	7.90E-09	Hvorslev (1951)
L19-P98-OB5	98-074	Clay till and sand layers	2.90E-06	Hvorslev (1951)
L19-P98-OB6	98-115	Clay till	9.60E-07	Hvorslev (1951)
L19-P98-OB8	98-064	Clay till	Frozen	Hvorslev (1951)
		Geometric Mean	2.80E-07	

6.1.1.2 Groundwater Flow in Surficial Material in Organic Plain

Due to the differences in hydraulic conductivity with depth in peat, the groundwater flow direction in the peat is also variable with depth. When the active layer of peat is saturated from top to bottom, water flows laterally through the more permeable upper strata, and vertically through the less permeable deeper strata. During dryer seasonal periods when the water table in the peat is closer to the base of the active layer, vertical flow in the less permeable material predominates. The hydraulic gradient between the peat and underlying sands has not been determined from piezometer testing; however, in the areas of fens one would presume that the gradient is directed upward across the low permeability layers. This upward gradient would vary seasonally with the water level in the peat.

The organic plain is discontinuously covered with permeable sand which overlies less permeable till. The groundwater flow in the sand is controlled by two factors: the hydraulic conductivity; and the topography of the ground and underlying geologic units. Figure 30 shows an interpretation of the direction of horizontal flow in the surficial sand and gravel based on the water level data presented in Table 9.

The direction of horizontal flow is controlled by the site topography and by the intersection of fluvial deposits with surface water bodies including streams and fens.

Table 9 Water Level Data for the Project LSA

Standpipe Piezometer	Monitoring Location	East NAD83	North NAD83	Ground Elevation (mAMSL)	Stick-Up (m)	Reference Elevation (mAMSL)	Date	Depth to Water (m)	Water Level Elevation (mAMSL)
Surficial Sands									
FL1-BRDG-4	FL1-BRDG-4	472934	6317640	246.97	0.91	247.87	3/1/95	4.43	243.44
FL1-BRDG-4	FL1-BRDG-4	472934	6317640	246.97	0.91	247.87	6/25/96	3.47	244.40
FL1-BRDG-4	FL1-BRDG-4	472934	6317640	246.97	0.91	247.87	10/21/96	3.22	244.65
FL1-BRDG-4	FL1-BRDG-4	472934	6317640	246.97	0.91	247.87	7/4/97	3.09	244.78
FL1-BRDG-4	FL1-BRDG-4	472934	6317640	246.97	0.91	247.87	11/27/97	3.10	244.77
FL1-BRDG-AP-4	FL1-BRDG-AP-4	472934	6317640	246.97	NA	NA	3/1/95	NA	243.80
L97-P95-OB-1	L9795OB1	475104	6316935	331.20	0.90	332.10	3/1/95	6.90	325.20
L97-P95-OB-2	L9795OB2	475399	6315708	336.10	0.56	336.66	3/1/95	1.84	334.82
L97-P95-OB-2	L9795OB2	475399	6315708	336.10	0.56	336.66	6/24/96	0.75	335.91
L97-P95-OB-2	L9795OB2	475399	6315708	336.10	0.56	336.66	10/18/96	0.75	335.91
L97-P95-OB-2	L9795OB2	475399	6315708	336.10	0.56	336.66	7/2/97	0.80	335.86
L97-P95-OB-2	L9795OB2	475399	6315708	336.10	0.56	336.66	10/21/97	0.72	335.94
L97-P95-OB-3	L9795OB3	475519	6316250	338.20	0.71	338.91	3/1/95	4.10	334.81
L97-P95-OB-3	L9795OB3	475519	6316250	338.20	0.71	338.91	6/25/96	3.78	335.13
L97-P95-OB-3	L9795OB3	475519	6316250	338.20	0.71	338.91	10/18/96	3.42	335.49
L97-P95-OB-3	L9795OB3	475519	6316250	338.20	0.71	338.91	6/25/97	3.35	335.56
L97-P95-OB-3	L9795OB3	475519	6316250	338.20	0.71	338.91	11/26/97	3.65	335.26
L97-P95-OB-4	L9795OB4	475620	6316358	337.43	0.84	338.27	3/1/95	3.48	334.79
L97-P95-OB-4	L9795OB4	475620	6316358	337.43	0.84	338.27	10/18/96	2.64	335.63
L97-P95-OB-4	L9795OB4	475620	6316358	337.43	0.84	338.27	6/25/97	2.74	335.53
L97-P95-OB-5	L9795OB5	475448	6318910	336.95	0.90	337.85	3/1/95	2.17	335.68
L97-P95-OB-5	L9795OB5	475448	6318910	336.95	0.90	337.85	6/25/96	0.80	337.05
L97-P95-OB-5	L9795OB5	475448	6318910	336.95	0.90	337.85	10/19/96	0.80	337.05
L97-P95-OB-5	L9795OB5	475448	6318910	336.95	0.90	337.85	7/3/97	0.80	337.05
L97-P95-OB-5	L9795OB5	475448	6318910	336.95	0.90	337.85	10/22/97	0.73	337.12
L25-P98-OB1	98-103	476178	6311731	338	0.84	338.68	2/24/98	2.18	336.50
L25-P98-OB1	98-103	476178	6311731	338	0.84	338.68	2/25/98	1.70	336.98
L25-P98-OB1	98-103	476178	6311731	338	0.84	338.68	2/26/98	0.84	337.84
L25-P98-OB2	98-080	476070	6310362	339	0.55	339.55	2/24/98	1.00	338.55
L25-P98-OB2	98-080	476070	6310362	339	0.55	339.55	2/26/98	1.04	338.51
L25-P98-OB3	98-083	479178	6310244	352	0.61	352.18	2/24/98	3.44	348.74
L25-P98-OB3	98-083	479178	6310244	352	0.61	352.18	2/25/98	3.80	348.38
L25-P98-OB3	98-083	479178	6310244	352	0.61	352.18	2/26/98	3.57	348.61
L19-P98-OB4	98-117	475934	6307534	340	0.84	340.35	2/25/98	0.84	339.51
L19-P98-OB4	98-117	475934	6307534	340	0.84	340.35	2/26/98	0.87	339.48
L19-P98-OB5	98-074	480205	6304740	354	0.61	354.97	2/25/98	1.03	353.94
L19-P98-OB5	98-074	480205	6304740	354	0.61	354.97	2/26/98	1.03	353.94
L19-P98-OB6	98-115	477495	6307865	344	0.67	344.19	2/25/98	4.45	339.74
L19-P98-OB7	98-125	477123	6304038	349	0.48	349.48	2/25/98	dry	dry
L19-P98-OB8	98-064	479122	6304057	352	0.58	352.24	2/25/98	frozen	frozen
Basal Aquifer									
L19-AP95-16-KM	L1995003	481144	6309425	369.21	NA	NA	3/1/95	NA	303.00
FL1-P95-13-BA	FL195003	476184	6319805	345.07	0.40	345.47	3/1/95	39.42	306.05
FL3-P95-6-BA	FL395004	476074	6313625	339.25	0.96	340.21	3/1/95	58.17	282.04
FL3-P95-6-BA	FL395004	476074	6313625	339.25	0.96	340.21	6/24/96	58.34	281.87
FL3-P95-6-BA	FL395004	476074	6313625	339.25	0.96	340.21	6/25/96	58.34	281.87
FL3-P95-6-BA	FL395004	476074	6313625	339.25	0.96	340.21	10/19/96	58.35	281.86
FL3-P95-6-BA	FL395004	476074	6313625	339.25	0.96	340.21	7/3/97	53.77	286.44
FL3-P95-6-BA	FL395004	476074	6313625	339.25	0.96	340.21	10/21/97	28.39	311.82
L97-P95-1-BA	L9795008	475104	6316935	331.20	0.79	331.99	3/1/95	55.09	276.90
L97-P95-1-BA	L9795008	475104	6316935	331.20	0.79	331.99	10/22/96	55.10	276.89
L97-P95-1-BA	L9795008	475104	6316935	331.20	0.79	331.99	6/23/97	55.20	276.79
L97-P95-1-BA	L9795008	475104	6316935	331.20	0.79	331.99	10/23/97	55.23	276.76
L97-P95-3-BA	L9795005	474464	6316925	325.65	0.91	326.56	3/1/95	49.89	276.67

Table 9 Water Level Data for the Project LSA Continued

Standpipe Piezometer	Monitoring Location	East NAD83	North NAD83	Ground Elevation (mAMSL)	Stick-Up (m)	Reference Elevation (mAMSL)	Date	Depth to Water (m)	Water Level Elevation (mAMSL)
L97-P95-3-BA	L9795005	474464	6316925	325.65	0.91	326.56	6/24/96	49.80	276.76
L97-P95-3-BA	L9795005	474464	6316925	325.65	0.91	326.56	10/22/96	49.50	277.06
L97-P95-3-BA	L9795005	474464	6316925	325.65	0.91	326.56	7/3/97	50.02	276.54
L97-P95-3-BA	L9795005	474464	6316925	325.65	0.91	326.56	10/23/97	50.00	276.56
L97-P95-8-BA	L9795006	474844	6317125	330.66	0.94	331.60	3/1/95	52.47	279.13
L97-P95-8-BA	L9795006	474844	6317125	330.66	0.94	331.60	6/17/96	54.12	277.48
L97-P95-8-BA	L9795006	474844	6317125	330.66	0.94	331.60	10/22/96	54.10	277.50
L97-P95-8-BA	L9795006	474844	6317125	330.66	0.95	331.60	6/27/97	54.30	277.30
L97-P95-8-BA	L9795006	474844	6317125	330.66	0.95	331.60	10/23/97	54.40	277.20
Upper Devonian									
FL3-AP95-7A-L	FL395005A	475994	6313065	338.61	NA	NA	3/1/95	NA	254.20
FL3-AP95-7B-L	FL395005B	475994	6313065	338.61	NA	NA	3/1/95	NA	270.60
L97-AP95-14A-L	L9795022A	475454	6318905	337.22	NA	NA	3/1/95	NA	305.00
L97-AP95-14B-L	L9795022B	475454	6318905	337.22	NA	NA	3/1/95	NA	302.30
L97-AP95-15-L	L9795024	475984	6318525	343.23	NA	NA	3/1/95	NA	298.30
L97-AP95-4A-L	L9795015A	474644	6315315	318.75	NA	NA	3/1/95	NA	259.50
L97-AP95-4B-L	L9795015B	474644	6315315	318.75	NA	NA	3/1/95	NA	265.00
L97-AP95-5A-L	L9795010A	475404	6316695	337.61	NA	NA	3/1/95	NA	269.50
L97-AP95-5B-L	L9795010B	475404	6316695	337.61	NA	NA	3/1/95	NA	275.40
L97-AP95-9A-L	L9795001A	474014	6317185	315.21	NA	NA	3/1/95	NA	265.20
L97-AP95-9B-L	L9795001B	474014	6317185	315.21	NA	NA	3/1/95	NA	258.80
L97-P95-2-L	L9795014	475104	6315965	332.56	0.81	333.37	3/1/95	53.71	279.66
L97-P95-2-L	L9795014	475104	6315965	332.56	0.81	333.37	6/24/96	53.85	279.52
L97-P95-2-L	L9795014	475104	6315965	332.56	0.81	333.37	10/18/96	53.85	279.52
L97-P95-2-L	L9795014	475104	6315965	332.56	0.81	333.37	7/2/97	53.77	279.60
L97-P95-2-L	L9795014	475104	6315965	332.56	0.81	333.37	10/22/97	53.79	279.58

Note: For the standpipe piezometers installed during 1998, the coordinates and reference elevations were estimated from the original Suncor 1998 survey coordinates for exploration boreholes. The standpipe piezometers were drilled as offset boreholes. The coordinates and reference elevations for these piezometers are therefore approximate.

On the south side the Steepbank River, the majority of the organic plain slopes toward the Athabasca River. As shown on Figure 30, there is a surface flow divide very close to the left bank of the Steepbank River. Therefore, the majority of the shallow groundwater flows toward the Athabasca River. A small percentage of the groundwater flows toward the left bank of the Steepbank River. As it reaches the edge of the organic plain, the groundwater discharges into the colluvium on the valley slopes, and flows into the river valleys. The flux into each of the surface streams is discussed in Section 7.4.

In the till, the hydraulic gradient is probably downward except where the till has been incised by stream channels. This is due to the similarity between the hydraulic conductivity of the till and the hydraulic conductivity of the underlying Clearwater Formation. The rate of flow through the till is probably much less than the flow through the sandier shallow sediments.

6.1.1.3 Groundwater Chemistry in Surficial Materials in the Organic Plain

Water chemistry results for the peat are presented in the hydrologic impact analysis (Klohn-Crippen, 1998).

Groundwater samples were collected from piezometers in the organic plain in the Steepbank Mine area in 1995, 1996 and 1997. Standpipe piezometers installed in 1998 were sampled for groundwater but the analytical results were not available at the time of writing. The analytical results are representative of the groundwater obtained from drift deposits and are tabulated in Tables 10 to 13. A Piper plot, which is a graphical presentation of the major ion chemistry of the water, is shown on Figure 32 for each sampling event for 1997.

The surficial groundwater ranges from extremely fresh (TDS = 17 mg/L) to fresh (TDS = 638 mg/L). The Piper plot in Figure 32 illustrates that there are two types of water in the surficial sand deposits; low TDS water and high TDS water. The low TDS groundwater is generally a calcium-magnesium bicarbonate type water, while the high TDS groundwater is a sodium-bicarbonate type water. The ratio of sulphate to total dissolved solids is higher in the low TDS water than the high TDS water. There is a higher chloride concentration (although still less than 15 mg/L) in the high TDS water. The pH ranges from 5.4 to 8.1, with an average of 6.6 units.

Trace amounts of organics, including PAH and alkylated PAH's, were measured in the surficial groundwater as shown in Table 12. Naphthenic acid concentrations range from <3 to 7 mg/L, and Microtox toxicity testing indicates the water is non-toxic, as shown in Table 13.

Groundwater samples collected in October 1995 were analyzed for the stable isotopes deuterium and oxygen-18. Grab samples were also collected from the Steepbank River, Shipyard Lake, and La Saline Lake, which is north of the LSA. Stable isotope analyses are used to help understand the source of a water, and the processes that have affected it. A scatter plot of the deuterium and oxygen-18 concentrations in the water samples collected is shown in Figure 33. The groundwater from surficial deposits plots along the meteoric water line. This indicates that the groundwater is meteoric, and has not been affected by any processes such as evaporation.

Table 10 Major Ion Chemistry and Field Measured Parameters of Groundwater in the LSA

WELL	DATE	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Total Alk (mg/L)	pH pH	Bicarbonate (mg/L)	Specific Cond umhos/cm	TDS (mg/L)	Piper Group
SURFICIAL DEPOSITS													
FL1-BRDG-4	03/13/95	14.2	3.24	8.9	1.49	4.6	28.8	31.56	6.23	38.47	142	81.21	1&2
FL1-BRDG-4	07/06/95	17.7	3.4	11.1	1.4	4.2	26.5	51	6.48	62.17	174	96.12	1
FL1-BRDG-4	09/13/95	20.5	3.5	6.2	1.5	4.3	25.5	48	6.6	58.51	175	91.66	1
FL1-BRDG-4	06/25/96	17.1	2.86	6.24	1.31	4.3	31.8	22.96	6.19	27.99	139	79.29	3
FL1-BRDG-4	10/21/96	15.7	2.35	1.32	1.16	1.7	22.4	23	6.1	28.04	110.7	60.15	1&3
FL1-BRDG-4	7/4/97	44.3	6.35	4.36	2.13	2.3	115	27.7	6.15	33.8	321	193	3
FL1-BRDG-4	11/27/97	38.8	6.35	10.9	2.2	4.9	73.7	54.3	6.35	66.1	291	171	1&3
FL7-BRDG-4	03/13/95	14.2	3.24	8.9	1.49	4.6	28.8	31.56	6.23	38.47	142	81.21	1&2
FL7-BRDG-4	07/06/95	17.7	3.4	11.1	1.4	4.2	26.5	51	6.48	62.17	174	96.12	1
FL7-BRDG-4	09/13/95	20.5	3.5	6.2	1.5	4.3	25.5	48	6.6	58.51	175	91.66	1
L25-P96-OB-1	10/18/96	37.7	8.2	8.07	0.46	0.5	17.8	121	6.54	147.50	266.5	146.51	1
L25-P96-OB-1	6/25/97	34.5	8.22	7.59	0.51	-0.1	18	112	6.48	137	255	137	1
L25-P96-OB-1	11/26/97	38.3	8.82	8.73	0.52	0.8	16.3	125	6.77	152	271	150	1
L97-P95-OB-1	03/17/95	78	22	10.4	1.93	1.2	23.8	305	7.19	371.80	580	323.83	1
L97-P95-OB-1	07/03/95	79.8	19.9	8.8	2.3	0.7	18.3	262	7.68	319.38	514	290.18	1
L97-P95-OB-1	09/12/95	71.9	18.7	9.8	2.6	0.7	16.5	245	7.49	298.66	478	270.34	1
L97-P95-OB-2	03/17/95	25	7.4	186	4.18	9.6	0.7	491	7.56	598.53	873	532.22	4
L97-P95-OB-2	06/29/95	22.8	6.2	189	3.3	14.2	0.8	485	8.1	591.22	883	531.94	4
L97-P95-OB-2	09/13/95	21.4	6.1	195	3.1	10	0.8	481	7.75	586.34	885	529.57	4
L97-P95-OB-2	06/24/96	22.4	6.53	195	3.06	10	1.4	482	7.57	587.56	879.1	532.17	4
L97-P95-OB-2	10/18/96	20.8	6.03	200	3.1	10.4	0.5	483	7.65	588.78	878.5	535.33	4
L97-P95-OB-2	7/2/97	20.6	6.28	194	3.03	12	0.5	470	7.52	573	906	523	4
L97-P95-OB-2	10/21/97	18.8	5.81	181	2.8	10.8	-0.1	499	7.96	608	882	523	4
L97-P95-OB-3	03/17/95	5.1	0.89	1.66	0.51	<0.5	10.2	9.86	5.56	12.02	43	24.49	1&3
L97-P95-OB-3	07/04/95	3.3	0.9	4.2	0.7	<0.5	9.9	7.14	5.65	8.70	35	23.76	1&2
L97-P95-OB-3	09/12/95	3.8	1.1	4.6	1.2	9.7	9	8	5.61	9.75	39	34.38	2&3
L97-P95-OB-3	06/25/96	3.15	0.77	1.92	0.53	<0.5	9.2	7.21	5.51	8.79	35.26	20.10	1&3
L97-P95-OB-3	10/18/96	2.83	0.75	1.57	0.47	<0.5	8.7	7.6	5.39	9.26	36.86	19.04	1&3
L97-P95-OB-3	6/25/97	2.94	0.78	1.61	0.52	-0.1	9.7	5.7	5.60	6.9	39	19	1&3
L97-P95-OB-3	11/26/97	2.4	0.88	1.58	0.6	-0.1	8.2	5.9	5.71	7.2	32	17	1&3
L97-P95-OB-4	03/13/95	4.35	1.29	2.3	1.12	<0.5	9.7	14.72	5.62	17.94	48	28.00	1&3
L97-P95-OB-4	07/03/95	7.7	1.5	3.2	0.8	3.1	11	12.44	5.87	15.16	54	35.02	1&3
L97-P95-OB-4	09/12/95	4.6	1.4	5.2	1.1	2.2	10.5	8.01	5.76	9.76	50.3	30.17	2&3
L97-P95-OB-4	10/18/96	4.14	1.12	1.5	0.49	<0.5	10.4	9.68	5.53	11.80	45.21	23.89	1&3
L97-P95-OB-4	6/25/97	4.34	1.18	1.67	0.61	-0.1	11.5	8.4	5.52	10.2	47	25	1&3
L97-P95-OB-5	03/13/95	64	17.8	159	2.85	7.8	10.2	566	7.13	689.95	1010	606.75	4
L97-P95-OB-5	07/05/95	53.7	14.4	178	2.1	9.3	5.4	576	7.45	702.14	1011	613.97	4
L97-P95-OB-5	09/14/95	52	14	190	2.4	10.2	5	573	7.44	698.49	1048	622.84	4
L97-P95-OB-5	06/25/96	58.3	15.2	179	2.14	9	6.5	575	7.16	700.93	1031	620.62	4
L97-P95-OB-5	10/19/96	53.4	14.5	185	2.57	8.8	6.8	574	7.34	699.71	1024	621.03	4
L97-P95-OB-5	7/3/97	65.7	18.1	174	6.61	9.2	9.9	581	7.62	708	1025	638	3
L97-P95-OB-5	10/22/97	50.6	14.7	171	2.23	10.6	8.6	583	7.73	711	1025	613	4
minimum		2.40	0.75	1.32	0.46	-0.10	-0.10	5.70	5.39	6.90	32.00	17.00	
maximum		79.80	22.00	200.00	6.61	14.20	115.00	583.00	8.10	711.00	1048.00	638.00	
median		20.55	5.92	8.85	1.50	4.45	10.20	52.65	6.51	64.13	260.75	141.75	
mean		27.60	6.90	65.13	1.81	5.55	16.43	216.26	6.64	263.61	430.32	254.82	

Table 10 Major Ion Chemistry and Field Measured Parameters of Groundwater in the LSA (Continued)

WELL	DATE	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Total Alk (mg/L)	pH pH	Bicarbonate (mg/L)	Specific Cond umhos/cm	TDS (mg/L)	Piper Group
BASAL AQUIFER													
FL1-P96-2-BA	06/27/96	38	24.9	1760	23.9	1850	1.6	1470	7.57	1791.93	7809	4594.76	2
FL1-P96-2-BA	10/21/96	39.2	28.8	2000	26.1	2270	0.2	1668	7.64	2033.29	9300	5380.95	2
FL1-P96-2-BA	7/2/97	40.7	27.6	2110	18.8	2190	0.1	1697	7.36	2069	9305	5422	2
FL1-P96-2-BA	10/21/97	31.4	27.6	2010	15.7	2270	-0.1	1788	7.68	2180	9350	5445	2&4
FL3-P95-13-BA	03/13/95	85	103	3230	26.8	3920	1.3	2045	7.13	2492.86	14010	8612.58	2
FL3-P95-13-BA	07/05/95	89.1	80.5	3150	26.2	3920	0.5	2099	7.19	2558.68	13709	8545.64	2
FL3-P95-13-BA	07/05/95	89.1	81.2	3080	26.4	3883	<0.5	2097	7.22	2556.24	13709	8438.02	2
FL3-P95-13-BA	09/14/95	90.6	82.7	3050	24.1	4090	0.6	2073	7.21	2526.99	14499	8601.49	2
FL3-P95-6-BA	03/13/95	190	158	6720	82.2	10200	5	1451	7.11	1768.77	30840	18239.82	2
FL3-P95-6-BA	07/10/95	193	209	9140	85.3	12800	11.3	2011	7.15	2451.41	39218	23664.30	2
FL3-P95-6-BA	09/15/95	198	223	10700	62	16850	80	2083	7.12	2539.18	43358	29382.62	2
FL3-P95-6-BA	06/25/96	205	222	8990	63.6	14900	0.7	2159	6.88	2631.82	45070	25697.21	2
FL3-P95-6-BA	10/19/96	216	255	11600	74.2	16300	<0.1	2204	7.28	2686.68	44150	29789.07	2
FL3-P95-6-BA	7/3/97	208	249	9830	52.8	15600	0.8	2353	7.37	2868	46150	27370	2
FL3-P95-6-BA	10/22/97	265	301	9820	62.9	17600	0.6	2348	7.31	2862	43540	29480	2
L97-P95-1-BA	03/13/95	76	105	4880	31.6	6520	1	2125	6.98	2590.38	21860	12908.92	2
L97-P95-1-BA	06/28/95	87.3	92.6	5040	36.7	6220	0.5	2146	7.44	2615.97	21467	12785.09	2
L97-P95-1-BA	09/12/95	85.4	102	5030	34.8	6685	1	2161	7.19	2634.26	21506	13255.36	2
L97-P95-1-BA	06/17/96	95	101	5270	30.9	7310	<0.5	2188	7.1	2667.17	22360	14140.49	2
L97-P95-1-BA	10/22/96	74	112	5150	30	6920	0.7	2181	7.59	2658.64	22880	13616.96	2
L97-P95-1-BA	6/23/97	93.5	110	4980	31.3	6880	1	2199	7.25	2681	22260	13440	2
L97-P95-1-BA	10/23/97	133	135	4610	33.6	6450	0.1	2210	6.98	2694	20750	12710	2
L97-P95-3-BA	03/13/95	45	57	3290	29.9	3880	1.2	1878	7.2	2289.28	14220	8447.79	2
L97-P95-3-BA	07/04/95	52.3	53.8	3320	25.1	4220	<0.5	1886	7.4	2299.03	14025	8820.86	2
L97-P95-3-BA	09/13/95	47.1	43.3	3140	17.8	4090	30.5	1888	7.33	2301.47	14326	8519.44	2
L97-P95-3-BA	06/24/96	52.8	56.9	3050	18.1	4180	<0.5	1893	7.3	2307.57	14300	8511.58	2
L97-P95-3-BA	10/22/96	50.3	51	2940	20.7	3970	7.4	1866	7.63	2274.65	14520	8176.73	2
L97-P95-3-BA	7/3/97	49.8	56.2	3200	18	3760	-0.1	1952	7.59	2379	14440	8274	2
L97-P95-3-BA	10/23/97	47.9	57.3	3140	17.1	3970	0.1	1940	7.21	2365	14020	8416	2
L97-P95-8-BA	06/28/95	16	8.4	1080	28.6	599	6.9	1445	7.76	1761.46	4238	2619.64	4
L97-P95-8-BA	09/13/95	13.7	7.8	1180	20	678	13	1797	7.45	2190.54	4948	3007.77	4
L97-P95-8-BA	06/17/96	18.2	11.8	1320	19.7	615	0.9	1874	7.3	2284.41	5118	3127.82	4
L97-P95-8-BA	10/22/96	17.7	12.2	1300	19.2	660	9.3	1944	7.74	2369.74	5320	3203.37	4
L97-P95-8-BA	6/27/97	14.9	11.3	1320	15.5	590	0.3	1972	7.50	2404	5261	3154	4
L97-P95-8-BA	10/30/97	20.2	16.6	1320	18.8	615	0.3	2010	7.48	2450	5342	3216	4
minimum		13.70	7.80	1080.00	15.50	590.00	-0.10	1445.00	6.88	1761.46	4238.00	2619.64	
maximum		265.00	301.00	11600.00	85.30	17600.00	80.00	2353.00	7.76	2868.00	46150.00	29789.07	
median		74.00	80.50	3200.00	26.40	4090.00	0.85	2010.00	7.30	2450.00	14326.00	8545.64	
mean		87.66	93.56	4335.71	33.38	5927.29	5.89	1974.31	7.33	2406.70	19062.23	11686.15	

Table 10 Major Ion Chemistry and Field Measured Parameters of Groundwater in the LSA (Continued)

WELL	DATE	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	Total Alk (mg/L)	pH pH	Bicarbonate (mg/L)	Specific Cond umhos/cm	TDS (mg/L)	Piper Group
							UPPER DEVONIAN						
FL1-P96-1-L	06/25/96	133	32.6	60.9	3.63	21.5	171	352	6.99	429.09	1010	637.28	1
FL1-P96-1-L	10/21/96	144	33.8	89.7	5.85	16.6	243	371	7.3	452.25	1123	759.17	1&3
FL1-P96-1-L	7/2/97	140	34.3	112	4.63	21.3	315	396	7.09	483	1171	869	1&3
FL1-P96-1-L	10/21/97	127	32.6	68.3	2.53	7.4	220	379	7.34	462	1062	689	1
L97-P95-2-L	03/13/95	25.8	20.5	1560	25.8	1440	2.4	1602	7.39	1952.84	6967	4050.99	2&4
L97-P95-2-L	06/29/95	27.7	21.6	1860	24.4	1535	0.5	1826	7.74	2225.89	7860	4582.15	2&4
L97-P95-2-L	09/14/95	26.3	24.7	1870	24.1	1690	16.5	1913	7.65	2331.95	8226	4817.57	2&4
L97-P95-2-L	09/14/95	24.1	20.5	1850	21	1860	<0.5	1901	7.56	2317.32	8261	4934.41	2&4
L97-P95-2-L	06/24/96	24.3	25.7	2000	18.2	1750	<0.5	1954	7.58	2381.93	8621	5009.19	2&4
L97-P95-2-L	10/18/96	23.7	23.8	1970	18.7	1910	0.1	2014	7.57	2455.07	8544	5173.83	2&4
L97-P95-2-L	7/2/97	25.6	23.9	2070	15.2	1830	0.4	1983	7.54	2417	8747	5174	2&4
L97-P95-2-L	10/22/97	28.8	28.6	2040	15.1	1820	0.1	2081	7.42	2537	8698	5201	2&3
minimum		23.70	20.50	60.90	2.53	7.40	0.10	352.00	6.99	429.09	1010.00	637.28	
maximum		144.00	34.30	2070.00	25.80	1910.00	315.00	2081.00	7.74	2537.00	8747.00	5201.00	
median		27.00	25.20	1855.00	16.70	1612.50	9.45	1863.50	7.48	2271.61	8043.00	4699.86	
mean		62.53	26.88	1295.91	14.93	1158.48	96.90	1397.67	7.43	1703.78	5857.50	3491.47	

Note: Groundwater Piper Groups

Group 1: Fresh Water
Group 2 Saline Water
Group 3 Sulphate Water
Group 4 Alkaline Water

Table 11 Concentrations of Dissolved Metals and Cyanide in Groundwater in the LSA (mg/L)

		Surficial Sand				Basal Aquifer				Upper Devonian			
Parameter	Units	Minimum	Maximum	Mean	Count	Minimum	Maximum	Mean	Count	Minimum	Maximum	Mean	Count
S	(mg/L)	0.4	12.100	4.750	32	0.300	25.700	3.884	25	2.500	82.700	21.075	8
Al	(mg/L)	ND	0.500	0.080	32	ND	0.080	0.025	25	ND	0.180	0.038	8
As	(ug/l)	ND	0.500	0.250	6	ND	1.600	0.640	5	0.600	0.600	0.600	1
Ba	(mg/L)	ND	0.210	0.071	29	0.150	3.000	0.987	25	0.140	0.250	0.205	8
Be	(mg/L)	ND	0.030	0.003	32	ND	0.016	0.003	25	ND	0.003	0.001	8
B	(mg/L)	ND	0.790	0.179	32	2.330	4.790	3.954	25	0.340	4.480	3.025	8
Cd	(ug/l)	ND	4.000	0.132	32	ND	3.000	0.148	25	ND	1.400	0.175	8
Cr	(mg/L)	ND	0.013	0.002	29	ND	0.024	0.006	25	ND	0.003	0.001	8
Co	(mg/L)	ND	0.004	0.001	32	ND	0.031	0.006	25	ND	0.008	0.002	8
Cu	(mg/L)	ND	0.013	0.001	32	ND	0.074	0.005	25	0.001	0.007	0.003	8
Fe	(mg/L)	ND	0.500	0.101	32	ND	8.080	1.440	25	ND	0.820	0.485	8
Pb	(mg/L)	ND	0.002	0.000	32	ND	0.040	0.005	25	ND	0.001	0.000	8
Li	(mg/L)	ND	0.420	0.040	32	0.316	1.790	0.859	25	0.066	0.387	0.289	8
Mn	(mg/L)	ND	0.589	0.121	32	0.029	4.020	0.746	25	0.034	0.689	0.147	8
Hg	(ug/l)	ND	0.100	0.007	16	ND	1.600	0.238	9	ND	0.230	0.083	4
Mo	(mg/L)	ND	0.035	0.002	32	ND	0.019	0.003	25	ND	0.010	0.004	8
Ni	(mg/L)	ND	0.018	0.004	30	ND	0.113	0.020	25	ND	0.043	0.010	8
P	(mg/L)	ND	0.400	0.041	32	ND	0.700	0.164	25	ND	0.300	0.063	8
Se	(ug/l)	ND	0.400	0.068	15	ND	0.800	0.138	8	ND	ND	ND	4
Ag	(ug/l)	ND	3.000	0.228	32	ND	5.000	1.192	25	ND	3.000	0.588	8
Sr	(mg/L)	ND	0.302	0.114	30	0.487	16.100	5.077	25	0.563	1.490	1.204	8
Tl	(mg/L)	ND	ND	ND	10	ND	ND	ND	5	ND	ND	ND	2
Ti	(mg/L)	ND	0.053	0.006	32	ND	0.012	0.001	25	ND	ND	ND	8
U	(mg/L)	ND	ND	ND	29	ND	0.002	0.000	25	ND	0.002	0.001	8
V	(mg/L)	ND	0.008	0.001	29	ND	0.009	0.002	25	ND	0.007	0.003	8
Zn	(mg/L)	ND	0.049	0.013	32	ND	0.092	0.007	25	0.001	0.014	0.005	8
Zr	(ug/L)	ND	1.200	0.133	9	3.500	19.800	13.640	5	2.700	4.000	3.350	2
Cyanide	(mg/L)	ND	0.001	0.001	15	ND	0.002	0.001	11	0.001	0.001	0.001	3

Table 12 Concentrations of Organic Compounds in Groundwater in the LSA (µg/L)

	Surficial Sand				Basal Aquifer				Upper Devonian			
Parameter	**Minimum**	**Maximum**	**Mean**	**Count**	**Minimum**	**Maximum**	**Mean**	**Count**	**Minimum**	**Maximum**	**Mean**	**Count**
PAH and Alkylated PAH's												
Naphthalene	<0.02	<0.02	<0.02	6	<0.02	0.200	0.057	10	<0.02	0.050	0.033	4
Acenaphthene	<0.02	<0.02	<0.02	6	<0.02	0.200	0.057	10	<0.02	0.080	0.048	4
Acenaphthylene	<0.02	<0.02	<0.02	6	<0.02	0.080	0.014	10	<0.02	0.030	0.008	4
Fluorene	<0.02	<0.02	<0.02	6	<0.02	0.530	0.081	10	0.030	0.080	0.065	4
Dibenzothiophene	<0.02	<0.02	<0.02	6	<0.02	0.590	0.061	10	<0.02	0.060	0.030	4
Phenanthrene	<0.02	<0.02	<0.02	6	0.020	1.700	0.244	10	0.110	0.220	0.168	4
Anthracene	<0.02	<0.02	<0.02	6	<0.02	<0.02	<0.02	10	<0.02	<0.02	<0.02	4
Fluoranthene	<0.02	<0.02	<0.02	6	<0.02	0.130	0.013	10	<0.02	0.030	0.013	4
Pyrene	<0.02	0.020	0.003	6	<0.02	0.440	0.047	10	<0.02	0.110	0.050	4
Benzo(a)anthracene/Chrysene	<0.02	<0.02	<0.02	6	<0.02	0.810	0.091	10	<0.02	0.110	0.038	4
Benzo(a)pyrene	<0.02	<0.02	<0.02	6	<0.02	0.110	0.011	10	<0.02	<0.02	<0.02	4
Benzo(b&k)fluoranthene	<0.02	<0.02	<0.02	6	<0.02	0.120	0.012	10	<0.02	<0.02	<0.02	4
Indeno(c,d-123)pyrene	<0.02	<0.02	<0.02	6	<0.02	0.040	0.004	10	<0.02	<0.02	<0.02	4
Dibenzo(a,h)anthracene	<0.02	<0.02	<0.02	6	<0.02	0.060	0.006	10	<0.02	<0.02	<0.02	4
Benzo(ghi)perylene	<0.02	<0.02	<0.02	6	<0.02	0.060	0.006	10	<0.02	<0.02	<0.02	4
Methyl naphthalene	<0.02	<0.02	<0.02	6	<0.02	1.100	0.153	10	<0.02	0.070	0.028	4
C2 sub'd naphthalene	<0.04	<0.04	<0.04	6	<0.04	2.000	0.319	10	<0.04	0.310	0.113	4
C3 sub'd naphthalene	<0.04	0.170	0.028	6	0.040	7.300	1.012	10	0.310	0.610	0.440	4
C4 sub'd naphthalene	<0.04	0.200	0.042	6	<0.04	6.800	0.852	10	0.100	0.480	0.280	4
Biphenyl	<0.04	<0.04	<0.04	6	<0.04	0.280	0.028	10	<0.04	<0.04	<0.04	4
Methyl biphenyl	<0.04	<0.04	<0.04	6	<0.04	0.220	0.027	10	<0.04	0.040	0.010	4
C2 sub'd biphenyl	<0.04	<0.04	<0.04	6	<0.04	1.800	0.212	10	<0.04	0.130	0.088	4
Methyl acenaphthene	<0.04	<0.04	<0.04	6	<0.04	1.800	0.233	10	<0.04	0.200	0.093	4
Methyl fluorene	<0.04	0.040	0.007	6	<0.04	1.800	0.248	10	0.060	0.200	0.128	4
C2 sub'd fluorene	<0.04	0.060	0.010	6	<0.04	3.500	0.452	10	0.090	0.410	0.203	4
Methyl phenanthrene/anthracene	<0.04	<0.04	<0.04	6	0.050	4.600	0.609	10	0.220	0.540	0.390	4
C2 sub'd phenanthrene/anth	<0.04	0.050	0.008	6	<0.04	6.500	0.815	10	0.150	1.100	0.620	4
C3 sub'd phenanthrene/anth	<0.04	0.0[illegible]	0.010	6	<0.04	5.900	0.724	10	0.110	0.940	0.583	4
C4 sub'd phenanthrene/anth	<0.04	<0.04	<0.04	6	<0.04	2.400	0.298	10	0.040	0.350	0.210	4
1-Methyl-7-isopropylphenanth	<0.04	<0.04	<0.04	6	<0.04	<0.04	<0.04	5	<0.04	<0.04	<0.04	4
Methyl dibenzothiophene	<0.04	<0.04	<0.04	6	<0.04	3.900	0.491	10	0.120	0.370	0.273	4
C2 sub'd dibenzothiophene	<0.04	0.040	0.007	6	<0.04	7.900	0.944	10	0.150	0.870	0.510	4
C3 sub'd dibenzothiophene	<0.04	0.060	0.010	6	<0.04	6.600	0.809	10	0.190	1.000	0.533	4
C4 sub'd dibenzothiophene	<0.04	<0.04	<0.04	6	<0.04	5.300	0.602	10	<0.04	0.740	0.335	4
Methyl fluoranthene/pyrene	<0.04	<0.04	<0.04	6	<0.04	1.300	0.158	10	<0.04	0.280	0.133	4
Methyl B(a)A/chrysene	<0.04	<0.04	<0.04	6	<0.04	1.600	0.179	10	<0.04	0.170	0.055	4
C2 sub'd B(a)A/chrysene	<0.04	<0.04	<0.04	6	<0.04	2.600	0.290	10	<0.04	0.250	0.078	4
Methyl B(b&k)F/B(a)P	<0.04	<0.04	<0.04	6	<0.04	0.610	0.061	10	<0.04	0.090	0.023	4
C2 sub'd B(b&k)F/B(a)P	<0.04	<0.04	<0.04	6	<0.04	0.280	0.028	10	<0.04	<0.04	<0.04	4
Phenolic Compounds in Water												
Phenol	<0.1	<0.1	<0.1	6	<0.1	1.100	0.140	10	<0.1	<0.1	<0.1	4
m-Cresol	<0.1	<0.1	<0.1	6	<0.1	0.300	0.030	10	<0.1	<0.1	<0.1	4
o-Cresol	<0.1	<0.1	<0.1	6	<0.1	0.200	0.030	10	<0.1	0.100	0.050	4
p-Cresol	<0.1	<0.1	<0.1	6	<0.1	5.300	0.640	10	<0.1	15.000	3.900	4
2,4-Dimethylphenol	<0.1	<0.1	<0.1	6	<0.1	<0.1	<0.1	10	<0.1	0.200	0.075	4
2,4-Dinitrophenol	<2	<2	<2	6	<20	<20	<20	10	<2	<2	<2	4
2-Nitrophenol	<2	<2	<2	6	<2	<2	<2	10	<2	<2	<2	4
4,6-Dinitro-2-methylphenol	<2	<2	<2	6	<20	<20	<20	10	<2	<2	<2	4
4-Nitrophenol	<2	<2	<2	6	<20	<20	<20	10	<2	<2	<2	4
PANH and Alkylated PANH's												
Quinoline	<0.02	<0.02	<0.02	6	<0.02	<0.02	<0.02	10	<0.02	<0.02	<0.02	4
7-Methyl quinoline	<0.02	<0.02	<0.02	6	<0.02	4.000	0.402	10	<0.02	<0.02	<0.02	4
C2 Alkyl subst'd quinolines	<0.02	<0.02	<0.02	6	<0.02	0.320	0.037	10	<0.02	<0.02	<0.02	4
C3 Alkyl subst'd quinolines	<0.02	<0.02	<0.02	6	<0.02	<0.02	<0.02	10	<0.02	<0.02	<0.02	4
Acridine	<0.02	<0.02	<0.02	6	<0.02	<0.02	<0.02	10	<0.02	<0.02	<0.02	4

Table 12 Concentrations of Organic Compounds in Groundwater in the LSA (µg/L) (Continued)

	Surficial Sand				Basal Aquifer				Upper Devonian			
Parameter	**Minimum**	**Maximum**	**Mean**	**Count**	**Minimum**	**Maximum**	**Mean**	**Count**	**Minimum**	**Maximum**	**Mean**	**Count**
Methyl acridine	<0.02	<0.02	<0.02	6	<0.02	<0.02	<0.02	10	<0.02	<0.02	<0.02	4
Phenanthridine	<0.02	<0.02	<0.02	6	<0.02	0.040	0.004	10	<0.02	<0.02	<0.02	4
Carbazole	<0.02	<0.02	<0.02	6	<0.02	<0.02	<0.02	10	<0.02	<0.02	<0.02	4
Methyl carbazoles	<0.02	<0.02	<0.02	6	<0.02	<0.02	<0.02	10	<0.02	<0.02	<0.02	4
C2 Alkyl subst'd carbazoles	<0.02	<0.02	<0.02	6	<0.02	0.030	0.003	10	<0.02	<0.02	<0.02	4
Volatile Organics (MS):Water												
1,1,1-Trichloroethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,1,2,2-Tetrachloroethane	<5	<5	<5	6	<5	<5	<5	10	<5	<5	<5	5
1,1,2-Trichloroethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,1-Dichloroethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,1-Dichloroethene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,2,3-Trichloropropane	<2	<2	<2	6	<2	<2	<2	10	<2	<2	<2	5
1,2-Dichlorobenzene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,2-Dichloroethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,2-Dichloropropane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,3-Dichlorobenzene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
1,4-Dichlorobenzene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
2-Butanone (MEK)	<100	<100	<100	6	<100	<100	<100	10	<100	<100	<100	5
2-Chloroethylvinylether	<5	<5	<5	6	<5	<5	<5	10	<5	<5	<5	5
2-Hexanone	<200	<200	<200	6	<200	<200	<200	10	<200	<200	<200	5
4-Methyl-2-pentanone (MIBK)	<200	<200	<200	6	<200	<200	<200	10	<200	<200	<200	5
Acetone	<100	<100	<100	6	<100	<100	<100	10	<100	<100	<100	5
Acrolein	<100	<100	<100	6	<100	<100	<100	10	<100	<100	<100	5
Acrylonitrile	<100	<100	<100	6	<100	<100	<100	10	<100	<100	<100	5
Benzene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Bromodichloromethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Bromoform	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Bromomethane	<10	<10	<10	6	<10	<10	<10	10	<10	<10	<10	5
Carbon disulfide	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Carbon tetrachloride	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Chlorobenzene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Chloroethane	<10	<10	<10	6	<10	<10	<10	10	<10	<10	<10	5
Chloroform	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Chloromethane	<10	<10	<10	6	<10	<10	<10	10	<10	<10	<10	5
cis-1,3-Dichloropropene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
cis-1,4-Dichloro-2-butene	<2	<2	<2	6	<2	<2	<2	10	<2	<2	<2	5
Dibromochloromethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Dibromomethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Dichlorodifluoromethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Ethanol	<100	<100	<100	6	<100	<100	<100	10	<100	<100	<100	5
Ethyl methacrylate	<200	<200	<200	6	<200	<200	<200	10	<200	<200	<200	5
Ethylbenzene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Ethylene dibromide	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Iodomethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
m+p-Xylenes	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Methylene chloride	<1	<1	<1	6	<1	3.000	0.300	10	<1	<1	<1	5
o-Xylene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Styrene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Tetrachloroethylene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Toluene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
trans-1,2-Dichloroethene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
trans-1,3-Dichloropropene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
trans-1,4-Dichloro-2-butene	<5	<5	<5	6	<5	<5	<5	10	<5	<5	<5	5
Trichloroethene	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Trichlorofluoromethane	<1	<1	<1	6	<1	<1	<1	10	<1	<1	<1	5
Vinyl acetate	<100	<100	<100	6	<100	<100	<100	10	<100	<100	<100	5
Vinyl chloride	<20	<20	<20	6	<20	<20	<20	10	<20	<20	<20	5
Hydrocarbons, Recoverable (mg/l)	<1	<1	<1	3	<1	5.000	2.700	3	<1	<1	<1	5

Table 13 Naphthenic Acid and Microtox Test Results in Groundwater from the LSA

WELL	DATE	Microtox IC50 15min %	Microtox IC50 5min %	Microtox IC40 15min %	Microtox IC30 15min %	Microtox IC20 15min %	Microtox IC20 5min %	Naph-thenic Acid
Surficial Sands								
FL1-BRDG-4	07/06/95	100		100	100	100		2
FL1-BRDG-4	09/13/95	100		100	100	100		1
FL1-BRDG-4	06/25/96	>100	>100			>100	>100	
FL1-BRDG-4	10/21/96							
FL7-BRDG-4	03/13/95							
FL7-BRDG-4	07/06/95	100		100	100	100		2
FL7-BRDG-4	09/13/95	100		100	100	100		1
L25-P96-OB-1	10/18/96	>100	>100			82	85	
L97-P95-OB-1	03/17/95							
L97-P95-OB-1	07/03/95	100		100	100	100		<4
L97-P95-OB-1	09/12/95	100		100	100	100		5
L97-P95-OB-2	03/17/95							
L97-P95-OB-2	06/29/95	100		100	100	100		6
L97-P95-OB-2	09/13/95	100		100	100	100		5
L97-P95-OB-2	06/24/96	>100	>100			82	82	
L97-P95-OB-2	10/18/96							
L97-P95-OB-3	03/17/95							
L97-P95-OB-3	07/04/95	100		100	100	100		<3
L97-P95-OB-3	09/12/95	100		100	100	100		4
L97-P95-OB-3	06/25/96	>100	>100			82	82	
L97-P95-OB-3	10/18/96							
L97-P95-OB-4	03/13/95							
L97-P95-OB-4	07/03/95	100		100	100	100		<3
L97-P95-OB-4	09/12/95	100		100	100	100		4
L97-P95-OB-4	10/18/96							
L97-P95-OB-5	03/13/95							
L97-P95-OB-5	07/05/95	100		100	100	100		6
L97-P95-OB-5	09/14/95	100		100	100	100		7
L97-P95-OB-5	06/25/96	>100	>100			75	82	
L97-P95-OB-5	10/19/96							
Basal Aquifer								
WELL	DATE	Microtox IC50 15min %	Microtox IC50 5min %	Microtox IC40 15min %	Microtox IC30 15min %	Microtox IC20 15min %	Microtox IC20 5min %	Naph-thenic Acid
FL1-P96-2-BA	6/27/96							
FL1-P96-2-BA	10/21/96	>100	>100			>100	>100	
FL1-P96-2-BA	7/2/97	>100	>100			>75	70	
FL1-P96-2-BA	10/21/97	>100	>100			>100	>100	
FL1-P95-13-BA	3/13/95							
FL1-P95-13-BA	7/5/95	100		100	100	100		13
FL1-P95-13-BA	7/5/95	100		100	100	100		12

Table 13 Napthenic Acid and Microtox Tests Results in Groundwater from the LSA Continued.

Basal Aquifer Continued								
WELL	DATE	Microtox IC50 15min %	Microtox IC50 5min %	Microtox IC40 15min %	Microtox IC30 15min %	Microtox IC20 15min %	Microtox IC20 5min %	Naph-thenic Acid
FL1-P95-13-BA	9/14/95	100		100	100	100		12
FL3-P95-6-BA	3/13/95							
FL3-P95-6-BA	7/10/95	100		100	100	100		8
FL3-P95-6-BA	9/15/95	100		100	100	100		9
FL3-P95-6-BA	6/25/96							
FL3-P95-6-BA	10/19/96							
FL3-P95-6-BA	7/3/97							
FL3-P95-6-BA	10/22/97							
L97-P95-1-BA	3/13/95							
L97-P95-1-BA	6/28/95	100		100	100	100		22
L97-P95-1-BA	9/12/95	100		100	100	100		21
L97-P95-1-BA	6/17/96							
L97-P95-1-BA	10/22/96							
L97-P95-1-BA	6/23/97							
L97-P95-1-BA	10/23/97							
L97-P95-3-BA	3/13/95							
L97-P95-3-BA	7/4/95	100		100	100	100		31
L97-P95-3-BA	9/13/95	100		100	100	71		29
L97-P95-3-BA	6/24/96							
L97-P95-3-BA	10/22/96							
L97-P95-3-BA	7/3/97							
L97-P95-3-BA	10/23/97							
L97-P95-8-BA	6/28/95	100		100	100	80		31
L97-P95-8-BA	9/13/95	100		100	91	34		36
L97-P95-8-BA	6/17/96							
L97-P95-8-BA	10/22/96							
L97-P95-8-BA	6/27/97							
L97-P95-8-BA	10/30/97							
Upper Devonian								
WELL	DATE	Microtox IC50 15min %	Microtox IC50 5min %	Microtox IC40 15min %	Microtox IC30 15min %	Microtox IC20 15min %	Microtox IC20 5min %	Naph-thenic Acid
FL1-P96-1-L	6/25/96	>100	>100			30	29	
FL1-P96-1-L	10/21/96	>100	>100			64	80	
FL1-P96-1-L	7/2/97	>100	>100			>100	>100	
FL1-P96-1-L	10/21/97	>100	>100			>100	>100	
L97-P95-2-L	3/13/95							
L97-P95-2-L	6/29/95	100		100	100	59		47
L97-P95-2-L	9/14/95	100		100	100	49		57
L97-P95-2-L	9/14/95	100		100	100	75		52
L97-P95-2-L	6/24/96							
L97-P95-2-L	10/18/96							
L97-P95-2-L	7/2/97							
L97-P95-2-L	10/22/97							

In general, the chemistry of surficial groundwater from the organic plain in the LSA is similar to the regional data presented in Table 6. As a preliminary assessment, it appears that the low TDS groundwater is associated with interaction with water from the peat. The high TDS groundwater in the surficial sand is probably more closely associated with flow from till and bedrock deposits.

6.1.2 Valley Slopes

Groundwater flow in the slope colluvium is expected to be in the direction of the slope. Localized groundwater discharge occurs along some breaks in slope, and where contrasts in hydraulic conductivity occur.

Evidence of groundwater discharge from the surficial deposits was apparent on both the left and right banks of the Steepbank River and on the right bank of Wood Creek. The slopes are locally unstable and three areas of slope failure were observed during a helicopter reconnaissance survey. These areas include:

- the left bank of the Steepbank River approximately 8.5 km upstream of the confluence with the Athabasca River;
- the left bank of the Steepbank River approximately 18 km upstream of the confluence with the Athabasca River; and
- the right bank of Wood Creek approximately 2.5 km upstream of the confluence with the Athabasca River.

In the three areas listed above, one or more of the following characteristics was observed:

- apparent retrogressive movement with multiple head scarps;
- water ponded behind the heard scarp of apparent rotational/translational movement.; and
- toppled trees.

The groundwater flowing through the colluvium is expected to originate mainly from the surficial deposits on the organic plain. The chemistry of the groundwater in the colluvium is therefore probably similar to the chemistry of water in the surficial deposits in the organic plain. In localized areas, seepage from the oilsands beneath the colluvium is likely to be occurring. Where there is seepage, the groundwater in the colluvium may be brackish, with high concentrations of sodium, chloride, and possibly some organic compounds.

6.1.3 Floodplain

6.1.3.1 Hydraulic Conductivity of Surficial Material in Floodplain

One piezometer was completed in the alluvium in the Athabasca River valley (FL1-BRDG-#4). Unfortunately, as the piezometer could not be adequately developed, tests were not conducted to determine hydraulic conductivity. The colluvium at the site consisted of 85% sand and 15% silt and clay . The hydraulic conductivity of the alluvium is therefore expected to be similar to values measured in sand at Suncor which range from 1.1×10^{-8} m/s to 1.0×10^{-3} m/s, with a mean of 1.1×10^{-5} m/s (Table 4).

The hydraulic conductivity of meltwater sediments in the floodplain has not been measured in the LSA. The expected hydraulic conductivity of sand and gravel at Suncor ranges from 7.0×10^{-6}m/s to 1.0×10^{-3}m/s, with a mean of 3.8×10^{-4}m/s.

6.1.3.2 Groundwater Flow in Surficial Material in the Floodplain

The direction of groundwater flow in the floodplain deposits is toward the Athabasca River, with a slight downstream component reflecting the influence of the gradient of the river. The surficial material is believed to be in hydraulic connection with the slope colluvium, the Basal Aquifer and the Upper Devonian.

6.1.3.3 Groundwater Chemistry in Surficial Material in the Floodplain

The groundwater from FL1-BRDG-#4 is representative of one type of water that will be found in the floodplain. Because the predominant direction of groundwater flow in all hydrogeologic units is toward the Athabasca River, the groundwater in the floodplain probably contains mixtures of freshwater from precipitation and surficial deposits, brackish water from bedrock discharge, and possibly river water from bank storage. The chemistry of groundwater in the floodplain is therefore expected to be quite variable, both spatially and temporally.

The major ion chemistry of groundwater samples collected from piezometer FL1-BRDG#4, screened in the sediments of the floodplain, is shown in Table 10. The water is very fresh, with TDS concentrations ranging from 81 to 96 mg/L. As shown in the Piper plot in Figure 32, the water from FL1-BRDG-#4 is very similar to the low TDS groundwater found in the organic plain. It is probably groundwater from peat and shallow sand deposits that is flowing from the organic plain, down through the colluvium toward the river.

Microtox toxicity testing indicates the groundwater is non toxic. Naphthenic acid values range from 1 to 2 mg/L, as shown in Table 13. The surficial groundwater isotopes from this well plot on the meteoric water line (Figure 33).

6.2 Bedrock Materials

6.2.1 Clearwater Formation

6.2.1.1 Hydraulic Conductivity of Clearwater Formation

The hydraulic conductivity of the Clearwater Formation has not been measured in the LSA. Hackbarth and Nastasa (1979) found that the hydraulic conductivity ranged from 1.0×10^{-9} m/s to 1.0×10^{-6} m/s, with a mean of 1.5×10^{-7} m/s as shown in Table 5. These values are slightly higher than would be expected for a massive shale deposit. They indicate that fractures and sandstone layers influence the hydraulic conductivity of the formation.

6.2.1.2 Groundwater Flow in Clearwater Formation

The primary direction of groundwater flow in the Clearwater Formation is expected to be downward in the LSA. The hydraulic head in the overlying surficial deposits is near ground surface level. The head in the Basal Aquifer is 30 m to 70 m below ground, as shown in the cross sections A to E (Figures 10 to 15). Therefore, the hydraulic gradient across the Clearwater is downward. Because the Clearwater Formation has relatively low hydraulic conductivity, the rate of flow through the shale is low.

6.2.1.3 Chemistry of Groundwater in Clearwater Formation

No groundwater samples have been collected from the Clearwater Formation in the LSA. The regional data in Table 7 indicates that the groundwater in the Clearwater Formation is slightly brackish, with sodium and bicarbonate being the major ions.

6.2.2 McMurray Oil Sands

6.2.2.1 Hydraulic Conductivity of Oilsands

The oilsands has also not been tested for hydraulic conductivity in the LSA. As shown in Table 5, the hydraulic conductivity of oilsands in the region has been found to range between 3.5 x^{-9} m/s and 3.2 x 10^{-7} m/s. Hydraulic conductivity in the order of 1.5 x 10^{-7} m/s is expected to be representative of oil sands in the LSA.

6.2.2.2 Groundwater Flow in McMurray Oil Sands

The direction and rate of groundwater flow in the oilsands is similar to flow in the Clearwater Formation The hydraulic gradient is predominantly downward in the LSA. The rate of flow in the oilsands is low, because of the relatively low hydraulic conductivity of the unit.

Where the oil sands is exposed in the river valleys, some groundwater may seep out of the slope face from zones of lower oil saturation. The amount of water flowing through these zones is expected to be small.

6.2.2.3 Chemistry of Groundwater in McMurray Oil Sands

No groundwater samples have been collected from the oilsands in the LSA. The regional groundwater chemistry data in Table 7 indicates that the groundwater in the oilsands varies widely from fresh to saline. Sodium, chloride and bicarbonate are the major ions in groundwater. Organic compounds are also found in groundwater from the oilsands.

6.2.3 Basal Aquifer

6.2.3.1 Hydraulic Conductivity of the Basal Aquifer

Four piezometers in the Basal Aquifer in the LSA were subjected to short term pumping tests. Table 14 shows the transmissivity calculated from the response in the piezometers. The transmissivity ranged from 0.07 m^2/day to 11.2 m^2/day, with a mean of 2.0 m^2/day. The hydraulic conductivity range from 8.6 x 10^{-8} m/s to 2.6 x 10^{-5} m/s, with a mean of 4.1 x 10^{-6} m/s. These values are approximately an order of magnitude less than what was found in the Alsands area (Table 5). This indicates that the Basal Aquifer in the LSA may not be quite as productive as in the Alsands area.

Table 14 Summary of Transmissivity and Hydraulic Conductivity Measured in Bedrock in the LSA

Piezometer/Well Number	Location	Date	Thickness (m)	Flow (Q) (m^3/day)	Transmissivity (T) (m^2/day)	Hydraulic Conductivity (m/s)
L97-P95-1-BA	7-20-92-9W4	1995/03	5.8	6	11.2	2.2×10^{-5}
L97-P95-3-BA	6-20-92-9W4	1995/03	3.6	5	1.8	5.8×10^{-6}
FL3-P95-6-BA	12-9-92-9W4	1995/03	9.8	3	0.07	8.6×10^{-8}
FL1-P95-13-BA	13-28-92-9W4	1995/03	5.0	11	11.2	2.6×10^{-5}
			Geometric Mean		2.0	4.1×10^{-6}
Waterways Fm.						
L97-P-95-2-L	15-17-92-9W4	1995/03	4.5	6	2.2	5.8×10^{-6}

6.2.3.2 Groundwater Flow in the Basal Aquifer

The predominant direction of groundwater flow in the Basal Aquifer is west, toward the Athabasca River. The head in the aquifer is 306 mASL in piezometer FL1-P95-13-BA. Closer to the Athabasca River, the head approaches the level of the river. Farther to the east, the head in the aquifer is expected to approach ground level, as has been found at Alsands. Pneumatic piezometers were installed in three locations in the bedrock during the 1998 drilling program to bring the total number of piezometers to 25. The newly installed pneumatic piezometers include L25-AP98-1A, L25-AP98-2A/2B, and LA25-AP98-3A/3B (Figure 31). At the time of writing, geologic information other than the borehole geophysical logs was not available. Therefore, there remains some uncertainty with respect to the presence of Basal Aquifer at these locations. Water levels were calculated from pressure readings taken on February 25. It is unknown whether these readings represent equilibrium conditions. The geology information must be compiled and additional pressure readings recorded and interpreted before these piezometer locations may be incorporated into the overall hydraulic head interpretation of the Basal Aquifer.

A horizontal component of flow in the Basal Aquifer is also expected to be directed toward the Steepbank River. This flow occurs in places where the Steepbank River has incised below the bottom of the oil sands. In places where the Upper Devonian surface is high, and the Basal Aquifer is absent, groundwater may flow from the Basal Aquifer through the Devonian. Therefore, at the west end of the Steepbank River, which has cut into the limestone, groundwater may flow from the Basal Aquifer, through the limestone, and discharge into the river. This interpretation is supported by the fact that both the Basal Aquifer and Upper Devonian have similar hydraulic conductivities and heads in this area. The groundwater flow map presented in Figure 31 shows the direction of flow in the Basal Aquifer and Upper Devonian.

6.2.3.3 Chemistry of Groundwater in the Basal Aquifer

Groundwater from six piezometers (L97-P95-1-BA, L97-P95-3-BA, FL3-P95-6-BA, FL1-P96-2-BA, L97-P95-8-BA and FL3-P95-13-BA) was collected between 1995 and 1997. No standpipe piezometers were installed in this unit in 1998. The data in Table 10 shows groundwater in the Basal Aquifer is brackish to saline. The major ions are sodium, potassium, chloride and bicarbondate. The TDS concentrations in the groundwater ranged from 2620 mg/L to 29 789 mg/L, with a mean of 11 686 mg/L. This is slightly higher than the range of concentrations found in the Basal Aquifer in the Alsands area (Table 7). In general, the water quality in the aquifer in the LSA is very similar to the regional water quality in the Basal Aquifer.

Organic compounds, including PAH, alkylated PAH's, PANH and alkylated PANH's, were detected in groundwater from the Basal Aquifer as shown in Table 12. Naphthenic acid values range from 8 to 36 mg/L with a mean of 20 mg/L (Table 13). Microtox toxicity testing indicates the groundwater is non-toxic. Basal Aquifer groundwater isotopes plot on the meteoric water line, (Figure 33) indicating the water is meteoric.

6.2.4 Upper Devonian

6.2.4.1 Hydraulic Conductivity of the Upper Devonian

Piezometer L97-P95-2-L was subjected to a short pumping test. The transmissivity of the Upper Devonian limestone calculated from the test results was 2.2 m^2/day, as shown in Table 14. In terms of hydraulic conductivity, this equates to 5.8×10^{-6} m/s. This is within the range of values found for the Upper Devonian elsewhere in the region (Table 5). It is also the same order of magnitude as the hydraulic conductivity of the Basal Aquifer.

6.2.4.2 Groundwater Flow in the Upper Devonian

As has been discussed in Section 6.3.2 groundwater flow in the Basal Aquifer and Upper Devonian may be interconnected. Because the two units may have similar hydraulic conductivity, there is no hydraulic barrier to impede flow between them. Furthermore, as observed in the cross sections, the Upper Devonian surface protrudes above the top of the Basal Aquifer in many locations. Therefore, water flowing horizontally through the Basal Aquifer may flow through the highs in the Upper Devonian surface and back into the Basal Aquifer. This interpretation is consistent with observations made by Hackbarth and Nastasa (1979).

As in the Basal Aquifer, the primary direction of groundwater flow in the Upper Devonian is toward the Athabasca River. There is also a component of groundwater flow toward the lower reach of the Steepbank River, where the river is incised below the bottom of the oil sands. The direction of horizontal flow in the Upper Devonian and Basal Aquifer is illustrated in the groundwater flow map in Figure 31.

Vertical hydraulic gradients, both upward and downward, are also present in the Upper Devonian strata. These gradients were measured in pairs of nested pneumatic piezometers (L97-AP95-4A,B-L, L97-AP95-5A,B-L, L97-AP95-7A,B-L, L97-AP95-9A,B-L, and L97-AP95-14A,B-L). The locations of the piezometers are shown in Figure 31. The pattern of vertical gradients in the Upper Devonian strata is not yet understood.

6.2.4.3 Chemistry of Groundwater in the Upper Devonian

Groundwater samples from the Upper Devonian limestone were collected from piezometer L97-P95-2-L and FL1-P96-1L in June and October 1997. The major ion chemistry of the water is shown in Table 10. The groundwater from the limestone is fresh to brackish, with TDS concentrations ranging from 637 to 5201 mg/L. This is within the range of concentrations from in the Upper Devonian at Alsands and Suncor, but lower than the mean regional level of 11 807 mg/L (Table 7). The major ions in the groundwater are sodium, chloride and bicarbonate, which is also consistent with what has been found elsewhere in the region.

Organic compounds, including PAH, alkylated PAH's and phenolic compounds, were detected in groundwater from the Upper Devonian limestone (Table 12). Naphthenic acid values range from 47 to 57 mg/L, with a mean of 52 mg/L (Table 13). Microtox toxicity testing indicates the groundwater is non-toxic. Upper Devonian groundwater isotopes plot on the meteoric water line, indicating the groundwater is meteoric (Figure 33).

6.3 Potential for Groundwater Use as a Resource

Currently, there are no groundwater users in the LSA aside from Suncor. There are no water wells within 10 km of the LSA on the east side of the Athabasca River or south of the Steepbank River.

The potential for groundwater to be used in the area as a resource is dependent upon the productivity of the aquifers, and the natural quality of the groundwater. The productivity of the aquifers has been assessed on the basis of long term yield. In Alberta, this is commonly quantified by calculating the 20-year yield, or Q_{20} (Alberta Environment 1983). The Q_{20} is an estimate of the maximum rate at which water can be withdrawn from a well for 20 years that will not lower the water level in the well below the top of the aquifer. It is calculated using the following equation:

$$Q_{20} = 0.683\ T\ H\ F$$

where,

T = transmissivity of the aquifer, m2/day
H = available drawdown in the aquifer, m
F = a factor of safety, in this case assumed to be 0.7.

The recommended minimum Q_{20} for a single dwelling in Alberta is 1 m^3/day (Alberta Environment 1983).

The water quality of the aquifers has been assessed on the basis of a comparison with CCME (1991) criteria (Table 15). The water quality of the aquifers has also been assessed based on the concentrations of naturally occurring organic compounds (Table 12).

The sand aquifer in the organic plain, and the sand and gravel in the Athabasca River valley are the two potential sources of groundwater from surficial deposits.

Table 15 Groundwater Quality Parameters Which Exceed CCME Guidelines

	Sodium (mg/L)	Chloride (mg/L)	TDS (mg/L)	Iron (mg/L)	Mercury (mg/L)	Manganese (mg/L)
Median Concentration Found in Groundwater at Steepbank Mine						
Surficial Aquifer	8.8	4.2	150	0.04	<0.05	0.064
Basal Aquifer	3200	4090	8546	0.26	<0.05	0.194
Limestone	1855	1613	4700	0.38	0.025	0.082
CCME Guidelines						
Drinking Water	200	250	500	0.3	1	-
Irrigation	-	-	500-3500	5	-	0.01-0.05
Watering Livestock	-	100-700	3000	-	-	0.5

In the organic plain, the water quality in the sand aquifer is good, as discussed in Section 5.1.

The mean hydraulic conductivity of the surficial sand and gravel is 3.1 x 10^{-6} m/s (Table 8). This hydraulic conductivity may range to as high as two orders of magnitude higher in the southwest part of the LSA where gravel and cobbles have been observed in the subsurface. The aquifer ranges in thickness from less than 1 m to 36 m. Based on the isopach map of surficial sand and gravel, the average thickness over the mapping domain is 2 m, and locally this average is about 5 m. The available drawdown, which is the difference between the elevations of the potentiometric surface and the top of the aquifer, is approximately 2 m. This is based on a potentiometric surface near ground surface and the overlying material consisting of about 2 m of peat and/or till. The range of parameters discussed above, were used to calculate an expected range in the Q_{20} for the surficial sand and gravel (Table 16). The results indicate the surficial sand and gravel locally constitutes a resource suitable for a domestic supply.

Table 16 Potential for Groundwater Use as a Resource

K (m/sec)	K (m/day)	b (m)	T (m^2/day)	H (m)	f	Q_{20} (m^3/day)
3.10×10^{-06}	2.68×10^{-1}	2	0.54	2	0.683	0.73
3.10×10^{-06}	2.68×10^{-1}	5	1.34	2	0.683	1.83
3.10×10^{-04}	2.68×10^{1}	2	53.57	2	0.683	73.17
3.10×10^{-04}	2.68×10^{1}	5	133.92	2	0.683	182.93

In the Athabasca River valley, the surficial sand and gravel aquifer is expected to be more productive. As has been discussed in Section 5.1, the hydraulic conductivity of the aquifer is expected to be in the order of 3.8×10^{-4} m/s (Table 4). Although the areal extent of the aquifer is limited to the valley, it is hydraulically connected to the river. Therefore, wells can probably be constructed in the aquifer that will induce water from the Athabasca River. The long-term yield from this aquifer is expected to be greater than 780 m^3/day.

In the bedrock aquifers (the Basal Aquifer and Upper Devonian limestone), the estimated transmissivity is 2 m^2/day, and the available drawdown is approximately 40 m. Therefore, the Q_{20} for the bedrock aquifers is approximately 40 m^3/day, which would be adequate for many water supply purposes. The measured groundwater concentrations of sodium, chloride, mercury, iron, manganese, and total dissolved solids exceed CCME criteria (Table 15). Furthermore, as shown in Tables 12 and 13, the bedrock groundwater contains naturally-occurring organic compounds. The groundwater is therefore not considered suitable as a source for drinking water or agricultural use without treatment, but could be used for industrial water supply.

6.4 Groundwater/Surface Water Interaction

This section discusses the rate of groundwater discharge to the surface water bodies in the LSA: the Athabasca River, the Steepbank River, Shipyard Lake, and the small creeks that drain the LSA; Leggett Creek, Wood Creek, McLean Creek and an unnamed creek (Figure 6).

6.4.1 Methodology

The groundwater discharge to the surface water was estimated for flow from surficial deposits and bedrock. Flow from peat is presented in the hydrology component of the EIA.

The discharge of groundwater has been estimated using the following equations, which are adaptations of Darcy's Law:

from surficial aquifers;

$$Q = K\,b\,i\,L$$

from bedrock aquifers

$$Q = T\,i\,L$$

where;

Q= the rate of discharge into the river
K= the hydraulic conductivity of the aquifer, m/s
b = the thickness of the aquifer, m
T = the transmissivity of the aquifer, m^2/day
I = the hydraulic gradient in the aquifer, m/m

L = the length of reach over which the aquifer is exposed to the surface water body, m.

Sandy material is present within the surficial deposits over most of the organic plain in the LSA. Because the hydraulic conductivity of the sand is much higher than that of any other surficial deposits, the sand is the only surficial deposit for which groundwater discharge has been calculated. The mean hydraulic conductivity of the sand is 3.1×10^{-6} m/s (Table 8). The baseline discharge estimates were completed using a mean hydraulic conductivity of 3.7×10^{-6} m/s for all basins north of and including the Wood Creek Basin. It was believed that this value is more representative of the conditions on site. In the area of the McLean Creek Basin a value of 3.7×10^{-4} m/s was used based on the presence of gravel and cobbles. There is not enough water level information from the surficial aquifer to accurately determine the hydraulic gradient. It has therefore been assumed that the hydraulic gradient in the surficial aquifer in the organic plain is equal to the gradient of the land surface.

The surficial sand and gravel is confined by peat and till over most of the organic plain. The sand and gravel is exposed to surface where it has been incised by the creek and river valleys. The length of reach over which the aquifer is exposed was estimated by comparing the sand and gravel isopach map (Figure 18) to the ground topography (Figure 6).

In the bedrock, the two main aquifers are the Basal Aquifer and the limestone in the Upper Devonian strata. The formations that are above these deposits (McMurray Oil Sands and Clearwater shale) are several orders of magnitude less permeable to water than these aquifers. The mean transmissivity of the Basal Aquifer is 2.0 m^2/day (Table 14). The transmissivity of the limestone has been estimated at 2.2 m^2/day. The Basal Aquifer is present under about one half of the area that will actually be excavated to mine the ore. The limestone is present over the entire site. As the transmissivities of the two units appear to be so similar, and the Basal Aquifer is discontinuous, groundwater discharge from bedrock has been calculated using a transmissivity of 2.0 m^2/day.

The estimated rates of groundwater discharge from the surficial and bedrock aquifers to surface water are shown in Tables 17 and 18 respectively along with the parameters used to determine the rates. A summary of these results is presented in Table 19. Results are reported in terms of the discharge to each surface water basin outflow point identified in the hydrology baseline report (Klohn-Crippen 1998). Surface water basins are shown on Figure 6. The discharge to each surface water body is discussed below.

Table 17 Average Conditions Surficial Aquifers

Drainage	Length (m)	Thickness (m)	Gradient	Hydraulic Conductivity (m/sec)	Q (m^3/sec)	Q (L/sec)
Steepbank River	35000	3	0.002	3.70×10^{-6}	7.8×10^{-4}	0.78
Basin A	4690	2	0.01	3.70×10^{-6}	3.5×10^{-4}	0.35
Shipyard Creek	4410	0.5	0.01	3.70×10^{-6}	8.2×10^{-5}	0.08
Shipyard Lake	3150	0.5	0.01	3.70×10^{-6}	5.8×10^{-5}	0.06
Leggett Creek	1400	2	0.002	3.70×10^{-6}	2.1×10^{-5}	0.02
Basin B	1050	2	0	3.70×10^{-6}	0.0×10^{0}	0.00
Wood Creek	5600	2	0.002	3.70×10^{-6}	8.3×10^{-5}	0.08
Basin C	1680	6	0	3.70×10^{-4}	0.0×10^{0}	0.00
McLean Creek	4200	6	0.002	3.70×10^{-4}	1.9×10^{-2}	18.65
Basin D	700	3	0	3.70×10^{-4}	0.0×10^{0}	0.00
Totals					2.0×10^{-2}	20.02

Table 18 Average Conditions Bedrock Aquifers

Drainage	Length (m)	Thickness (m)	Gradient	Hydraulic Conductivity (m/sec)	Q (m3/sec)	Q (L/sec)
Steepbank River	5000	5	0.008	4.10×10^{-6}	8.2×10^{-4}	0.82
Basin A	4550	26	0.008	4.10×10^{-6}	3.9×10^{-3}	3.88
Shipyard Creek	4410	26	0.008	4.10×10^{-6}	3.8×10^{-3}	3.76
Shipyard Lake	3220	26	0.008	4.10×10^{-6}	2.7×10^{-3}	2.75
Leggett Creek	210	26	0.008	4.10×10^{-6}	1.8×10^{-4}	0.18
Basin B	1820	26	0.008	4.10×10^{-6}	1.6×10^{-3}	1.55
Wood Creek	210	26	0.008	4.10×10^{-6}	1.8×10^{-4}	0.18
Basin C	2310	26	0.008	4.10×10^{-6}	2.0×10^{-3}	1.97
McLean Creek	210	26	0.008	4.10×10^{-6}	1.8×10^{-4}	0.18
Basin D	1260	26	0.008	4.10×10^{-6}	1.1×10^{-3}	1.07
Totals					1.6×10^{-2}	16.34

Table 19 Summary of Flows to Surface Water

Length of Reach (m)	Steepbank River	Shipyard Creek	Leggett Creek	Wood Creek	McLean Creek	Athabasca River
	35000	4410	1400	5600	4200	8120
	(L/sec)	(L/sec)	(L/sec)	(L/sec)	(L/sec)	(L/sec)
Surficial sand and gravel	0.8	0.1	0.0	0.1	18.6	0.3
Bedrock	0.8	3.8	0.2	0.2	0.2	8.5
Total	1.6	3.8	0.2	0.3	18.8	8.8

6.4.2 Athabasca River

The length of reach of the Athabasca River in the LSA that will be adjacent to the mine area is approximately 8 km. This length includes Basin A through Basin D summarized in Tables 17 and 18. This is the length over which groundwater will discharge directly to the Athabasca River.

The gradient of the groundwater surface in the organic plain ranges from .01 in the northwest to .002 in the southeast. Therefore, as explained above, the hydraulic gradient of the surficial aquifer is estimated to range between .01 and .002 in the LSA.

Creek valley capture zones were estimated using trench de-watering equations.

The de-watering equation for flow from an unconfined aquifer to one side of a dewatering ditch of unit length is given by the following equation described by Driscoll (1989).

$$\frac{Q}{x} = \frac{K(H^2 - h^2)}{2Lo}$$

where:

K	=	Hydraulic Conductivity (m/day)
H	=	Saturated thickness before pumping (m)
h	=	Depth of water in well (ditch) while pumping (m)
Lo	=	Distance from point of greatest drawdown to point of no drawdown (m)
x	=	Unit length; the length of the trench (m) across the width of the basin
Q	=	Discharge rate (m^3/day), the muskeg discharge across the width of the basin

The trench de-watering equation for the unconfined case (Driscoll, 1989) was used for a range of thicknesses and assuming an average hydraulic conductivity as follows:

Table 20 Estimates of the Groundwater Capture Zones of Small Creeks; Unconfined Conditions

Creek	K (m/sec)	H (m)	h (m)	Q (m^3/sec)	x (m)	Lo/x (m)	Lo (m)
Leggett	3.1×10^{-6}	2	0.1	1.74×10^{-5}	1400	0.36	500
Wood	3.1×10^{-6}	2	0.1	3.47×10^{-5}	2800	0.18	500
McLean	3.7×10^{-4}	6	0.1	9.32×10^{-3}	2100	0.71	1500

The discharge (Q) in the previous calculations is the baseline discharge determined through application of Darcy's Law.

For a confined aquifer :

$$\frac{Q}{x} = \frac{K\,b\,(H - h)}{Lo}$$

where:

b = Aquifer thickness (m)

Table 21 Estimates of the Groundwater Capture Zones of Small Creeks; Confined Conditions

Creek	K (m/sec)	b (m)	H (m)	h (m)	Q (m^3/sec)	x (m)	Lo/x (m)	Lo (m)
Leggett	3.1×10^{-6}	2	2	0.1	1.74×10^{-5}	1400	0.68	950
Wood	3.1×10^{-6}	2	2	0.1	3.47×10^{-5}	2800	0.34	950
McLean	3.7×10^{-4}	6	6	0.1	9.32×10^{-3}	2100	1.40	2950

The confined aquifer is more consistent with the terrestrial mapping that has been completed to date at the site, and the vertical hydraulic gradients that have been measured at locations instrumented with standpipe piezometers.

Based on the results of the analysis presented above, the zones of capture of the surficial groundwater due to discharge to the Leggett and Wood Creek incised valleys are each about 950 m. Similarly the zone of capture due to discharge to the McLean Creek incised valley is about 2950 m. The distance between the Leggett Creek valley and the Wood Creek valley at the Athabasca River valley escarpment is about 2100 m. Therefore, the combined capture zones of the two valleys (1900 m) is expected to capture all of the water and prevent any discharge directly to Basin C. The gradient for the surficial aquifer discharge to Basin C has therefore been set to zero in Table 17. Similarly, the discharge to Basin B is also zero. Likewise, the distance between Wood Creek and McLean Creek is about 1050 m. The zones of capture of these two valleys capture all surficial groundwater preventing any groundwater from discharging directly to Basin D.

The total surficial aquifer discharge to the Athabasca River is 0.3 L/s (26 m^3/day) and occurs entirely within Basin A under baseline conditions.

6.4.3 Steepbank River

The length of the reach of the Steepbank River that will be adjacent to the proposed mine area is approximately 35 km. The slope of the ground surface, and therefore the hydraulic gradient in the surficial aquifer, is approximately 0.002. Therefore, the rate of groundwater discharge from the surficial aquifer to the Steepbank River is 0.78 L/s (67 m^3/day).

The hydraulic gradient toward the Steepbank River from the bedrock aquifers is about 0.008 over a length of about 5 km. Therefore, the groundwater discharge from the bedrock aquifers to the Steepbank River is 0.82 L/s (70 m^3/day).

6.4.4 Shipyard Lake/Shipyard Creek

The groundwater discharge from the LSA to Shipyard Lake can be estimated in the same manner as was done for discharge to the Athabasca River. The only change between the two calculations is the length of wetland over which the discharge occurs. Shipyard Lake is approximately 3 km long. Therefore, the rate of groundwater discharge into the wetland from the surficial aquifer is 0.06 L/s (5.2 m^3/day). The rate of groundwater discharge into the wetlands from the bedrock aquifers is 2.75 L/s (237.6 m^3/day). It is possible that some of the groundwater flowing in the bedrock aquifers may pass under Shipyard Lake, and discharge into the Athabasca River.

The Shipyard Lake catchment is actually a subcatchment within the overall Shipyard Creek catchment. The total discharge for Shipyard Creek is 0.08 L/s (6.9 m^3/day) for the surficial aquifer and 3.76 L/s (234.9 m^3/day) for the bedrock.

6.4.5 Leggett Creek

The length of reach of Leggett Creek that incises into the surficial aquifer is approximately 1400 m. Using a gradient of 0.002 the rate of groundwater discharge from the surficial aquifer to this valley is 0.02 L/s (1.7 m^3/d).

The hydraulic gradient toward the Leggett Creek valley from the bedrock aquifer is about 0.008. Therefore, the groundwater discharge from the bedrock is about 0.18 L/s (15.6 m^3/day).

6.4.6 Wood Creek

The length of reach of Wood Creek that incises into the surficial aquifer is approximately 5600 m. Using a gradient of 0.002 the rate of groundwater discharge from the surficial aquifer to this valley is 0.08 L/s (6.9 m^3/d).

Likewise, the groundwater discharge from the bedrock is about 0.18 L/s (15.6 m^3/d).

6.4.7 McLean Creek

The length of reach of McLean Creek that incises into the surficial aquifer is approximately 4200 m. Using a gradient of 0.002 the rate of groundwater discharge from the surficial aquifer to this valley is 18.65 L/s (1611 m^3/d).

Likewise, the groundwater discharge from the bedrock is about 0.18 L/s (15.6 m^3/d).

6.4.8 Summary of Groundwater/Surface Water Interaction

The rates of groundwater discharge from the surficial and bedrock aquifers in the LSA to surface waters are small in comparison with the minimum monthly flows in the Athabasca River and the Steepbank River. As shown in Table 16, the total rate of groundwater discharge to all surface water bodies in the LSA is estimated to be 33.5 L/s. The rates of groundwater discharge to the Athabasca River, the Steepbank River, and Shipyard Creek are 8.8 L/s, 1.6 L/s and 3.8 L/s, respectively.

These values are compared with the minimum monthly flows in the Steepbank River and the Athabasca River in Table 20. As Table 20 shows, the total groundwater discharge to the Athabasca River and Steepbank River comprises less than 1% of the average flow in these rivers.

Table 22 - Minimum Monthly Flows

Length of Reach (m) Snapshot	Steepbank River (L/sec)	Shipyard Creek (L/sec)	Leggett Creek (L/sec)	Wood Creek (L/sec)	McLean Creek (L/sec)	Athabasca River (L/sec)	Total Excluding Steepbank River
Total Groundwater Discharge in the LSA	1.60	3.84	0.20	0.26	18.83	8.82	31.96
Total Surface Water Discharge in the LSA	-	190	66	197	130	71	654
Groundwater as a Percentage of Surface Water Discharge in the LSA	-	2%	0.3%	0.13%	14.48%	12.42%	4.89%
Minimum Monthly Flows	168	-	-	-	-	101000	-
Groundwater as a Percentage of Minimum Monthly Flows	0.95%	-	-	-	-	0.01%	-

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7. CONCLUSIONS

7.1 Geology

The geology of the surficial deposits is characterized in three physiographic settings; organic plain, valley slopes and floodplain. The stratigraphy of surficial deposits in the organic plain is, from top to bottom:

- Peat
- Stratified Sediments
- Till
- Deep Undifferentiated Till and Stratified Sediments
- Bedrock

Most of the organic plain is covered with peat, which is 0.8 m to 1.5 m thick. The underlying stratified sediments form a discontinuous layer of sand over the LSA. The sand appears to be glaciolacustrine or glaciofluvial in origin. The sand ranges in thickness from less than 1 m to 36 m. These deposits are elongated in a northwest to southeast direction, similar to the Mildred Lake Aquifer deposit. Beneath the stratified sediments, till rests on bedrock over nearly the entire organic plain. The till ranges from being sandy, where it rests on sandstone, to very clayey, where it is in contact with shale. From its lithology, the till appears to be the Firebag till described by McPherson and Kathol (1977). The thickness of the till ranges from zero at the edge of the organic plain to 28 m. The total thickness of the surficial deposits in the organic plain ranges from 1 m to 45 m. The thickest deposits appear to be in Lease 19.

The valley slopes along the Steepbank River and the Athabasca River are covered with colluvium, which consists mainly of sandy and silty material, with some bituminous sand.

The floodplain on the east bank of the Athabasca River is comprised of organic material and alluvial sand silt and clay, with some sand and gravel meltwater deposits. The thickness of sediments in the floodplain is as great as 45 m.

The simplified bedrock stratigraphy in the area is:

- Clearwater Formation
- McMurray Oil Sands
- Basal Aquifer
- Upper Devonian

Shale of the Clearwater Formation is the uppermost bedrock unit over most of the organic plain. The shale is approximately 80 m thick in the east portion of the LSA, and thins toward the west.

The oil sands deposit in the LSA is between 50 m and 75 m thick. It subcrops in the Athabasca River valley and outcrops along the lower reaches of the Steepbank River.

The Basal Aquifer is an extensive discontinuous unit within the McMurray Formation. The aquifer is generally positioned at the bottom of the oil sands, and is commonly absent above topographic highs in the surface of the underlying Devonian. The aquifer is up to 50 m thick in Fee Lot 1, and ranges from zero to 30 m thick throughout the rest of the LSA. The Basal Aquifer is absent in the south half of Lease 97, and the northwest of Fee Lot 1.

The Upper Devonian deposit is limestone of the Waterways Formation. The Upper Devonian surface has 100 m of relief, with numerous depressions and topographic highs. The highly irregular surface may be the result of karstification. The rock observed in outcrops and core samples is weathered and highly fractured. The Upper Devonian is exposed along the Athabasca River, and the lower reaches of the Steepbank River.

7.2 Hydrogeology

Groundwater flow in the stratified surficial sediments is toward the Steepbank and Athabasca Rivers. South of the Steepbank, the vast majority of the groundwater in the surficial sand flows toward the Athabasca River. The mean hydraulic conductivity of the sand is 3.1×10^{-6} m/s.

The direction of hydraulic gradients in the till, the Clearwater Formation and the McMurray Oil Sands is predominantly vertically downward. These units have relatively low hydraulic conductivity, in the order of 1×10^{-7} m/s.

The groundwater in the Basal Aquifer and the Upper Devonian is flowing predominantly toward the Athabasca River. In the vicinity of the lower reach of the Steepbank River, where the river has cut below the bottom of the oil sands, a component of the flow in the aquifer is toward the Steepbank River.

Under most of the organic plain area, the hydraulic head in both the Basal Aquifer and the Upper Devonian is above the bottom of the McMurray Oil Sands. The Basal Aquifer and Upper Devonian appear to have similar hydraulic conductivities locally. The mean hydraulic conductivity of the Basal Aquifer is 4.1×10^{-6} m/s. The hydraulic conductivity measured in one piezometer completed in the Upper Devonian is 5.8×10^{-6} m/s.

The groundwater in surficial deposits is quite fresh. The concentration of total dissolved solids ranges from 17 mg/L to 638 mg/L. The freshest water is similar to water found in the peat. The water with higher TDS is associated with till and bedrock. The major ions in the surficial groundwater are calcium, magnesium and bicarbonate. The water with higher TDS levels also tends to have higher concentrations of sodium.

In the oil sands, Basal Aquifer and Upper Devonian, the groundwater chemistry ranges from brackish to saline. The units contain similar water, with the major ions being sodium, chloride and bicarbonate. The water in the oil sands also contains organic compounds, including naphthenic acid. In the Basal Aquifer, the concentration of TDS ranges from 2620 mg/L to 29 789 mg/L. The concentration of naphthenic acid in the Basal Aquifer ranges from 6 mg/L to 36 mg/L. In the Upper Devonian, the concentration of TDS has been found to range from 637 mg/L to 5201 mg/L. In the LSA, the median TDS in groundwater from the one piezometer completed in the Upper Devonian was 4700 mg/L. The median concentration of naphthenic acid in the limestone was 52 mg/L.

In terms of groundwater resources, the surficial aquifer in the organic plain was found to conform to minimum standards for domestic supply. The long-term yield (Q_{20}) from the surficial aquifer is adequate (locally greater than 1 m^3/day) and the water quality is suitable for domestic supply. The bedrock aquifers are capable of yielding higher volumes of water. However, the water quality in the bedrock aquifers is poor, and could not be utilized for drinking water or agricultural purposes without pre-treatment.

The surficial aquifer in the Athabasca River valley is expected to be a viable source of groundwater.

The contribution of groundwater discharge to surface water has been found to be very minor. The total rate of groundwater discharge from surficial and bedrock aquifers to all water bodies in the LSA is estimated to be 33.5 L/s. The rates of groundwater discharge are less than 1% of the minimum average surface water flows in the Athabasca and Steepbank Rivers.

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9. GLOSSARY OF TERMS

Aquifer	A body of rock or soil which contains sufficient amounts of saturated permeable material to yield economic quantities of water to wells or springs.
Aquitard	A lithologic unit that impedes ground water movement and does not yield water freely to wells or springs but that may transmit appreciable water to or from adjacent aquifers. Where sufficiently thick, may act as a ground water storage zone. Synonymous with confining unit.
Available Drawdown	The vertical distance that the equipotential surface of an aquifer can be lowered; in confined aquifers, this is to the top of the aquifer; in unconfined aquifers, this is to the bottom of the aquifer.
Baseline	A surveyed condition which serves as a reference point to which later surveys are coordinated or correlated.
Bedrock	The body of rock which underlies the gravel, soil or other superficial material.
Borehole Log	The record of geologic units penetrated, drilling progress, depth, water level, sample recovery, volumes and types of materials used, and other significant details regarding the drilling of an exploratory borehole or well.
Confined Aquifer	An aquifer in which the potentiometric surface is above the top of the aquifer.
Consolidated Tailings	The portion of ore that is deposited after washing and milling and which has undergone a reduction in volume and increase in density. (See also "Consolidation")
Consolidation	The gradual reduction in volume of a soil mass resulting from an increase in applied load. a) Initial consolidation (initial compression): A comparatively sudden reduction in volume of a soil mass under an applied load due principally to release or the squeezing out and compression of gas in the soil voids preceding primary consolidation

b) Primary consolidation (primary compression) (primary time effect): The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to a squeezing out of water from the void spaces of the mass and accompanied by a transfer of the load from the soil water to the soil solids.
c) Secondary consolidation (secondary compression) (secondary time effect): The reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to the adjustment of the internal structure of the soil mass after most of the load has been transferred from the soil water to the soil solids.

Darcy's Law — A law describing the rate of flow of water through porous media. (Named for Henry Darcy of Paris who formulated it in 1856 from extensive work on the flow of water through sand filter beds.)

Deposit — Material left in a new position by a natural transporting agent such as water, wind, ice or gravity, or by the activity of man.

De-pressurize — The process of reducing the pressure in an aquifer, by withdrawing water from it.

Deuterium — A stable isotope of hydrogen, which has two neutrons.

Energy Dissipation — A structure designed to dissipate the excessive structure energy of a high velocity fluid (i.e. water), to establish a safe flow condition and prevent scour or minimize erosion. (See also "Hydraulic structure")

Ephemeral — A phenomena, feature, marriage which only lasts for a short time (ie., an ephemeral stream is only present for short periods during the year.

Equipotential Level — The level on which the potential everywhere is constant; the level at surface which the pressure head of a body of groundwater is the same.

Floodplain — Land near rivers and lakes that may be flooded during seasonally high water levels.

Fluvial — Relating to a stream or river.

Glacial Till	Unsorted and unstratified glacial drift, generally unconsolidated, deposited directly by a glacier without subsequent reworking by water from the glacier, and consisting of a heterogeneous mixture of clay, silt, sand, gravel and boulders varying widely in size and shape.
Glacio-Lacustrine	Relating to the lakes that formed of the edge of glaciers as the glaciers receded. Glacio-lacustrine sediments are commonly laminar deposits of fine sand, silt and clay.
Ground Penetrating	Method of mapping subsurface layer geometry using radar.
Groundwater	Water that is found below the ground surface, in soil and rock.
Groundwater Level	The level below which the rock and subsoil, to unknown depths, are saturated.
Groundwater Regime	Water below the land surface in a zone of saturation.
Groundwater Velocity	The speed at which groundwater advances through the ground. The way that the term is used in this document, it technically refers to the average linear velocity of the groundwater.
Head	The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. It is used in various compound terms such as pressure head, velocity head, and loss of head.
Hydraulic Conductivity	The permeability of soil or rock to water.
Hydraulic Gradient	A measure of the force moving groundwater through soil or rock. It is measured as the rate of change in total head per unit distance of flow in a given direction. Hydraulic gradient is commonly shown as being dimensionless, since its units are m/m, ft/ft.
Hydraulic Head	The elevation with respect to a specified reference level at which water stands in a piezometer connected to the point in question in the soil. Its definition can be extended to soil above the water table if the piezometer is replaced by a tensiometer. The hydraulic head in systems under atmospheric

	pressure may be identified with a potential expressed in terms of the height of a water column. More specifically, it can be identified with the sum of gravitational and capillary potentials, and may be termed the hydraulic potential.
Hydraulic Structure	Any structure which is designed to handle water in any way. This includes the retention, conveyance, control, regulation, and dissipation of the energy of water.
Hydrogeology	The study of the factors that deal with subsurface water, and the related geologic aspects of surface water.
Inorganics	Pertaining or relating to a compound that contains no carbon. (See also "Organic compounds")
Landform	Any physical, recognizable form or feature of the Earth's surface, having a characteristic shape, and produced by natural causes.
Lean Oil Sands	Oil bearing sands, which do not have a high enough saturation of oil to make mining of them economically feasible.
Microtox	A measure of toxicity in a sample. (See also "Toxicity")
Organic Compounds	Chemicals (naturally occurring or otherwise) which contain carbon, with the exception of carbon dioxide (CO^2) and carbonates (e.g., CACO3)
Overburden	The soil, sand, silt, or clay that overlies bedrock. In mining terms, this includes all material which has to be removed to expose the ore.
Oxygen-18	A stable isotope of oxygen which has two more neutrons than the more common oxygen-16.
Piezometer	An instrument for measuring pressure. In groundwater and geotechnical investigations, piezometers are commonly Poly Vinyl Chloride pipe that has been sealed in a drill hole. The height to which groundwater rises in the pipe is a measure of the water pressure at the bottom of the piezometer.
Piezometric Surface	If water level elevations in wells completed in an aquifer are plotted on a map and contoured, the resulting surface described

	by the contours is known as a potentiometric or piezometric surface.
Pneumatic Piezometer	A type of piezometer in which the hydraulic head is measured using a compressed gas.
Pore Water	Water that is present between the grains of a soil or rock.
Potentiometric Surface	An imaginary surface representing the static head of groundwater. The water table is a particular potentiometric surface.
Sediment Sampling	A field procedure relating to a methodology for determining the configuration of sediment deposits.
Sedimentation	The process of subsidence and deposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material.
Stable Isotopes	Isotopes of a particular element have the same number of protons; but different numbers of neutrons. Isotopes are stable if they do not naturally undergo radioactive decay.
Static Water Level	The elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping.
Stratigraphy	The succession and age of strata of rock and unconsolidated material. Also concerns the form, distribution, lithologic composition, fossil content and other properties of the strata.
Surficial Aquifer	A surficial deposit containing water to be considered an aquifer.
Surficial Deposit	A geologic deposit (like clay, silt or sand) that has been placed above bedrock. (See also "Overburden")
Tailings	The portion of ore, after washing and milling, which is too low grade to warrant further processing.
Total Dissolved	The total concentration of all dissolved compounds solids found in a water

Solids (TDS)	sample.
Toxicity	The tendency of a chemical or condition to cause harm to the life process.
Twenty Year	An estimation of the long term rate at which a water well will produce
Safe Yield (Q_{20})	water. The Q20 is the rate at which a well can be pumped continuously for 20 years, without the water level dropping below the top of the aquifer. (See also "Available drawdown")
Unconfined Aquifer	An aquifer in the which the water level is below the top of the aquifer.
Water Equivalent	As relating to snow; the depth of water that would result from melting.
Water Table	The shallowest saturated ground below ground level - technically, that surface of a body of unconfined groundwater in which the pressure is equal to atmospheric pressure.
Wetlands	Area of surface water ponding which forms the habitat for a variety of wildlife including water fowl.

APPENDIX I

BOREHOLE LOGS

TEST HOLE LOG

VERTICAL SCALE: 1cm = 1.0m	DATE DRILLED: 19 FEB 98 - 19 FEB 98
SAMPLE DATA	DRILL TYPE: Wet Rotary
HAMMER WEIGHT kg	ELEV. GROUND (m): 337.84
DROP HEIGHT m	CO-ORDINATES (m): N 6,311,731 E 476,178

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
0.0–1.07					Muskeg		Steel casing protector installed at surface 0.84m of riser pipe stick up Riser Pipe (0.0 to 2.2m) - 2 inch Sch. 40 PVC Well Seal (0.0 to 1.7m) - bentonite
1.07–3.66					Sand - fine and medium grained - cobble fragments - brown		Filter Pack (1.7 to 4.3) - pea gravel Well Screen (2.2 to 3.6) - 2 inch Sch. 40 #10 slot PVC
3.66–4.57					Clay Till - low plasticity, silty, sandy - fine and medium grained gravel, dark grey		Backfill (4.3 to 4.57m) - slough
4.57					End of Hole at 4.57m		Water Level Measurement: 1.70m (0.86m bgs) on 25 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO:	PA 2839.03.04
PROJECT:	Project Millennium
LOCATION:	L25-P98-OB1
LOGGED BY: M.T.	CHECKED BY:
PLATE: 1 of 1	HOLE NO: 98-103

TEST HOLE LOG

VERTICAL SCALE: 1cm = 1.0m

DATE DRILLED: 19 FEB 98 - 19 FEB 98

DRILL TYPE: Wet Rotary

ELEV. GROUND (m): 339.00

CO-ORDINATES (m): N 6,310,362 E 476,070

SAMPLE DATA

HAMMER WEIGHT kg

DROP HEIGHT m

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
					Muskeg		Steel casing protector installed at surface 0.55 m of riser pipe stick up
1.0					1.50		Riser Pipe (0.0 to 5.55m) - 2 inch Sch. 40 PVC
2.0					Sand - medium to coarse grained - trace fine gravel - brown		Backfill (0.0 to 4.04m) - drill cuttings
3.0							
4.0							Well Seal (4.04 to 4.88m) - bentonite
5.0							Filter Pack (4.88 to 9.14m) - pea gravel
6.0					6.10		
7.0					Sand - medium grained, some fine grained sand - brown 7.62		Well Screen (5.55 to 8.60m) - 2 inch Sch. 40 #10 slot PVC
8.0					Sand - medium and coarse grained - trace fine gravel - brown		Slough from 7.37 to 8.60m
9.0							
10.0							Backfill (9.14 to 11.28m) - slough
11.0					10.97 11.28 Brown Clay		
					End of Hole at 11.28m		Water Level Measurement: 1.04m (0.49m bgs) on 26 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO: PA 2839.03.04

PROJECT: Project Millennium

LOCATION: L25-P98-OB2

LOGGED BY: M.T. CHECKED BY:

PLATE: 1 of 1 HOLE NO: 98-080

TEST HOLE LOG

VERTICAL SCALE: 1cm = 1.0m

DATE DRILLED: 19 FEB 98 - 19 FEB 98

DRILL TYPE: Wet Rotary

ELEV. GROUND (m): 351.57

CO-ORDINATES (m): N 6,310,244 E 479,178

SAMPLE DATA

HAMMER WEIGHT kg

DROP HEIGHT m

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
0.0 – 1.52					Muskeg		Steel casing protector installed at surface 0.61 m of riser pipe stick up
1.52 – 1.80					Sand - fine grained, silty, brown		
1.80 – 9.75					Clay Till - low plasticity - some sand, some silt - some fine to medium grained gravel - trace coarse grained gravel, angular to subangular - grey		Riser Pipe (0.0 to 11.58m) - 2 inch Sch. 40 PVC Backfill (0.0 to 7.95m) - drill cuttings Well Seal (7.95 to 10.34m) - bentonite
9.75 – 13.72					Clay Till - medium plasticity - trace silt, some sand - some fine to medium grained gravel - angular to subangular, grey		Filter Pack (10.34 to 15.24m) - pea gravel Well Screen (11.58 to 14.63m) - 2 inch Sch. 40 #10 slot PVC
13.72 – 15.24					Clay Till - same as 9.75 - 13.72m above except trace fine grained gravel		
15.24					End of Hole at 15.24m		Water Level Measurement: 3.80m (3.19m bgs) on 25 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO: PA 2839.03.04

PROJECT: Project Millennium

LOCATION: L25-P98-OB3

LOGGED BY: M.T. CHECKED BY:

PLATE: 1 of 1 HOLE NO: 98-083

TEST HOLE LOG

VERTICAL SCALE: 1cm = 1.0m

DATE DRILLED: 20 FEB 98 - 20 FEB 98
DRILL TYPE: Wet Rotary
ELEV. GROUND (m): 339.51
CO-ORDINATES (m): N 6,307,534 E 475,934

SAMPLE DATA

HAMMER WEIGHT kg
DROP HEIGHT m

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
0.0–0.91					Muskeg		Steel casing protector installed at surface 0.84 m of riser pipe stick up Backfill (0.0 to 1.27m) - drill cuttings Well Seal (1.27 to 2.58m) - bentonite Riser Pipe (0.0 to 3.40m) - 2 inch Sch. 40 PVC
0.91–5.18					Sand - medium and coarse grained - some fine grained sand - some fine to medium grained gravel - subrounded to rounded, brown		Filter Pack (2.58 to 6.10m) - pea gravel Well Screen (3.40 to 4.93m) - 2 inch Sch.40 #10 slot PVC
5.18–6.10					Clay Till - low plasticity - some silt, some sand - trace fine to medium grained gravel, angular to subangular - grey		
					End of Hole at 6.10m		2 IGPM produced during air lift developing Water Level Measurement: 0.84m (0.0m bgs) on 25 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO: PA 2839.03.04
PROJECT: Project Millennium
LOCATION: L19-P98-OB4
LOGGED BY: M.T. CHECKED BY:
PLATE: 1 of 1 HOLE NO: 98-117

TEST HOLE LOG

VERTICAL SCALE: 1cm = 2.0m

DATE DRILLED: 21 FEB 98 - 21 FEB 98

DRILL TYPE: Wet Rotary

ELEV. GROUND (m): 354.36

CO-ORDINATES (m): N 6,304,740 E 480,205

SAMPLE DATA

HAMMER WEIGHT kg

DROP HEIGHT m

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
					0.74 Muskeg		Steel casing protector installed at surface 0.61m of riser pipe stick up
					1.35 Sand - fine and medium grained, silty, brown		
					Clay Till - low plasticity - silty, sandy - some fine and medium grained gravel, angular to subangular, brown 6.10		Riser Pipe (0.0 to 20.50m) - 2 inch Sch.40 PVC Backfill (0.0 to 16.23m) - drill cuttings
					Clay Till - low plasticity, silty, sandy - some fine and medium grained gravel - trace coarse grained gravel, angular to subangular, grey 9.75		
10.0					Sand 10.67 - medium grained, some silt, brown		
					Clay Till - same as 6.1 - 9.75m interval 13.72		
					Clay Till - low plasticity, sandy, silty - trace fine grained gravel, angular to subangular, grey 16.76		
20.0					Clay Till - low to medium plasticity, sandy, silty - trace fine grained gravel, angular, grey - increased resistance to drilling with depth 21.95		Well Seal (16.23 to 18.36m) - bentonite Filter Pack (18.36 to 24.38m) - pea gravel
					Clay Till - low plasticity - silty, trace fine grained gravel, grey 24.38		Well Screen (20.5 to 23.55m) - 2 inch Sch.40 #10 Slot PVC
					End of hole at 24.38m		4 IGPM produced during air lift developing Water Level Measurement: 1.03m (0.42m bgs) on 25 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO:	PA 2839.03.04
PROJECT:	Project Millennium
LOCATION:	L19-P98-OB5
LOGGED BY:	M.T. CHECKED BY:
PLATE:	1 of 1 HOLE NO: 98-074

TEST HOLE LOG

VERTICAL SCALE: 1cm = 1.0m	DATE DRILLED: 19 FEB 98 - 19 FEB 98
HAMMER WEIGHT kg	DRILL TYPE: Wet Rotary
DROP HEIGHT m	ELEV. GROUND (m): 343.52
	CO-ORDINATES (m): N 6,307,865 E 477,495

SAMPLE DATA

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
0.0–3.10					Muskeg		Steel casing protector installed at surface 0.67 m of riser pipe stick up Riser Pipe (0.0 to 11.58m) - 2 inch Sch. 40 PVC
3.10–7.92					Clay Till - low plasticity - some sand, some silt - some fine to medium grained angular to subangular gravel - trace coarse grained gravel, grey		Backfill (0.0 to 8.05m) - drill cuttings
7.92–10.97					Clay Till - low plasticity - sandy, trace fine grained gravel, angular to subangular - grey		Well Seal (8.05 to 10.08m) - bentonite
10.97–15.24					Clay Till - medium plasticity - trace sand, trace silt - some fine to medium grained angular to subangular gravel - trace coarse grained gravel, grey		Filter Pack (10.08 to 15.24m) - pea gravel Well Screen (11.58 to 14.63m) - 2 inch Sch. 40 #10 slot PVC
					End of Hole at 15.24m		Water Level Measurement: 4.45m (3.78m bgs) on 25 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO:	PA 2839.03.04
PROJECT:	Project Millennium
LOCATION:	L19-P98-OB6
LOGGED BY:	M.T.
CHECKED BY:	
PLATE:	1 of 1
HOLE NO:	98-115

TEST HOLE LOG

VERTICAL SCALE: **1cm = 1.0m**

DATE DRILLED: **21 FEB 98 - 21 FEB 98**

DRILL TYPE: **Wet Rotary**

ELEV. GROUND (m): **349.00**

CO-ORDINATES (m): **N 6,304,038 E 477,123**

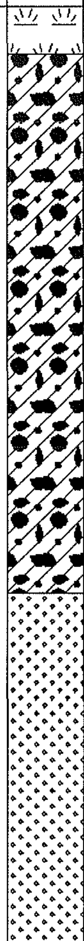
SAMPLE DATA

HAMMER WEIGHT kg

DROP HEIGHT m

Depth (m)	Type	Blows .15m	Sample No.
1.0			
2.0			
3.0			
4.0			
5.0			
6.0			
7.0			
8.0			
9.0			
10.0			
11.0			
12.0			

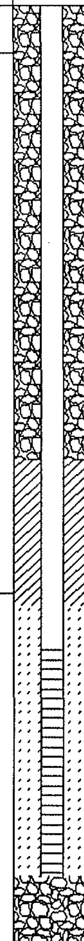
SYMBOL



DESCRIPTION OF MATERIALS

Depth (m)	Description
0.61	Muskeg
7.62	Clay Till - low plasticity - sandy, silty - some fine to medium grained gravel, angular to subangular - hydrocarbon (bitumen) sheen and smell - brown
12.20	Medium Grained Sand - some coarse grained sand - trace silt, brown
	End of Hole at 12.20m

WELL DETAILS



NOTES

Steel protective casing installed at surface
0.48 m of riser pipe stick up

Riser Pipe (0.00 to 8.22m)
- 2 inch Sch. 40 PVC

Backfill (0.0 to 5.87m)
- drill cuttings

Well Seal (5.87 to 7.77m)
- bentonite

Filter Pack (7.77 to 11.28m)
- pea gravel

Well Screen (8.22 to 11.28m)
- 2 inch Sch. 40 #10 slot PVC

Slough (11.28 to 12.2m)
- borehole collapsed

Water Level Measurement:
Well was dry on 25 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO:	**PA 2839.03.04**
PROJECT:	**Project Millennium**
LOCATION:	**L19-P98-OB7**
LOGGED BY: **M.T.**	CHECKED BY:
PLATE: **1 of 1**	HOLE NO: **98-125**

TEST HOLE LOG

VERTICAL SCALE: 1cm = 1.0m

DATE DRILLED: 20 FEB 98 - 20 FEB 98

DRILL TYPE: Wet Rotary

ELEV. GROUND (m): 351.66

CO-ORDINATES (m): N 6,304,057 E 479,122

SAMPLE DATA

HAMMER WEIGHT kg

DROP HEIGHT m

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
0.0 – 3.96					Muskeg		Steel casing protector installed at surface 0.58 m of riser pipe stick up
3.96 – 9.14					Clay Till - low plasticity, sandy, silty - trace fine gravel - dark grey		Riser Pipe (0.0 to 11.6m) - 2 inch Sch. 40 PVC Surface Seal (0.0 to 2.1m) - bentonite Backfill (2.1 to 9.75m) - drill cuttings
9.14 – 15.50					Clay Till - low plasticity, silty, sandy - fine and medium grained gravel - trace coarse gravel - dark grey		Well Seal (9.75 to 10.67m) - bentonite Filter Pack (10.67 to 15.5m) - pea gravel Well Screen (11.6 to 14.66m) - 2 inch Sch. 40 #10 Slot PVC
15.50					End of Hole at 15.50m		Water Level Measurement: Well was frozen on 25 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO:	PA 2839.03.04
PROJECT:	Project Millennium
LOCATION:	L19-P98-OB8
LOGGED BY:	M.T.
CHECKED BY:	
PLATE:	1 of 1
HOLE NO:	98-064

TEST HOLE LOG

VERTICAL SCALE: **1cm = 5.0m**	DATE DRILLED: **22 FEB 98 - 22 FEB 98**
SAMPLE DATA	DRILL TYPE: **Wet Rotary/Coring**
HAMMER WEIGHT kg	ELEV. GROUND (m): **333.60**
DROP HEIGHT m	CO-ORDINATES (m): **N 6,312,272 E 475,841**

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
					Material description not available at time of writing		Surface Seal (0 to 5m) - bentonite
6.10					Drill casing installed to this depth using wet rotary Coring began after this depth		
10.0							
20.0							Backfill (5 to 80m) - borehole collapse
30.0							
40.0							
50.0					1A-L on 26 Feb 1998: 54.4m bgs		
60.0							
70.0							
78.00					Bedrock contact inferred from geophysical log and subject to change		
80.0							Well Seal (80 to 82m) - bentonite Filter Pack (82 to 85m) - pea gravel Pneumatic Piezometer Tip at 85.85m - Serial No. 98070 Slough (85 to 86.87m) - borehole collapse
86.87					End of Hole at 86.87m		Water Level Measurement: 310kPa (54.4m bgs) on 26 Feb 1998

KLOHN-CRIPPEN

22/04/98

JOB NO:	**PA 2839.03.04**
PROJECT:	**Project Millennium**
LOCATION:	**L25-AP98-1A**
LOGGED BY: **M.T.**	CHECKED BY:
PLATE: **1 of 1**	HOLE NO: **98-067**

TEST HOLE LOG

VERTICAL SCALE: 1cm = 5.0m	DATE DRILLED: 24 FEB 98 - 24 FEB 98
SAMPLE DATA	DRILL TYPE: Wet Rotary/Coring
HAMMER WEIGHT kg	ELEV. GROUND (m): 345.95
DROP HEIGHT m	CO-ORDINATES (m): N 6,312,412 E 477,641

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
0					Material description not available at time of writing		Surface Seal (0 to 5m) - bentonite
20.0							Backfill (5 to 63m) - borehole collapse
30.0					2B-BA on 26 Feb 1998: 31.5m bgs		
60.0					2A-L on 26 Feb 1998: 61.3m bgs		
							Well Seal (63 to 65m) - bentonite
							Pneumatic Piezometer Tip at 67.76m - Serial No. 98067 (2B-BA)
70.0							Filter Pack (65 to 70.67m) - pea gravel
							Slough (70.67 to 79m)
76.00					Bedrock contact inferred from geophysical log and subject to change		
80.0							Well Seal (79 to 80.87m) - bentonite
							Filter Pack (80.87 to 86.74m) - pea gravel
							Pneumatic Piezometer Tip at 84.84m - Serial No. 98120 (2A-L)
90.0					90.00		Backfill (86.74 to 90m) - slough
					End of Hole at 90.0m		Water Level Measurement: on 26 Feb 1998: 2B-BA (upper): 357kPa (31.5m bgs) 2A-L (lower): 231kPa (61.3m bgs)

Depth scale: 10.0, 20.0, 30.0, 40.0, 50.0, 60.0, 70.0, 80.0, 90.0

KLOHN-CRIPPEN

22/04/98

JOB NO:	PA 2839.03.04
PROJECT:	Project Millennium
LOCATION:	L25-AP98-2A/2B
LOGGED BY: M.T.	CHECKED BY:
PLATE: 1 of 1	HOLE NO: 98-070

TEST HOLE LOG

VERTICAL SCALE: 1cm = 5.0m	DATE DRILLED: 25 FEB 98 - 25 FEB 98
SAMPLE DATA	DRILL TYPE: Wet Rotary/Coring
HAMMER WEIGHT kg	ELEV. GROUND (m): 366.20
DROP HEIGHT m	CO-ORDINATES (m): N 6,312,295 E 480,599

Depth (m)	Type	Blows .15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
					0.60 Muskeg		Surface Seal (0.0 to 5.0m) - bentonite
					Material description not available at time of writing		
10.0							
20.0					21.50		Backfill (5.0 to 109.0m) - borehole collapse
					Drill casing installed to this depth using wet rotary Coring began after this depth		
30.0							
40.0							Two Pneumatic Piezometers Installed
50.0							
60.0					3B-BA on 26 Feb 1998: 62.3m bgs 3A-L on 26 Feb 1998: 62.9m bgs		
70.0							
80.0							
90.0							

Continued

KLOHN-CRIPPEN

22/04/98

JOB NO:	PA 2839.03.04		
PROJECT:	Project Millennium		
LOCATION:	L25-AP98-3A/3B		
LOGGED BY:	M.T.	CHECKED BY:	
PLATE:	1 of 2	HOLE NO:	98-076

TEST HOLE LOG

VERTICAL SCALE: 1cm = 5.0m	DATE DRILLED: 25 FEB 98 - 25 FEB 98
SAMPLE DATA	DRILL TYPE: Wet Rotary/Coring
HAMMER WEIGHT kg	ELEV. GROUND (m): 366.20
DROP HEIGHT m	CO-ORDINATES (m): N 6,312,295 E 480,599

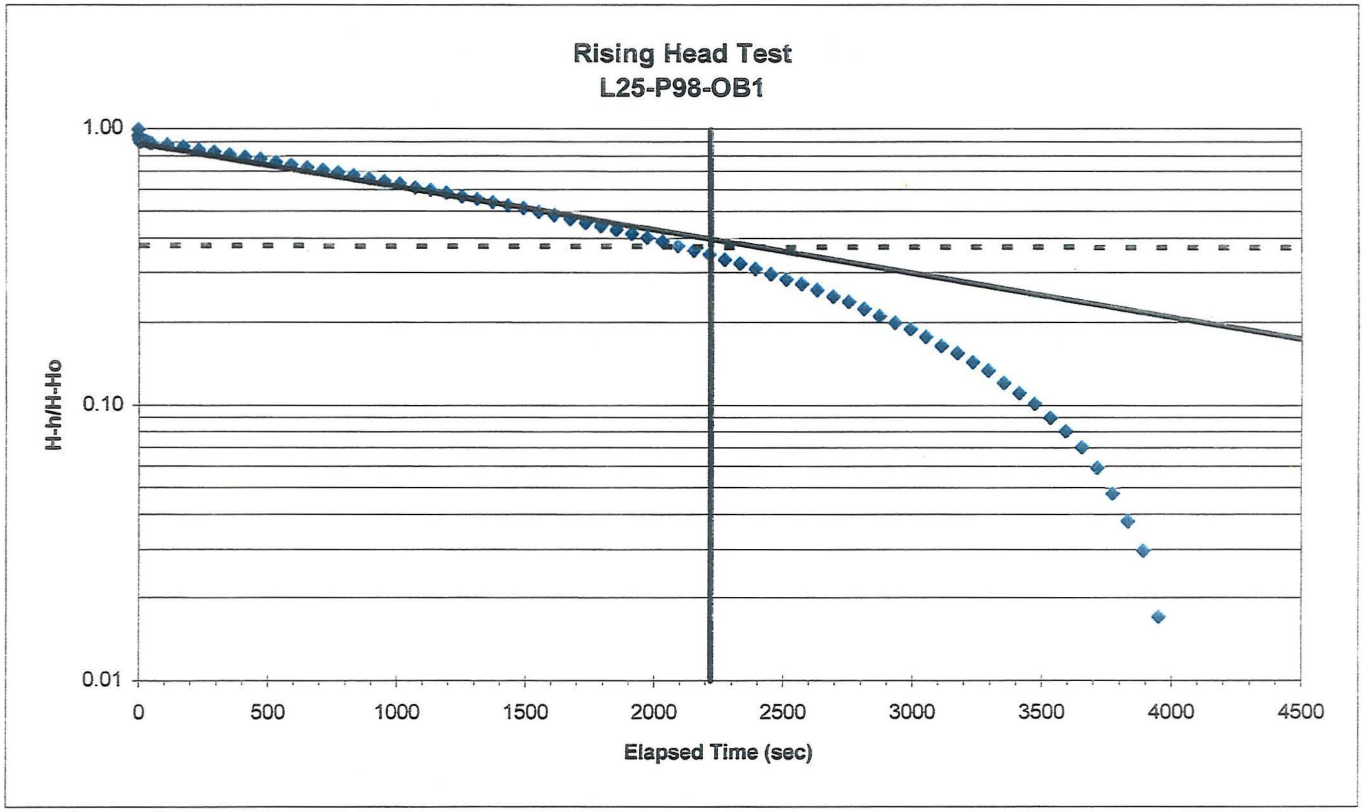
Depth (m)	Type	Blows/.15m	Sample No.	SYMBOL	DESCRIPTION OF MATERIALS	WELL DETAILS	NOTES
110.0							Well Seal (109.0 to 111.5m) - bentonite Filter Pack (111.5 to 114.5m) - pea gravel Pneumatic Piezometer Tip at 114.0m - Serial No. 98074 (3B-BA)
					113.00 Bedrock contact inferred from geophysical log and subject to change		Well Seal (114.5 to 117.0m) - bentonite Pneumatic Piezometer Tip at 117.5m - Serial No. 98096 (3A-L) Filter Pack (117.0 to 118.0m) - pea gravel Backfill (118.0 to 121.0m) - slough
120.0					121.00 End of Hole at 121.0m		
							Water Level Measurement: on 26 Feb 1998: 3B-BA (upper): 507kPa (62.3m bgs) 3A-L (lower): 537kPa (62.9m bgs)

KLOHN-CRIPPEN

22/04/98

JOB NO:	PA 2839.03.04		
PROJECT:	Project Millennium		
LOCATION:	L25-AP98-3A/3B		
LOGGED BY:	M.T.	CHECKED BY:	
PLATE:	2 of 2	HOLE NO:	98-076

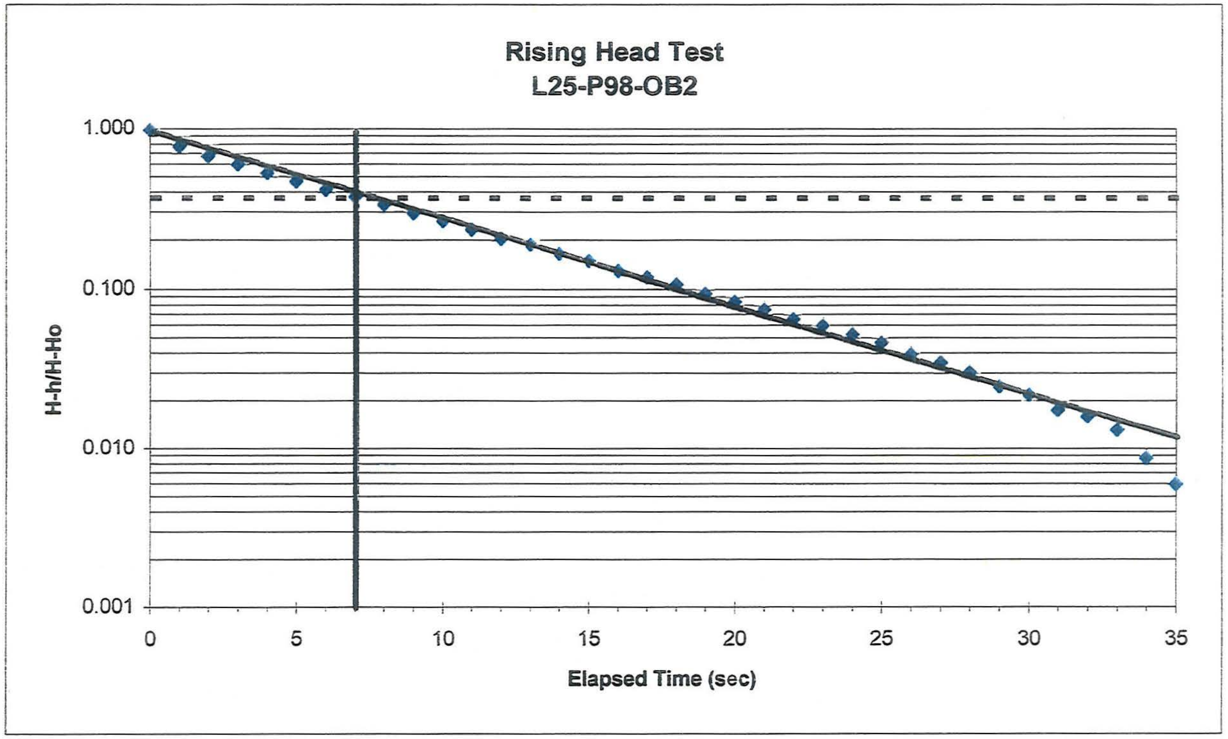
APPENDIX II
RISING HEAD TESTS



$$K = \frac{r^2 \ln(L/R)}{2LTo}$$

where: r = radius of the riser pipe
L = Monitoring interval length
R = Monitoring interval radius
To = Basic time lag
K = hydraulic conductivity

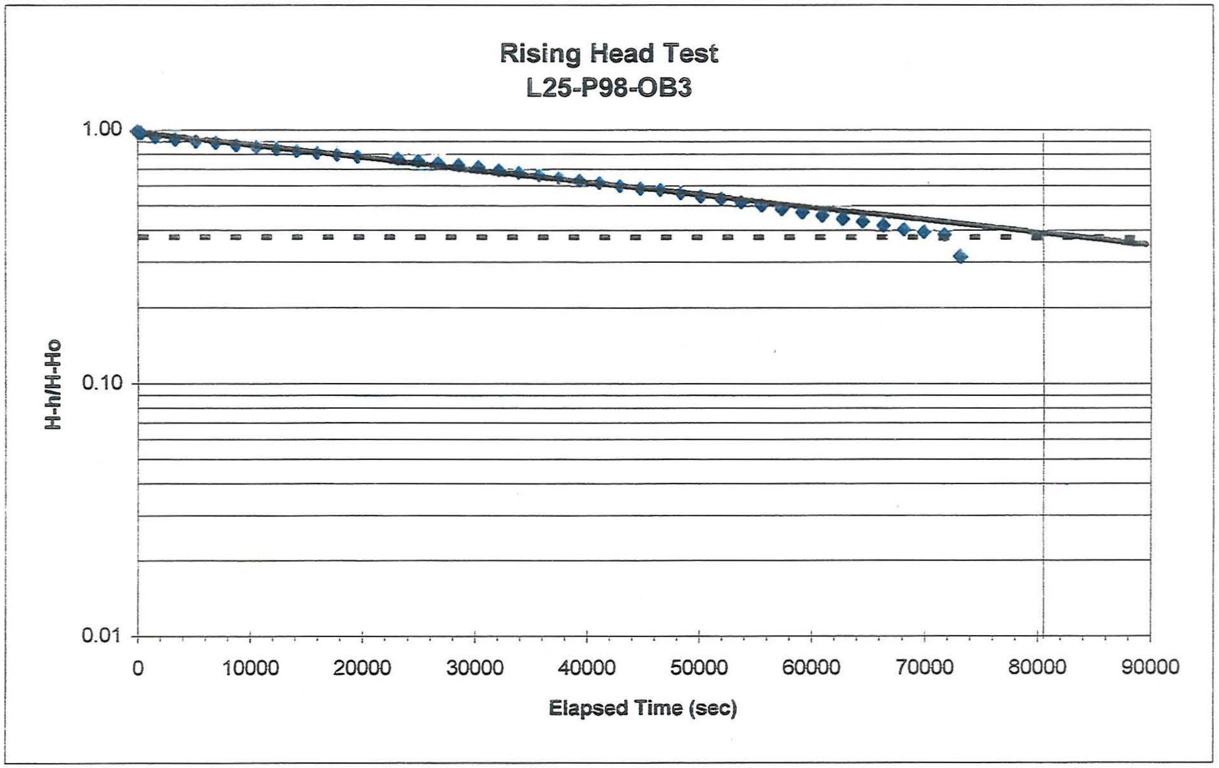
r =	0.0254	m
L =	1.524	m
R =	0.0762	m
To =	2200	sec
K =	**2.9E-07**	**m/s**



$$K = \frac{r^2 \ln (L/R)}{2LTo}$$

where: r = radius of the riser pipe
L = Monitoring interval length
R = Monitoring interval radius
To = Basic time lag
K = hydraulic conductivity

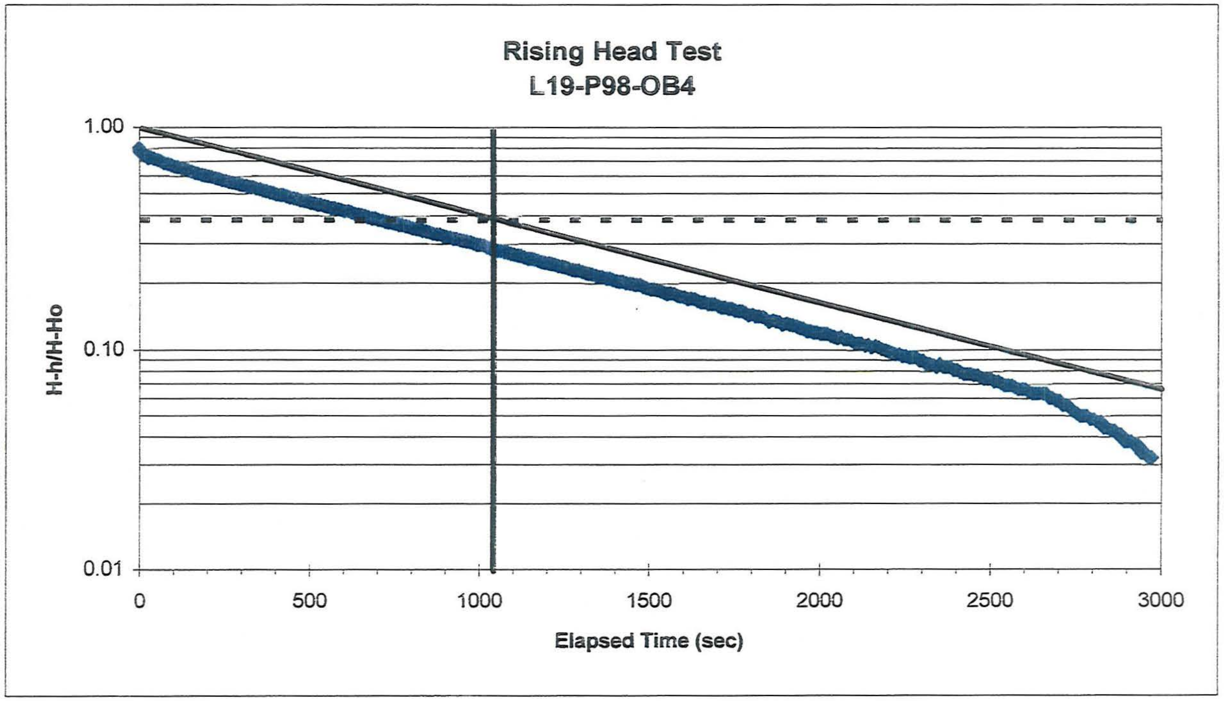
r =	0.0254 m
L =	1.524 m
R =	0.0762 m
To =	7 sec
K =	**9.1E-05 m/s**



$$K = \frac{r^2 \ln (L/R)}{2LTo}$$

where: r = radius of the riser pipe
L = Monitoring interval length
R = Monitoring interval radius
To = Basic time lag
K = hydraulic conductivity

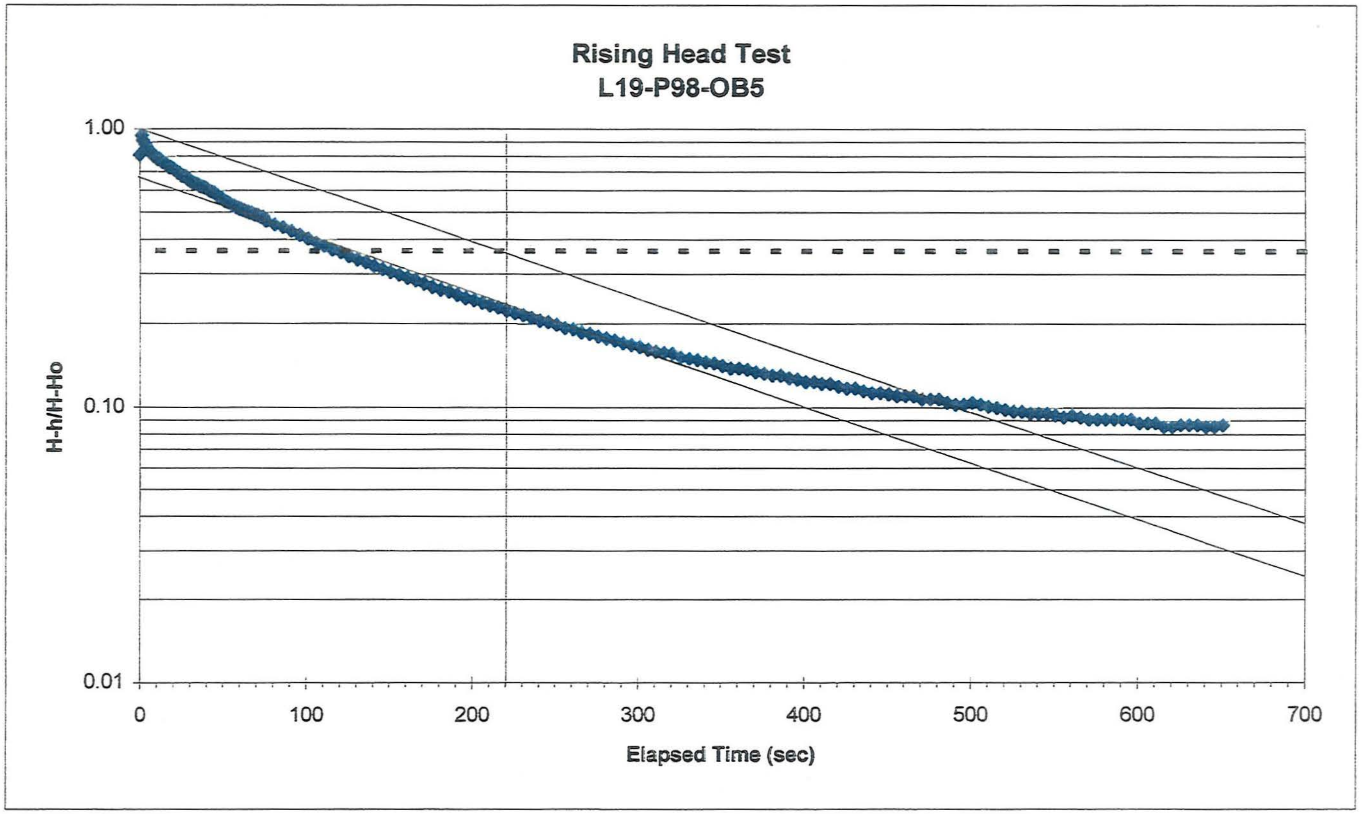
r =	0.0254 m
L =	1.524 m
R =	0.0762 m
To =	80400 sec
K =	**7.9E-09 m/s**



$$K = \frac{r^2 \ln(L/R)}{2LTo}$$

where: r = radius of the riser pipe
L = Monitoring interval length
R = Monitoring interval radius
To = Basic time lag
K = hydraulic conductivity

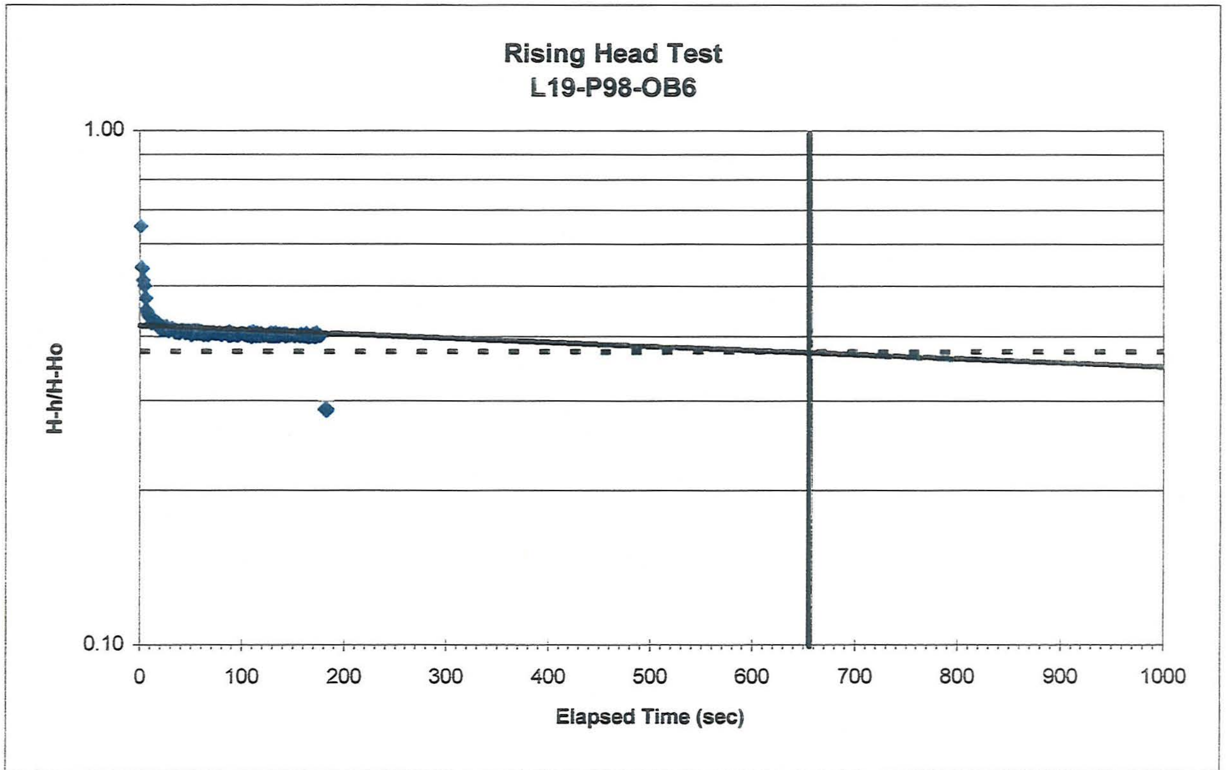
r =	0.0254	m
L =	1.524	m
R =	0.0762	m
To =	1040	sec
K =	**6.1E-07**	**m/s**



$$K = \frac{r^2 \ln (L/R)}{2LTo}$$

where: r = radius of the riser pipe
L = Monitoring interval length
R = Monitoring interval radius
To = Basic time lag
K = hydraulic conductivity

r =	0.0254	m
L =	1.524	m
R =	0.0762	m
To =	220	sec
K =	**2.9E-06**	**m/s**

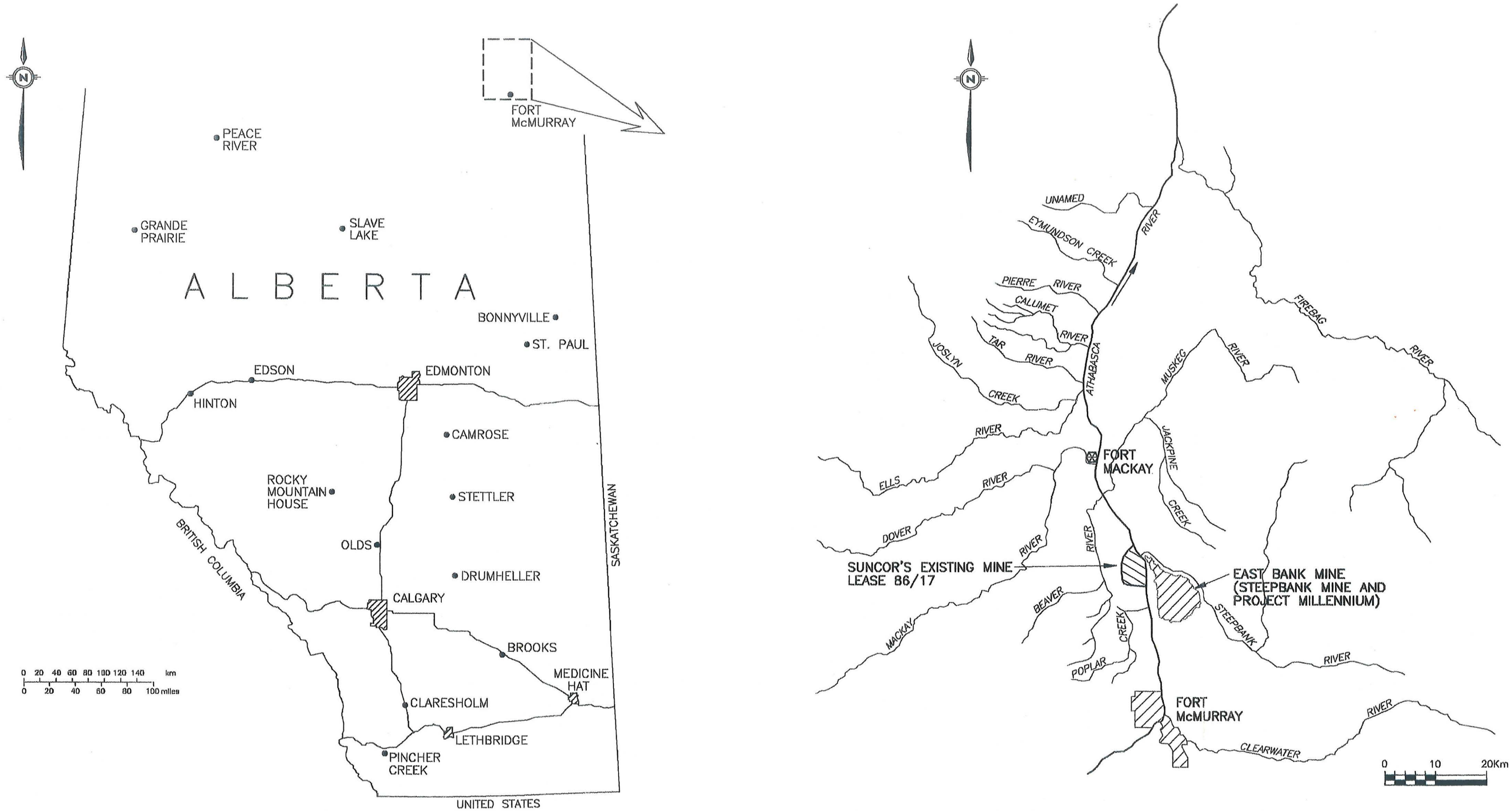


$$K = \frac{r^2 \ln(L/R)}{2LT_o}$$

where: r = radius of the riser pipe
L = Monitoring interval length
R = Monitoring interval radius
To = Basic time lag
K = hydraulic conductivity

r =	0.0254	m
L =	1.524	m
R =	0.0762	m
To =	660	sec
K =	**9.6E-07**	**m/s**

FIGURES



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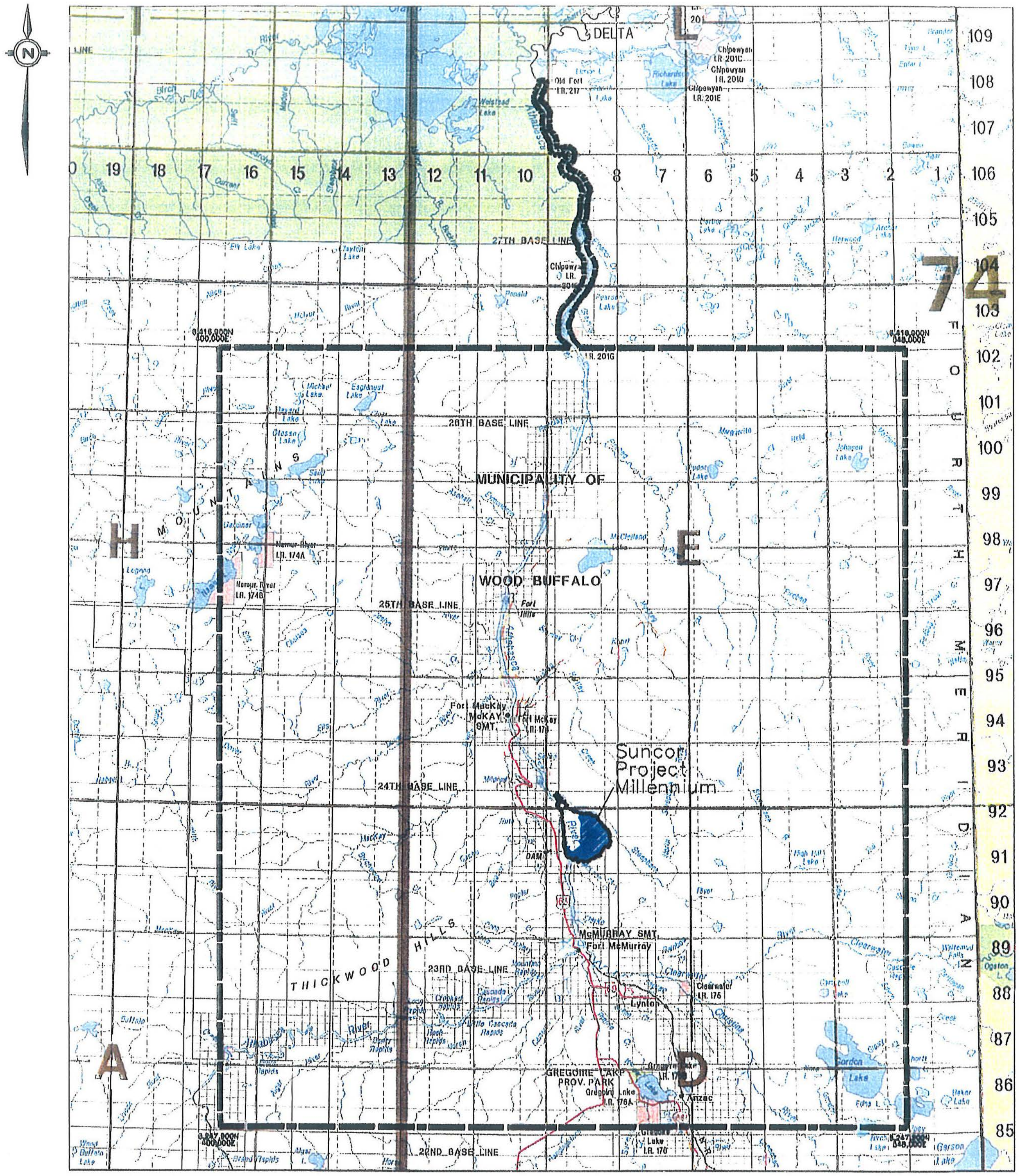
LOCATION PLAN

APRIL 1998	FIGURE 1	DRAWN BY: K.C.B. / C.S.F.



LEGEND

REGIONAL STUDY AREA

0 10 20 30 40 50km

SCALE 1:1,250,000

REFERENCE

SCANNED IMAGE OF ALBERTA ENVIRONMENTAL PROTECTION PROVINCIAL BASE MAP 1997, ORIGINAL SCALE 1:1,000,000

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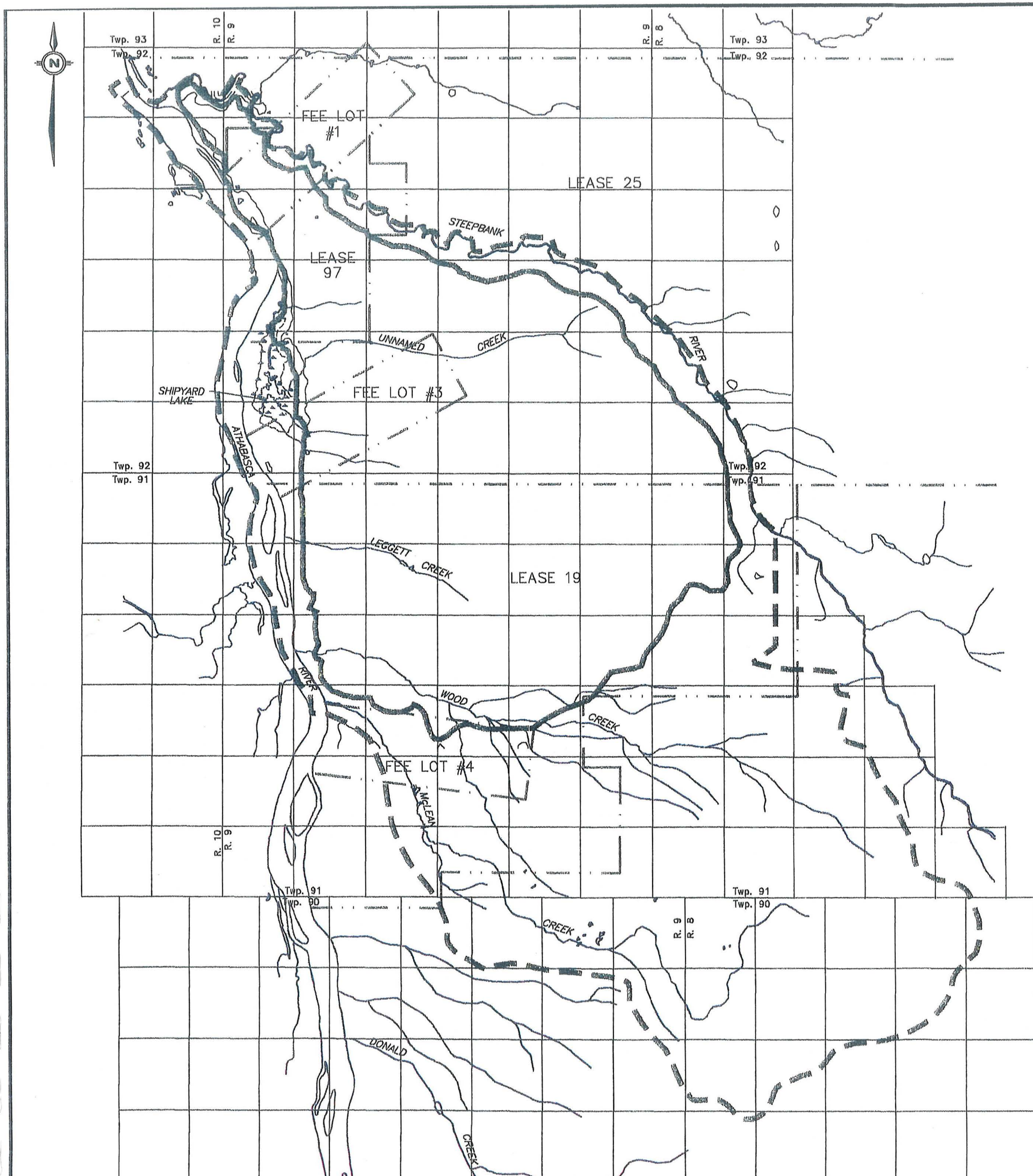
REGIONAL STUDY AREA

APRIL 1998	FIGURE 2	DRAWN BY: C.L.F.

2839w182.dwg



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA

1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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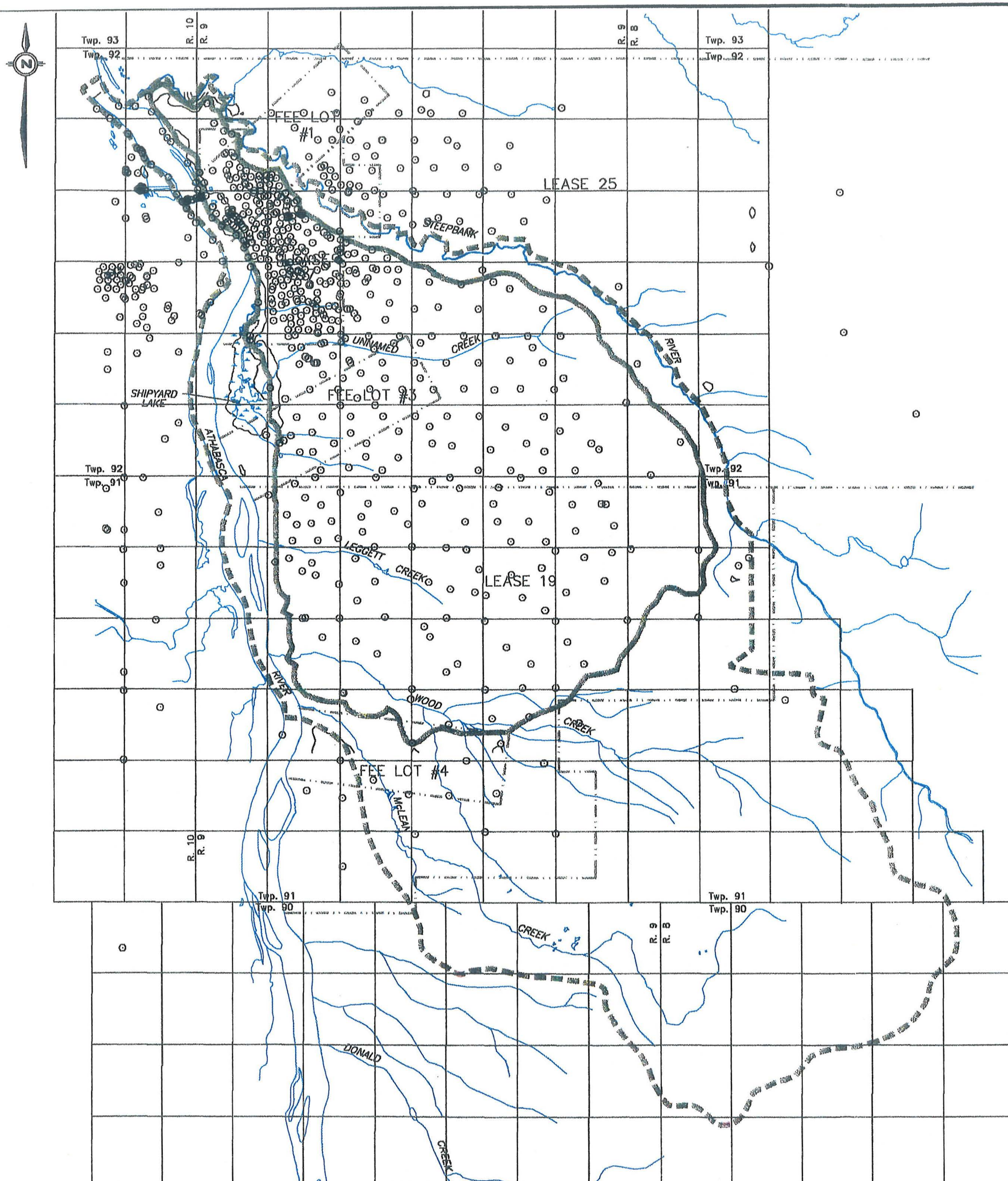
SITE MAP AND LOCAL STUDY AREA

APRIL 1998	FIGURE 3	DRAWN BY: K.C.B. / C.S.F.



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- BOREHOLE LOCATIONS

MAP PROJECTION: UTM 12
DATUM: NAD 83

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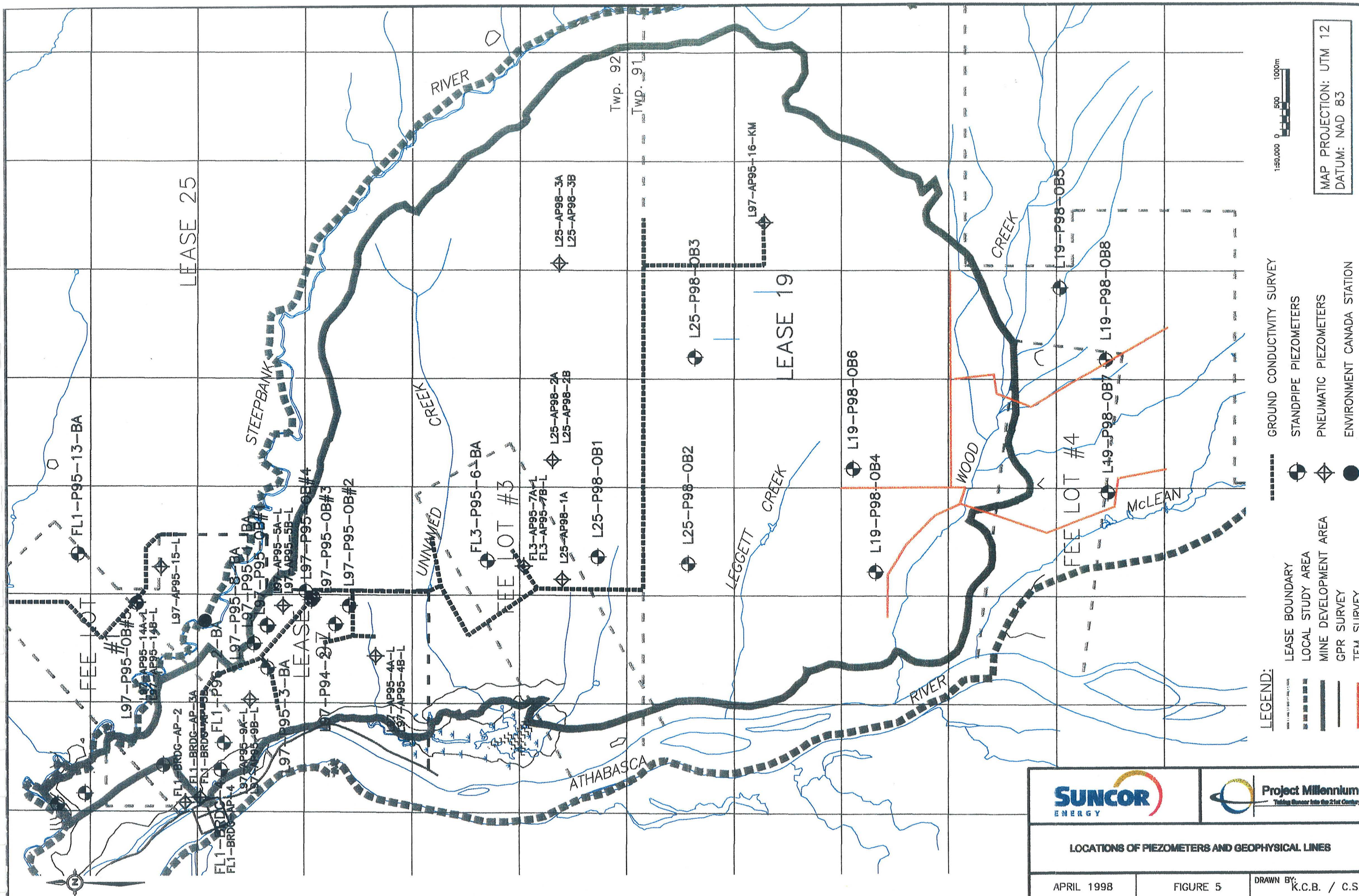
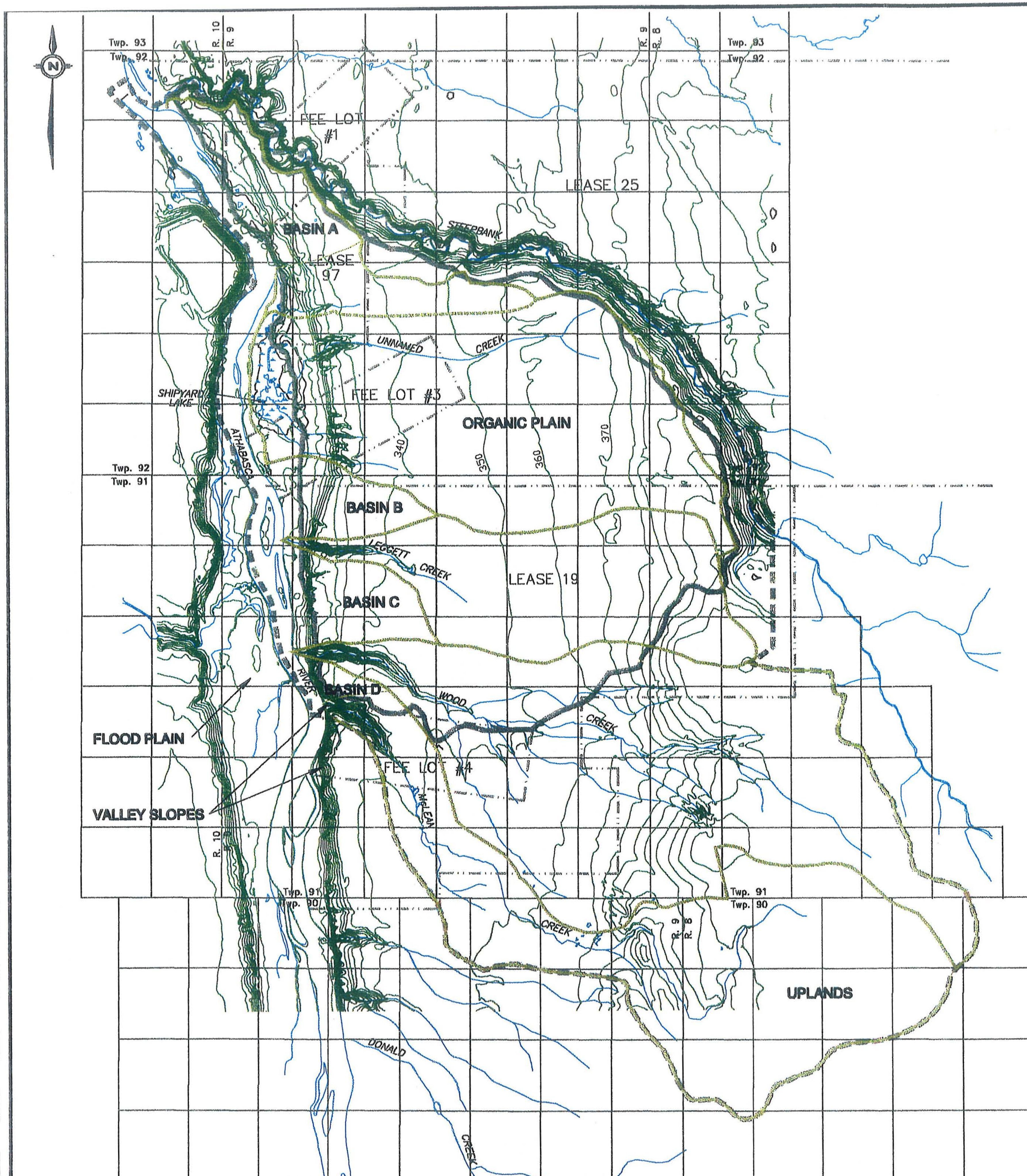
DATA DISTRIBUTION FOR MAPPING

APRIL 1998	FIGURE 4	DRAWN BY: K.C.B. / C.S.F.



LOCATIONS OF PIEZOMETERS AND GEOPHYSICAL LINES

APRIL 1998 | FIGURE 5 | DRAWN BY: K.C.B. / C.S.F.



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- GROUND TOPOGRAPHY
- DRAINAGE BOUNDARY

1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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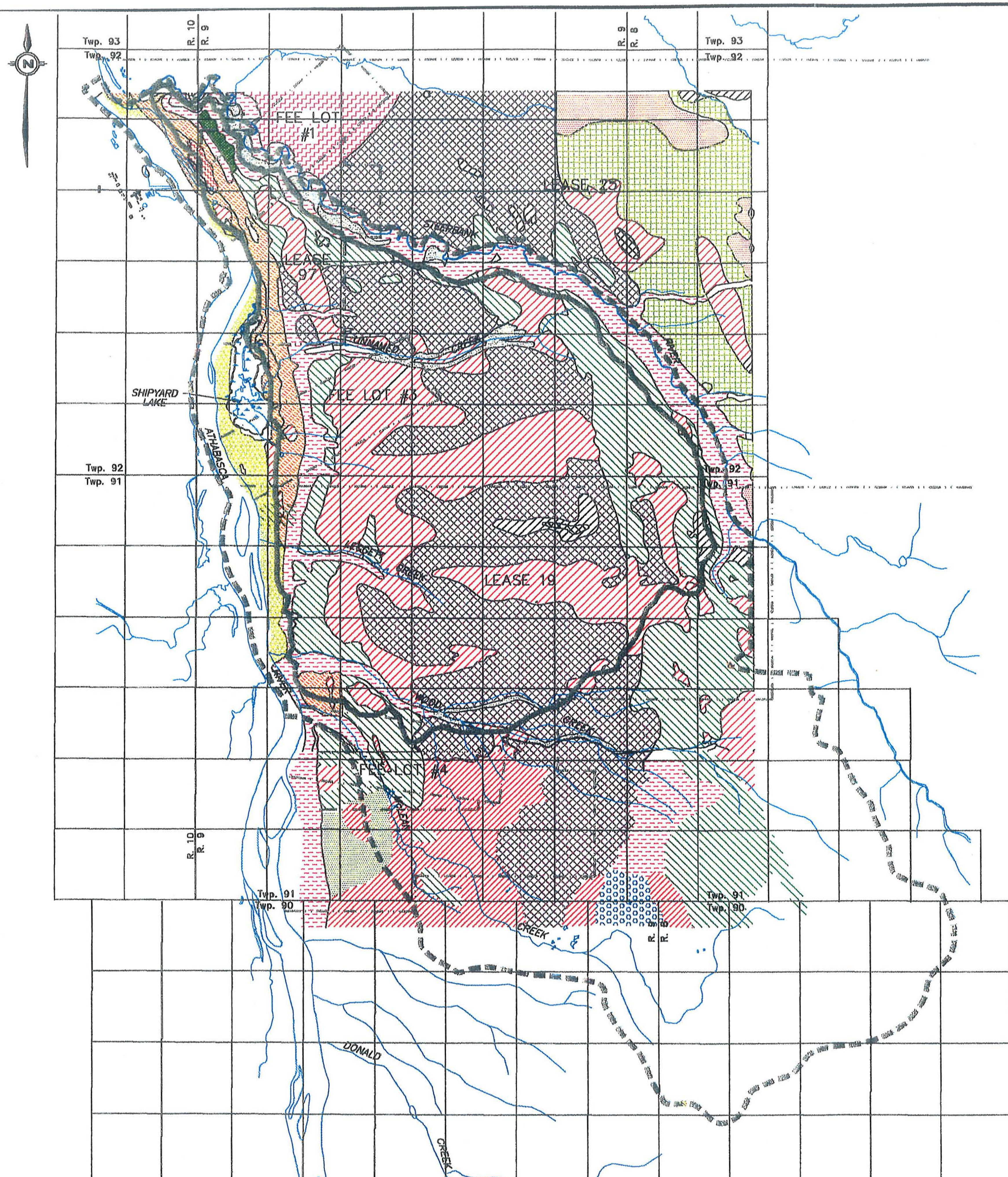
GROUND SURFACE TOPOGRAPHY - BASELINE CONDITIONS

APRIL 1998	FIGURE 6	DRAWN BY: K.C.B. / C.S.F.

2839w035.dwg



LEGEND:

- LOW RELIEF TILL, a) OVERLAIN BY DISCONTINUOUS MUSKEG
- OUTWASH SAND, a) OVERLAIN BY DISCONTINUOUS MUSKEG
- MELTWATER CHANNEL SEDIMENT, a) OVERLAIN BY DISCONTINUOUS MUSKEG
- MIXED GLACIOLACUSTRINE DEPOSITS, a) OVERLAIN BY DISCONTINUOUS MUSKEG
- ALLUVIAL SILT AND CLAY, OVERLAIN BY ALLUVIAL SAND AND GRAVEL
- ALLUVIAL SAND
- MUSKEG
- ERODED SLOPE, STREAM GULLEY
- KAMES AND KAME MORAINE

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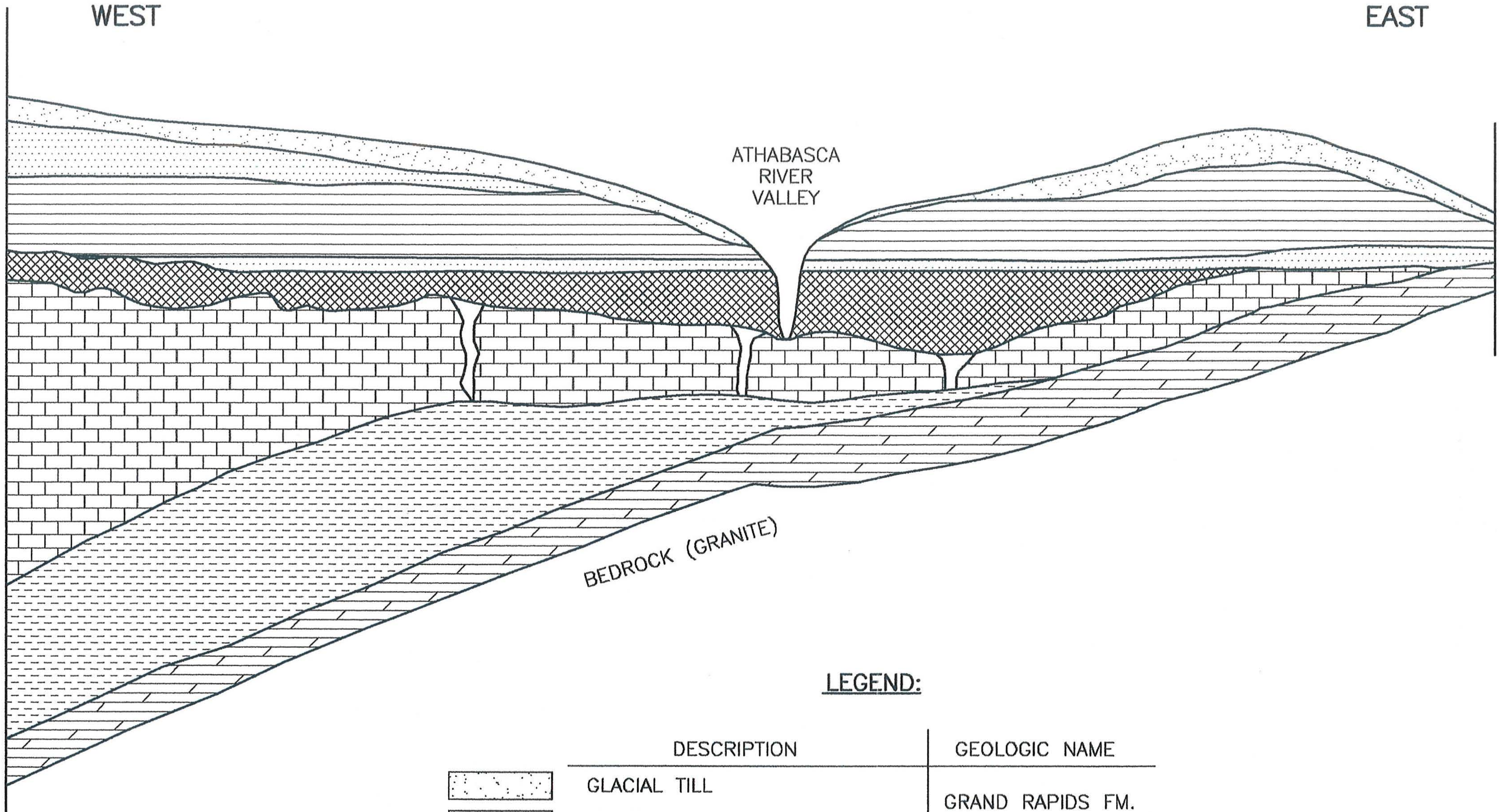
SURFICIAL GEOLOGY MAP (AFTER McPHERSON AND KATHOL 1977)

APRIL 1998	FIGURE 7	DRAWN BY: K.C.B. / C.S.F.

2830w12B.dwg



LEGEND:

DESCRIPTION	GEOLOGIC NAME
GLACIAL TILL	GRAND RAPIDS FM. CLEARWATER FM. –WABISKAW MBR.
SHALE	
SAND	
BITUMINOUS SANDS	McMURRAY FM.
LIMESTONE	UPPER DEVONIAN
SALT (IMPERMEABLE LAYER)	
DOLOMITE	MIDDLE DEVONIAN
SINK HOLES	

0 5 20Km
VERTICAL EXAGGERATION x85

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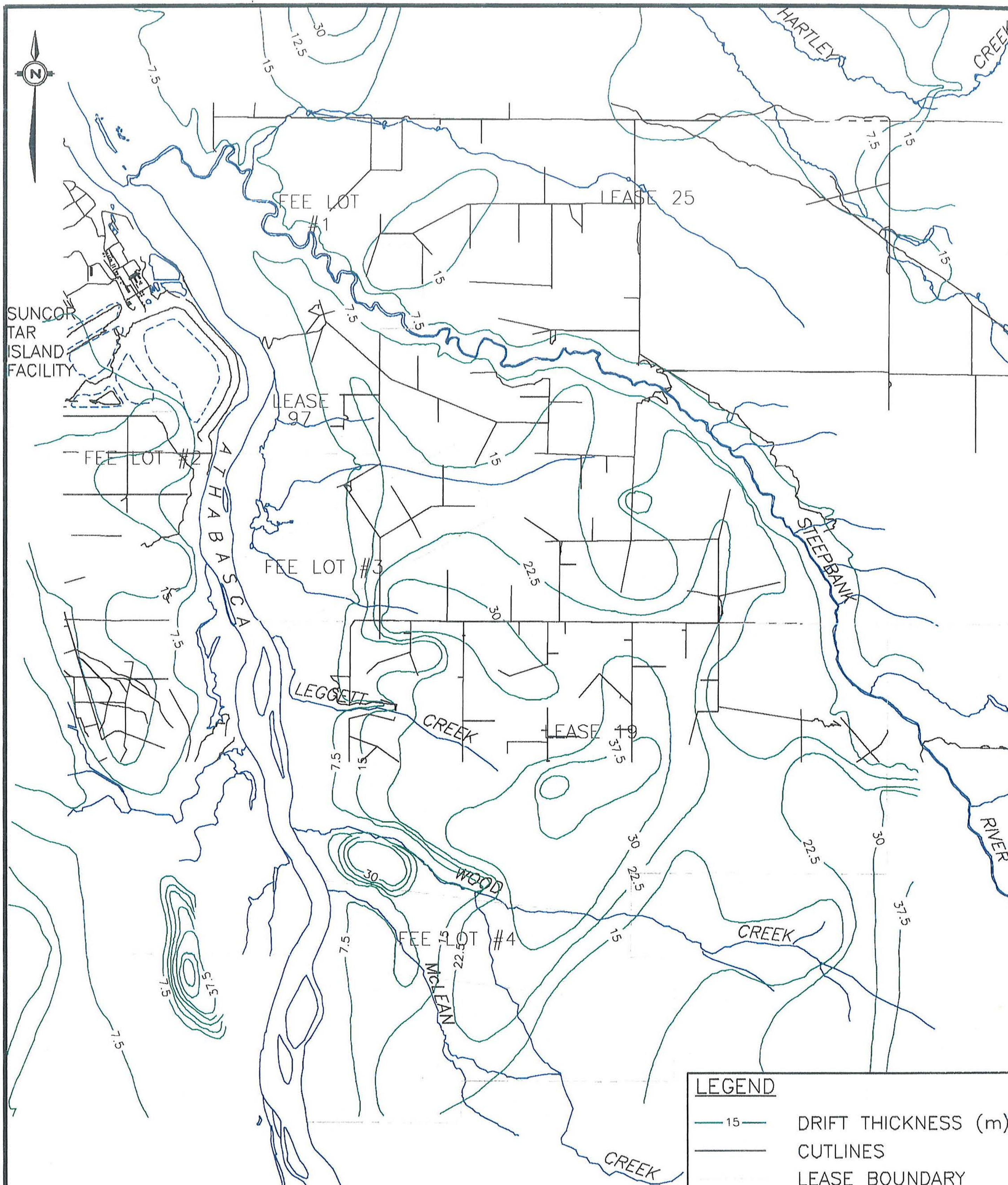
CONCEPTUALIZED REGIONAL GEOLOGY CROSS SECTION (MODIFIED FROM CARRIGY, 1973)

APRIL 1998	FIGURE 9	DRAWN BY: K.C.B. / C.S.F.

2839w041.dwg



1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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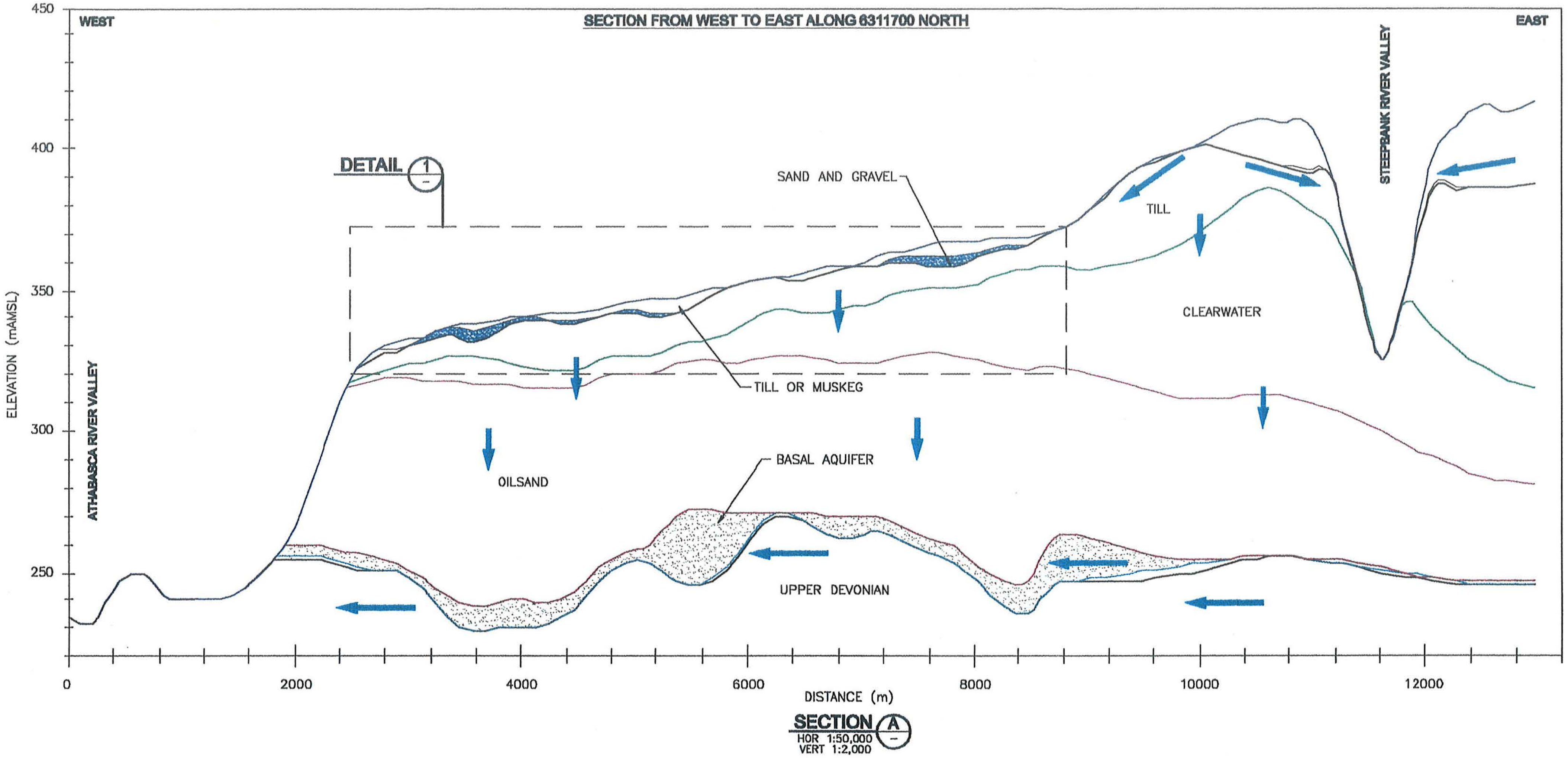
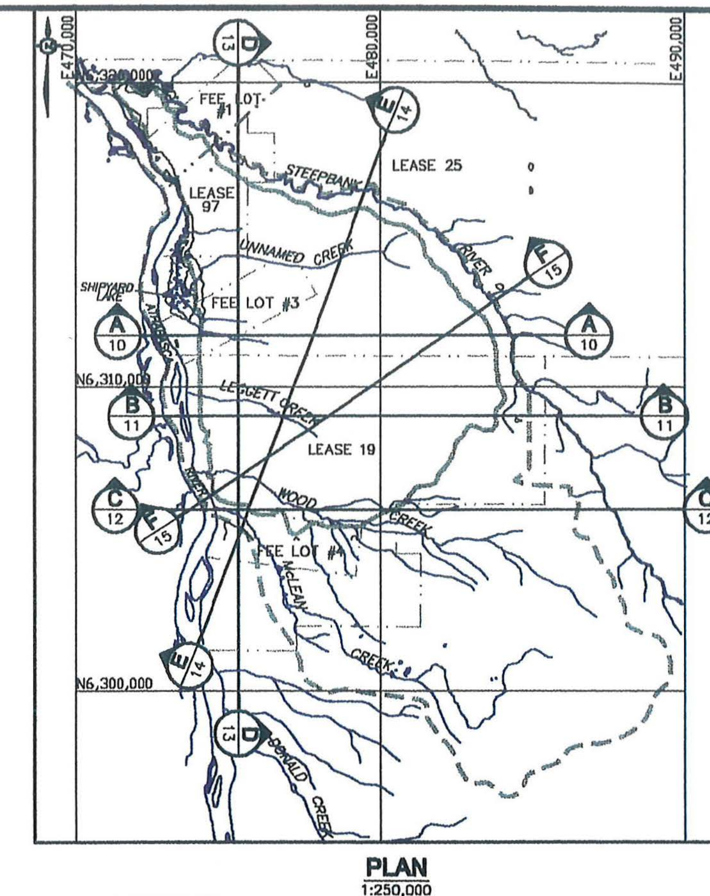
DRIFT THICKNESS (AFTER MCPHERSON AND KATHOL 1977)

APRIL 1998	FIGURE 8	DRAWN BY: K.C.B. / C.S.F.

2B39w042.dwg



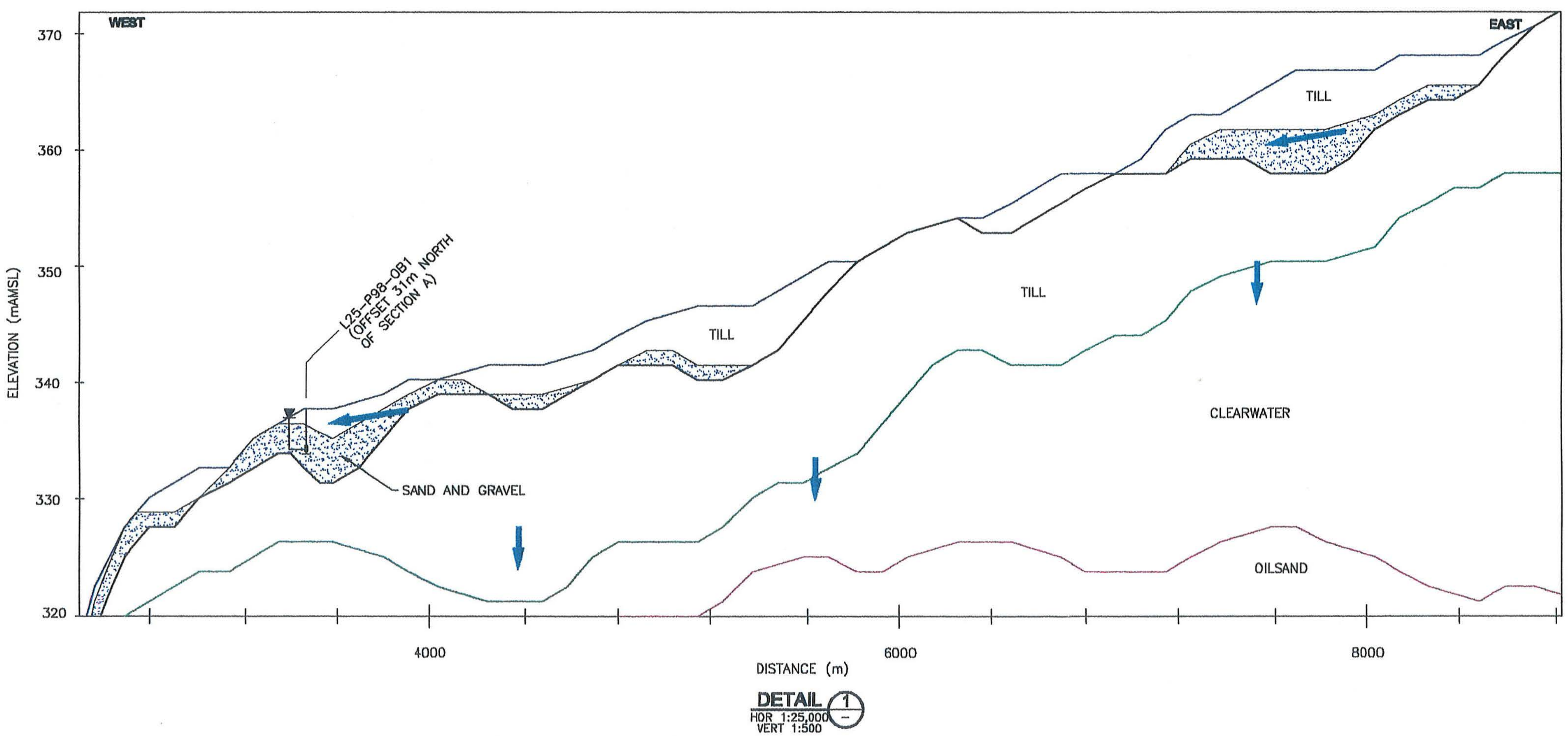


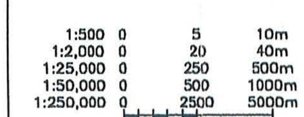
LEGEND:

- GROUND SURFACE
- TOP OF SAND AND GRAVEL
- SAND AND GRAVEL
- TOP OF TILL
- TOP OF CLEARWATER
- TOP OF McMURRAY
- TOP OF BASAL AQUIFER
- BASE OF BASAL AQUIFER
- BASAL AQUIFER
- TOP OF UPPER DEVONIAN
- HYDRAULIC HEAD
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE COMPLETION ZONES OF PIEZOMETERS OFFSET FROM THE SECTION MAY NOT LINE UP WITH THE SECTIONS STRATIGRAPHY.





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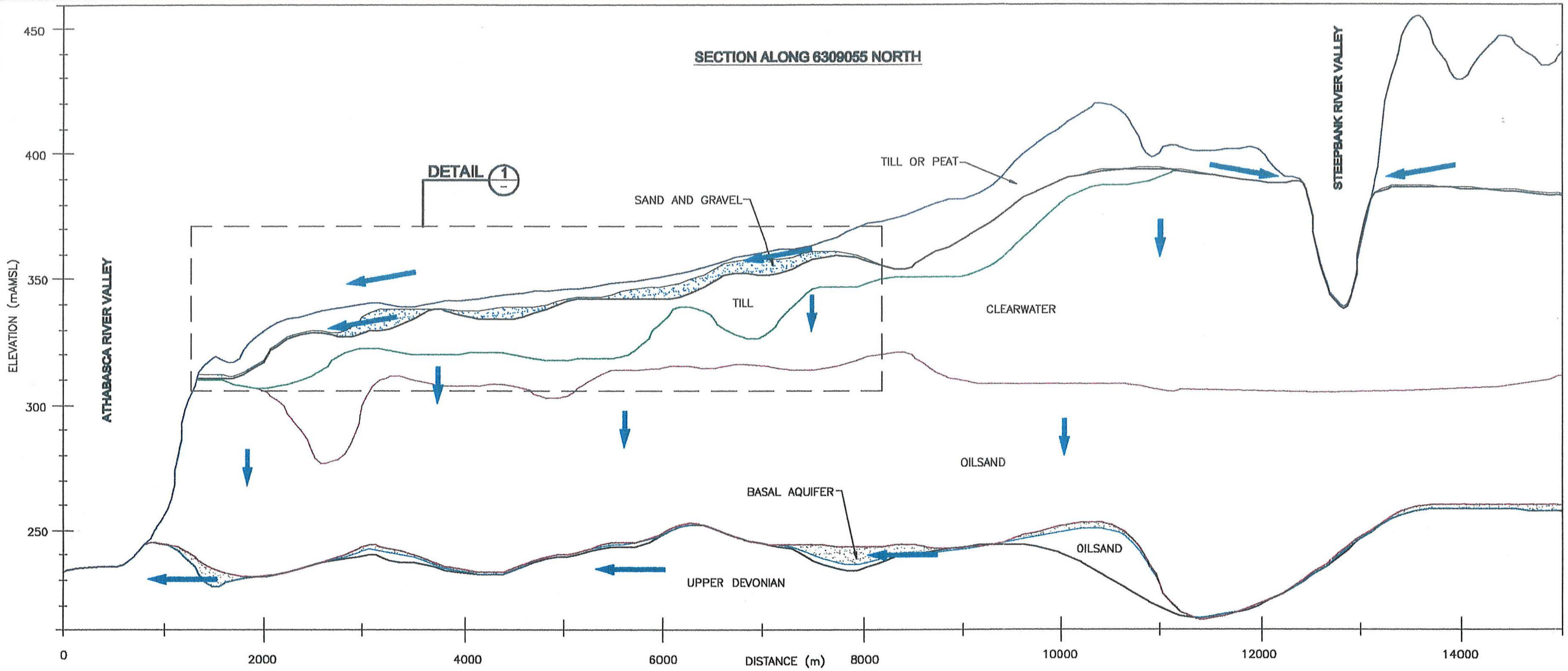
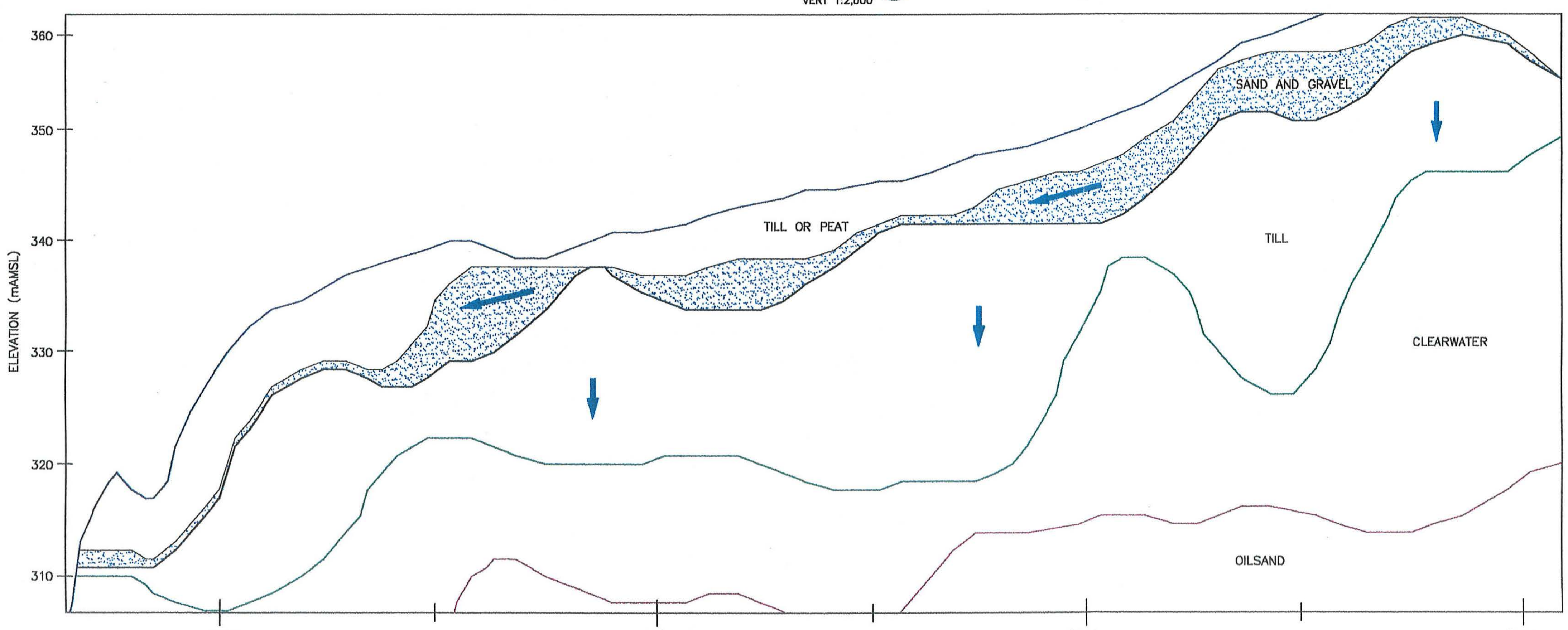
SECTION A

APRIL 1998	FIGURE 10	DRAWN BY: K.C.B. / C.S.F.

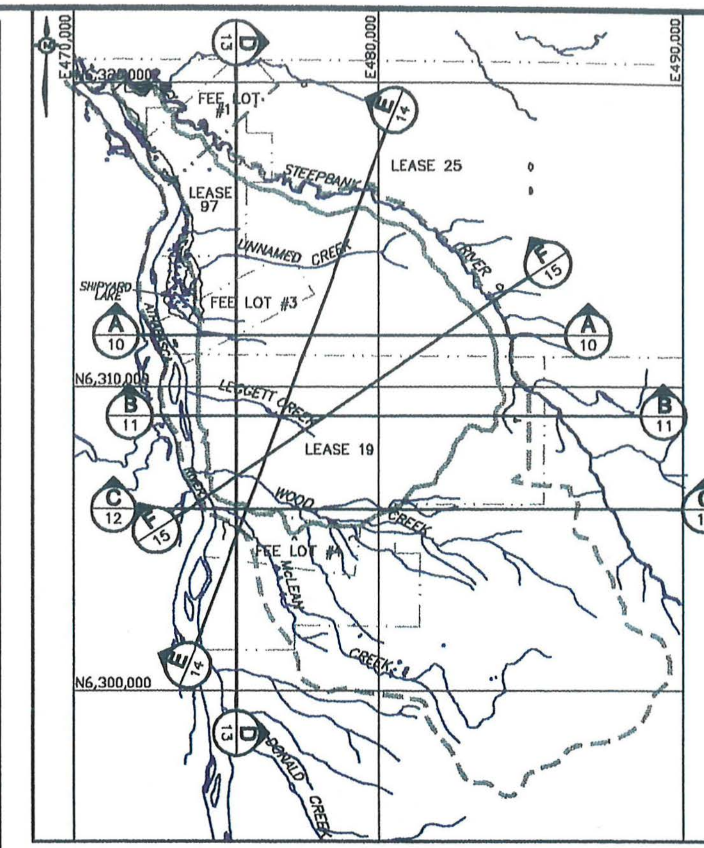
2839w100.dwg



SECTION B
HOR 1:50,000
VERT 1:2,000



DETAIL 1
HOR 1:25,000
VERT 1:500



PLAN
1:250,000

LEGEND:

- GROUND SURFACE
- TOP OF SAND AND GRAVEL
- SAND AND GRAVEL
- TOP OF TILL
- TOP OF CLEARWATER
- TOP OF McMURRAY
- TOP OF BASAL AQUIFER
- BASE OF BASAL AQUIFER
- BASAL AQUIFER
- TOP OF UPPER DEVONIAN
- HYDRAULIC HEAD
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE COMPLETION ZONES OF PIEZOMETERS OFFSET FROM THE SECTION MAY NOT LINE UP WITH THE SECTIONS STRATIGRAPHY.

1:500	0	5	10m
1:2,000	0	20	40m
1:25,000	0	250	500m
1:50,000	0	500	1000m
1:250,000	0	2500	5000m

SUNCOR ENERGY

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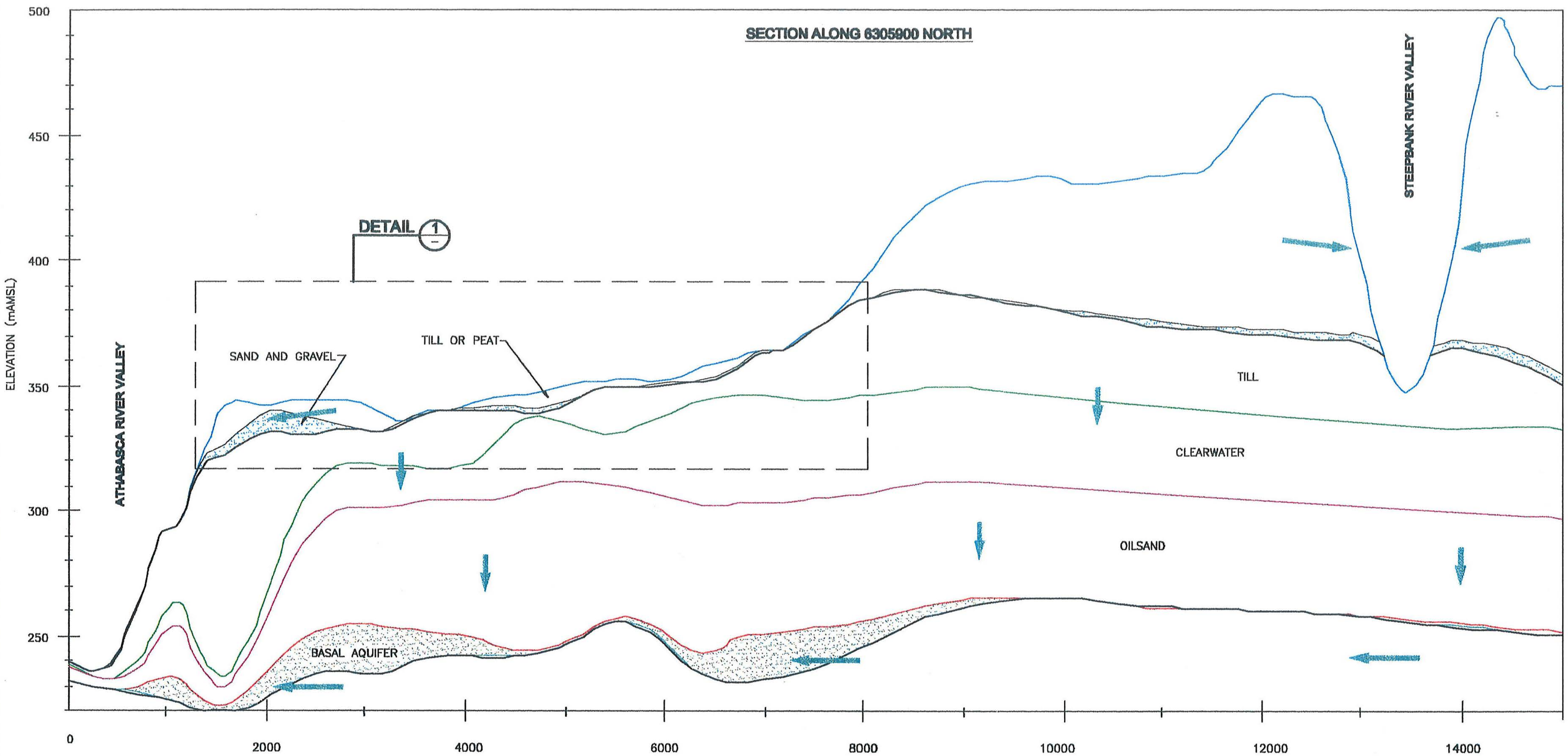
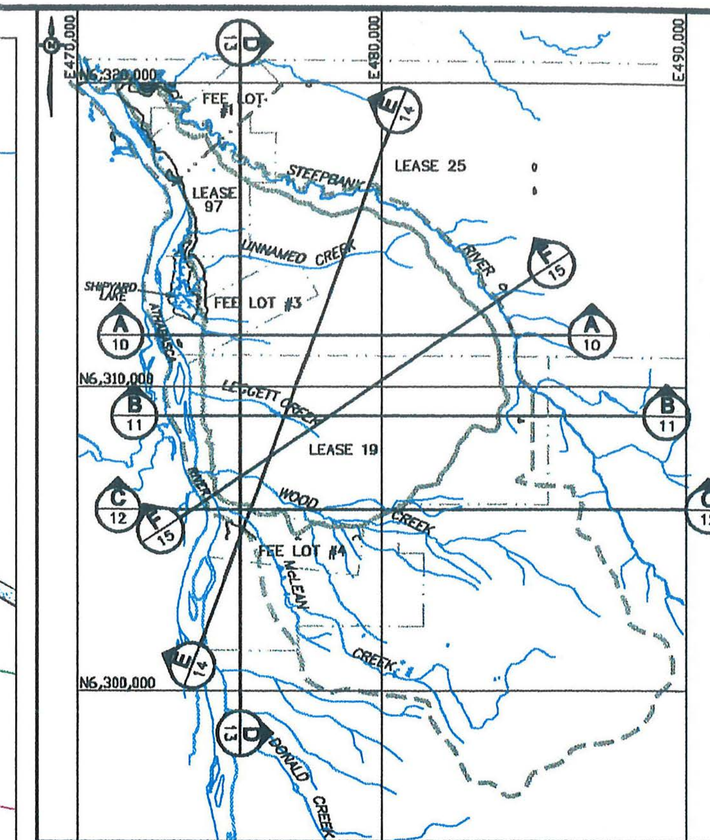
SECTION B

APRIL 1998	FIGURE 11	DRAWN BY: K.C.B. / C.S.F.

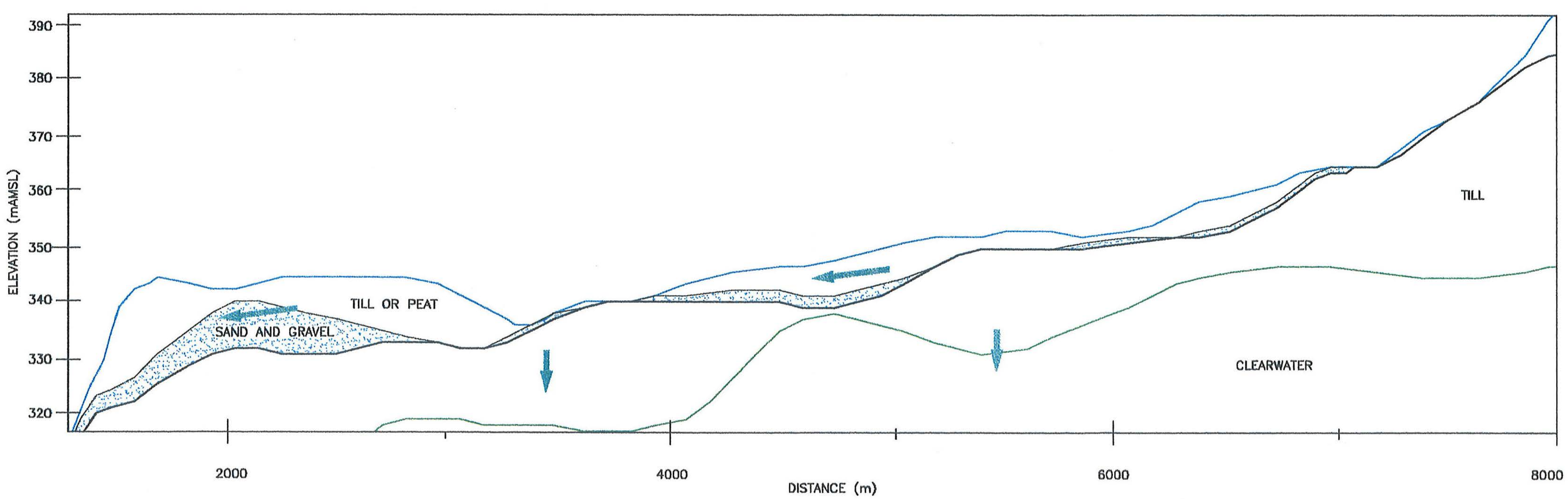
2839w101.dwg



SECTION C
HOR 1:50,000
VERT 1:2,000



PLAN
1:250,000



DETAIL 1
HOR 1:25,000
VERT 1:1,000

LEGEND:

- GROUND SURFACE
- TOP OF SAND AND GRAVEL
- SAND AND GRAVEL
- TOP OF TILL
- TOP OF CLEARWATER
- TOP OF McMURRAY
- TOP OF BASAL AQUIFER
- BASE OF BASAL AQUIFER
- BASAL AQUIFER
- TOP OF UPPER DEVONIAN
- HYDRAULIC HEAD
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE COMPLETION ZONES OF PIEZOMETERS OFFSET FROM THE SECTION MAY NOT LINE UP WITH THE SECTIONS STRATIGRAPHY.

Scale			
1:1,000	0	10	20m
1:2,000	0	20	40m
1:25,000	0	250	500m
1:50,000	0	500	1000m
1:250,000	0	2500	5000m

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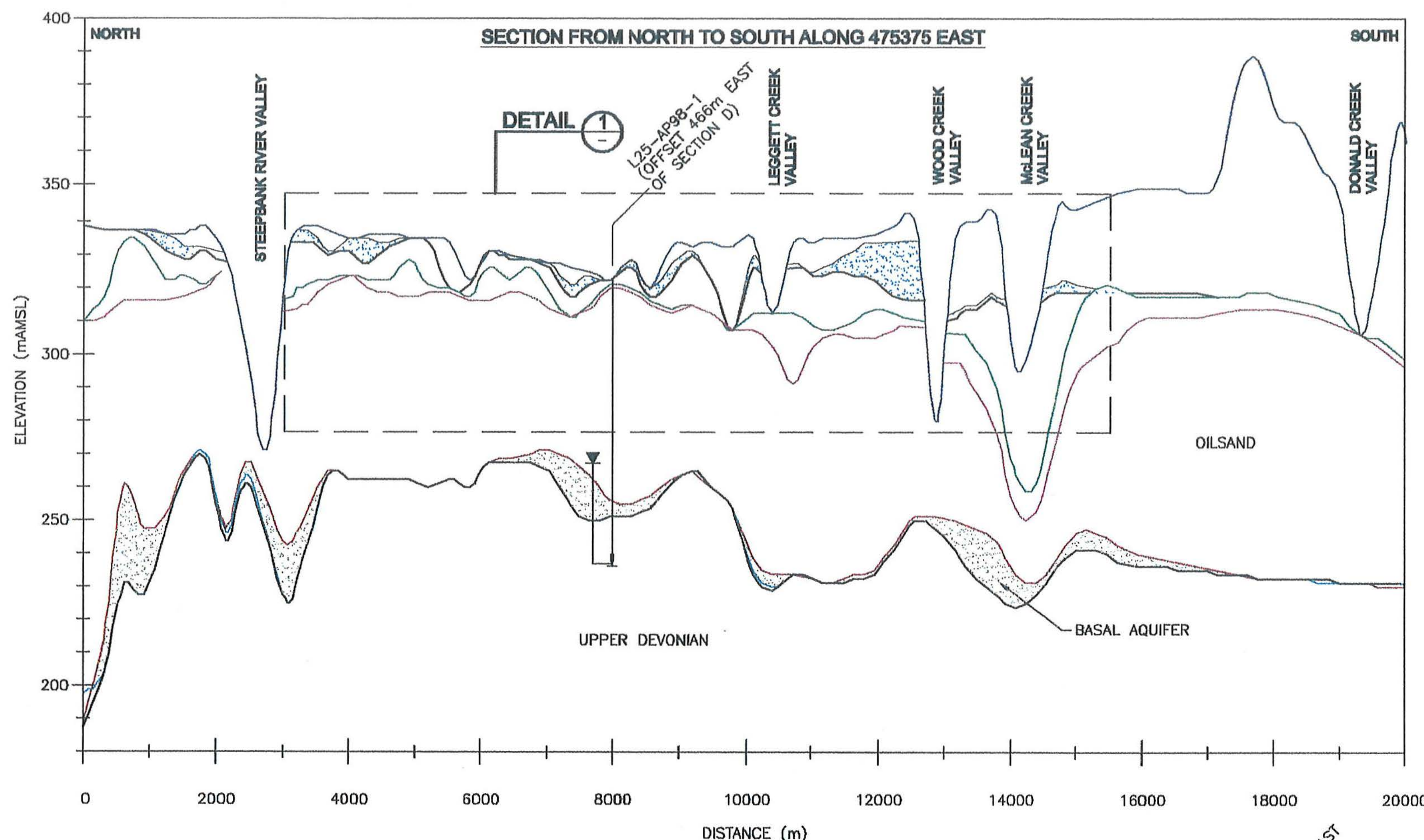
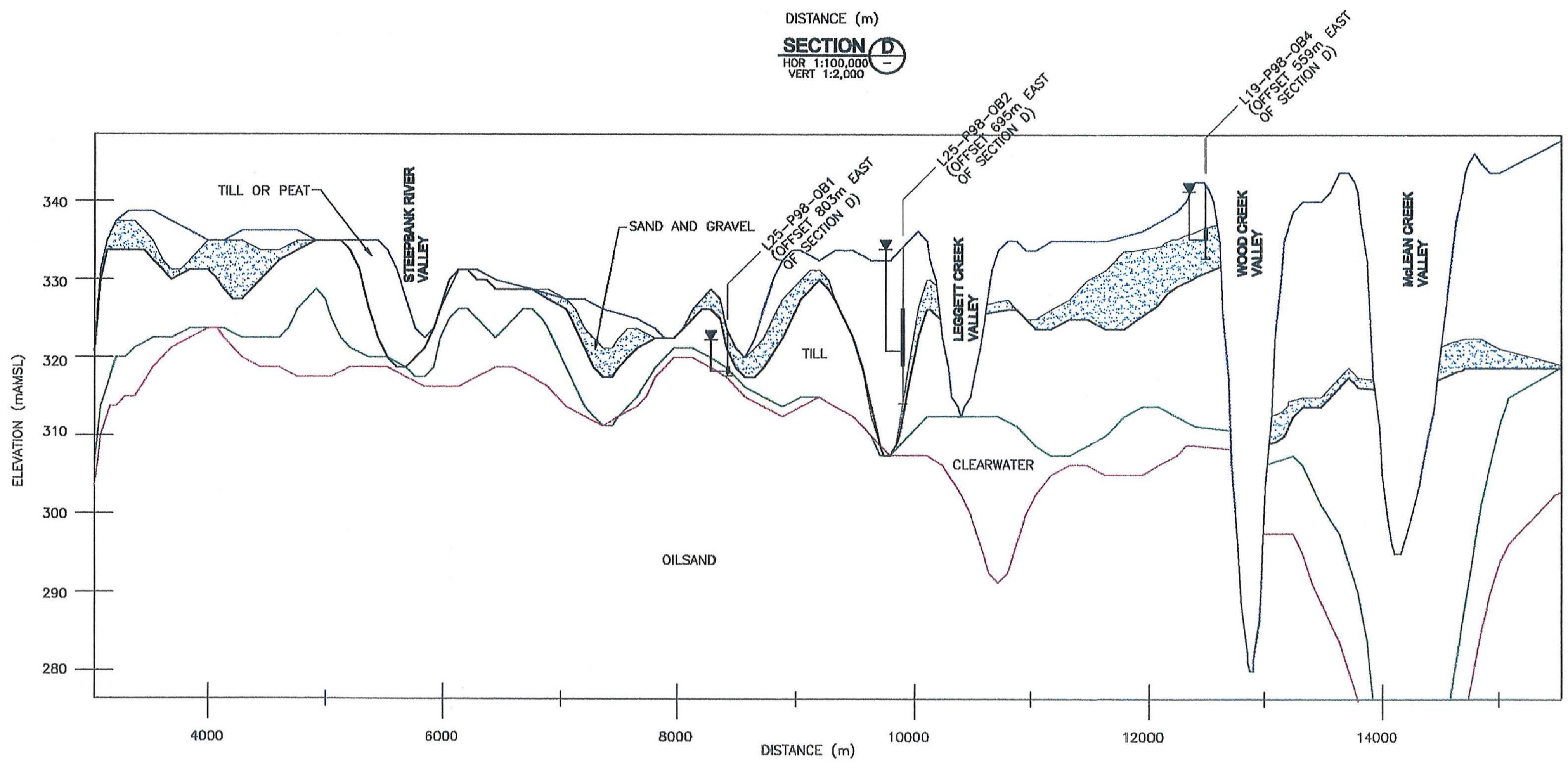
SECTION C

APRIL 1998	FIGURE 12	DRAWN BY: K.C.B. / C.S.F.

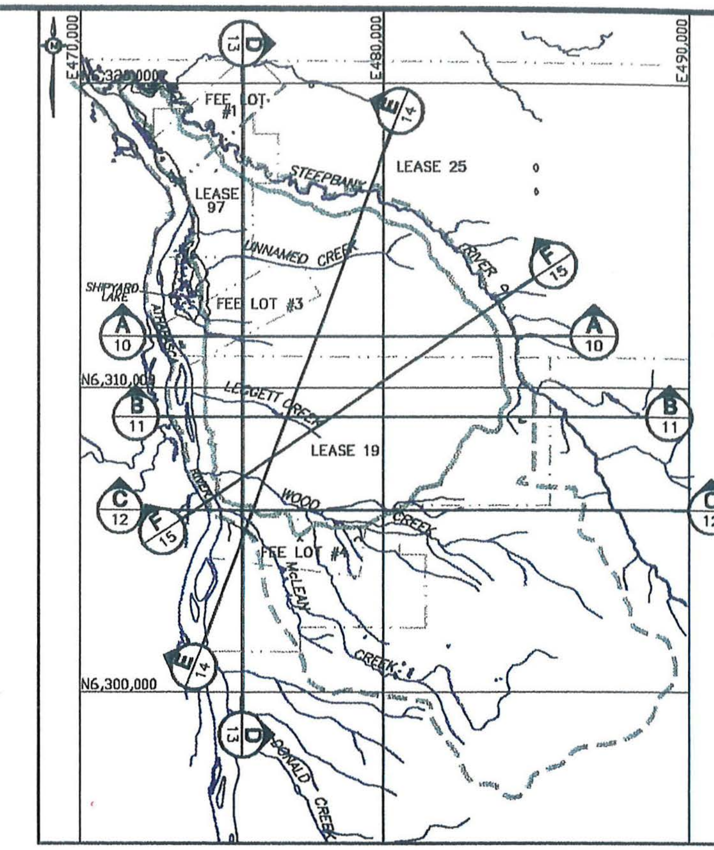
2839w102.dwg



SECTION D
HOR 1:100,000
VERT 1:2,000



DETAIL 1
HOR 1:50,000
VERT 1:750



PLAN
1:250,000

LEGEND:

- GROUND SURFACE
- TOP OF SAND AND GRAVEL
- SAND AND GRAVEL
- TOP OF TILL
- TOP OF CLEARWATER
- TOP OF McMURRAY
- TOP OF BASAL AQUIFER
- BASE OF BASAL AQUIFER
- BASAL AQUIFER
- TOP OF UPPER DEVONIAN
- HYDRAULIC HEAD

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE COMPLETION ZONES OF PIEZOMETERS OFFSET FROM THE SECTION MAY NOT LINE UP WITH THE SECTIONS STRATIGRAPHY.

1:750	0	7.5	15m
1:2,000	0	20	40m
1:50,000	0	500	1000m
1:100,000	0	1000	2000m
1:250,000	0	2500	5000m

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SECTION D

APRIL 1998	FIGURE 13	DRAWN BY: K.C.B. / C.S.F.

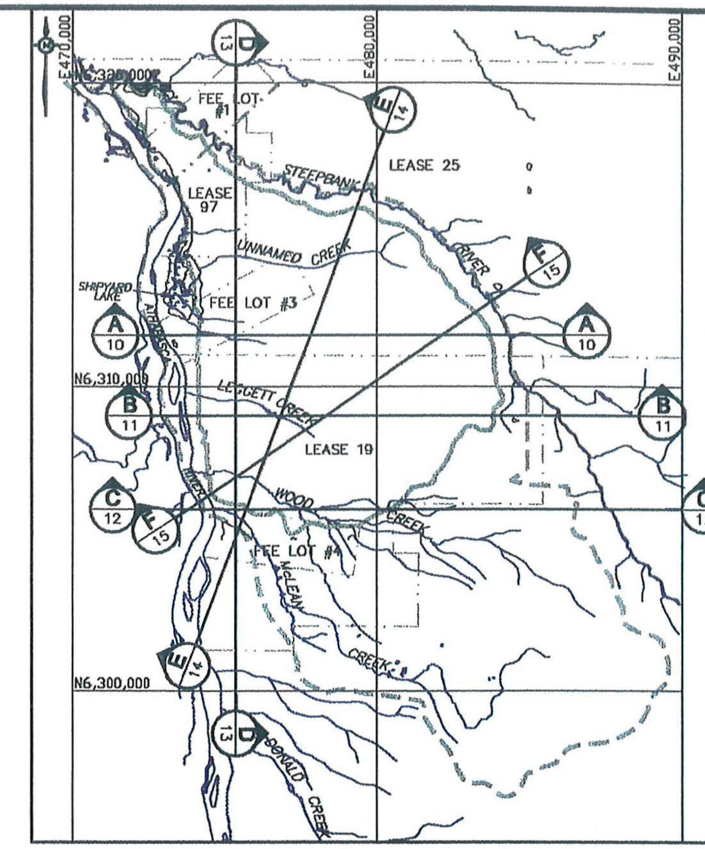
2839w103.dwg

LEGEND:

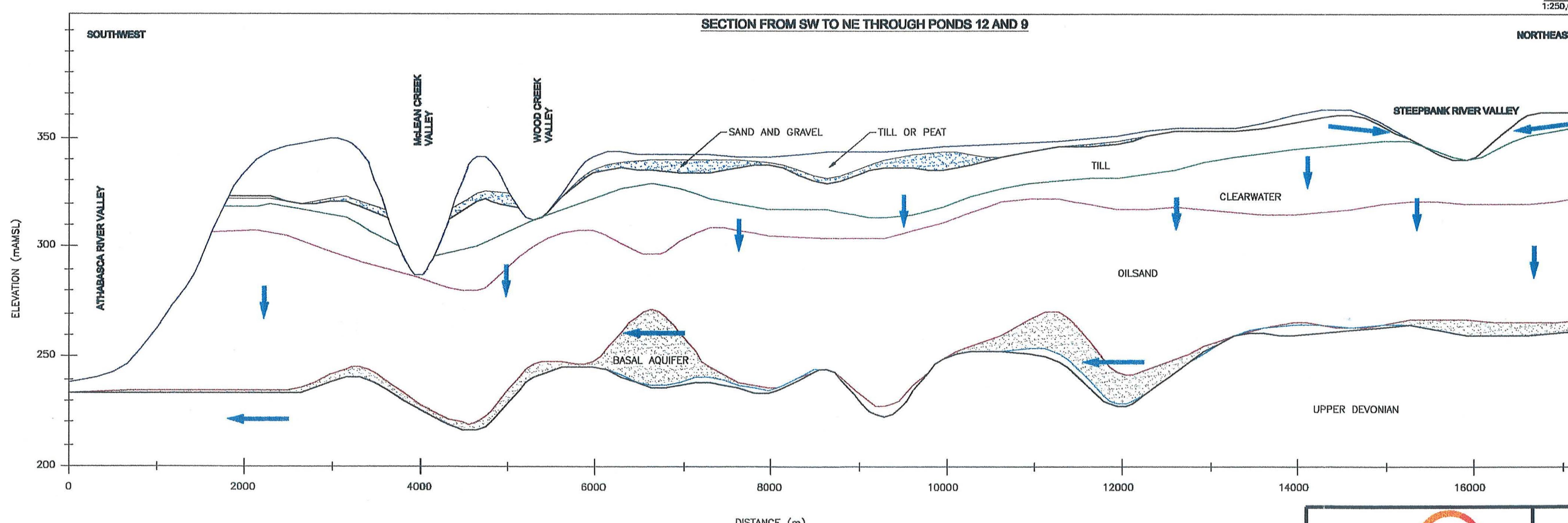
- GROUND SURFACE
- TOP OF SAND AND GRAVEL
- SAND AND GRAVEL
- TOP OF TILL
- TOP OF CLEARWATER
- TOP OF McMURRAY
- TOP OF BASAL AQUIFER
- BASE OF BASAL AQUIFER
- BASAL AQUIFER
- TOP OF UPPER DEVONIAN
- HYDRAULIC HEAD
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE COMPLETION ZONES OF PIEZOMETERS OFFSET FROM THE SECTION MAY NOT LINE UP WITH THE SECTIONS STRATIGRAPHY.



PLAN
1:250,000



SECTION E
HOR 1:50,000
VERT 1:2,000

1:2,000 0 20 40m
1:50,000 0 500 1000m
1:250,000 0 2500 5000m

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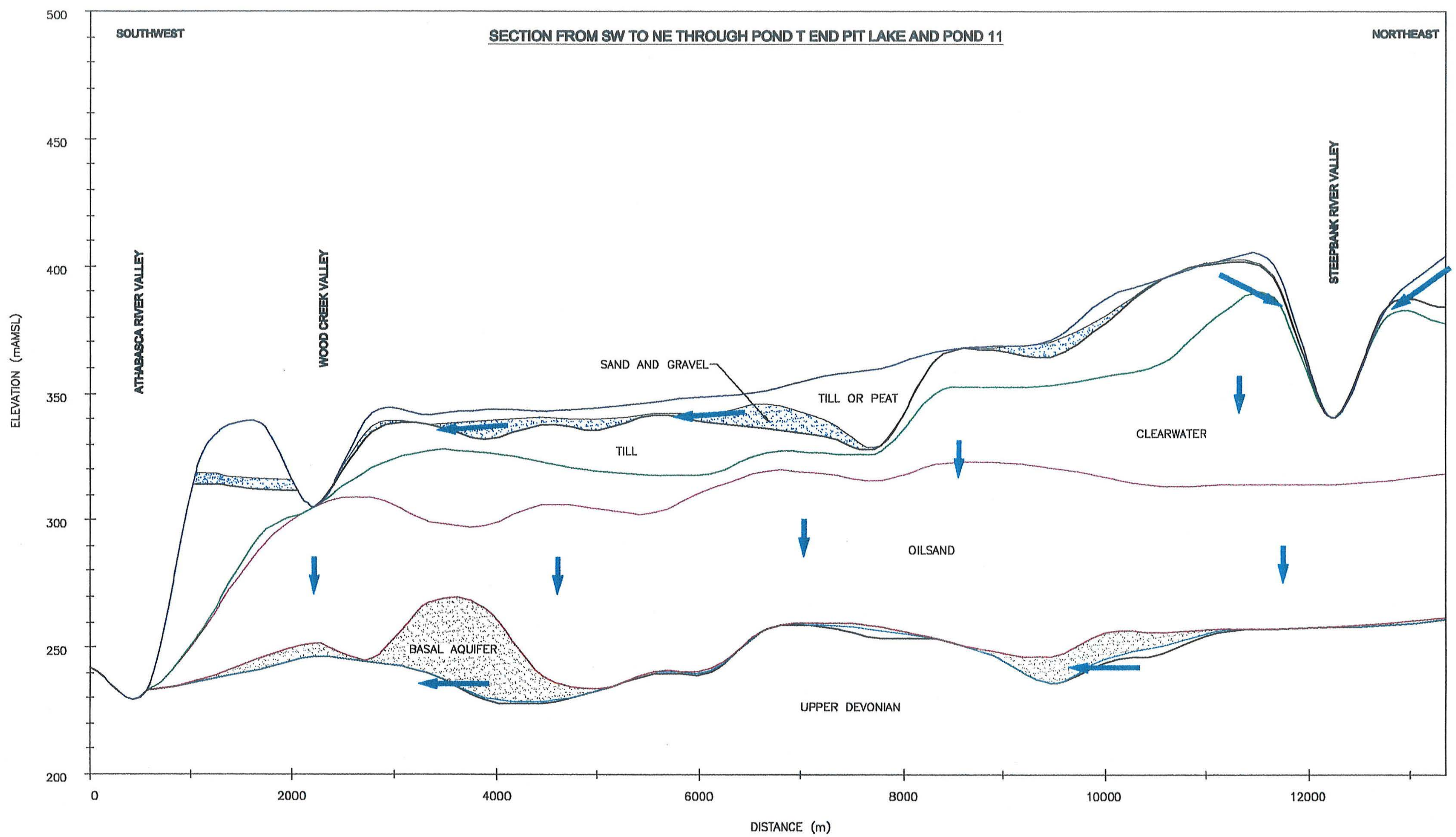
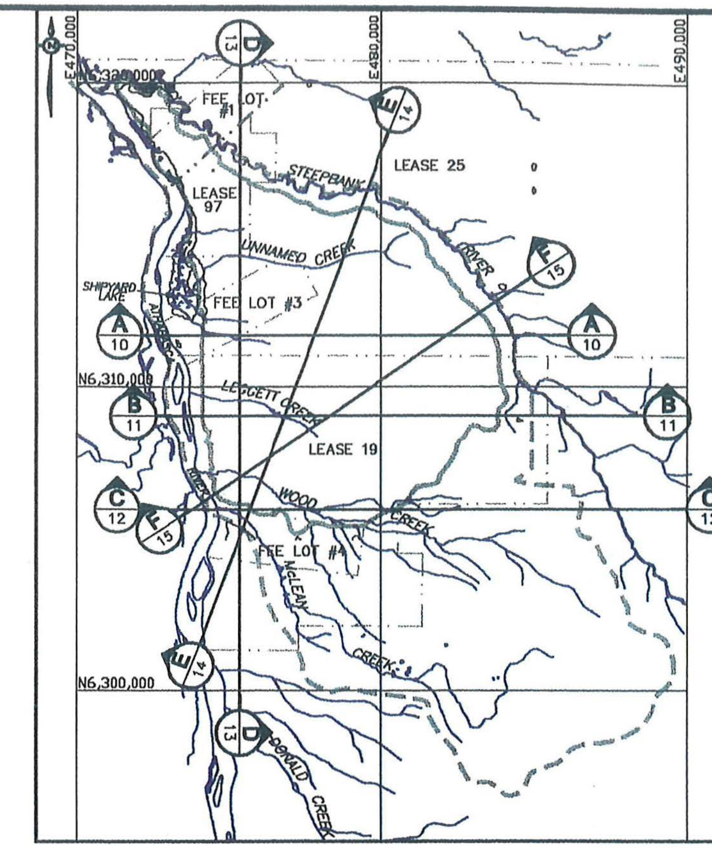
SECTION E

APRIL 1998	FIGURE 14	DRAWN BY: K.C.B. / C.S.F.

2839w104.dwg



SECTION F
HOR 1:50,000
VERT 1:2,000



PLAN
1:250,000

LEGEND:

- GROUND SURFACE
- TOP OF SAND AND GRAVEL
- SAND AND GRAVEL
- TOP OF TILL
- TOP OF CLEARWATER
- TOP OF McMURRAY
- TOP OF BASAL AQUIFER
- BASE OF BASAL AQUIFER
- BASAL AQUIFER
- TOP OF UPPER DEVONIAN
- HYDRAULIC HEAD
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE COMPLETION ZONES OF PIEZOMETERS OFFSET FROM THE SECTION MAY NOT LINE UP WITH THE SECTIONS STRATIGRAPHY.

1:2,000 0 20 40m
1:50,000 0 500 1000m
1:250,000 0 2500 5000m

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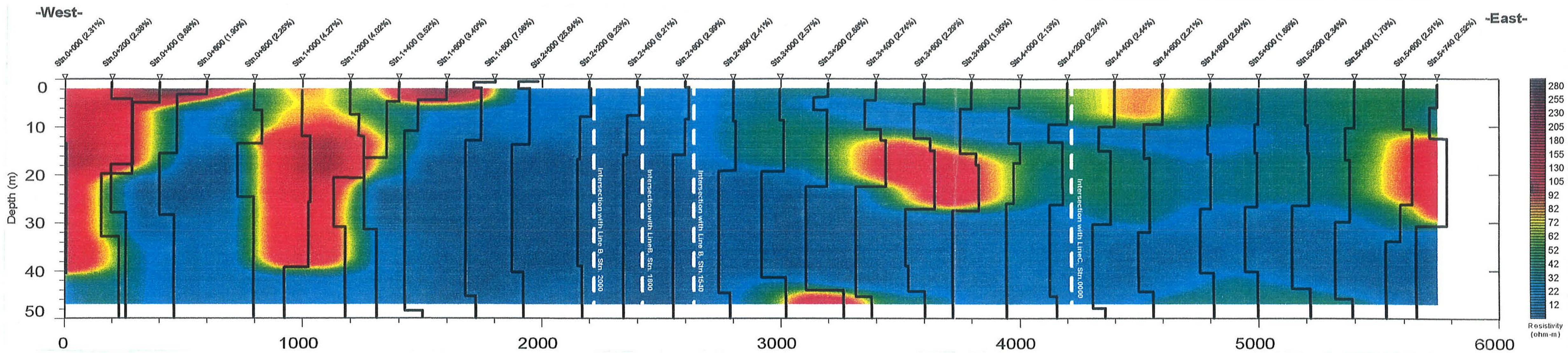
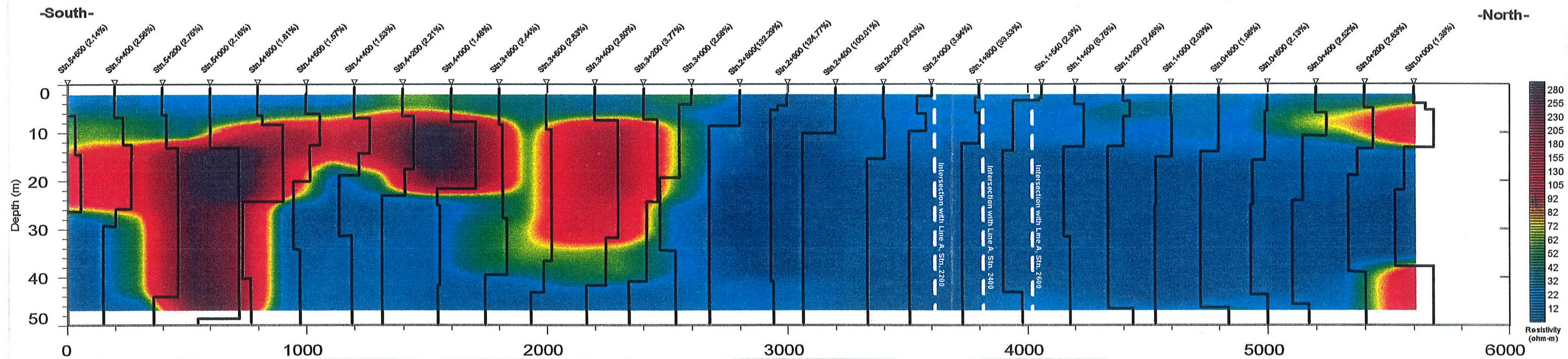
SECTION F

APRIL 1998	FIGURE 15	DRAWN BY: K.C.B. / C.S.F.

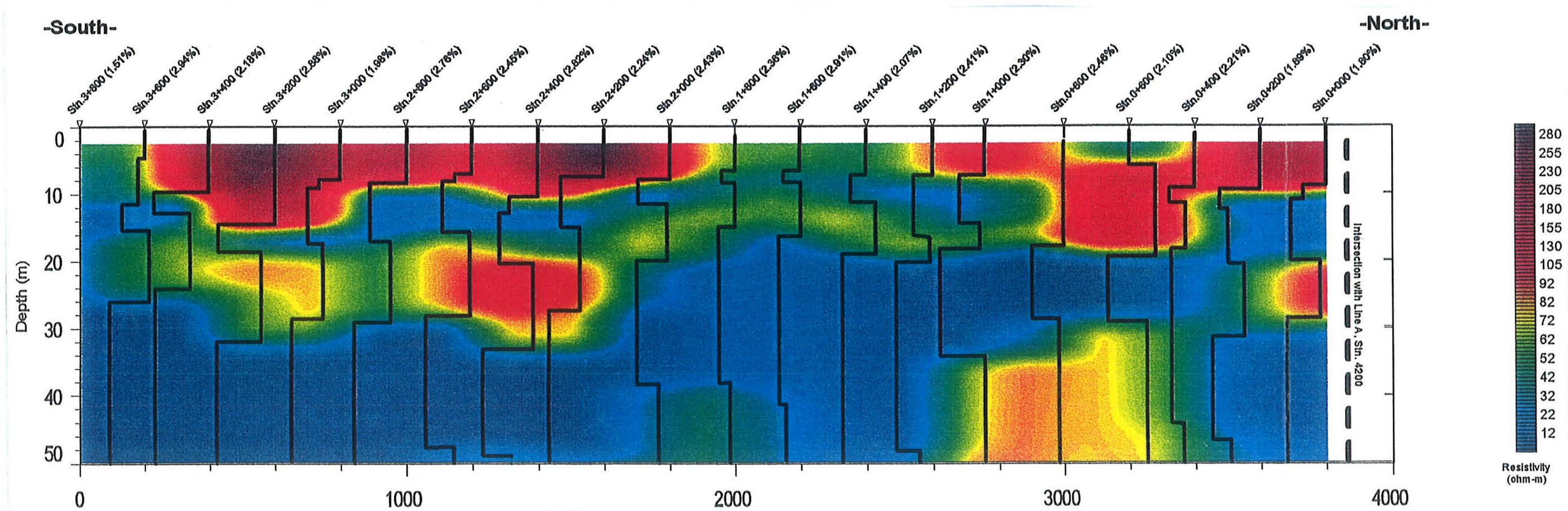
2839w105.dwg



LINE A-A



LINE B-B



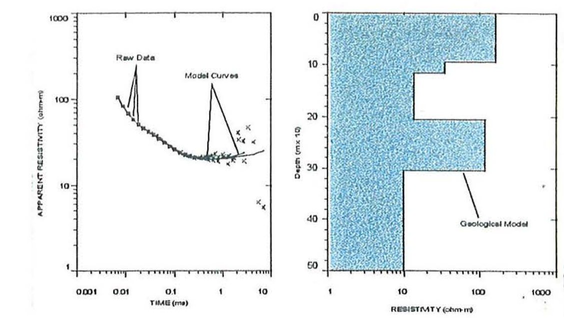
LINE C-C

TEM Modeling and Presentation:

The coloured cross-section describes the resistivity distribution of the initial 45 m of overburden. The image is derived from approximated geological models, which are plotted on top of the coloured resistivity image.

Forward inversion of an initial geological model estimate synthesizes the model curve. This curve can be iteratively adjusted to best-fit the raw data. The geologcal model adjusts as the corresponding model curve attempts to mimic the raw data. Fitting errors between the model curve and raw data are posted beside each measurement station in (%).

Equivalence theory of thickness-conductivity models suggests a multitude of model curves that could fit any raw data. In the absence of borehole information, the geological model is established by interpretive input and trend continuity of created models.



Technical Summary:

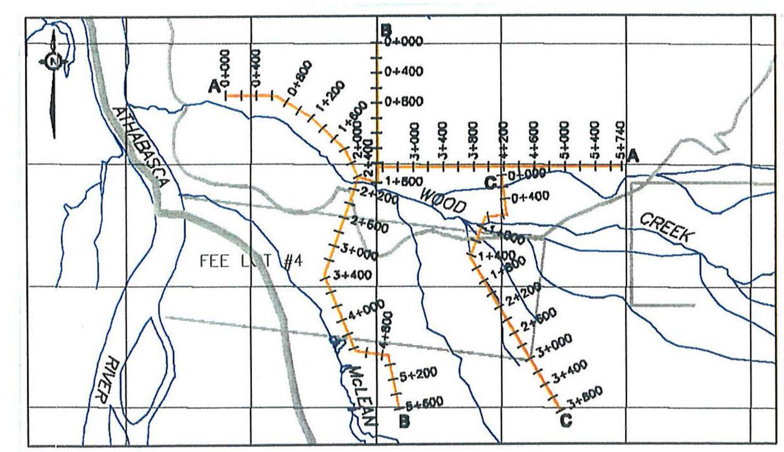
Tx Instrument: Geonics EM47
Rx Instrument: EM58/Protem D

Tx Loop Size: 20 m x 20 m
Tx Loop Current: 3 A
Sweep Frequencies: 285 Hz, 75 Hz, 30 Hz

Rx LoopSize: 31.4 m*m
Turn-off: 2.0 usecs.
Integration Time: 30 secs.

Note:

1. Coloured contour interval is not linear.
2. Units of measurement stations are in metres.
3. Percentages posted beside station numbers are errors-of-fit of model curves to raw data.



KEY PLAN
1:100,000

1:100,000 0 1000 2000m

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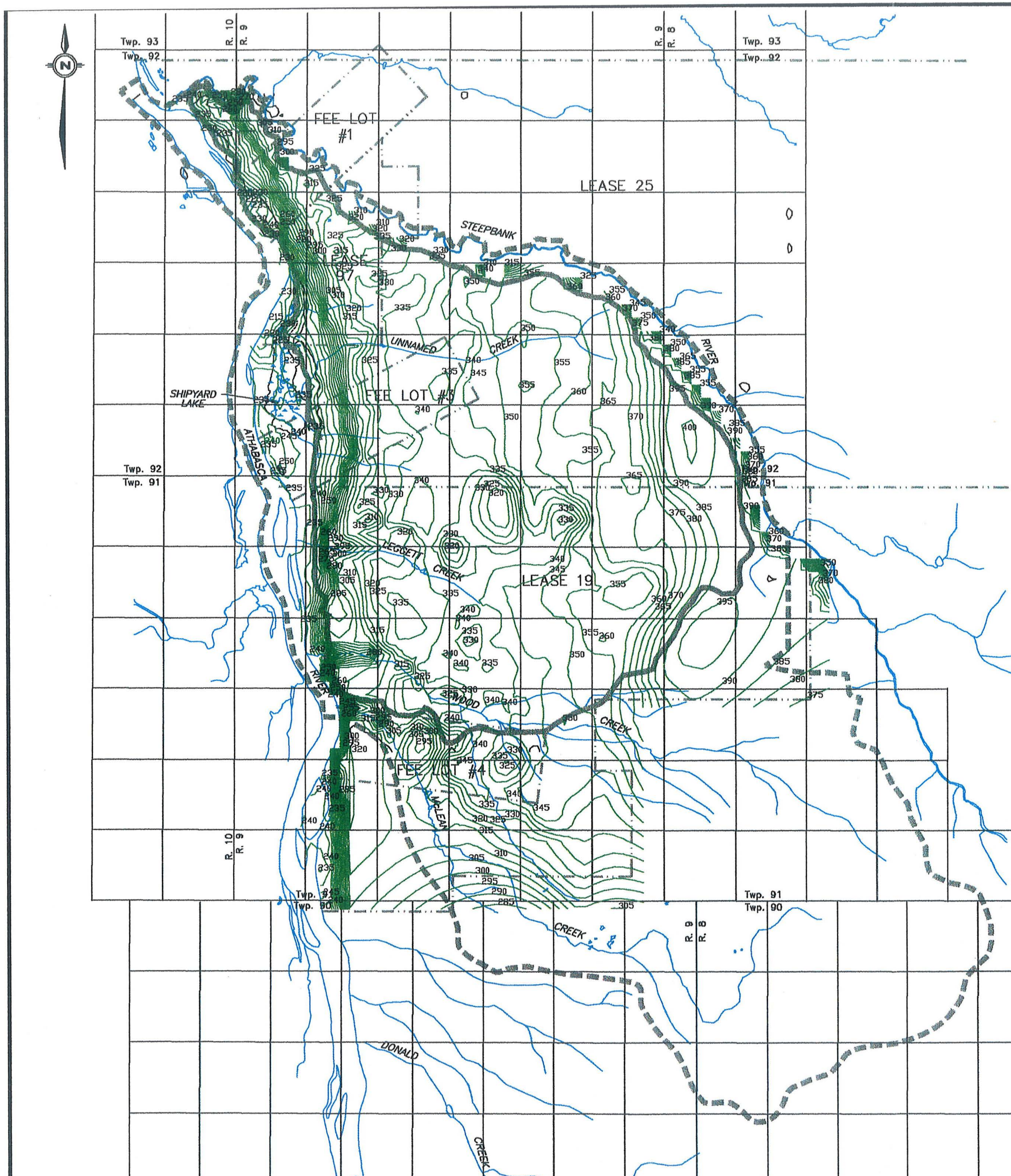
TEM RESISTIVITY PROFILES

APRIL 1998	FIGURE 16	DRAWN BY: K.C.B. / C.S.F.

2839w108.dwg



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- 352 TOP OF TILL (mAMSL)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 5m

1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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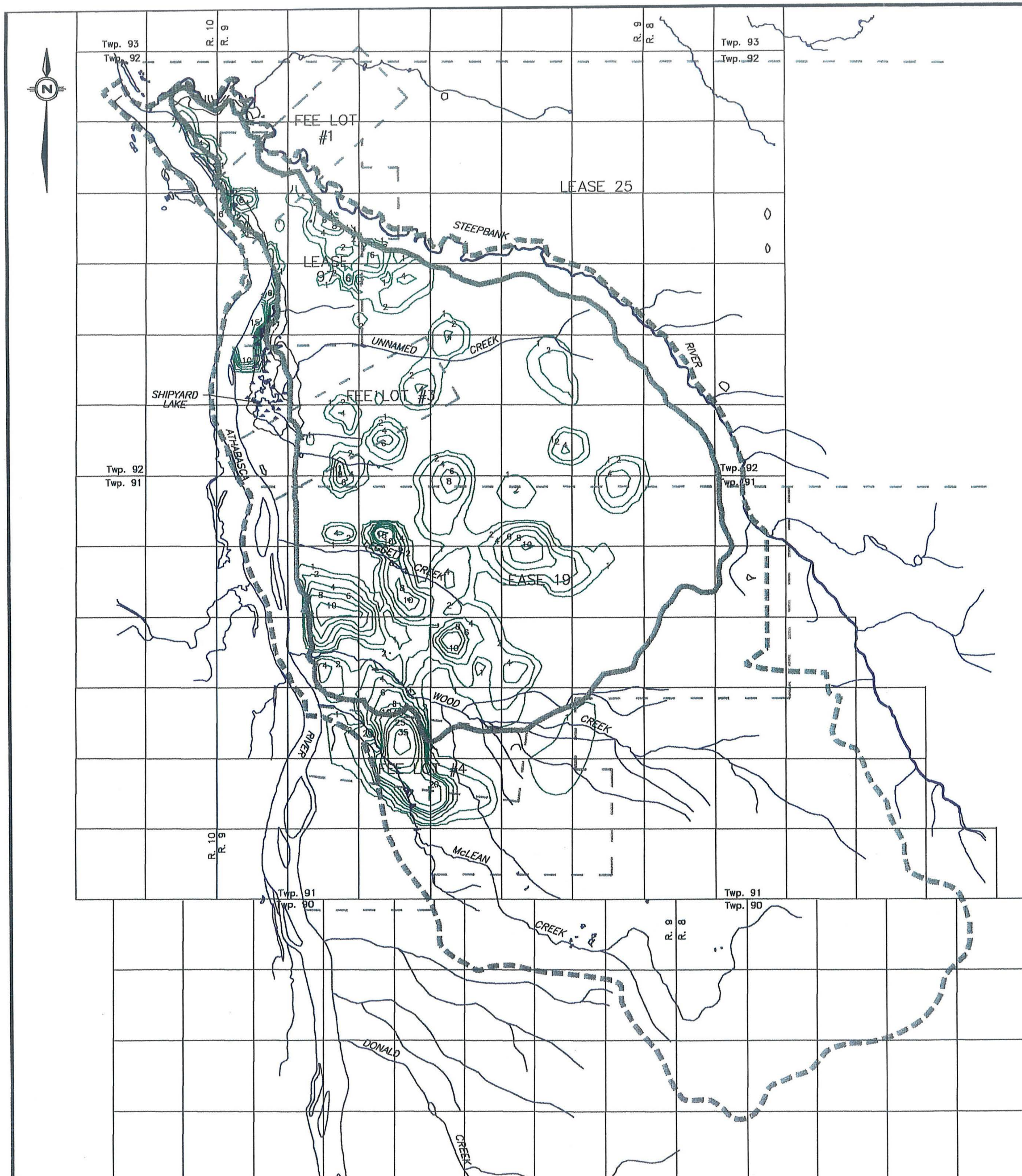
ELEVATION OF THE BASE OF THE SHALLOW SAND AND GRAVEL

APRIL 1998	FIGURE 17	DRAWN BY: C.S.F.

2839w117.dwg



LEGEND:

LEASE BOUNDARY

LOCAL STUDY AREA

MINE DEVELOPMENT AREA

2 ISOPACH OF SAND AND GRAVEL (m)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 2m

1:100,000 0 1 2km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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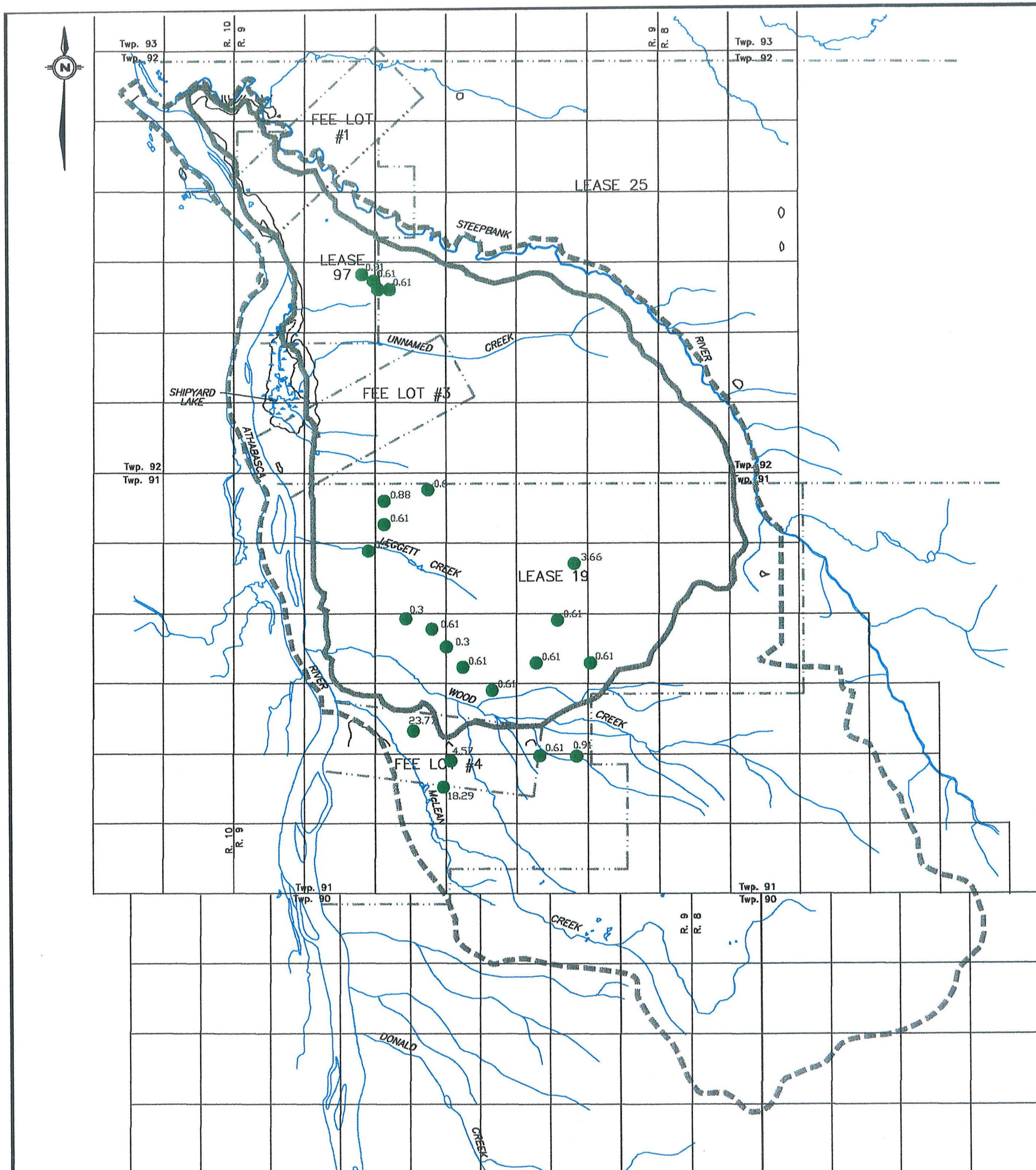
ISOPACH MAP OF SURFICIAL SAND AND GRAVEL

APRIL 1998	FIGURE 18	DRAWN BY: K.C.B. / C.S.F.

2839w045.dwg



1:100,000 0 1000 2000m

LEGEND:

LEASE BOUNDARY
LOCAL STUDY AREA
MINE DEVELOPMENT AREA
0.61 DEEP CONFINDED SAND AND GRAVEL LOCATIONS ESOPACH (m)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.

MAP PROJECTION: UTM 12
DATUM: NAD 83

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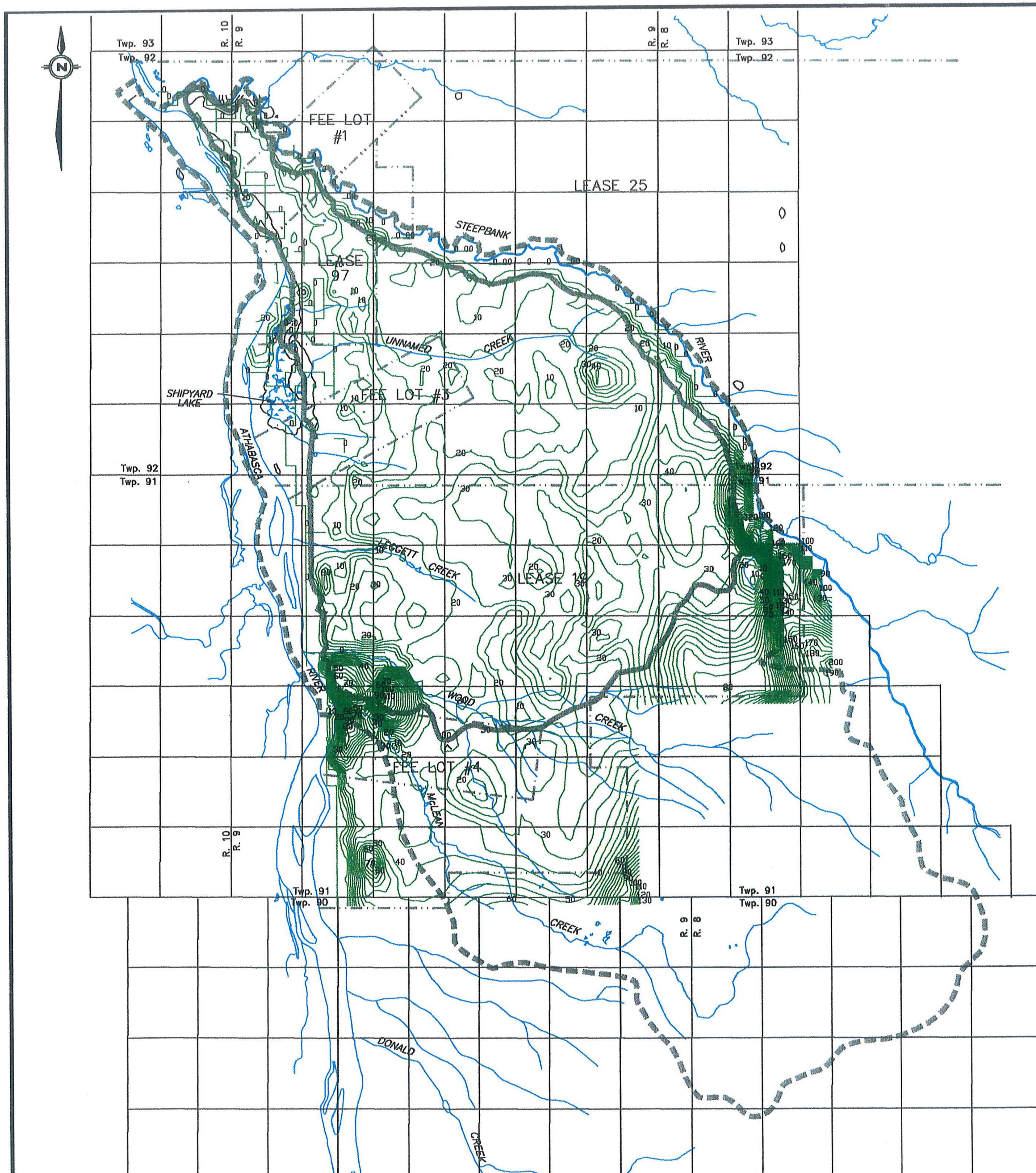
LOCATIONS WHERE DEEP CONFINED SAND AND GRAVEL WAS OBSERVED

APRIL 1998 | FIGURE 19 | DRAWN BY: K.C.B. / C.S.F.

2839w116.dwg



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- 20 DRIFT THICKNESS (m)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 5m

1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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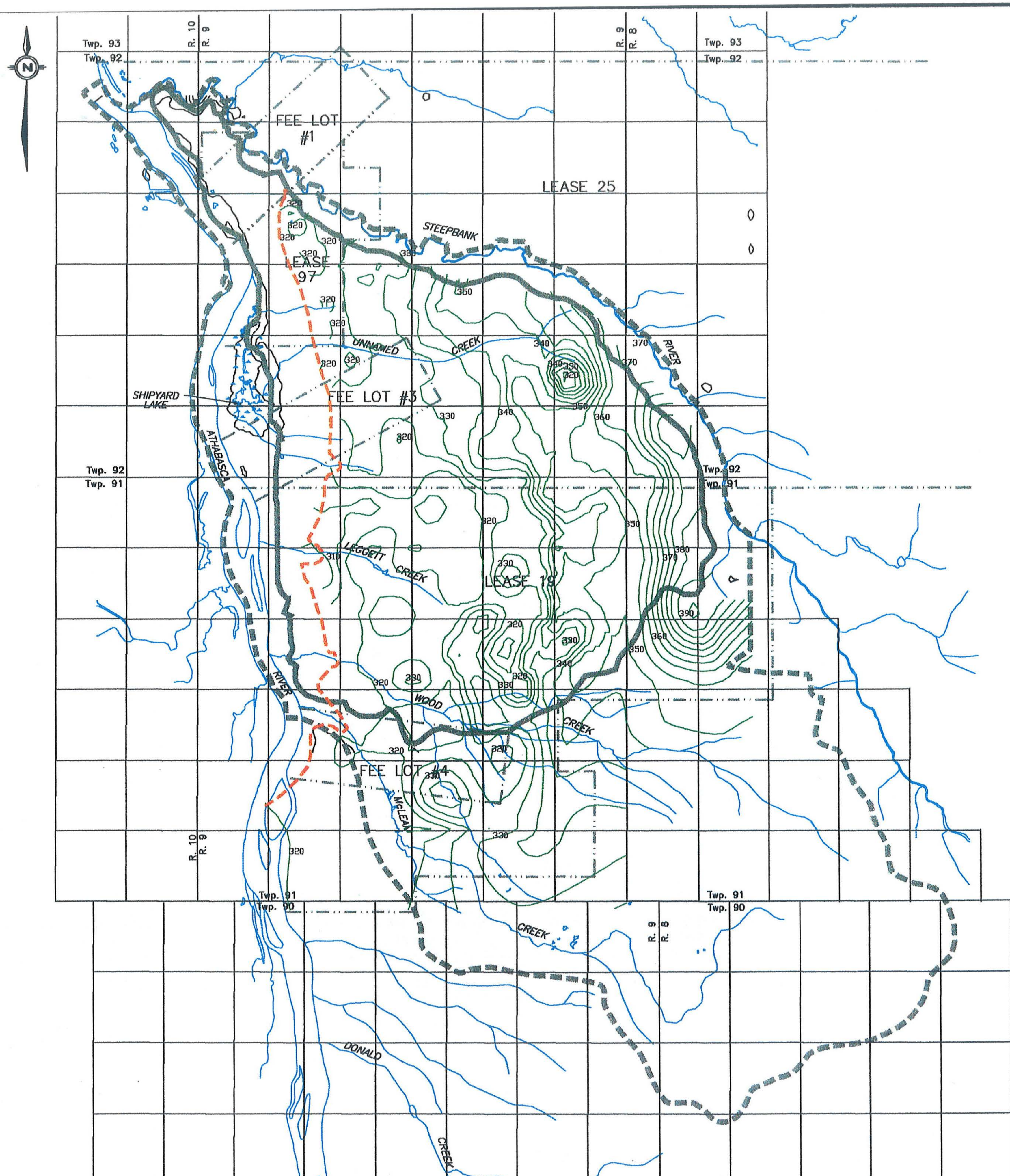
ISOPACH MAP OF SURFICIAL DEPOSITS (DRIFT THICKNESS)

APRIL 1998	FIGURE 20	DRAWN BY: K.C.B. / C.S.F.



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- 350 — TOP OF THE CLEARWATER FORMATION (mAMSL)
- APPROXIMATE ZERO EDGE OF CLEARWATER FORMATION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 5m

1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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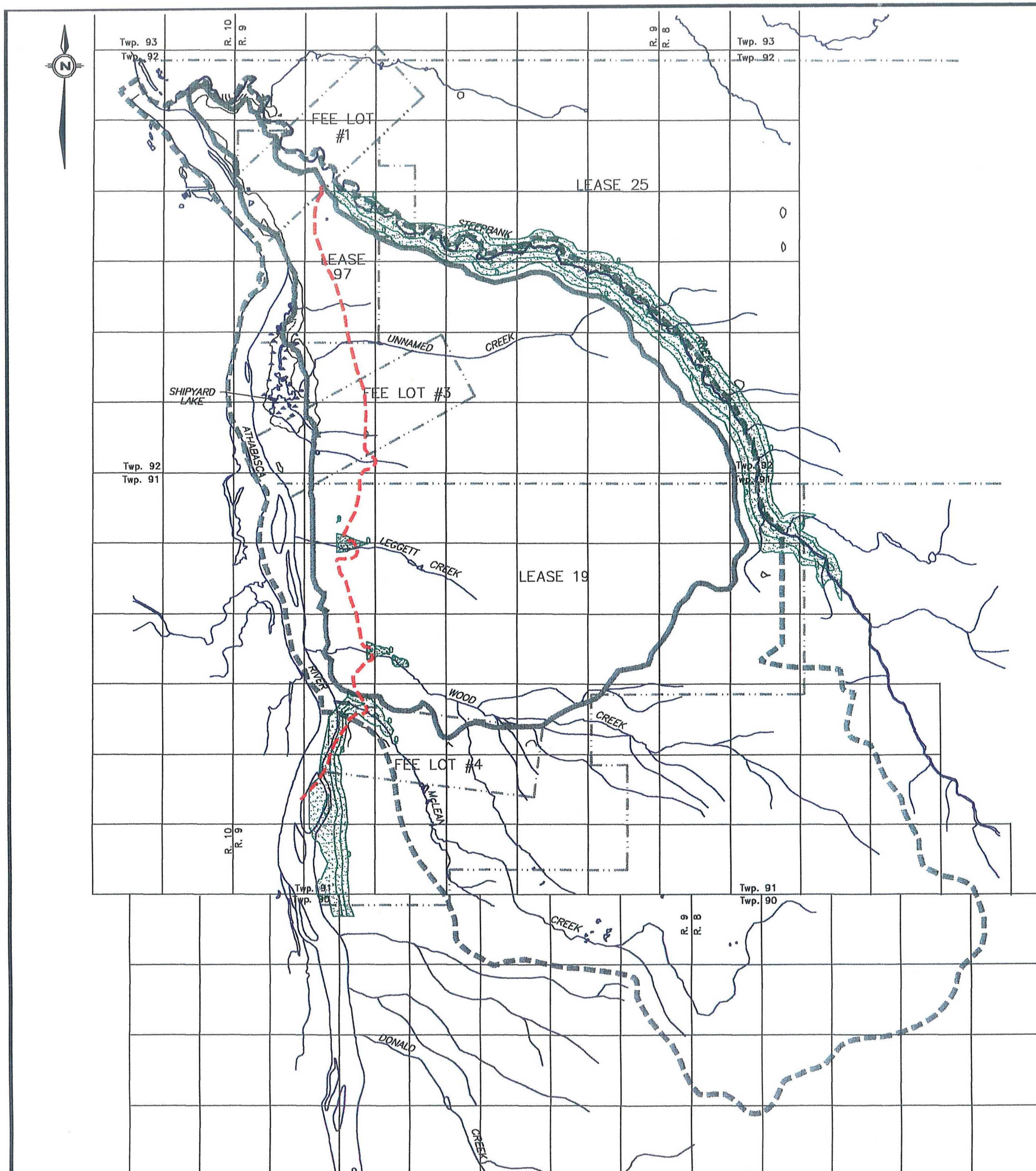
STRUCTURE CONTOUR MAP OF THE TOP OF THE CLEARWATER FORMATION

APRIL 1998	FIGURE 21	DRAWN BY: K.C.B. / C.S.F.

2839w047.dwg



1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- APPROXIMATE CLEARWATER FORMATION OUTCROP AREA
- APPROXIMATE ZERO EDGE OF CLEARWATER FORMATION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE GREEN STIPPLE REPRESENTS THE AREA WHERE THE TOP OF THE FORMATION WAS INTERPOLATED ABOVE GROUND. THE MAP THEREFORE DEPICTS THE LENGTH OF INCISED VALLEY ALONG WHICH OUTCROP IS MOST LIKELY TO OCCUR.

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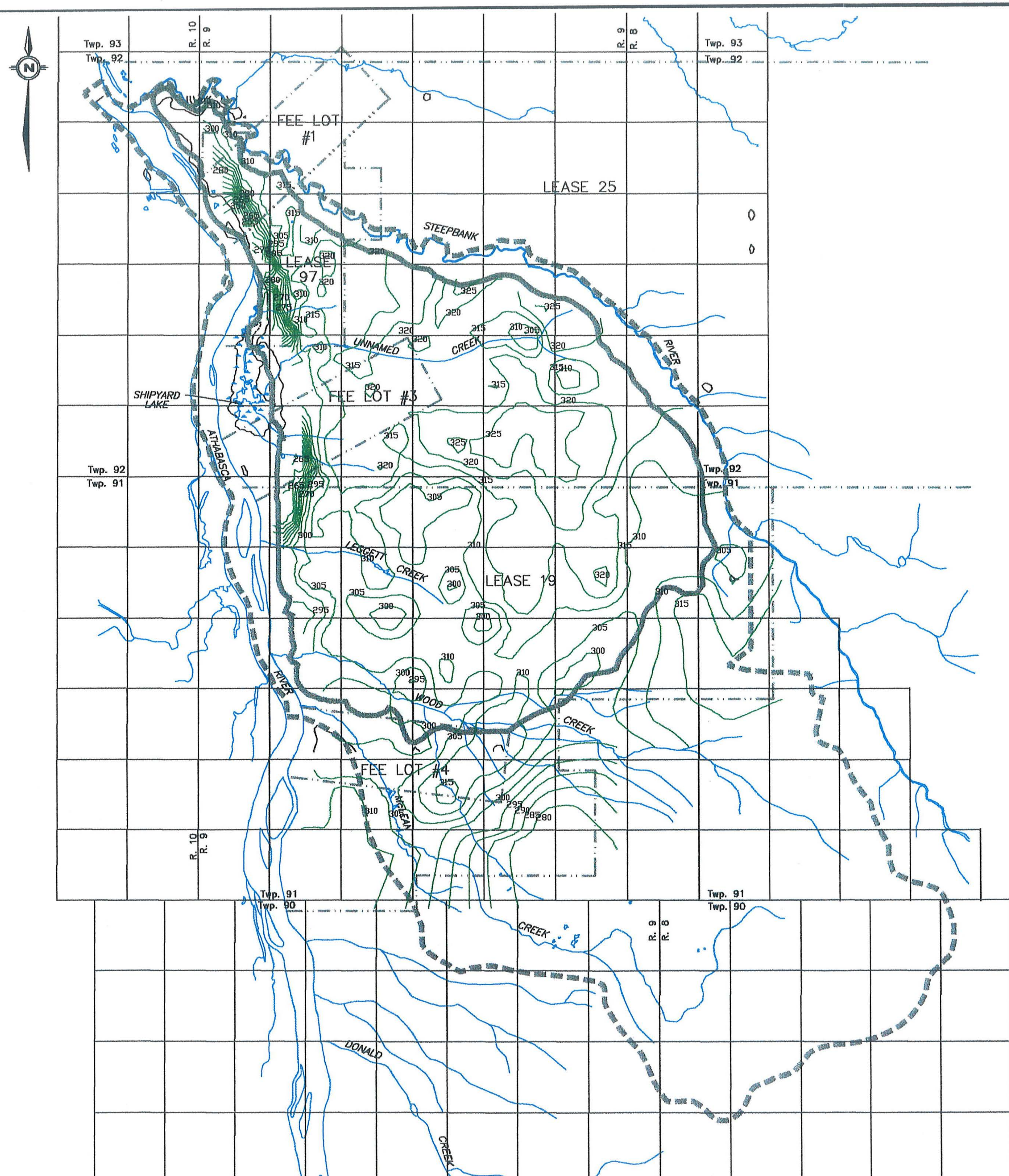
CLEARWATER FORMATION OUTCROP AREA

APRIL 1998	FIGURE 22	DRAWN BY: K.C.B. / C.S.F.

2839w112.dwg



1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- 302 — TOP OF THE McMURRAY FORMATION (mAMSL)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 5m

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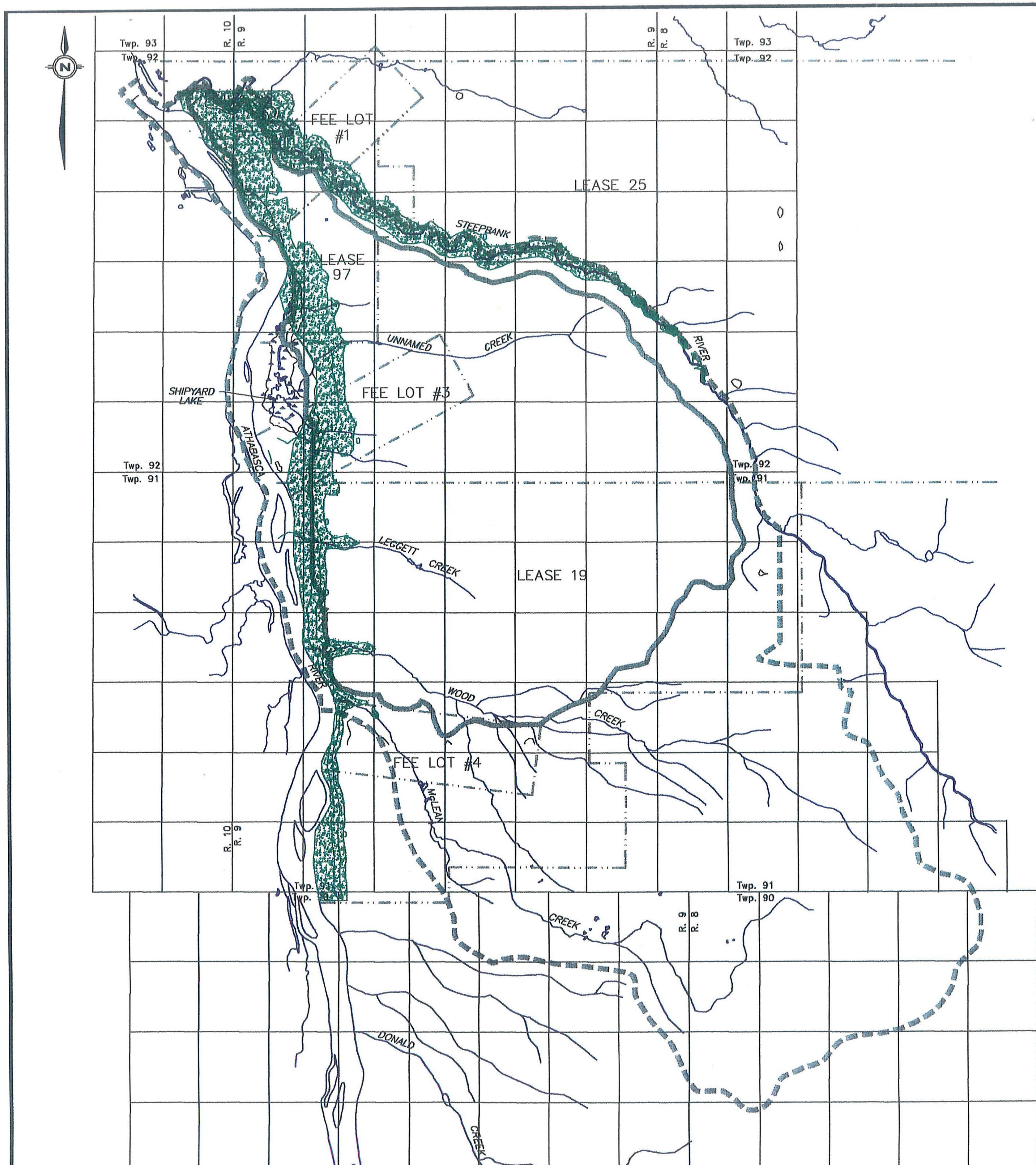
STRUCTURE CONTOUR MAP OF THE TOP OF THE McMURRAY FORMATION

APRIL 1998	FIGURE 23	DRAWN BY: K.C.B. / C.S.F.

2839w048.dwg



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- APPROXIMATE McMURRAY FORMATION OUTCROP AREA

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE GREEN STIPPLE REPRESENTS THE AREA WHERE THE TOP OF THE FORMATION WAS INTERPOLATED ABOVE GROUND. THE MAP THEREFORE DEPICTS THE LENGTH OF INCISED VALLEY ALONG WHICH OUTCROP IS MOST LIKELY TO OCCUR.

MAP PROJECTION: UTM 12
DATUM: NAD 83

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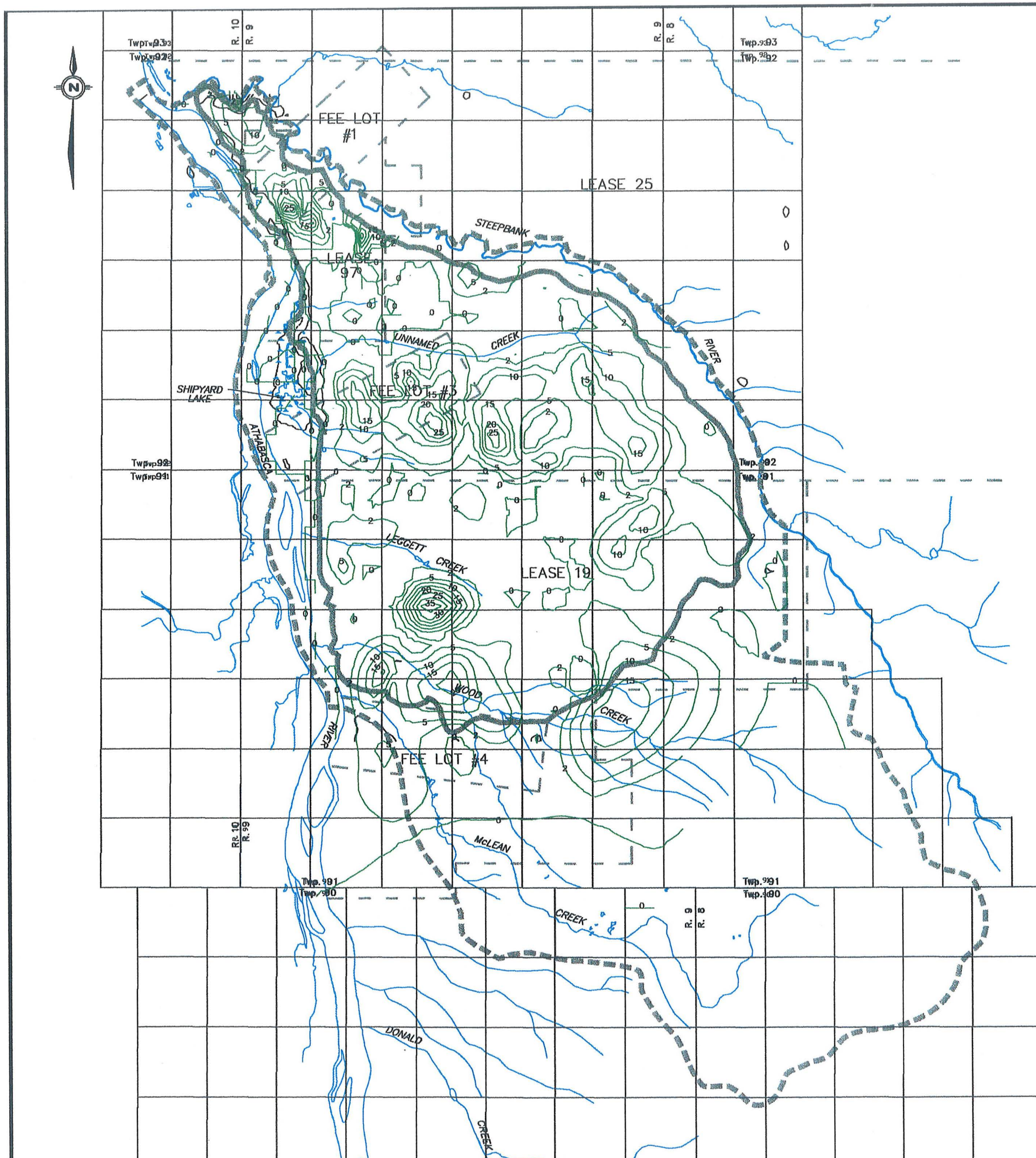
McMURRAY FORMATION OUTCROP AREA

APRIL 1998	FIGURE 24	DRAWN BY: K.C.B. / C.S.F.

2839w113.dwg



LEGEND:

LEASE BOUNDARY

LOCAL STUDY AREA

MINE DEVELOPMENT AREA

302 TOP OF THE McMURRAY FORMATION (m)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 5m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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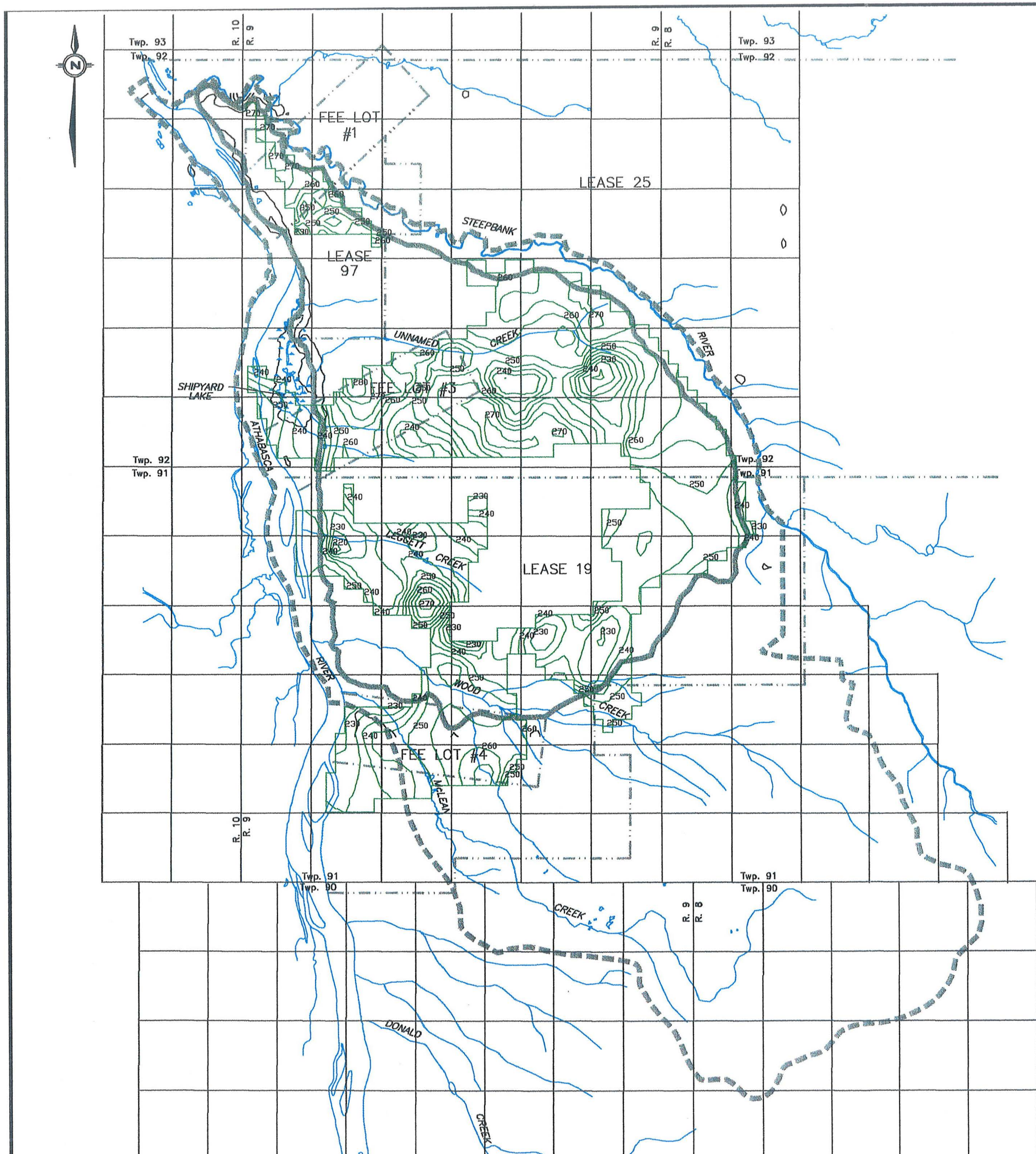
ISOPACH MAP OF THE BASAL AQUIFER

APRIL 1998	FIGURE 25	DRAWN BY: K.C.B. / C.S.F.

2839w049.dwg



LEGEND:

LEASE BOUNDARY

LOCAL STUDY AREA

MINE DEVELOPMENT AREA

302 — TOP OF THE BASAL AQUIFER FORMATION (mAMSL)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 5m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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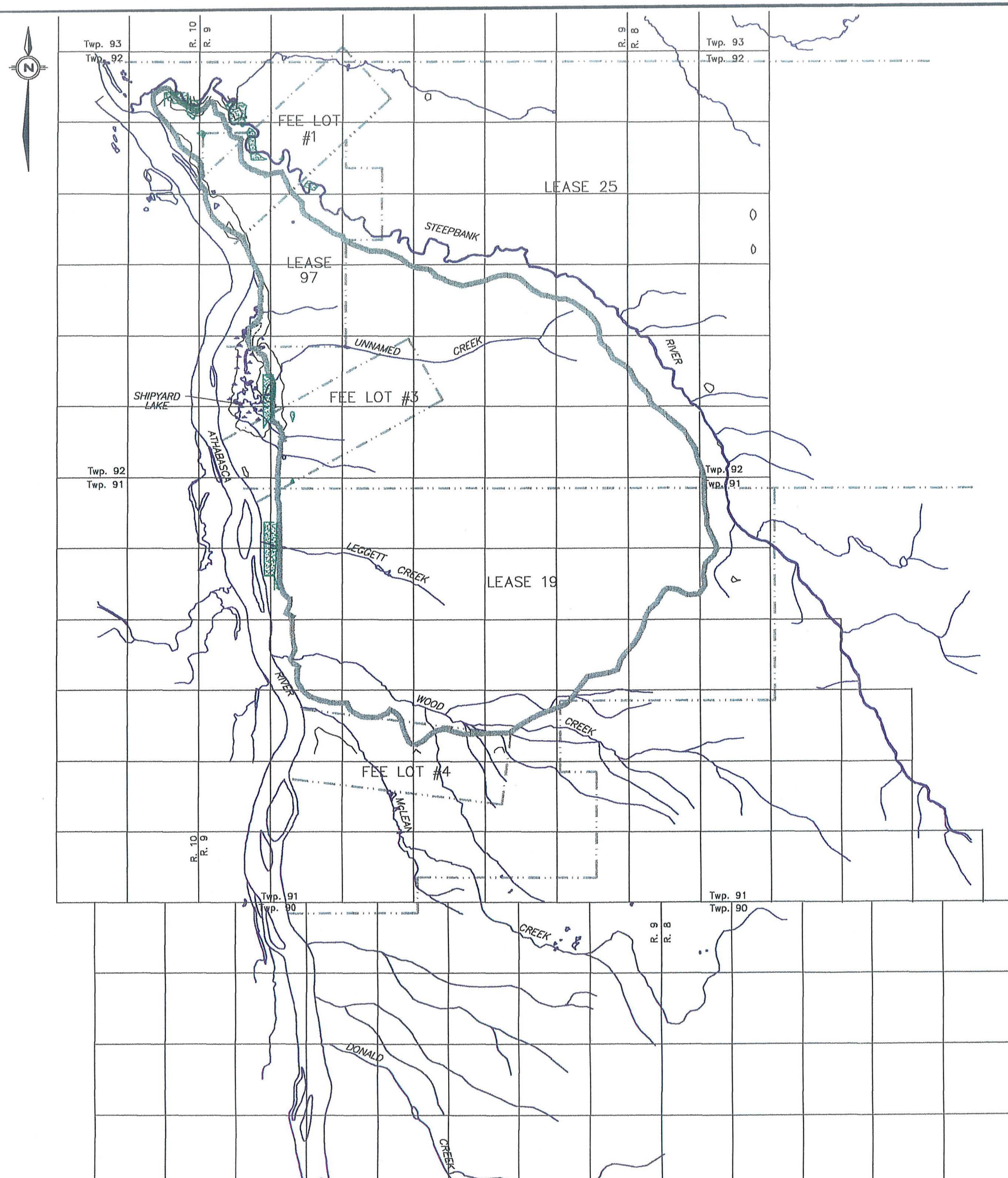
STRUCTURE CONTOUR MAP OF THE TOP OF THE BASAL AQUIFER FORMATION

APRIL 1998	FIGURE 26	DRAWN BY: K.C.B. / C.S.F.

2839w050.dwg



MAP PROJECTION: UTM 12
DATUM: NAD 83

LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- APPROXIMATE BASAL AQUIFER OUTCROP AREA

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. THE GREEN STIPPLE REPRESENTS THE AREA WHERE THE TOP OF THE FORMATION WAS INTERPOLATED ABOVE GROUND. THE MAP THEREFORE DEPICTS THE LENGTH OF INCISED VALLEY ALONG WHICH OUTCROP IS MOST LIKELY TO OCCUR.

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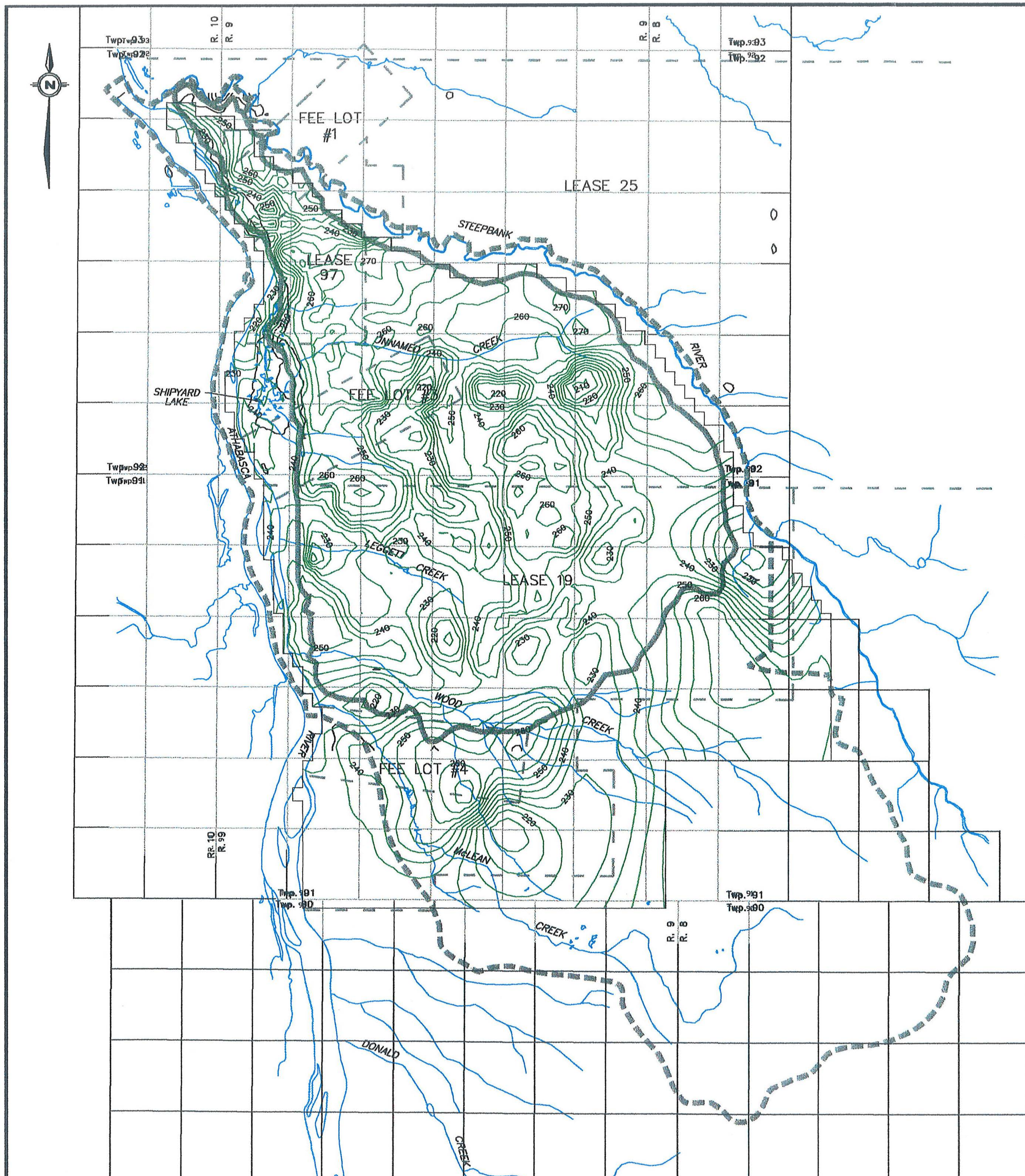
BASAL AQUIFER FORMATION OUTCROP AREA

APRIL 1998	FIGURE 27	DRAWN BY: K.C.B. / C.S.F.

2839w114.dwg



LEGEND:

LEASE BOUNDARY

LOCAL STUDY AREA

MINE DEVELOPMENT AREA

302 TOP OF THE DEVONIAN (mAMSL)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. CONTOUR INTERVAL – 5m

1:100,000 0 1 2km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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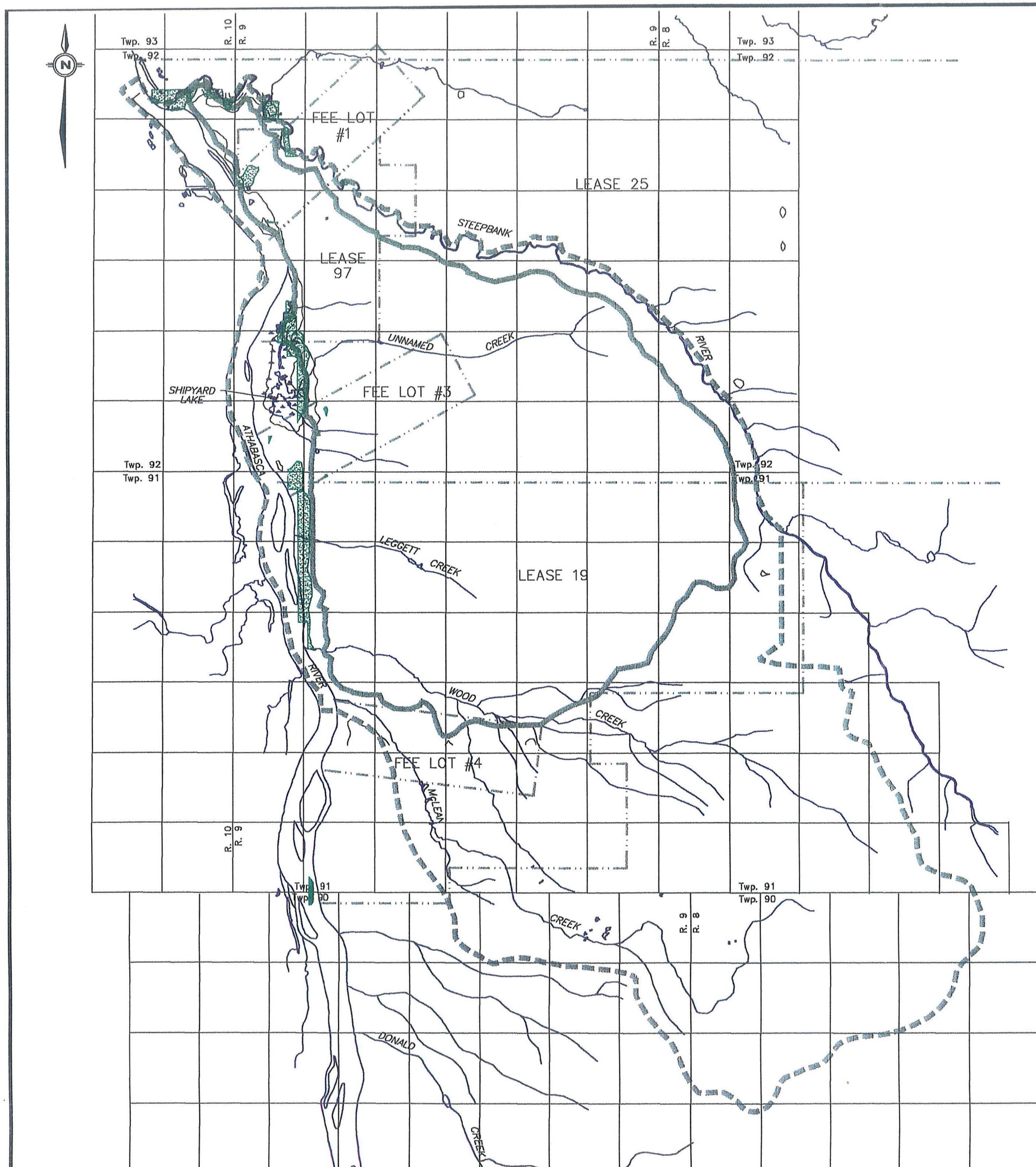
STRUCTURE CONTOUR MAP OF THE TOP OF THE DEVONIAN

APRIL 1998	FIGURE 28	DRAWN BY: K.C.B. / C.S.F.

2839w051.dwg



LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- APPROXIMATE DEVONIAN OUTCROP AREA

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.

2. THE GREEN STIPPLE REPRESENTS THE AREA WHERE THE TOP OF THE FORMATION WAS INTERPOLATED ABOVE GROUND. THE MAP THEREFORE DEPICTS THE LENGTH OF INCISED VALLEY ALONG WHICH OUTCROP IS MOST LIKELY TO OCCUR.

1:100,000 0 1000 2000m

MAP PROJECTION: UTM 12
DATUM: NAD 83

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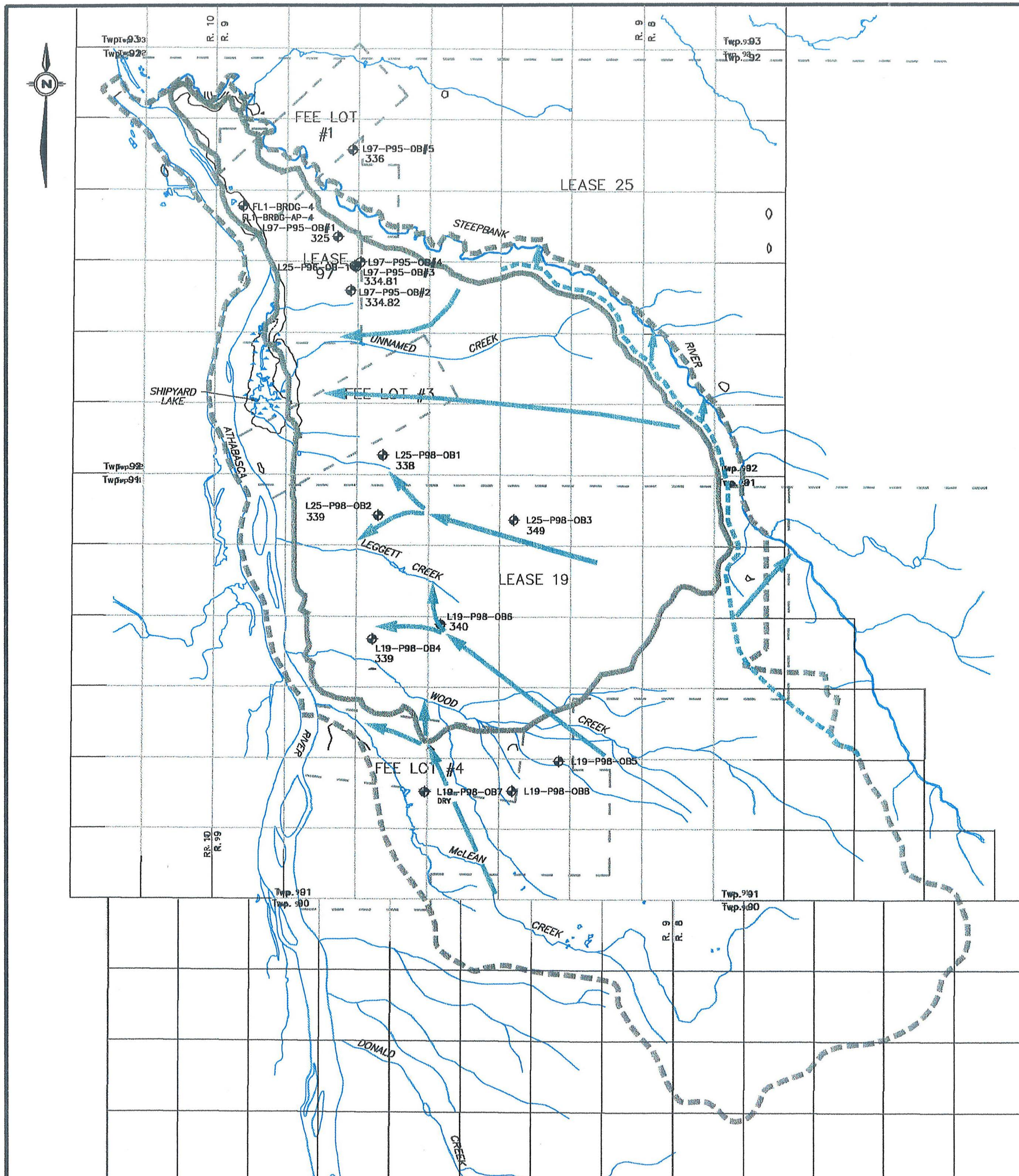
UPPER DEVONIAN OUTCROP AREA

APRIL 1998	FIGURE 29	DRAWN BY: K.C.B. / C.S.F.

2839w115.dwg



1:100,000 0 1 2km

MAP PROJECTION: UTM 12
DATUM: NAD 83

LEGEND:

- LEASE BOUNDARY
- LOCAL STUDY AREA
- MINE DEVELOPMENT AREA
- STANDPIPE PIEZOMETERS AND WATER LEVELS
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.
2. WATER LEVELS FOR THE P98 SERIES OF WELLS WERE MEASURED DURING FEBRUARY 1998.
3. WATER LEVELS FOR THE P95 SERIES OF WELLS WERE MEASURED DURING MARCH 1995.

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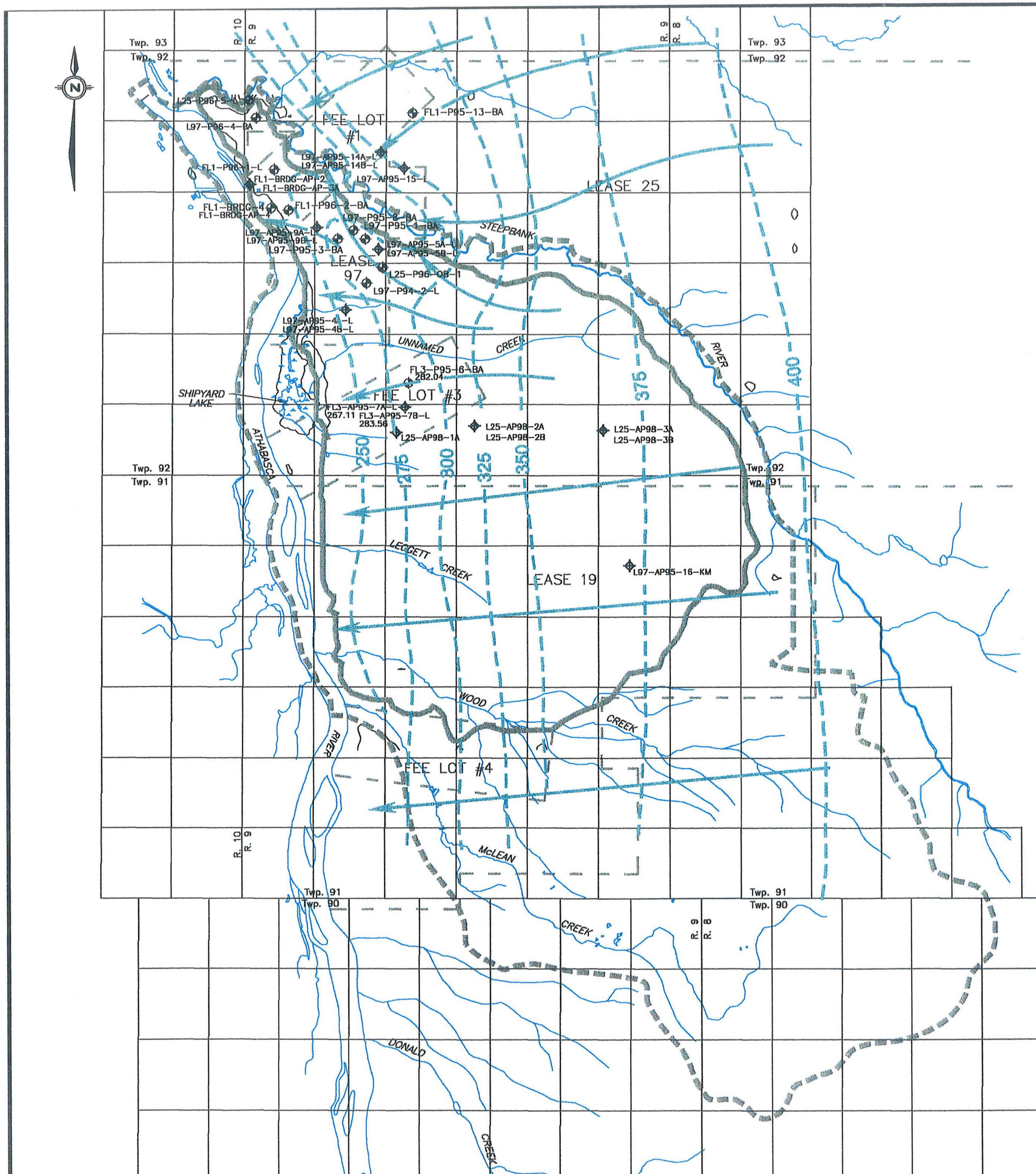
DIRECTION OF GROUNDWATER FLOW IN THE SURFICIAL MATERIALS

APRIL 1998	FIGURE 30	DRAWN BY: K.C.B. / C.S.F.

2839w118.dwg



LEGEND:

LEASE BOUNDARY

LOCAL STUDY AREA

MINE DEVELOPMENT AREA

PNEUMATIC PIEZOMETERS

APPROXIMATE GROUNDWATER FLOW DIRECTION

PIEZOMETRIC SURFACE CONTOUR (MARCH 1995 DATA)

NOTE:

1. STRATIGRAPHY IS INTERPRETED FROM AVAILABLE INFORMATION, ACTUAL GEOLOGY MAY VARY FROM THAT SHOWN.

1:100,000 0 1 2km

MAP PROJECTION: UTM 12
DATUM: NAD 83

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DIRECTION OF GROUNDWATER FLOW IN THE BASAL AQUIFER AND UPPER DEVONIAN

APRIL 1998	FIGURE 31	DRAWN BY: C.S.F.

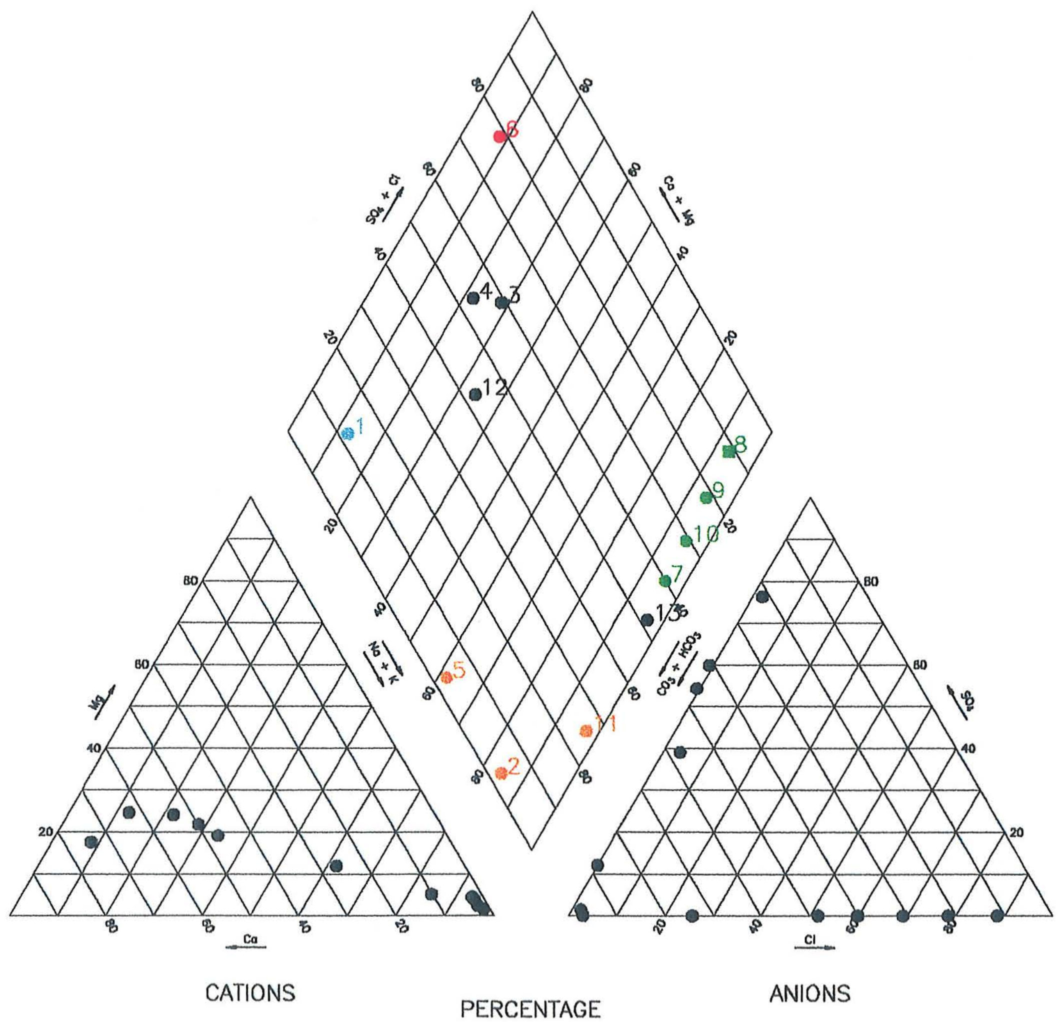
2839w127.dwg

Monitoring Well Samples – Spring 1997

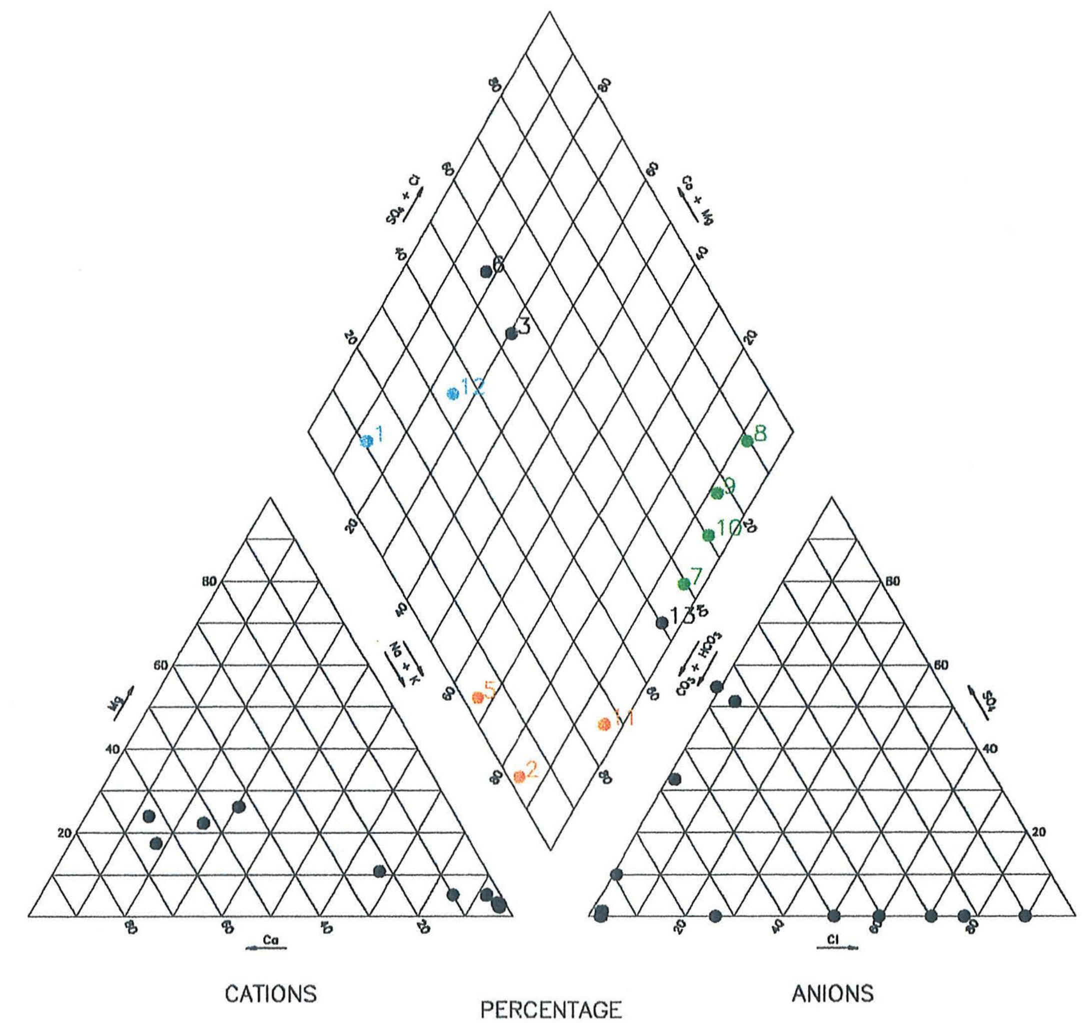
Plot Number	Monitoring Point	Monitor Interval (ft)	Material Type	Total Dissolved Solids (mg/L)	Groundwater Piper Group
1	L25–P96–OB–1	8 – 18	Overburden Sand	137	1
2	L97–P95–OB–2	9.8 – 17	Overburden Sand	523	4
3	L97–P95–OB–3	6.9 – 17.4	Overburden Sand	19	1–3
4	L97–P95–OB–4	7.9 – 18	Overburden Sand	25	1–3
5	L97–P95–OB–5	5.9 – 12.5	Overburden Sand	638	4
6	FL1–BRDG–4	4.9 – 17	Limestone	193	3
7	FL1–P96–2–BA	180.4 – 190	Sand	5422	2
8	FL3–P95–6–BA	269 – 300	Sand	27370	2
9	L97–P95–1–BA	305 – 315	Sand	13440	2
10	L97–P95–3–BA	283 – 293	Sand	8274	2
11	L97–P95–8–BA	253 – 273	Sand	3154	4
12	FL1–P96–1–L	26 – 35.8	Limestone	869	1–3
13	L97–P95–2–L	216 – 226	Limestone	5174	2–4

Monitoring Well Samples – Fall 1997

Plot Number	Monitoring Point	Monitor Interval (ft)	Material Type	Total Dissolved Solids (mg/L)	Groundwater Piper Group
1	L25–P96–OB–1	8 – 18	Overburden Sand	150	1
2	L97–P95–OB–2	9.8 – 17	Overburden Sand	523	4
3	L97–P95–OB–3	6.9 – 17.4	Overburden Sand	17	1–3
	L97–P95–OB–4	7.9 – 18	Overburden Sand		Not Sampled
5	L97–P95–OB–5	5.9 – 12.5	Overburden Sand	613	4
6	FL1–BRDG–4	4.9 – 17	Limestone	171	1–3
7	L97–P95–1–BA	305 – 315	Sand	12710	2
8	L97–P95–3–BA	283 – 293	Sand	8416	2
9	L97–P95–8–BA	253 – 273	Sand	3216	2
10	FL1–P96–2–BA	180.4 – 190	Sand	5445	2
11	FL3–P95–6–BA	269 – 300	Sand	29480	4
12	FL1–P96–1–L	26 – 35.8	Limestone	689	1
13	L97–P95–2–L	216 – 226	Limestone	5201	2–4



Groundwater Piper Groups
Group 1: Fresh water
Group 2: Saline water
Group 3: Sulphate water
Group 4: Alkaline water



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PIPER PLOTS

APRIL 1998 | FIGURE 32 | DRAWN BY: C.P.B.

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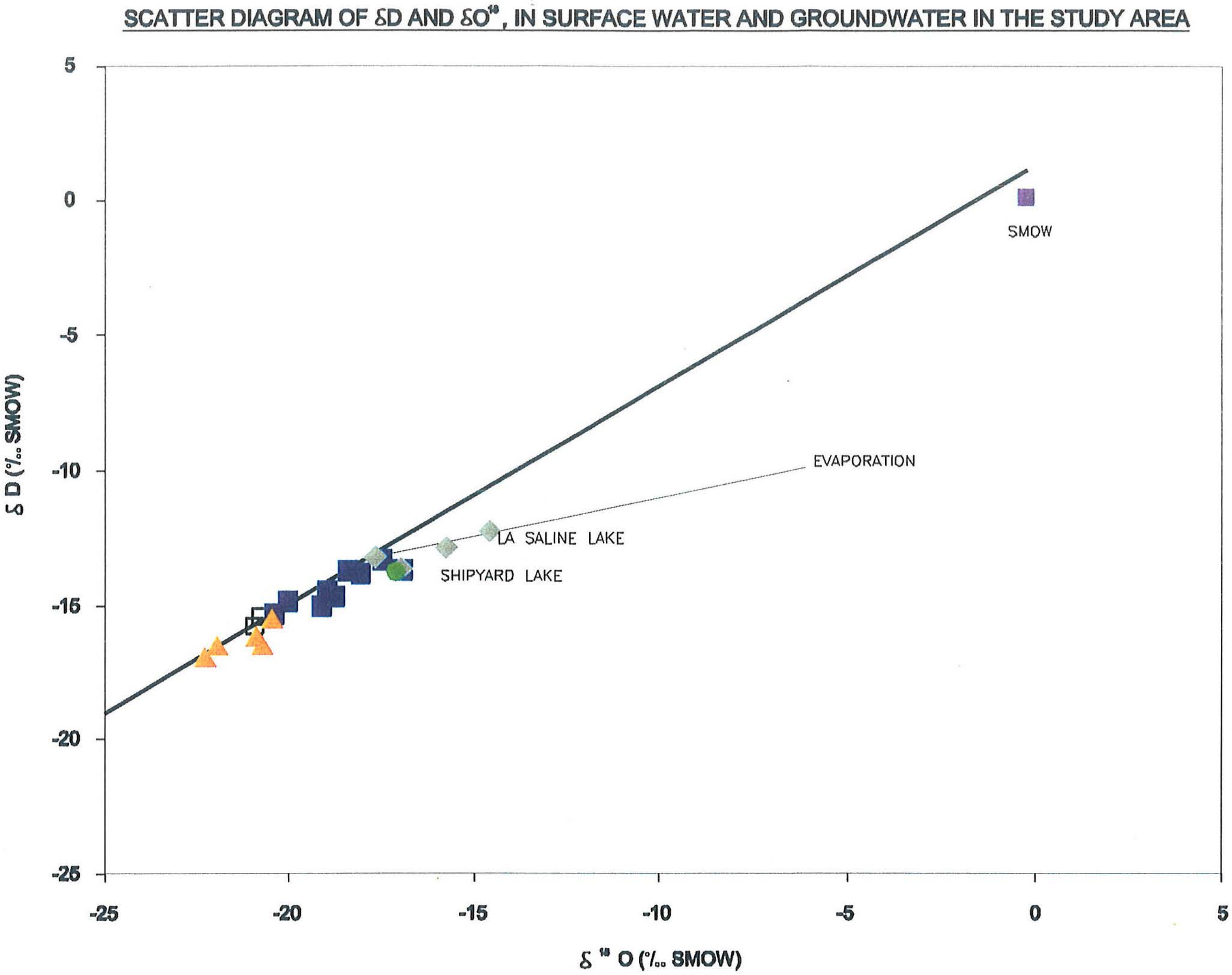

LEGEND:

- METEORIC WATER LINE
- EVAPORATION LINE
- SURFICIAL GROUNDWATER
- BASAL AQUIFER
- OILSAND GROUNDWATER (SUNCOR MINE)
- LIMESTONE GROUNDWATER (STUDY AREA)
- WETLANDS AND STEEPBANK RIVER
- SMOW (STANDARD MEAN OCEAN WATER)

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STABLE ISOTOPES ANALYSIS

APRIL 1998	FIGURE 33	DRAWN BY: C.L.F.

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