Millennium EMS Solutions Ltd.

STP McKay Thermal Project – Phase 2 Hydrogeology

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1.0 INTRODUCTION

Southern Pacific Resource Corp. (STP) is proposing to expand its oil sands development located approximately 40 km northwest of Fort McMurray in the Athabasca Oil Sands area. The STP McKay Thermal Project – Phase 2 (herein referred to as Phase 2) is designed to be an expansion of the company's existing STP McKay Thermal Project – Phase 1 (Phase 1).

STP is currently constructing Phase 1, a Steam Assisted Gravity Drainage (SAGD) project on its McKay oil sands leases located in Township 91, Ranges 14 & 15, West of the 4th Meridian. Phase 1 is expected to commence circulation and subsequent steam injection in the 2nd quarter of 2012. It is located on the west side of the MacKay River and was designed to produce 1,908 m^3/d (12,000 bpd) of bitumen.

Phase 2, which will have a CPF on the east side of the MacKay River, is designed to process an additional 3,816 m^3/d (24,000 bpd) of bitumen for approximately 25 years. The total combined design capacity of the STP McKay Thermal Project (Phase 1 and Phase 2) will be 5,724 m^3/d (approximately 36,000 bpd). The details of the Project are outlined in (STP 2011, Part B).

This report describes the existing hydrogeologic conditions in the vicinity of the Project and evaluates potential effects to groundwater resources related to the Project.

Water for steam generation will be sourced from existing and proposed wells completed in the Quaternary Empress Formation within the MacKay Channel. The steady-state make-up water requirements are estimated at 1,708 m^3/d. Approximately 4,000 m^3/d of make-up water will be required during start-up for the first two years of operation.

Waste water will be trucked to approved off-site disposal wells; no disposal wells are proposed in the Project.

2.0 ASSESSMENT APPROACH

2.1 Terms of Reference

The final Terms of Reference was issued by Alberta Environment (AENV) on July 22nd, 2011. Requirements relating to hydrogeology are identified in Section 3.2 of the Terms of Reference.

2.2 Regulatory Considerations

Key government regulations or guidelines applicable to the Project and relating to hydrogeology are;

- Alberta *Environmental Protection and Enhancement Act* (EPEA) (AENV 1992) as amended;
- Alberta *Water Act* (AENV 2000);
- *Water Conservation and Allocation Guideline for Oilfield Injection* (AENV 2006);
- Groundwater Evaluation Guideline (AENV 2003); and

- Northern Athabasca Oil Sands Region (NAOS) DRAFT Groundwater Management Framework (AENV 2010).

2.3 Study Areas

2.3.1 Local Study Area

The hydrogeology local study area (HLSA) includes a buffer around the proposed Project area and is shown in Figure 1. The HLSA is intended to include the extent of Project related impacts beyond which the potential effects of the Project are expected to be non-detectable. Detailed mapping was conducted for the HLSA as a minimum extent.

2.3.2 Regional Study Area

The hydrogeology regional study area (HRSA) defined for the hydrogeology assessment extends between townships 87 and 94 and range 19 East to the Athabasca River (approximately range 10). The HRSA is shown on Figure 1. The HRSA boundaries were selected based on major hydrologic-hydrogeologic features, such as the Athabasca River, which is a regional groundwater discharge feature and was selected as the southern and eastern boundary. The HRSA also includes sufficient distances where there are not anticipated to be measureable effects associated with the Project, but where residual effects from the Project have potential to interact cumulatively with the residual effects of other projects.

2.4 Temporal Boundaries

The period of groundwater diversion associated with the Project is 2014 to 2048. The hydrogeology assessment begins in 1984 in order to consider impacts from existing and approved projects within the baseline (pre-development) scenario in the HRSA. The total Project life is 25 years.

2.5 Issues and Assessment Criteria

Components of the Project that have been identified as having the potential to affect groundwater resources include:

- groundwater withdrawal;
- operation of surface facilities; and
- steaming and production.

The potential impact to groundwater resources are evaluated in terms of the following criteria for residual effects:

- effect direction;
- magnitude;
- geographic extent of impact;

- duration of impact;
- frequency;
- reversibility;
- probability of occurrence;
- confidence rating; and
- final impact rating.

Definitions for these effects criteria are provided in STP 2011, Part C with specific definitions for the hydrogeology assessment provided below as appropriate. Potential effects are assessed for the Project and at a regional cumulative effects level.

Magnitude describes the size of the impact relative to an environmental standard. The magnitude is classified as negligible (residual effect is not detectable), low (residual effect is detectable but well within environmental standards), moderate (residual effect is approaching environmental standard), and high (residual effect exceeds environmental standard). The magnitude definitions for specific effects identified in the relevant sections of the Methodology (Section 3).

Geographic extent of impact identifies the area within which the effect occurs. The geographic extent is defined as local (within the HLSA), regional (within the HRSA) and provincial (beyond the RSA). Effects associated with operation of surface facilities and steaming and production are anticipated to be only local in extent and these assessments are limited to the Application case.

Duration of Impact is the period of time until the effect subsides to baseline conditions. The duration of impact is determined to be short-term (less than one year), medium-term (less than the Project duration), long-term (up to 10 years past the Project decommissioning) and residual (more than 10 years past the Project decommissioning).

Potential impacts were assessed for the following resources;

- surface water bodies and wetland areas;
- shallow drift aquifers;
- Empress Aquifer; and
- Grand Rapids Aquifers.

Impacts to vegetation, wildlife and aquatic resources are identified as applicable. The valued environmental components (VECs) for hydrogeology are water quantity (water levels) and/or water quality. In summary, this assessment evaluates the following;

- effects of the groundwater withdrawals on water quantity;
- effects of the surface facilities on water quality; and

- effects of the production and injection wells on water quality.

3.0 METHODOLOGY

3.1 Information Sources

The baseline study was completed based on a review of publically available information and Project specific information obtained by STP. Key information sources include the following:

- hydrogeological environmental assessment submitted for Phase 1 (STP 2009);
- groundwater supply evaluations in support of groundwater diversion applications for Phase 1 (Millennium EMS Solutions Ltd (Millennium) 2009; 2011);
- hydrogeology portions of Environmental Impact Assessments for the Dover Commercial Project (Dover Operating Corp. 2010), Athabasca Oil Sands Corp. (AOSC) MacKay River Commercial Project (AOSC 2009) and Petro-Canada MacKay River Expansion (2005).
- Alberta Research Council (ARC) and Alberta Geological Survey (AGS) reports on regional geology and hydrogeology;
- water well driller's reports and chemical analyses in Alberta Environment's Groundwater Information Centre database (AENV 2011);
- hydrogeological information obtained for this assessment; and
- water diversion license information from the AENV Authorization/Approval database.

In addition, a proprietary well log database was used to determine formation tops, total formation thickness and thickness of key stratigraphic units.

3.2 Assessment of Impacts due to Groundwater Withdrawal

The percent reduction in groundwater level (% DD) is determined by comparing the change in water level (Δs) to the available head (Ha) as follows:

$$\% DD = \Delta s / Ha * 100\%$$

Under the *Water Conservation and Allocation Guideline for Oilfield Injection* (AENV 2006) the drawdown in the production aquifer is limited to 35 % in the first year and 50 % over the life of the Project for the use of non-saline groundwater for oilfield injection. These restrictions are measured at an observation well 150 m from the production well.

The magnitude effect criteria was assessed using the following definitions;

- Negligible: percent reduction in groundwater level (% DD) likely not detectable (less than 5 %).
- Low: percent reduction in groundwater level (% DD) is detectable but well within AENV guidelines for non-saline use (5 % to 15 %).

- Moderate: percent reduction in groundwater level (% DD) is approaching the AENV guidelines for non-saline use (15 % to 50 %).
- High: percent reduction in groundwater level (% DD) exceeds environmental standard (drawdown at a distance of more than 150 m from a water supply well is greater than 35% in the first year or 50 % at any subsequent interval).

A quantitative assessment of the change in surface-groundwater interactions along the MacKay River was completed. This was undertaken by using the numerical model outputs to calculate the amount of groundwater recharge to the MacKay River and making comparisons to the baseline flux.

4.0 BASELINE SETTING

4.1 Physiography and Climate

The HRSA is located within the MacKay Plain physiographic region, which is an area of generally flat topography in the vicinity of the MacKay River (Andriashek 2001) (Figure 1). The ground surface is mainly at elevations of 520 to 460 metres above sea level (masl). The Birch Mountains form an upland to the northwest of the HRSA with an elevation of more than 800 masl. The northwest corner of the HRSA is on the south slope of the Birch Mountains where elevations exceed 650 masl. The Thickwood Hills form a low upland area towards the south boundary of the HRSA. The Athabasca River is cut into the plain with an elevation of about 335 masl at the southwest corner of the HRSA and dropping steadily downstream to the east and north reaching an elevation of roughly 225 masl at the north end of the HRSA. Within the HLSA, the MacKay River is only slightly incised at an elevation of about 450 masl. Key rivers within the HRSA include the MacKay, Dunkirk and Dover, which all drain into the Athabasca River near Fort Mackay. Surface drainage within the HLSA is generally towards local creeks and the MacKay River.

Mean monthly temperatures are below zero from November through March with a mean annual precipitation of 435 mm (nhc 2011). Roughly one quarter of the annual precipitation is snowfall. Annual potential evaporation is expected to exceed precipitation for the months of May to August and October as well as annually (Ozoray et al. 1980).

4.2 Geology

The region is underlain by an unconformable sequence of Quaternary, Cretaceous and Devonian sediments on the Precambrian crystalline basement. The stratigraphy within the HRSA is summarized in Figure 2. Regional Quaternary deposits are divided into two units; undifferentiated drift deposits that blanket the region and buried channel deposits. Cretaceous units include the La Biche, Viking and Joli Fou of the Colorado Group and the Grand Rapids, Clearwater and McMurray formations of the Mannville Group. Subcropping bedrock units, predominantly Cretaceous units, are shown on Figure 3. Devonian units present in the HRSA include the Woodbend, Beaverhill Lake and Elk Point groups; of these the Beaverhill and Woodbend Groups subcrop beneath the pre-Cretaceous unconformity (Figure 4). There are bitumen deposits in the Cretaceous McMurray Formation, which are the subject of the SAGD operations assessed herein.

The following sections provide a description of the geological units within the HRSA and HLSA.

4.2.1 Beaverhill Lake Group

The Beaverhill Lake Group includes, in ascending order, the Fort Vermillion, Slave Point and Waterways Formations. The Fort Vermillion Formation is a dolostone, which is overlain by limestone of the Slave Point Formation. The Waterways Formation includes an alternating sequence of limey shales and argillaceous carbonates. The Mildred Member is the uppermost unit within the Waterways Formation and is the uppermost Devonian unit underlying the HLSA. The Waterways Formation outcrops along much of the Athabasca River within the HRSA (Figure 3).

Samples or core from boreholes in the HLSA that advanced about 15 m into the Waterways Formation encountered limestone with some marlstone, which is consistently identified as tight. The structure of the Devonian surface within the HLSA slopes to the southwest from elevations of 305 masl to below 270 masl (Figure 5).

4.2.2 Woodbend Group

The subcrop edge of the Woodbend Group is located to the southwest of the HLSA and therefore these units underlie the pre-Cretaceous unconformity across the southwest portion of the HRSA. The Woodbend Group includes the Ireton, Grosmont, and Cooking Lake Formations. The Ireton consists mainly of shale, while the Cooking Lake and Grosmont are predominantly limestone and dolomite, respectively.

4.2.3 Mannville Group

4.2.3.1 McMurray Formation

The McMurray Formation unconformably overlies the Woodbend Group or Waterways Formation within the HRSA and consists of fluvial and estuarine deposits, typically fine-grained sands. Regionally, the McMurray Formation is divided into three informal members, “lower”, middle” and “upper”. The lower McMurray is identified as containing conglomerate, sand, silt and shale. The middle McMurray is typically a uniform quartz sand, which is overlain by sand and mudstone of the upper McMurray (Andriashek and Atkinson 2007).

Within the HLSA, the upper McMurray member predominates with thin intervals of middle McMurray; the lower McMurray is absent. The structure on the surface of the McMurray Formation slopes to the southwest following a similar trend to the underlying Beaverhill Lake Group (Figure 6).

The McMurray is bitumen saturated across the HLSA with some areas of underlying thin discontinuous water-saturated sands (Figure 7). Regionally, small pockets of water-saturated sands are identified overlying the bitumen within the McMurray (Figure 8).

4.2.3.2 Clearwater Formation

The Wabiskaw Member found at the base of the Clearwater Formation disconformably overlies the McMurray Formation. Shale at the base of the Wabiskaw, above the McMurray, is 3.5 to 4 m thick and continuous across the HLSA. The Wabiskaw sandstone is bitumen saturated across the HLSA and ranges from 3 to 8 m in thickness. The structure on the surface of the Wabiskaw Member is at elevations between 326 and 308 masl (Figure 9) within the HLSA corresponding to an approximate depth of roughly 140 m.

The Clearwater Formation is largely composed of argillaceous shales with minor siltstone and occasional sandstone. Sample descriptions from coreholes within the HLSA identify some sandstone intervals of poor porosity with shale and siltstone in the upper portion of the Clearwater and predominantly shale in the lower portions above the Wabiskaw. The upper surface of the Clearwater Formation has been partially eroded along the MacKay Channel (Figure 10) where it has a minimum thickness of 38 m. The lower shale has not been reduced in thickness (Figure 11).

4.2.3.3 Grand Rapids Formation

The Grand Rapids Formation conformably overlies, and forms a gradational contact with, the argillaceous Clearwater marine deposits. The Grand Rapids succession was deposited in a shallow marine environment during the regional regression of the Clearwater Sea. The Grand Rapids is composed of a number of sand depositional cycles that are separated by shale and silty beds (Andriashek and Atkinson 2007). The formation subcrop edge is located to the northeast (Figure 3).

Regionally, the Grand Rapids Formation is composed of at least four coarsening-upward cycles, which are referred to as sand units 5, 4, 3 and 2 in ascending order. Within the HRSA the Grand Rapids 3, 4 and 5 sands are present. The Grand Rapids 3 sand is found to the northwest of the MacKay Channel, while the Grand Rapids 5 sand is found mainly to the southeast. The Grand Rapids 4 is widespread within the HRSA. The Grand Rapids is completely eroded within the MacKay and Birch Channels.

Both the Grand Rapids 5 and 4 sands have a typical thickness of 20 m or more where present (Figure 12 and 13) and can exceed 30 m in the southeast corner of the HLSA. The Grand Rapids 3 sand is not present within the HLSA, but within the HRSA reaches thicknesses of over 20 m (Figure 14).

4.2.4 Colorado Group

The Colorado Group includes both upper and lower Cretaceous Formations, the upper Cretaceous Labiche Formation (composed of the Colorado Shale, 2nd White Specks and Base of Fish Scales) and lower Cretaceous Viking and Joli Fou Formations. Both the Labiche and Joli Fou consist of marine shales, while the Viking Formation is a fine to medium grained marine sandstone. The Viking and Joli Fou subcrop in the northwest corner of the HLSA and do not underlie the Project (Figure 3).

4.2.5 Quaternary Deposits and Empress Formation

The Quaternary deposits have a thickness of 15 to 30 m to locally over 100 m (Figure 16). The Quaternary deposits include the undifferentiated glacial drift and the Empress Formation within the buried bedrock channel network, which includes the MacKay and Birch Channels within the HRSA.

Drilling within the HLSA has identified fine-grained sand and clay within the undifferentiated glacial drift. The fine-grained sand deposits are described as having occasional clay stringers and some pebbles and cobbles are noted.

The lower portion of the buried bedrock channels contains sand and/or gravel deposits of the Empress Formation that are typically 25 m thick (Figure 15). The thickness of the sand and gravel in the MacKay Channel in the HLSA is 14 to 31 m.

4.3 Hydrogeology

Regional aquifers include the Empress Formation, the Cretaceous Viking, Grand Rapids 3, 4 and 5 sands and the Devonian Beaverhill Lake - Cooking Lake aquifer system (Figure 2). Within the HRSA the permeable portions of the undifferentiated glacial drift and water saturated portions of the McMurray aquifer are interpreted as forming only localized aquifers. The Base of Groundwater Protection is established at an elevation of 287 masl at the Project (ERCB 2011) and the Clearwater Formation is identified as the deepest protected groundwater unit. Thus key units from a hydrogeological point of view that underlie the Project are the Quaternary glacial drift and buried channels and the Grand Rapids Formation. Other units will not be considered in detail as they are either below the Base of Groundwater Protection or do not underlie the Project.

A description of the hydrostratigraphic units is provided in the following sections with a focus on the protected non-saline aquifer units. Information regarding the hydraulic properties and groundwater quality for these units is summarized in Tables B1 to B4 of Appendix B. Figure 17 presents a hydrogeological cross section running from west to east through the HLSA.

4.3.1 Undifferentiated Drift Aquifer/Aquitard

The undifferentiated drift within the HLSA consists of predominantly clay till with intervals of sand, which is referred to as the Undifferentiated Drift Aquifer/Aquitard. Shallow sand intervals tested within the HLSA have horizontal hydraulic conductivities of 1×10^{-6} to 4×10^{-5} m/s (Appendix B, Table B1) as determined through falling and rising head hydraulic conductivity tests. The sand intervals are expected to form local aquifers within the glacial drift aquitard. The hydraulic conductivities of the clay till deposits were determined through falling and rising head hydraulic conductivity tests to be 3.3 x 10^{-8} to 2.3 x 10^{-7} m/s. The hydraulic conductivities measured within the HLSA are consistent with those identified through other studies (*e.g.,* Petro Canada 2005) within the HRSA and reflect the variable composition of the undifferentiated drift materials.

The water table is expected to mimic topography with flow patterns similar to surface runoff. Thus shallow groundwater flow within the HLSA is anticipated to be generally towards the MacKay River (Figure 18). Nested monitoring wells at several locations within the HLSA indicate a slight downward gradient. The water table is typically found at depths of 3 m or less and is occasionally above the ground surface. Average groundwater flow rates within the clay till deposits are approximately 0.1 m per year based on a hydraulic conductivity of 2.3 x 10^{-7} m/s, an estimated hydraulic gradient of 0.005 m/m and an assumed effective porosity of 0.3. Within the sand intervals, the rate of groundwater flow could average 4 m per year based on a geometric mean hydraulic conductivity of 8 x 10^{-6} m/s for the sands and the same gradient and porosity.

Groundwater quality and type in the undifferentiated drift is predominately calcium bicarbonate however the dominant cation is frequently a mixture of calcium- sodium- magnesium and some sulphate-dominated waters are also present (Appendix B, Table B2). The Total Dissolved Solids (TDS) concentrations measured within the undifferentiated drift in the HLSA range from 137 to 855 mg/L. TDS concentrations within the HRSA are generally less than 1,000 mg/L; however concentrations of over 8,000 mg/L have been measured within the undifferentiated drift (Petro Canada 2005).

4.3.2 Empress Aquifer

The Empress Formation is located at the base of buried bedrock channels within the HRSA including the MacKay and Birch Channels. The Empress Formation forms an aquifer with a thickness of up to 31 m along the thalweg of the MacKay Channel within the HLSA.

Three water supply wells (WSWs) have been completed by STP within the MacKay Channel. WSW1, WSW2 and WSW3 are located at 08-08-91-14-W4M, 16-08-91-14-W4M and 15-08-91-14-W4M respectively. Observation wells are installed at two of these locations within the Empress Formation, and in sand intervals within the overlying undifferentiated drift. Constant rate pump tests have identified higher horizontal hydraulic conductivity in the channel thalweg (up to 5.0 x 10^{-4} m/s) than at the margins of the channel deposits (*i.e.,* 4.8 x 10^{-5} m/s). The storativity was calculated as 2.6 x 10^{-4} for the MacKay Channel Empress Aquifer. These values are comparable to the results of testing completed by AOSC within the MacKay Channel at 06-05-091-14-W4M that determined a horizontal hydraulic conductivity of 3.2 x 10^{-4} m/s and specific storage of 8.0 x 10^{-5} m^{-1}.

Information from wells within the Birch Channel and Thickwood Channels indicates comparable aquifer characteristics and a similar pattern of higher hydraulic conductivities along the thalweg was also observed in the Birch Channel (Petro-Canada 2005).

During the pumping tests completed by STP, the MacKay Channel Empress Aquifer demonstrated confined aquifer behaviour with no drawdown observed in the shallower sand units. Geological mapping and pumping test responses indicate a hydraulic connection between the MacKay Channel Empress Aquifer and the Grand Rapids Sand 5 aquifer.

A comparison of water level measurements within the Empress Formation and the overlying glacial drift indicate a downward vertical gradient (Figure 17). The average vertical gradient is 0.04 m/m. Limited hydraulic head measurements are available for the Empress Aquifer and indicate generally higher heads in the Birch and Thickwood Channels with the exception of measurements in 93-12-W4M which are the lowest within the Birch-MacKay Channel network and suggest groundwater flow towards the northeast. The average groundwater flow rate within the MacKay Channel Empress Formation is estimated at 36 m per year based on a geometric mean hydraulic conductivity of 1.7×10^{-4} m/s, an estimated hydraulic gradient of 0.002 m/m and an assumed effective porosity of 0.3.

The groundwater within the MacKay Channel Empress aquifer is of sodium bicarbonate type with a TDS from 780 to 1,160 mg/L (Appendix B, Table B2).

4.3.3 Grand Rapids Aquifer/Aquitard

The Grand Rapids Formation is a regional aquifer (Bachu et al. 1993). Within the HRSA the Grand Rapids 3, 4 and 5 sand units form individual aquifers separated by intervals of shale. The Grand Rapids Formation in its entirety is referred to as the Grand Rapids aquifer/aquitard to reflect the variable behaviour of this unit.

Rising and falling head hydraulic testing of a monitoring well within the HLSA completed in the Grand Rapids 4 sand indicated a hydraulic conductivity of 6×10^{-5} m/s. This value is slightly higher than the value reported by AOSC (2009) of 7×10^{-6} m/s (Table B1). Reported values for the Grand Rapids 3 Sand average 1×10^{-5} m/s (AOSC 2009). The mean hydraulic conductivity for the Grand Rapids 5 Sand is 9×10^{-7} m/s.

Insufficient hydraulic head measurements are available to determine the lateral direction of groundwater flow within any of the individual aquifers (Figure 19). It is expected that the direction of flow is generally towards the subcrop edge to the east. A nested pair of monitoring wells completed in the Grand Rapids 4 Aquifer and Grand Rapids 5 Aquifer indicates an upward hydraulic gradient at 15-07-91-14-W4M. Measurements within 90-14-W4M suggest that the hydraulic head in the Grand Rapids 4 Aquifer is roughly 20 m higher than in the Grand Rapids 5 Aquifer.

The groundwater from both the Grand Rapids 4 and 5 sands is of sodium-bicarbonate type. TDS of the Grand Rapids 4 sand is measured as 1,180 mg/L and approximately 2,100 mg/L in the Grand

Rapids 5 sand within the HLSA (Table B2). These concentrations are higher overall than other measurements within the HRSA, which range up to 1,340 mg/L at 01-23-093-017-W4M (AOSC 2009).

4.3.4 Clearwater Aquitard

The Clearwater Formation is considered a regional aquitard (Bachu et al. 1993) and is continuous across the HRSA. The Clearwater Aquitard has a minimum thickness of 45 m within the HLSA. A mean hydraulic conductivity of 5.0 x 10^{-9} is identified for this unit in 93-12-W4M (Petro-Canada 2005). Elsewhere slightly higher hydraulic conductivities of 5.4 x 10^{-7} m/s are identified in sandstone intervals of the Clearwater (Hackbarth and Nastasa 1979).

Chemistry analyses of the Clearwater Formation within the HRSA indicate non-saline groundwater of sodium bicarbonate-chloride type (Table B2), although samples from Petro-Canada indicate sodium bicarbonate-sulphate type water and some saline groundwater with TDS up to 5,700 mg/L (Petro-Canada 2005).

4.3.5 Wabiskaw/McMurray Aquitard and Basal McMurray Aquifer

The Wabiskaw and McMurray are primarily bitumen saturated within the HRSA. As a result these units are anticipated as having a low hydraulic conductivity and are considered an aquitard. Only thin water-saturated zones of limited lateral extent are identified at the base of the McMurray Formation which could form local aquifers. Within the HLSA, water saturated intervals 0.5 to 1.5 m thick are identified at the base of the McMurray in three wells (Figure 7). No McMurray top water is identified in the vicinity of the HLSA (Figure 8). One of the Alberta Research Council observation wells indicates a hydraulic conductivity of 2 x 10^{-7} m/s in the McMurray and reported conductivities for the Wabiskaw Member range from 3 x 10^{-6} to 4 x 10^{-5} m/s (Hackbarth and Nastasa 1979; Petro-Canada 2005).

The McMurray Formation water quality is saline, of sodium-chloride type water and with reported TDS from 5,480 to over 10,000 mg/L (Petro-Canada 2005, AOSC 2009).

4.3.6 Beaverhill Lake Aquifer/Aquitard

The uppermost Devonian units are mapped as the Beaverhill Lake Group which is regionally interpreted as an aquifer (Bachu et al. 1993). Devonian units appear to have low conductivities in this region; tests from observation wells within the HRSA indicate hydraulic conductivities in the Beaverhill Lake Group of 5 x 10^{-9} to 10^{-10} m/s (Hackbarth and Nastasta 1979). A review of available geophysical logs in the area was completed by STP to investigate aquifer potential in the Beaverhill Lake Group. The review indicated a generally tight sequence, with no evidence of reefs.

Groundwater from Devonian aquifers is expected to be saline with TDS ranging from 7,000 to 11,000 in the Beaverhill Lake.

4.3.7 Groundwater Flow System

Groundwater flow within aquifers above the pre-Cretaceous unconformity is expected to be driven by physiography, with recharge in upland areas and flow towards topographic lows. The Birch Mountains and Thickwood Hills are expected to form areas of recharge with groundwater movement predominantly downwards and away from these topographic features. The Athabasca River is a regional groundwater discharge area for most Cretaceous units and the Devonian Waterways Formation, which subcrops along much of the river valley. Groundwater flow within the MacKay Plain is therefore expected to be generally eastward towards the Athabasca river valley. Higher hydraulic heads are observed within the Birch and Thickwood Channels underlying or adjacent to the upland areas and lower hydraulic heads are found in the Birch Channel towards the Athabasca River, which is consistent with this interpretation.

Generally downward hydraulic gradients are observed; however this is attributed to alternating high and low permeability layers in combination with the topographic relief (Hackbarth and Nastasa 1979), which restricts groundwater movement downward, resulting in the dominance of lateral groundwater flow.

Groundwater flow within the Undifferentiated Drift Aquifer/Aquitard is also expected to be topographically driven, but the result of more subtle changes in topography. Small areas that are topographically elevated could form localized areas of recharge with flow towards nearby topographic lows or into nearby surface water bodies. The overall result is a more complex pattern of hydraulic heads reflecting the local topography and shorter flow paths than those anticipated in the Cretaceous and Upper Devonian units.

4.3.8 Groundwater Use

Water well records on file with AENV were reviewed within the HRSA (Appendix B, Table B5). A total of 164 records were identified within the water well database. Of these records, roughly one third are for observation or monitoring wells and another third are for industrial wells. Only 22 records were identified for domestic wells and the use of the remaining wells is unknown. The nearest domestic water well is approximately 13 km to the west of the Project in 7-16-91-16-W4M (Figure 20). This well is completed at a depth of 85 to 88 m within sandstone.

Current groundwater licenses are summarized in Table B6 (Appendix B). Groundwater production within the HRSA is primarily industrial (on a volume basis); however there are several groundwater diversions allocated for camp (*i.e.,* domestic) use. The closest licensed camp well is operated by Marathon in 12-24-91-15-W4M, which is approximately 4 km northwest of the Project Area. The well is completed at depths of 48.8 to 50.3 m, which likely corresponds to the Grand Rapids 4 sand based on mapping by STP; however no information associated with the license or any corresponding water well record is available to provide corroboration.

Active groundwater production from the Empress Formation within the HRSA is occurring at licensed Suncor wells located in Township 93 Range 12. Suncor's allocations from the Empress Formation total 1,213,904 m^3 annually. STP has a license for Phase 1 in the amount of 419,750 m^3 annually from the Empress Formation. No other withdrawals appear to be currently allocated from the Empress Formation within the HRSA.

5.0 ENVIRONMENTAL IMPACT ASSESSMENT

5.1 Groundwater Withdrawals

5.1.1 Description of Potential Impacts

The water demands for the Project include start-up and make-up water for steam generation, sanitary and potable water. The estimated water demand for make-up water is summarized in Table 1.

Table 1 Summary of Project Water Requirements

Project Phase	Years	Average Make-up Demand (m^3/day)
Startup	1 to 2	4,000
Operations	4 to 25	1,708

STP has a license for groundwater withdrawal to provide make-up water for Phase 1 from two water supply wells completed in the MacKay Channel Empress Formation (Licence No. 00262149-00-00). This license permits a withdrawal of up to 419,750 m^3 annually, which corresponds to an average daily amount of 1,150 m^3. Additional water supplies will be required to meet the Project demands.

A review of potential groundwater sources was undertaken in accordance with the Water Conservation and Allocation Guideline for Oilfield Injection (AENV 2006) in which non-saline groundwater use for enhanced oil recovery is to be reduced or eliminated. Saline groundwater is frequently considered the most feasible alternative to non-saline groundwater use. Saline aquifers are not readily available in the HRSA. A brief summary is as follows:

- Potential saline aquifers include the McMurray Formation and Devonian units. The Grand Rapids sands contain non-saline water.
- Water-saturated portions of the McMurray Formation are localized and thin within the HRSA. Testing by AOSC (2009) at 10-01-90-14W4M and 11-29-089-12-W4M has demonstrated limited yields (<50 m^3/day) from the Basal McMurray Aquifer due to low hydraulic head and low hydraulic conductivity.
- Information for the Beaverhill Lake Group indicates low hydraulic conductivities at several locations surrounding the HLSA (Appendix B, Table B1).

STP will continue to evaluate the potential for alternative sources to reduce or replace non-saline water use. The additional water requirements for the Project are planned to be withdrawn from the Empress Aquifer.

Pumping of groundwater from a water supply well causes the formation pressure to decrease. This decrease in pressure spreads outwards over time as a cone of pressure in the potentiometric surface. The reduction in formation pressure could reduce available production for other wells that are completed in the same formation and could also alter seepage from or discharge to hydraulically-connected surface water bodies or other aquifers.

5.1.2 Impact Assessment

5.1.2.1 Assessment Approach

A numerical groundwater flow model was prepared to complete the assessment of potential impacts due to groundwater production from the Empress Formation. The model was developed using the finite difference code of United States Geological Survey (USGS) MODFLOW (McDonald and Harbaugh 1988) and the Visual MODFLOW interface developed by Schlumberger Water Services (2010). A complete description of the conceptual model, numerical model construction and calibration is included in Appendix C. The impact to groundwater resources for the application and cumulative effects assessments was determined using the model to predict changes in water level.

The conceptual model for the MacKay Channel Empress aquifer is described as the following:

- the channel is incised into the Clearwater Aquitard, which provides no substantial recharge to the Empress Aquifer;
- the Grand Rapids 5 Aquifer is in contact with the Empress Aquifer, particularly in the area of the Project and provides recharge to the Empress Aquifer;
- the MacKay and Birch Channels are interpreted to be hydraulically connected into one buried channel system;
- the Grand Rapids Aquifers subcrop to the east or northeast where they may discharge into surface water bodies; and
- the Empress Aquifer and Grand Rapids Aquifers are overlain by the predominately low permeability Undifferentiated drift Aquifer/Aquitard.

The baseline case for this assessment includes the following approved or existing projects with the potential to impact groundwater within the Empress Aquifer;

- Athabasca Oil Sands MacKay River Pilot Project;
- Suncor Dover Project;
- Suncor MacKay River and MacKay River Expansion Project; and

- STP's McKay Thermal Project - Phase 1.

The withdrawal schedule and aquifers used by each of these projects is summarized in Table 2. The Suncor Dover and MacKay Projects have approved withdrawals from the Birch Channel which began in 1984. The STP Phase 1 Project has an approved withdrawal from the MacKay Channel that is anticipated to begin production in 2012. AOSC's MacKay River Pilot Project was scheduled to begin producing groundwater from the Grand Rapids 4 and 5 Aquifers in 2010, although it is noted that no approvals have been issued yet for groundwater withdrawals.

The application case will consider the Project withdrawals from the Empress Aquifer in addition to those included in the baseline case.

Effects to groundwater quality are not expected to be detectable and are not evaluated.

Table 2 Groundwater Production Schedule within the HRSA (m^3/day) for Baseline and Application Cases

Project		Suncor Dover and MacKay	AOSC MacKay River Pilot Project	STP - Phase 1	STP - Phase 2
Aquifer Unit		Empress	Grand Rapids 4 and 5	Empress	Empress
Case	Baseline	✓	✓	✓	
	Application	✓	✓	✓	✓
	Planned	✓	✓	✓	✓
Start Date	End Date				
Oct-84	Sep-92	212			
Oct-92	Sep-95	907			
Oct-95	Sep-00	1487			
Oct-00	Sep-02	480			
Oct-02	Sep-06	1480			
Oct-06	Sep-09	1735			
Oct-09	Mar-10	5200			
Apr-10	Dec-10	4000	65		
Jan-11	Dec-11	4000	245		
Jan-12	Dec-12	4000	218	1060	
Jan-13	Dec-13	4000	201	882	
Jan-14	Dec-14	4000	180	596	4000
Jan-15	Dec-15	4000		596	4000
Jan-16	May-35	4000		596	1708
Jun-35	Dec-38			596	1708
Jan-39	Dec-41			596	
Jan-42	Dec-46			202	

5.1.2.2 Assessment Results

5.1.2.2.1 Empress Aquifer

The baseline case includes production from the Empress Aquifer by Suncor and STP and production from the Grand Rapids 4 sand and Grand Rapids 5 sand by AOSC. The model simulation starts in 1984, corresponding to the beginning of production by Suncor. The maximum predicted drawdown for the baseline case occurs at the end of the Suncor pumping in 2035 (Figure 22). Although STP pumping continues until 2046, the relatively small additional production by STP is offset by the overall reduction in production, resulting in no further drawdown for this period. The maximum drawdown predicted within the Empress Aquifer is 6 m at the STP source wells and 13 m at the Suncor source wells.

The production schedule for the Project (Table 2) was included in the application model simulation in addition to the production already simulated in the baseline case. Production at the Project results in the development of a cone of depression that reaches a near maximum drawdown near the STP source wells in 2015. This time corresponds to the decrease in Project pumping rates from 4,000 m^3/day at start up to a steady state production of 1,708 m^3/day. The drawdown cone continues to expand until the Suncor wells cease pumping in 2035 (Figure 23). The maximum drawdown near the STP source wells is 16 m in 2035 and 15 m near the Suncor source wells.

The percent reduction in groundwater level within the Empress Aquifer as a result of the Project production is therefore calculated (see Section 3.2) as 14% at the STP source wells based on an available head of 69 m. Similarly, the percent reduction in groundwater level (calculation is provided in Section 3.2) within the Empress Aquifer as a result of the Project production is 7% at the Suncor source wells based on an assumed available head of 30 m.

The available heads were selected based on available well information by selecting the well completion depth that provided the most appropriate indicator of the shallower portions of the Empress Aquifer. Specifically, STP's WSW1 and AOSC's 06-05 WSW EMP Empress Aquifer water source wells (Appendix B, Table B1) both indicate an available head of 69 m near the Project and Suncor's shallowest licensed well is completed from 30.6 to 52.4 m (Appendix B, Table B6) giving an estimated available head of 30 m (assuming the static water level is near surface). At both locations, available well completion information indicates portions of the Empress Aquifer are at greater depths and therefore the reduction in groundwater level would be less than the values calculated herein.

Potential Project effects are related to effects of groundwater withdrawals on groundwater quantity in the Empress Aquifer resulting from construction and operation of the Project. The application case effects are regional in extent, residual in duration, continuous in frequency, reversible in the long term, of low magnitude, and have a negative contribution. The confidence rating of the assessment is moderate, the probability of the effect is high, and overall, the Project impact rating is low.

5.1.2.2.2 Grand Rapids Aquifers

The model simulation drawdown predictions were used to evaluate effects to groundwater levels within the Grand Rapids 4 Aquifer and Grand Rapids 5 Aquifer. The nearest receptor locations identified are the AOSC MacKay River Pilot Project well for the Grand Rapids 5 Aquifer and the Marathon well located in 12-24-91-15-W4M, which is interpreted as completed within the Grand Rapids 4 Aquifer (Section 4.3.8). Predicted drawdowns for the Grand Rapids 3 Aquifer in the application simulation were assessed as zero in the vicinity of the Dover Central Pilot Project, so no further assessment of effects to water levels in the Grand Rapids 3 Aquifer was undertaken.

Available heads for these locations were estimated from available well information (Appendix B, Tables B1 and B6) as 49 m for the Grand Rapids 5 Aquifer and 47 for the Grand Rapids 4 Aquifer. The baseline drawdown is predicted as 1.5 m for the Grand Rapids 5 Aquifer and 3 m for the Grand Rapids 4 Aquifer. The application case simulation predicts 3 m of drawdown for the Grand Rapids 5 Aquifer and 6 m for the Grand Rapids 4 Aquifer. The percent reduction in groundwater level associated with the Project production is therefore 3 % for the Grand Rapids 5 Aquifer and 6 % for the Grand Rapids 4 Aquifer.

Potential Project effects are related to effects of groundwater withdrawals on groundwater quantity in the Grand Rapids Aquifers resulting from construction and operation of the Project. The application case effects are regional in extent, potentially residual in duration, continuous in frequency, reversible in the long term, of negligible to low magnitude, and have a negative contribution. The confidence rating of the assessment is moderate, the probability of the effect is medium reflecting some uncertainties regarding the regional relationships between the Empress Aquifer and the Grand Rapids Aquifers, and overall, the Project impact rating is low.

5.1.2.2.3 Shallow Drift Aquifers, Surface Water Bodies and Wetland Areas

Groundwater withdrawal from the Empress Aquifer has been shown to result in drawdown within shallower aquifer units, such as the Grand Rapids Aquifers. The effect of this drawdown could result in drawdown within shallow drift aquifers and could alter the recharge relationships by increasing downward recharge from shallow aquifers and cause surface water bodies to begin providing recharge to underlying sediments.

The influence of the drawdown would be controlled primarily by the characteristics of the surficial drift materials. Shallow drift aquifers are understood to be of limited extent and therefore drawdown impacts would be transmitted through the low permeability clay rich materials.

Predicted drawdowns in the uppermost layer of the model, which represents the base of the drift, vary from 0 to 6 m near STP and up to 13 m near Suncor in the baseline simulation at maximum drawdown in 2035. The extent of the drawdown cone (based on the 1 m drawdown contour interval) is approximately 10 km to the west of STP, 15 km to the south and extending northeast towards Suncor. The application simulation at 2035 shows a slightly greater extent of the drawdown cone with maximum values of 15 m near STP and 14 m at Suncor. The percent change in drawdown could be of high magnitude in the area immediately around STP, whereas at Suncor the incremental increase in drawdown due to Project effects is likely low. The impact would diminish away from these areas, becoming negligible towards the limits of the drawdown cone. The only groundwater wells indicated completed within the surficial drift for domestic use are Suncor wells located in 93-12-W4M (Appendix B, Table B5) where Project effects are anticipated to be low.

Potential Project effects are related to effects of groundwater withdrawals on groundwater quantity in the shallow drift aquifers resulting from construction and operation of the Project. The application case effects are regional in extent, potentially residual in duration, continuous in frequency, reversible in the long term, of low magnitude, and have a negative contribution. The confidence rating of the assessment is low reflecting uncertainties regarding the regional hydraulic relationship between the shallow drift and underlying aquifer units, the probability of the effect is medium, and overall, the Project impact rating is low.

The hydraulic head elevation of the Grand Rapids 4 Aquifer, which is the uppermost aquifer unit at STP, is 458 masl (Appendix B, Table B1) near the MacKay River relative to a river elevation of about 450 masl. This indicates a hydraulic relationship which is consistently observed between the MacKay River and the groundwater units (*i.e.,* shallow drift, the Grand Rapids 4 and 5 Aquifers and the Empress Aquifer), where the groundwater units have higher hydraulic heads compared to the river and are therefore providing recharge to the river.

An estimate of the flux change for MacKay River was made using an average drawdown of 3 m for the baseline simulation and 7 m for the application case. Baseline conditions at STP were assumed as representative of the regional relationships and a conservative value of 2×10^{-7} m/s was used for the hydraulic conductivity of the surficial drift. Based on this information the groundwater flux to the MacKay River is calculated as 0.01 m^3/s for the baseline case and 0.003 m^3/s for the application case. Thus the groundwater units are expected to continue to provide recharge to the MacKay River at a reduced rate. Relative to the mean seasonal flow of the MacKay River, which is 2.46 m/s (nhc 2011), the baseline recharge represents only 0.5% and any reduction in this amount would be quantitatively negligible.

Potential Project effects are related to effects of groundwater withdrawals on water quantity in surface water bodies and wetland areas resulting from construction and operation of the Project. The application case effects are regional in extent, potentially residual in duration, continuous in frequency, reversible in the long term, of negligible magnitude, and have a negative contribution. The confidence rating of the assessment is low given the uncertainties regarding the regional relationship between the MacKay River and groundwater aquifer units, the probability of the effect is medium, and overall, the Project impact rating is low.

5.1.3 Mitigation

Monitoring of water levels in the water source wells in addition to monitoring wells installed within the shallow drift aquifers, Grand Rapids Aquifers and Empress Aquifer at the Project will be undertaken as part of the monitoring programs (Section 7.0). Monitoring of groundwater levels will provide an early indication of potential impacts to surface water bodies or wetland areas and enable mitigative actions to be undertaken in order that impacts to these resources do not exceed a low magnitude. The facility monitoring program will identify targets for water levels and monitoring data will be reviewed to identify trends outside of these levels. In the event of a change in water levels, mitigative actions could include one or more of the following; reducing pumping rates in one or more source wells, adding more source wells to modify the drawdown distribution, completing water source wells in other aquifer units or utilizing alternative water sources.

5.2 Surface Facilities

5.2.1 Description of Potential Impacts

As a result of the best management practices and material handling methods outlined in STP 2011, there should be no possibility of potential effects to shallow groundwater quality, except through upset conditions, *i.e.,* accidental spills or leaks. Accidental releases may allow fluids to seep into the ground where they could alter shallow groundwater quality. The impact to groundwater quality will depend on the volume and type of fluids released, the characteristics of the surface materials at the release location, and the underlying groundwater conditions. Fluids handled at the surface facilities include bitumen, produced water, fuel, and small volumes of various process-related organic chemicals, such as glycol or lubricants. A spill response plan will help to mitigate effects in the event of upset conditions.

5.2.2 Impact Assessment

The Central Processing Facility (CPF) is located in an area that is anticipated to have intervals of sand underlain by clay rich deposits. Groundwater flow rates are anticipated to be variable; up to four metres per year within the sands, but generally slow within the clay rich deposits. It is expected that the sand will be removed and/or covered with compacted material which will reduce infiltration and allow runoff control to the storm water pond, which would facilitate the control of any surface contamination.

A facility groundwater monitoring program will be developed and enable early detection of any effects to groundwater quality (Section 7.1). The facility monitoring program will identify targets and thresholds for water quality parameters. Monitoring data from shallow groundwater monitoring wells near the facilities will be reviewed to identify values outside of these levels. In the event of a verified change in groundwater chemistry, a Groundwater Response Plan will be implemented. The Groundwater Response Plan will be effective at avoiding an undesirable effect on groundwater quality and preventing impacted groundwater from reaching surface water bodies.

Potential Project effects are related to effects of surface facilities on groundwater quality resulting from construction and operation of the Project. With mitigation, application case effects are local in extent, potentially long term in duration, occasional in frequency, reversible in the short to long term, of moderate magnitude, and have a negative contribution. The confidence rating of the assessment is moderate, the probability of the effect is medium, and the overall Project impact is low.

Impacts to groundwater quantity are expected to be non-detectable and have not been assessed.

5.2.3 Mitigation

Mitigation measures for minimizing or preventing impacts to shallow groundwater quality include best management practices, preparedness for upset conditions and a spill response plan. The facility groundwater monitoring program (Section 7.1) will include a groundwater monitoring network in the vicinity of the facilities. In the event of a verified change in groundwater chemistry, a Groundwater Response Plan will be implemented.

5.3 Production and Injection Wells

5.3.1 Description of Potential Impacts

Thermal changes along the well bore of the injection wells have the potential to locally alter groundwater chemistry in non-saline aquifers due to the response of geologic materials to heating along the well bore. In addition, potential accidental releases due to casing failure have the potential to impact groundwater quality of non-saline aquifers underlying the Project.

Dissolution of minerals resulting in increased concentrations of dissolved arsenic in the area of a thermal plume has been comprehensively investigated in the Cold Lake area (Canadian Natural Resources Ltd. (CNRL) 2006, CNRL 2009, Imperial Oil Limited 2009, and Fennell 2008) and these studies demonstrate the following;

- naturally occurring arsenic in the glacial deposits is mobilized (from minerals to water) by the change in the thermal regime caused by heat released into the glacial deposits from in-situ steam processes;
- concentrations of arsenic within tills in the Cold Lake area range up to 14 mg/kg (Andriashek 2000, Andriashek 2003)
- Arsenic moves with the groundwater flow, but with a retardation factor of approximately 1.6 (*i.e.,* 60% the distance that groundwater would move in the same time) due to sorption and mineral precipitation reactions;
- Arsenic concentrations are attenuated to background down gradient as the thermal regime returns to ambient temperature;
- velocity of groundwater flow is a major factor in the distance of movement down gradient; however the ultimate control lies with the temperature; and

- the operative distance for attenuation in the field is less than 400 m.

5.3.2 Impact Assessment

A till sample from 6 m beneath the Phase 1 CPF was found to have an arsenic concentration of 11 mg/kg, which is comparable to the concentrations measured in the Cold Lake tills. Baseline groundwater concentrations of arsenic have been measured within the undifferentiated drift, the Empress Formation, and the Grand Rapids sands (Appendix B, Table B3) in the HLSA and range up to 0.009 mg/L in the Empress Formation at 6-5-91-14-W4M.The highest average horizontal groundwater flow velocity in the HLSA is within the Empress Aquifer, which is estimated at 36 m per year (Section 4.3.2). The lifetime of each well pair is 7 to 10 years, following which temperature conditions would gradually return to pre-disturbance conditions.

Based on this information, there is potential for elevated arsenic concentrations to occur within non-saline aquifers underlying the Project that could extend approximately 250 m from the injection well within the Empress Formation. For comparison, CNRL has identified elevated concentrations of arsenic in groundwater within the Empress Formation 360 to 400 m downgradient after 18 years of operations (CNRL 2009). The groundwater flow rate within the Empress Formation reported by CNRL is 35 meters per year, which is consistent with the rate identified within the HLSA. The extent of any elevated arsenic concentrations in groundwater within the undifferentiated drift, Grand Rapids 4 sand or Grand Rapids 5 sand is expected to be less than 100 m as a result of the lower hydraulic conductivities within these units. Groundwater monitoring will be implemented to enable detection of any effects to groundwater quality in non-saline aquifers (Section 7.0).

Potential Project effects are related to operation of the production/injection wells on groundwater quality. The application case effects are local in extent, long term in duration, isolated in frequency, reversible in the long term, and have a negative contribution. The magnitude could be high during operations, but the residual magnitude is expected to be nil to low. The confidence rating of the assessment is moderate, the probability of the effect is medium, and overall, the Project impact rating is low.

Industry best practices and regulatory requirements associated with the production and injection wells relate to their construction, operating pressures and operational monitoring (STP 2011, Section B.4). As a result of these measures, casing failure and leakage into a non-saline aquifer during operations should not occur. Therefore it is determined that there is no potential Project impact on groundwater quality in non-saline aquifers.

5.3.3 Mitigation

Monitoring of water quality in non-saline aquifer units, *i.e.,* shallow drift aquifers, Grand Rapids Aquifers and the Empress Aquifer, will be undertaken in locations near well pads as part of the facility monitoring program (Section 7.1). The facility monitoring program will identify targets and thresholds for water quality parameters including arsenic based on baseline groundwater quality information.

Monitoring data will be reviewed to identify values outside of these levels and in the event of a verified change in groundwater chemistry; a Groundwater Response Plan will be implemented. Potential actions in the Groundwater Response Plan include remediation, risk assessment and/or risk management.

Casing failures should not occur as a result of best practices and regulatory requirements regarding the design and operation of production and injection wells, therefore mitigation measures are not warranted.

5.4 Environmental Impact Assessment Summary

The conclusions of the Project effects evaluations are summarized as follows:

- groundwater production from the Empress Formation should have low impact on the quantity of water in other groundwater aquifer units and the surface water resources;
- potential spills or leaks of bitumen, produced water or process-related chemicals at the surface facilities are assessed to have a low impact on the chemical quality of shallow groundwater resources in the undifferentiated drift; and
- the operation of the production and injection wells are assessed to have a low impact on the chemical quality of non-saline aquifers and no impact to surface water bodies and wetlands.

Table 3 Summary of Impact Ratings on Groundwater Valued Environmental Components

VEC	Nature of Potential Impact or Effect	Mitigation/ Protection Plan	Type of Effect	Geographic Extent[1]	Duration[2]	Frequency[3]	Ability for Recovery[4]	Magnitude[5]	Project Contribution[6]	Confidence Rating[7]	Probability of Occurrence[8]	Impact Rating[9]
1. Groundwater Quantity												
Empress Aquifer	Groundwater Withdrawals		Application	Regional	Residual	Continuous	Reversible – long term	Low	Negative	Moderate	High	Low Impact
			CEA	Regional	Residual	Continuous	Reversible – long term	Moderate	Negative	Moderate	High	Moderate Impact
Surface Water Bodies and Wetlands			Application	Regional	Residual	Continuous	Reversible – long term	Negligible	Negative	Low	Medium	Low Impact
			CEA	Regional	Residual	Continuous	Reversible – long term	Negligible	Negative	Low	Medium	Low Impact
Shallow Drift Aquifers			Application	Regional	Residual	Continuous	Reversible – long term	Low	Negative	Low	Medium	Low Impact
			CEA	Regional	Residual	Continuous	Reversible – long term	Low	Negative	Low	Medium	Low Impact
Grand Rapids Aquifers			Application	Regional	Residual	Continuous	Reversible – long term	Low	Negative	Moderate	Medium	Low Impact
			CEA	Regional	Residual	Continuous	Reversible – long term	Moderate	Negative	Moderate	Medium	Low Impact
2. Groundwater quality												
Shallow Drift Aquifers	Surface Facilities		Application	Local	Long-term	Occasional	Reversible – long term	Moderate	Negative	Moderate	Medium	Low Impact
			CEA	Not evaluated due to local extent of Project effects.								
Shallow Drift Aquifers	Production and Steaming		Application	Local	Long-term	Isolated	Reversible – long term	Low	Negative	Moderate	Medium	Low Impact
			CEA	Not evaluated due to local extent of Project effects.								
Surface Water Bodies and Wetlands			Application	Neutral	NA	NA	NA	NA	NA	Moderate	NA	No Impact
			CEA	Not evaluated due to local extent of Project effects.								

Table 3 Summary of Impact Ratings on Groundwater Valued Environmental Components

VEC	Nature of Potential Impact or Effect	Mitigation/ Protection Plan	Type of Effect	Geographic Extent[1]	Duration[2]	Frequency[3]	Ability for Recovery[4]	Magnitude[5]	Project Contribution[6]	Confidence Rating[7]	Probability of Occurrence[8]	Impact Rating[9]
Empress Aquifer			Application	Local	Long-term	Isolated	Reversible – long term	Low	Negative	Moderate	Medium	Low Impact
			CEA	Not evaluated due to local extent of Project effects.								
Grand Rapids Aquifers			Application	Local	Long-term	Isolated	Reversible – long term	Low	Negative	Moderate	Medium	Low Impact
			CEA	Not evaluated due to local extent of Project effects.								

1. EXTENT Local: within the HLSA; Regional: beyond the HLSA but within the RSA; Provincial: beyond the HRSA; 2. DURATION Short: less than one year; Long: less than the Project duration (35 years); Extended: > 35 years and extending to 10 years after decommissioning; Residual > 10 years after decommissioning; 3. FREQUENCY Isolated, Occasional, Periodic, Continuous; 4. ABILITY FOR RECOVERY Reversible in short term, Reversible in long term, Irreversible; 5. MAGNITUDE Negligible: residual effect is not detectable; Low: Residual effect is detectable but within applicable environmental standards; Moderate: Residual effect is approaching applicable environmental standard; High: Residual effect exceeds environmental standards; 6. PROJECT CONTRIBUTION Neutral, Positive, Negative; 7. CONFIDENCE Low, Moderate, High; 8. PROBABILITY OF OCCURRENCE Low, Medium, High; 9. IMPACT RATING No Impact, Low Impact, Moderate Impact, High Impact

6.0 CUMULATIVE EFFECTS ASSESSMENT

The numerical groundwater model used in the assessment of groundwater withdrawals (Section 5.1.2) was used to complete the cumulative effects assessment. Project effects associated with surface facilities and injection and production wells are evaluated as local in extent and therefore a cumulative effects assessment is not required for these components of the Project.

6.1 Assessment Approach

The planned development case includes withdrawals associated with anticipated projects in addition to those included in the Application case (Section 5.1.2). Planned projects include Athabasca Oil Sands Corporation's MacKay Commercial Project (AOSC 2009), the Dover Central Pilot Project and the Dover Commercial Project (Dover 2010). The MacKay Commercial Project is proposing to utilize groundwater from the Empress Aquifer to the south of the Project beginning in 2012. The Dover Central Pilot Project intends to use a water supply from the Grand Rapids 3 Aquifer beginning in 2013 and Empress Formation beginning in 2015. The Dover Commercial Project application concluded that the groundwater diversion identified for the Pilot Project would also be utilized, so no additional withdrawals have been assigned for this project (Dover 2010). The withdrawal schedule and aquifers used by these planned projects is summarized in Table 4.

Table 4 Groundwater Production Schedule within the HRSA (m^3/day) for Planned Development Case

Project		AOSC MacKay River Commercial Project	Dover Central Pilot Project	
Aquifer Unit		Empress	Grand Rapids 3	Empress
Start Date	End Date			
Jan-12	Dec-12	320		
Jan-13	Aug-13	320	541	
Sep-13	Jun-14	1955	541	
Jul-14	Dec-14	5800	541	
Jan-15	May-15	4800	541	
Jun-15	Jun-15	4800	3382	4559
Jul-15	Nov-15	3500	3382	4559
Dec-15	May-16	3500	3382	1266
Jun-16	Jun-59	3500	3382	
Jul-59	Jun-63		3382	

6.2 Assessment Results

6.2.1 Empress Aquifer

The production schedule for the planned case (Table 4) was added to the application model simulation to evaluate the impact of additional planned projects. Similar to the baseline and application simulations (Section 5.1.2.2.1) the maximum predicted drawdown was found to occur after the cessation of pumping at the Suncor projects in 2035 (Figure 24). At this time the drawdown measured near the STP wells reaches a maximum of 24 m. The maximum drawdown in the vicinity of the Suncor wells is 16 m. The increased drawdown in the area of the Project is mainly the result of additional production from the AOSC MacKay River Commercial Project which plans to withdraw a minimum of 3,500 m^3/day from the Empress Aquifer to the south of STP from 2014 to 2059.

The percent reduction in groundwater level in the Empress Aquifer as a result of the cumulative effect of the planned projects and the Project production is therefore calculated (see Section 3.2) as 26 % near the STP source wells based on an available head of 69 m. Similarly, the percent reduction in groundwater level (calculation is provided in Section 3.2) within the Empress Aquifer as a result of the Project production is 10 % at the Suncor source wells based on an assumed available head of 30 m.

Cumulative effects are related to effects of groundwater withdrawals on groundwater quantity (water levels) in the Empress Aquifer resulting from construction and operation of the Project and planned projects within the HRSA. The planned case effects are regional in extent, residual in duration, continuous in frequency, reversible in the long term, of moderate magnitude, and have a negative contribution. The confidence rating of the assessment is moderate, the probability of the effect is high, and overall, the impact rating is moderate.

6.2.2 Grand Rapids Aquifers

The model simulation drawdown predictions were reviewed for the Grand Rapids 4 Aquifer and Grand Rapids 5 Aquifer receptor locations evaluated in Section 5.1.2.2.2. The planned case simulation predicts 6 m of drawdown for the Grand Rapids 5 Aquifer and 11 m for the Grand Rapids 4 Aquifer. The percent reduction in groundwater level associated with the cumulative effects assessment is therefore 9 % for the Grand Rapids 5 Aquifer and 17 % for the Grand Rapids 4 Aquifer. The application case demonstrated no impact to the Grand Rapids 3 Aquifer in the area of the Dover Central Pilot Project, so no further cumulative assessment was undertaken for this unit.

Cumulative effects are related to effects of groundwater withdrawals on groundwater quantity in the Grand Rapids Aquifers resulting from construction and operation of the Project and planned projects within the HRSA. The planned case effects are regional in extent, potentially residual in duration, continuous in frequency, reversible in the long term, of low to moderate magnitude, and have a negative contribution. The confidence rating of the assessment is moderate, the probability of the effect is medium reflecting uncertainties regarding the regional relationships between the Empress Aquifer and the Grand Rapids Aquifers, and overall, the Project impact rating is low.

6.2.3 Shallow Drift Aquifers, Surface Water Bodies and Wetland Areas

Predicted drawdowns in the uppermost layer of the model, which represents the base of the drift, were reviewed for the planned case. The extent of the area of drawdown is noticeably greater in the planned case as a result of production at the Dover Central Project. Maximum drawdowns vary from 0 to 24 m near STP and up to 15 m near Suncor in the planned case simulation for 2035. The only groundwater wells identified as completed within the surficial drift for domestic use are Suncor wells located in 93-12-W4M (Appendix B, Table B5); the cumulative effects to these wells are anticipated to be low.

Cumulative effects are related to effects of groundwater withdrawals on groundwater quantity in the shallow drift aquifers resulting from construction and operation of approved and planned projects including the Phase 2 Project. The planned case effects are regional in extent, potentially residual in duration, continuous in frequency, reversible in the long term, of low magnitude, and have a negative contribution. The confidence rating of the assessment is low reflecting uncertainties regarding the regional hydraulic relationship between the shallow drift and underlying aquifer units, the probability of the effect is medium, and overall, the Project impact rating is low.

Assuming that the baseline conditions at STP are a reasonable approximation of the regional conditions, an average drawdown of 12 m was assumed for the planned case. Using this assumption the groundwater flux to the MacKay River is calculated as -0.02 m^3/s. This indicates the potential for a shift in the hydraulic relationship between the MacKay River and underlying groundwater units with the MacKay River now supplying recharge to the groundwater units. In a similar manner to before, this loss from the MacKay River is a negligible quantity in comparison to the mean seasonal flow of the MacKay River.

Cumulative effects are related to effects of groundwater withdrawals on water quantity in surface water bodies and wetland areas resulting from construction and operation of existing and planned projects including the Phase 2 Project. The planned case effects are regional in extent, potentially residual in duration, continuous in frequency, reversible in the long term, of negligible magnitude, and have a negative contribution. The confidence rating of the assessment is low given the uncertainties regarding the regional relationship between the MacKay River and groundwater aquifer units, the probability of the effect is medium, and overall, the Project impact rating is low.

7.0 GROUNDWATER MONITORING PROGRAM

The groundwater monitoring programs for the Project will have the following main purposes:

- to detect any impacts on the shallow groundwater quality resulting from spills or leaks from surface facilities at the plant site;
- to identify any changes of groundwater chemistry in the non-saline groundwater zones associated with the injection and production wells; and

- to evaluate the performance of the water supply wells in the Empress Aquifer and any impacts of groundwater production.

The details of the monitoring programs for the Project will be the subject of:

- the EPEA Approval coming out of this application; or
- the Water Act (in the case of the supply wells).

The groundwater monitoring program will be updated, if necessary, to meet the requirements of the Northern Athabasca Oil Sands Region (NAOS) Groundwater Management Framework (AENV 2010) once it is finalized. This section outlines the principles of the proposed monitoring programs.

7.1 Facility Groundwater Monitoring Program

A facility groundwater monitoring program was submitted under EPEA Approval 255245-00-00 for the STP McKay Thermal Project - Phase 1 and was approved by AENV. This program includes monitoring wells completed in the Undifferentiated Drift Aquifer/Aquitard around the Phase 1 plant site including one nested downgradient location. The monitoring wells within the drift have been preferentially completed within the more permeable intervals. Monitoring wells are also completed in the Grand Rapids 4 and 5 Aquifers in a location expected to be downgradient of the production and injection wells.

The existing monitoring program will be expanded to provide comparable coverage of the Project facilities. Additional wells will be required in the Undifferentiated Drift Aquifer/Aquitard and further monitoring locations within the Grand Rapids Aquifers and/or the Empress Aquifer may also be necessary.

Monitoring wells will be measured for water levels and sampled for chemistry analyses on a bi-annual basis after the establishment of baseline groundwater conditions. Samples will be submitted for the analysis of major ion and general chemistry, petroleum hydrocarbons, dissolved metals and selected organic parameters.

Results from the biannual monitoring program will be compared to the established pre-disturbance conditions. If the results are within acceptable ranges as defined in the program, then no actions will be taken. However, if the results are outside the defined ranges then a series of actions will be undertaken to determine whether the results reflect a change in groundwater chemistry requiring further evaluation or whether a laboratory or sampling error occurred. In the event of a change in groundwater chemistry, a Groundwater Response Plan will be implemented.

The results of the facility groundwater monitoring program will be reported to AENV on an annual basis.

7.2 Water Supply Monitoring Program

Currently three water source wells are completed in the Empress Aquifer. Two of these water supply wells are licensed (00262149-00-00) for a withdrawal of up to 419,750 m^3 annually, which corresponds to an average daily amount of 1,150 m^3. Additional wells are expected to be required to meet the Project water requirements. Additional withdrawal locations or further allocation amounts will be the subject of an application to AENV under the Water Act. This application will include a technical evaluation in accordance with the *Water Conservation and Allocation Guideline for Oilfield Injection* (AENV 2006) and Groundwater Evaluation Guideline (AENV 2003).

The water supply monitoring program will be conducted in accordance with the conditions of the license(s) issued under the Water Act, as is currently being undertaken for the existing license. These monitoring requirements (are expected to) include daily measurement of the total volume in cubic meters diverted from each water supply well and water levels in each water supply and observation well. An annual water sample will be analyzed for general chemistry and major ion parameters. Monitoring information will be reported in a timely manner at the end of each month through the AENV automated reporting system. The monitoring program for the water supply will include any additional requirements included on the license under the Water Act.

Results from the monitoring program will be reviewed and analyzed on an annual basis to evaluate the aquifer performance and provide recommendations for responsible management of the groundwater supply. These results would be submitted to AENV on an annual basis.

8.0 SUMMARY

The assessment of potential Project effects on groundwater resources is summarized as follows:

- groundwater production from the Empress Aquifer is proposed to meet the water requirements of the Project. STP will continue to evaluate the potential for alternative water supplies to reduce the use of non-saline water;
- wastewater will be disposed of at an approved facility and no disposal wells are included in the Project;
- Project activities with the potential to impact groundwater resources include withdrawals from the Empress Aquifer, operation of surface facilities and the operation of injection and production wells;
- the Valued Ecosystem Components for hydrogeology include water quality and water quantity (water levels);
- groundwater production from the Empress Formation should have a low impact on the quantity of water in other groundwater aquifer units and the surface water resources; however the cumulative effects assessment identified moderate impacts to groundwater quantity within the Empress Formation;
- potential spills or leaks of bitumen, produced water or process-related chemicals at the surface facilities are assessed to have a low impact on the chemical quality of the shallow groundwater resources in the undifferentiated drift; and
- the operation of the production and injection wells are assessed to have a low impact on the chemical quality of non-saline aquifers and no impact to surface water bodies and wetlands.

9.0 REFERENCES

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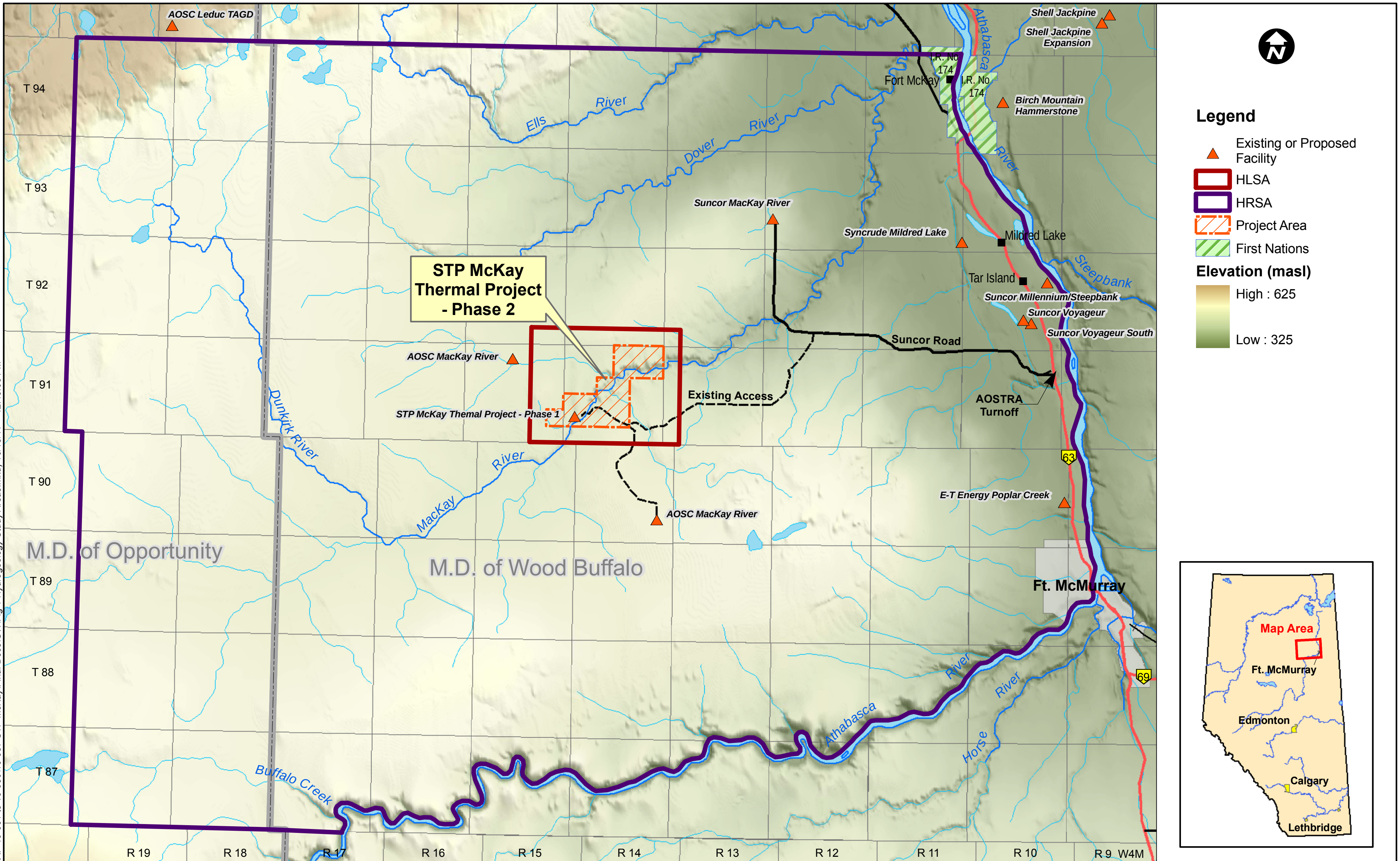
APPENDIX A: FIGURES



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REF: Geobase, 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

TITLE:

Hydrogeology Study Areas

Millennium EMS Solutions Ltd.

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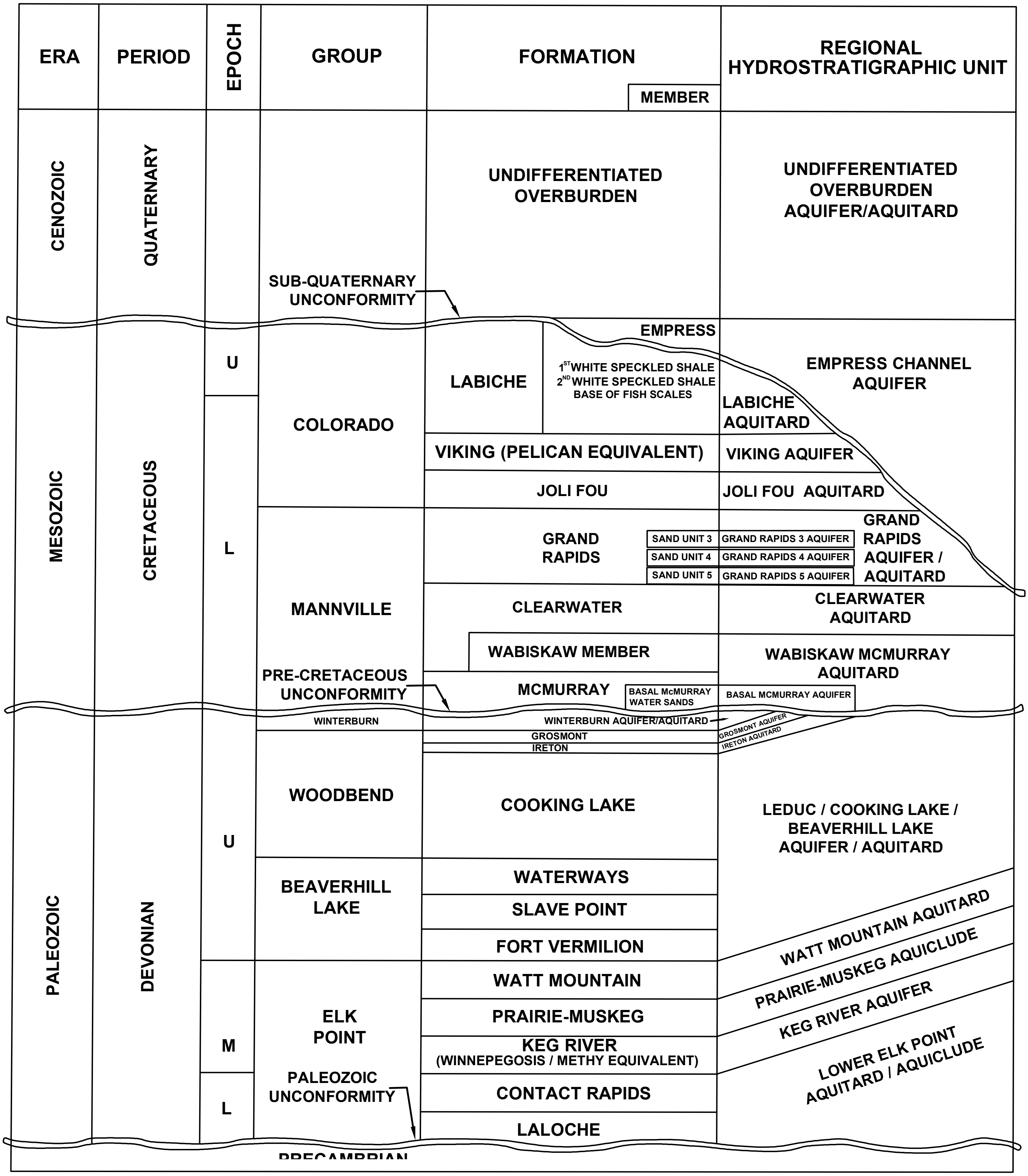
PROJECT: 10-037	



SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Stratigraphy/Hydrostratigraphy within the HRSA

FILE: ...Final Docs\GW\Fig 2 Stratigraphy.dwg

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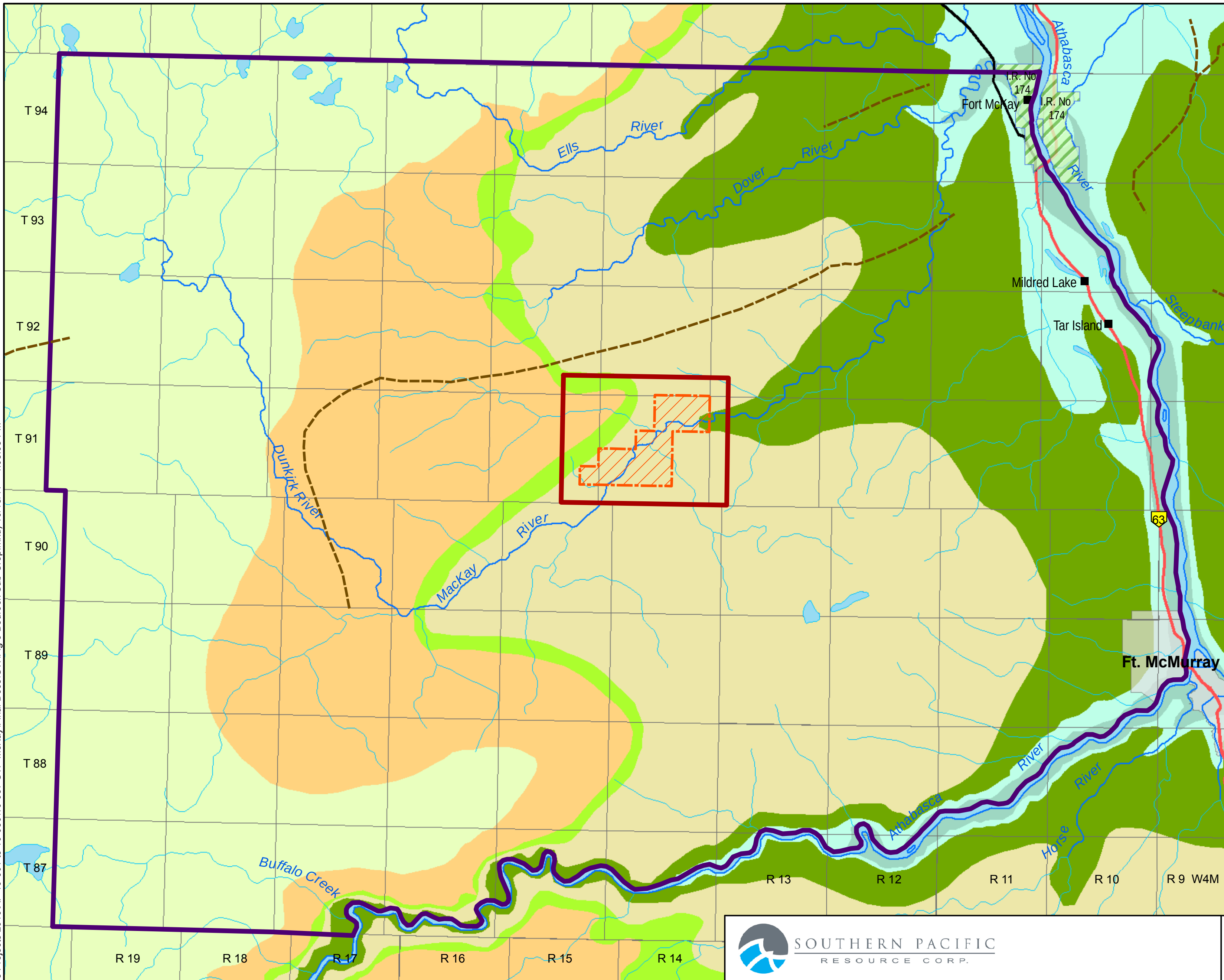
PROJECT: 10-037		

REF: Athabasca Oil Sands Corp., Figure 5.5-1 Stratigraphic/Hydrostratigraphic Column, 30Sep09.



Legend

- HLSA
- HRSA
- Project Area
- First Nations

Sub-Cropping Formations

- Labiche Formation
- Pelican Formation
- Joli Fou Formation
- Grand Rapids Formation
- Clearwater Formation
- McMurray Formation
- Waterways Formation
- Interpreted Buried Bedrock Channel/Valley Thalweg

0 5 10 20
Kilometres

REF: AGS, DIG0073, DIG 2007-0026.

Map Document: (K:\Active Projects 2010\AP 10-001 to 10-050\10-037 STP McKay\Final Docs\GW\Fig 3 Bedrock Sub-Crop.mxd) 10/18/11 -- 1:08:08 PM

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

TITLE:

Bedrock Sub-Crop within the HRSA

Millennium EMS Solutions Ltd.

DRAWN: JG/SL
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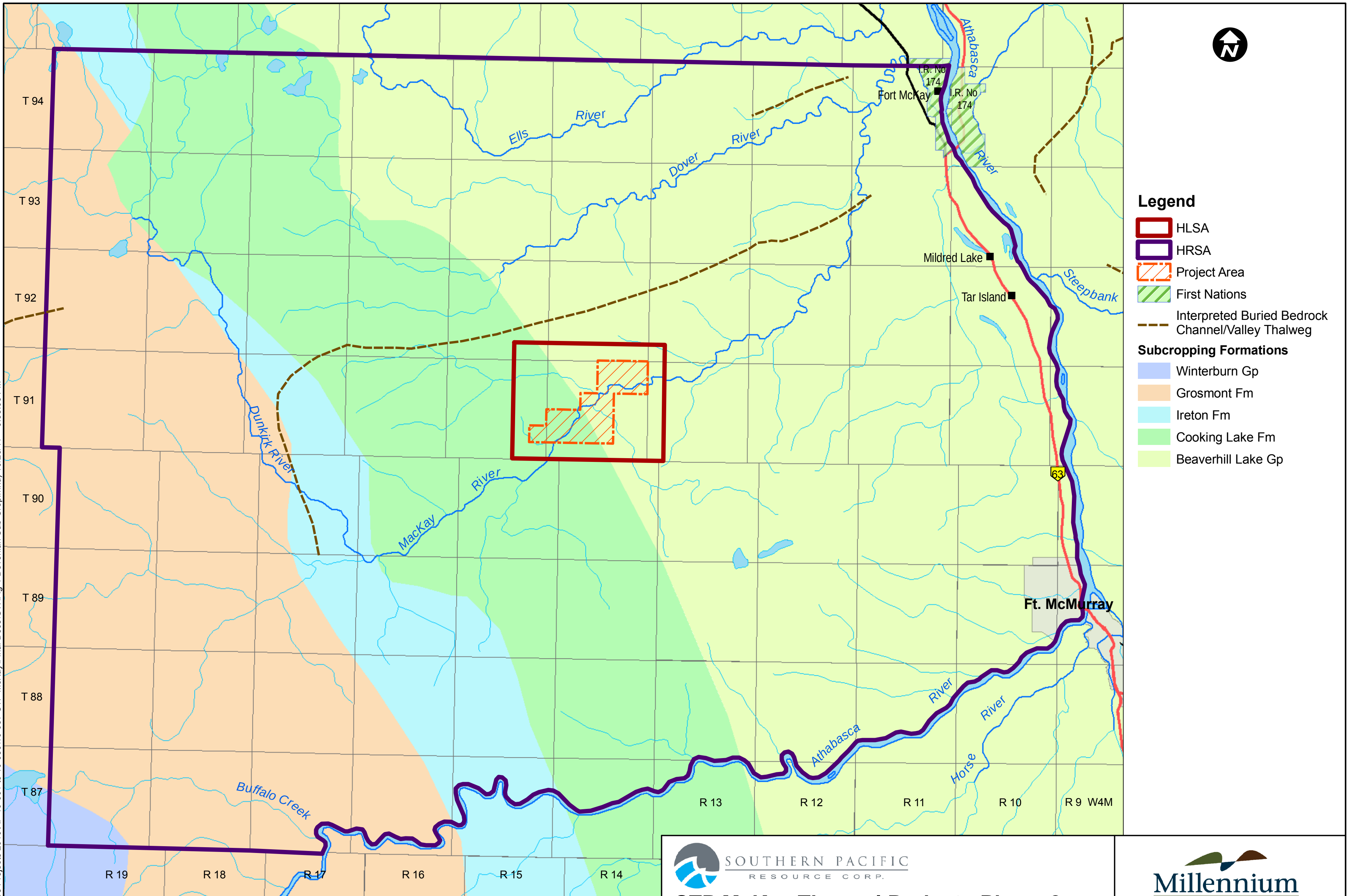
DATE: Oct 25/11
PROJECT: 10-037

FIGURE: 3



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REF: AGS, DIG0073, DIG 2007-0026.
Bachu et al., 1993.

SOUTHERN PACIFIC RESOURCE CORP.

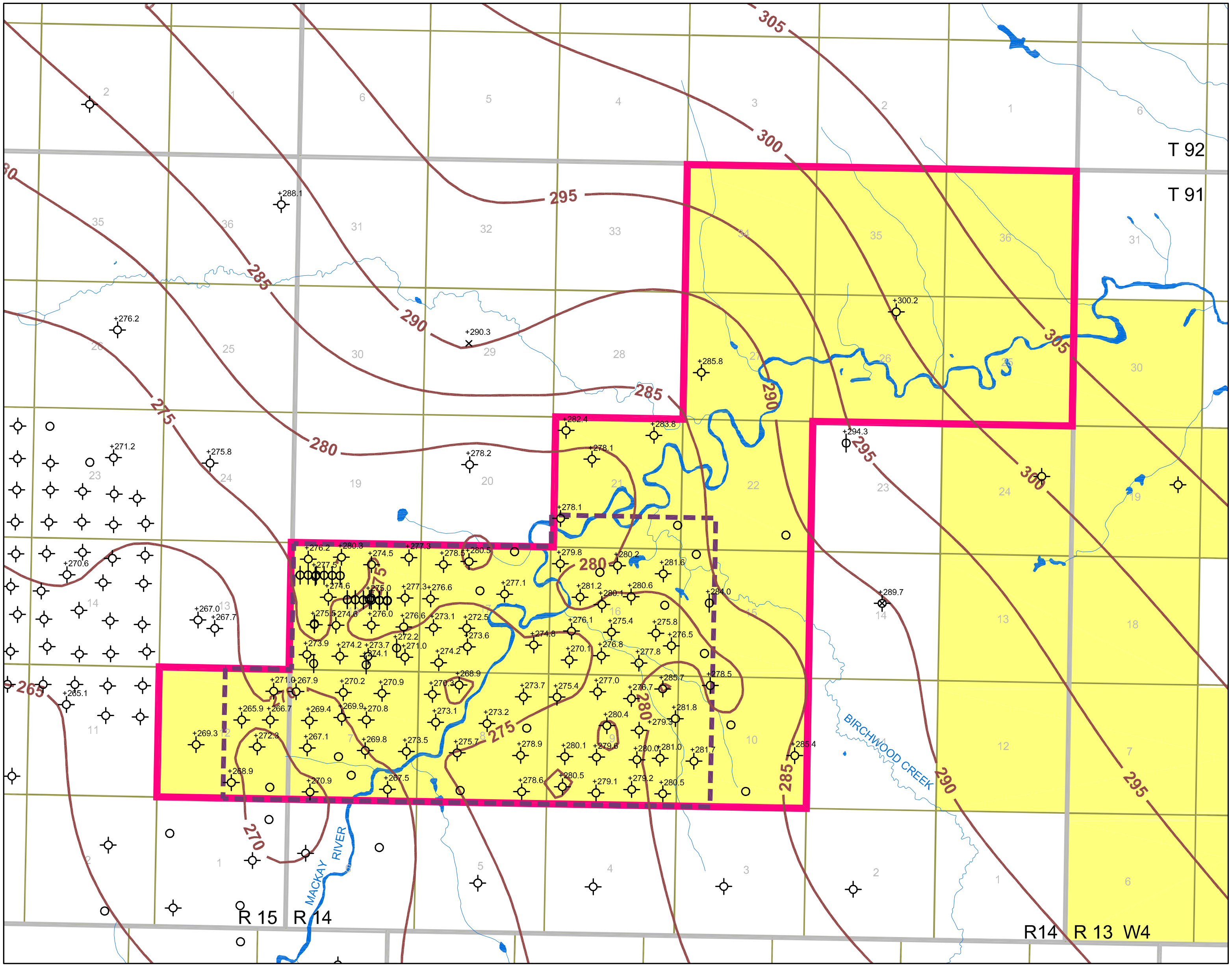
STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Devonian Formations Sub-Crop Map

DRAWN:	JG/SL
CHECKED:	NG
DATE:	Oct 25/11
PROJECT:	10-037
FIGURE:	4



Legend

- Well Symbol
- Development Area
- Project Area
- Structure Contour (5m Interval, a.s.l.)
- STP Oil Sands Leases

0 0.5 1 1.5 3km

Scale 1 : 75 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

TITLE:

Pre-Cretaceous Unconformity Structure Map

Millennium EMS Solutions Ltd.

FILE:	...Final Docs\GW\Geology Maps_75K.dwg
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CHECKED:	NG
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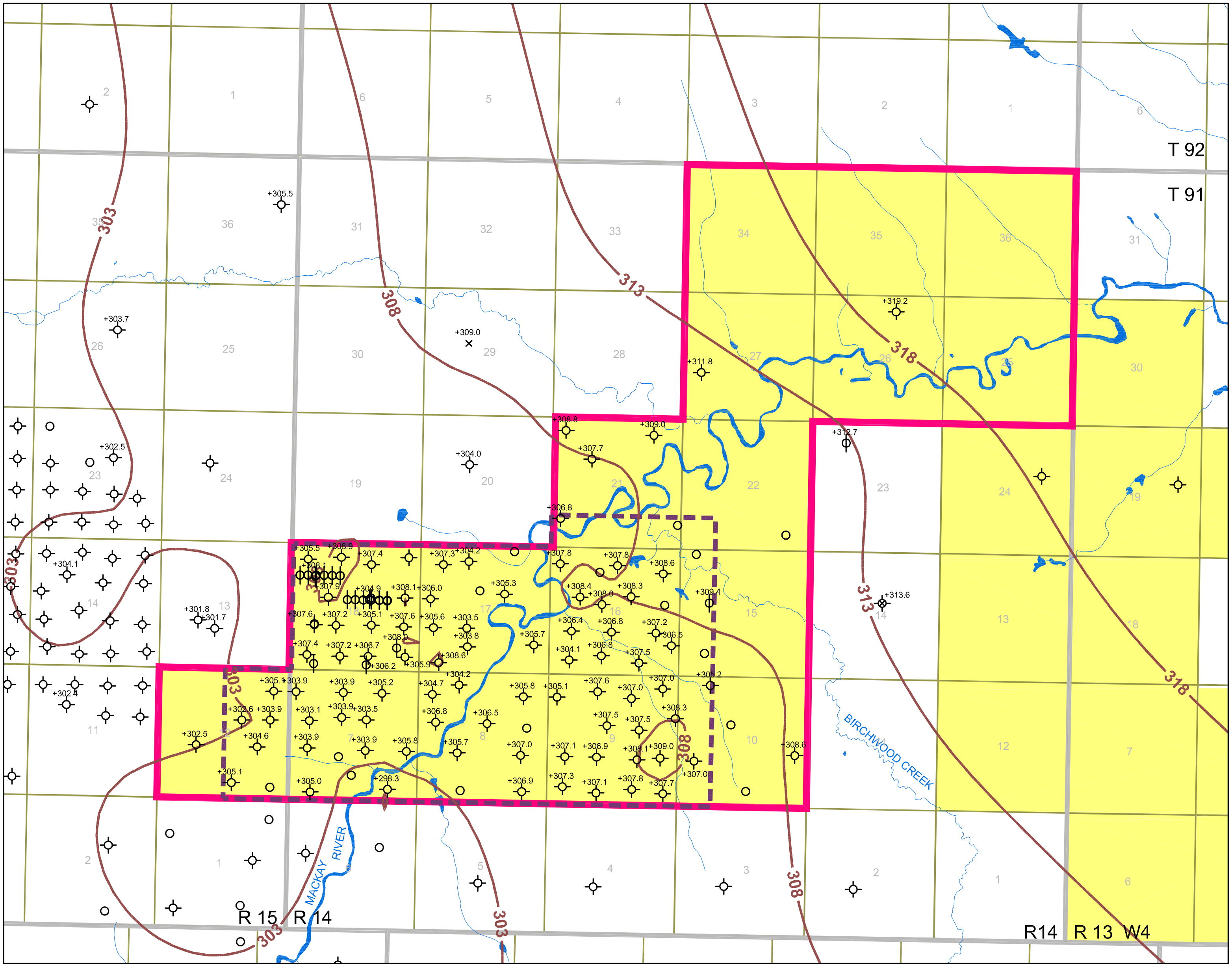
PROJECT:	10-037
FIGURE:	5



Legend

- Well Symbol
- Development Area
- Project Area
- Structure Contour (5m Interval, a.s.l.)
- STP Oil Sands Leases

0 0.5 1 1.5 3km

Scale 1 : 75 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC
RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium
EMS Solutions Ltd.

TITLE:

McMurray Formation Structure Map

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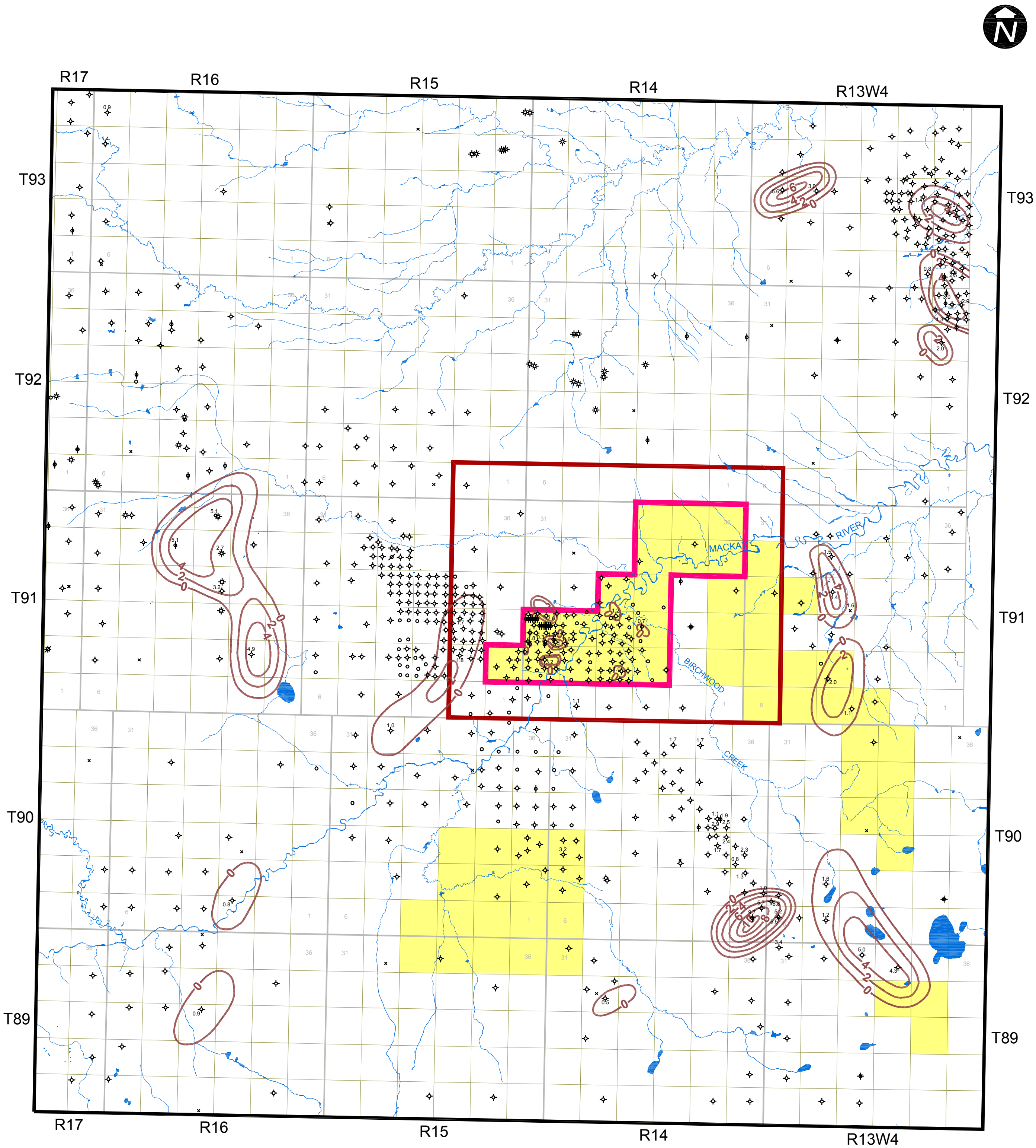
PROJECT: 10-037	



Legend

- Well Symbol
- HLSA
- Project Area
- Isopach Contour (2m Interval)
- STP Oil Sands Leases

0 2.5 5 10km

Scale 1 : 250 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

McMurray Bottom Water Isopach Map

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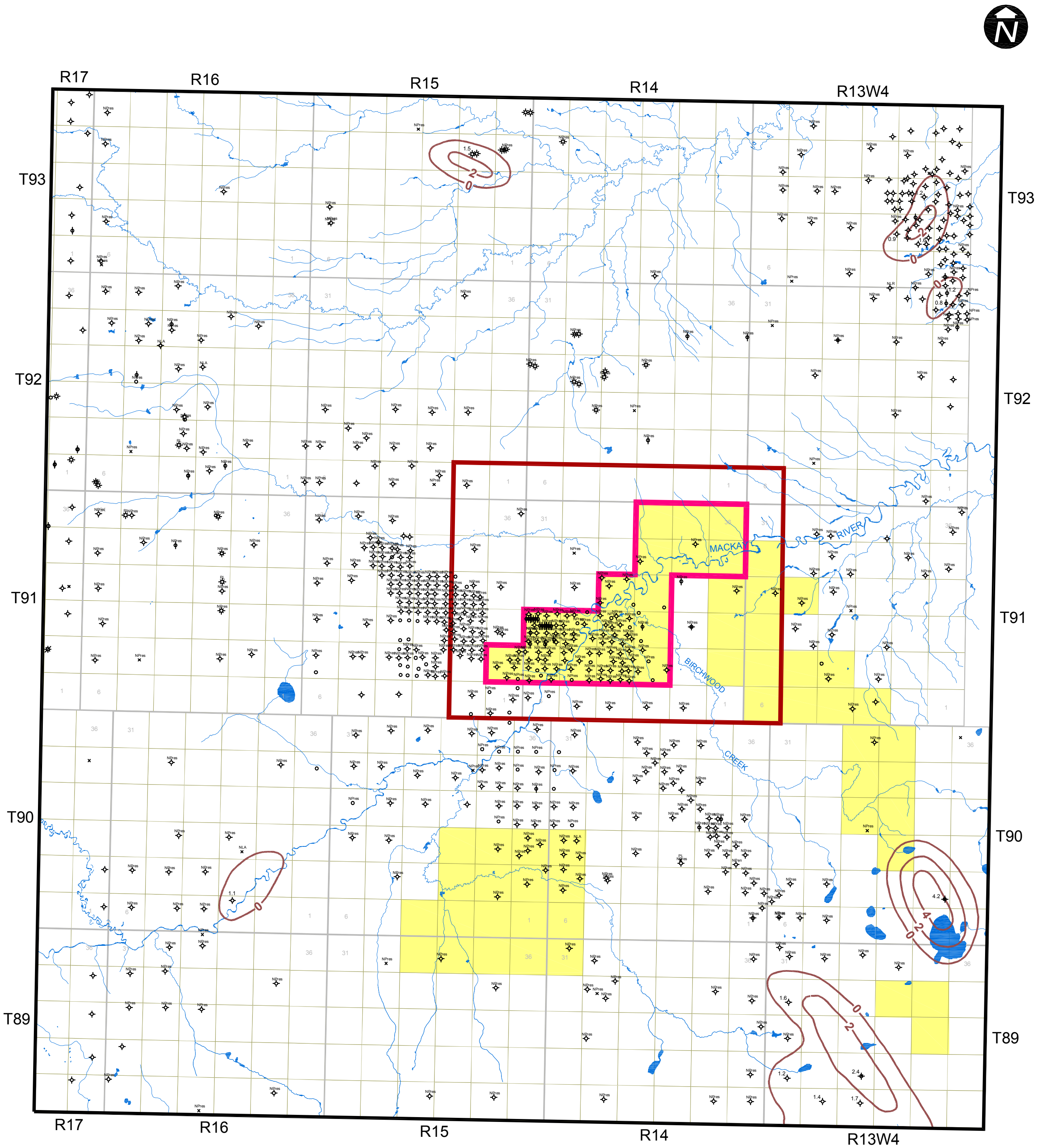

Legend

- Well Symbol
- HLSA
- Project Area
- Isopach Contour (2m Interval)
- STP Oil Sands Leases

0 2.5 5 10km

Scale 1 : 250 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

McMurray Top Water Isopach Map

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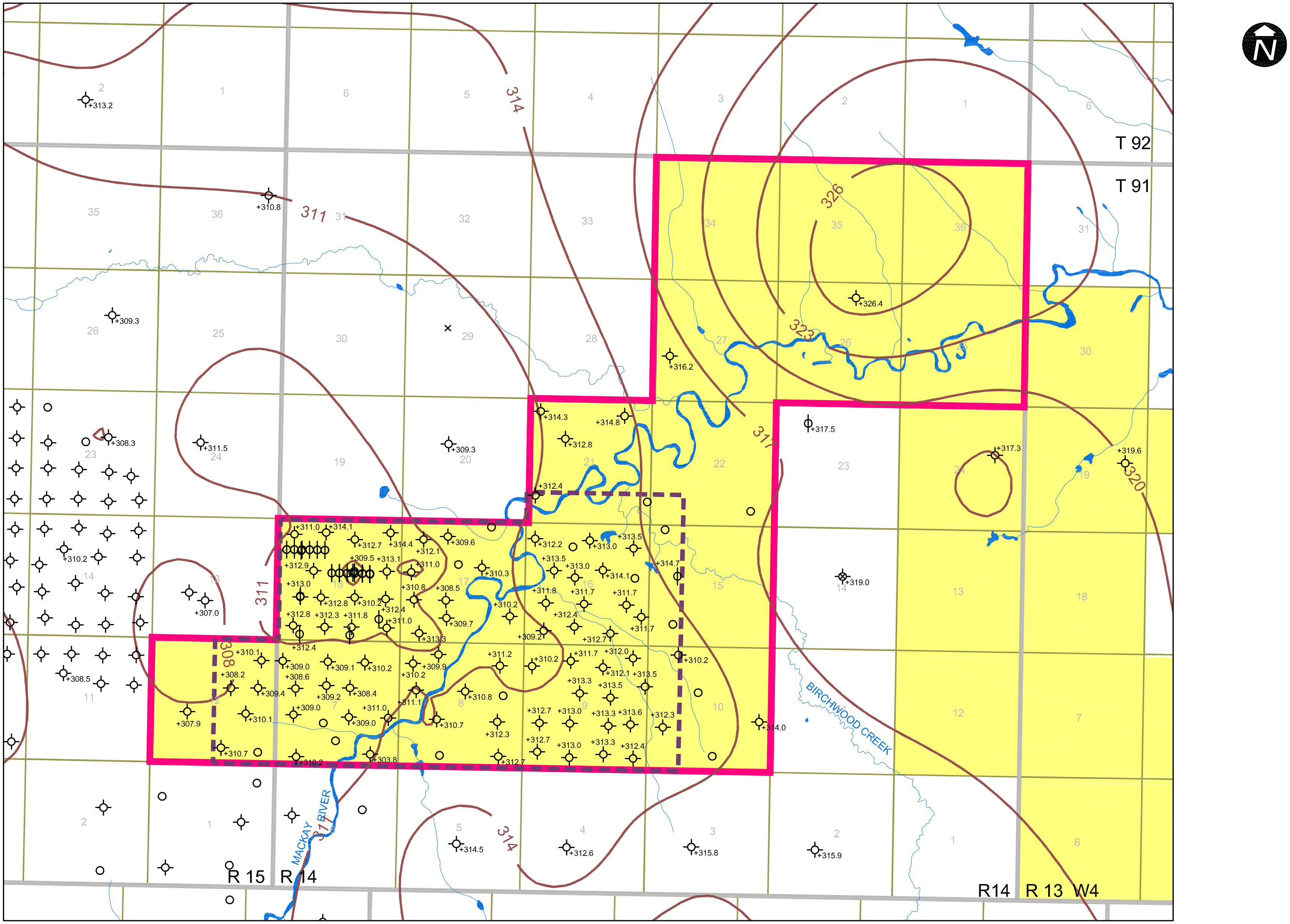
PROJECT: 10-037	



Legend

- Well Symbol
- Development Area
- Project Area
- Structure Contour (3m Interval, a.s.l.)
- STP Oil Sands Leases

0 0.5 1 1.5 3km

Scale 1 : 75 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

TITLE:

Wabiskaw Shale Structure Map

Millennium EMS Solutions Ltd.

FILE: ...Final Docs\GW\Geology Maps_75K.dwg

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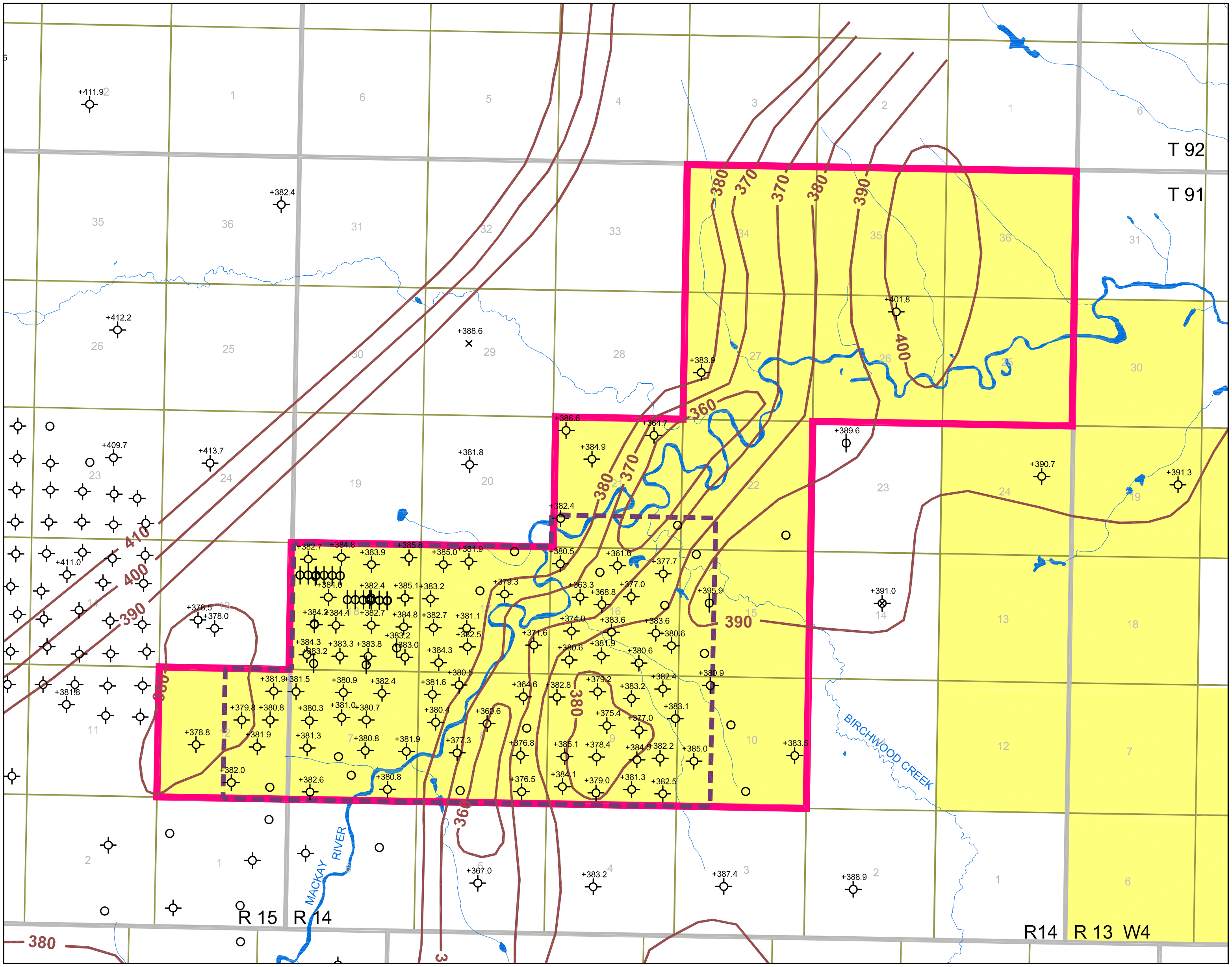
PROJECT:	10-037	



Legend

- Well Symbol
- Development Area
- Project Area
- Structure Contour (10m Interval, a.s.l.)
- STP Oil Sands Leases

0 0.5 1 1.5 3km

Scale 1 : 75 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Upper Clearwater Structure Map

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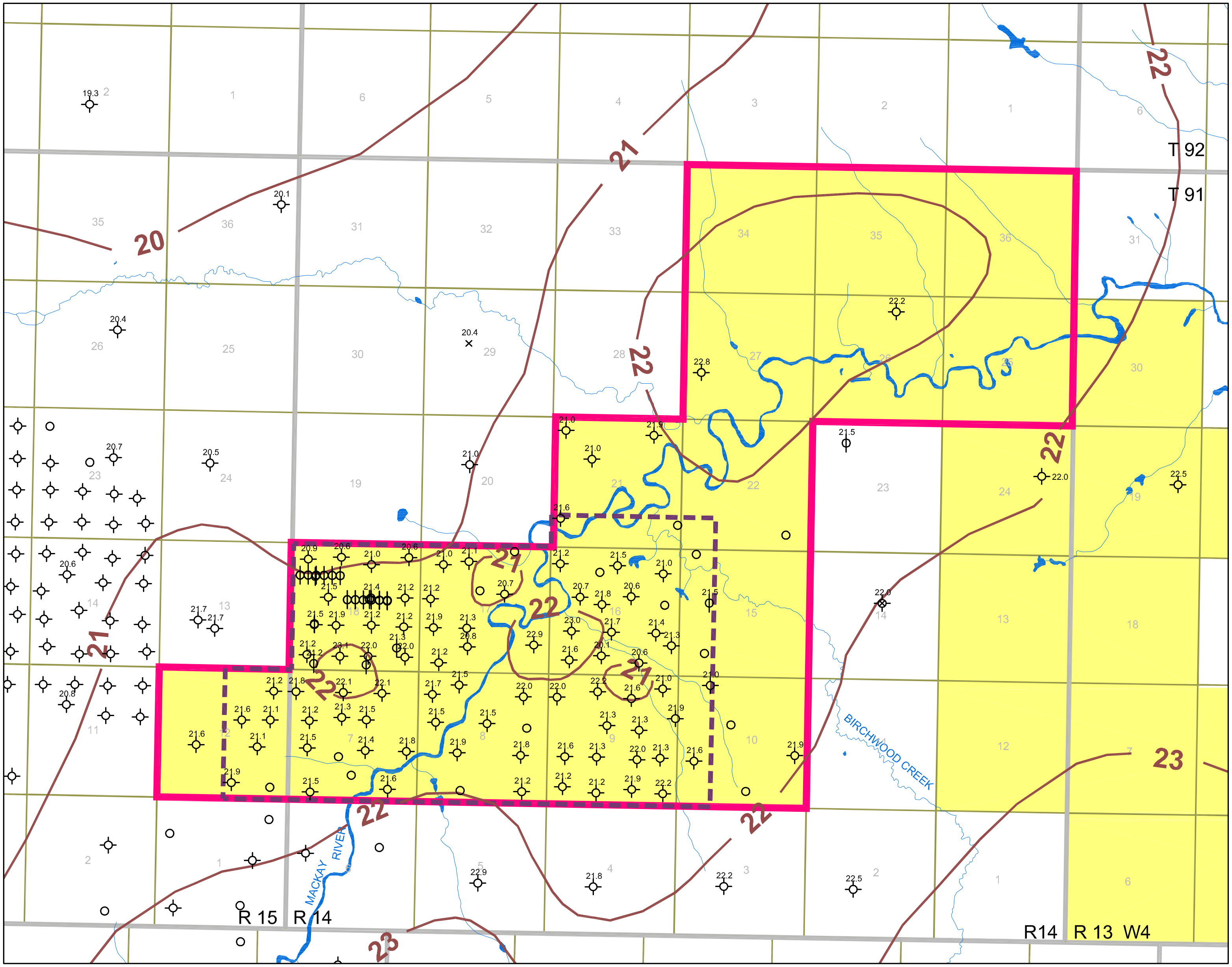

Legend

- Well Symbol
- Development Area
- Project Area
- Isopach Contour (1m Interval)
- STP Oil Sands Leases

0 0.5 1 1.5 3km

Scale 1 : 75 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Clearwater Shale Isopach Map

FILE: ...Final Docs\GW\Geology Maps_75K.dwg

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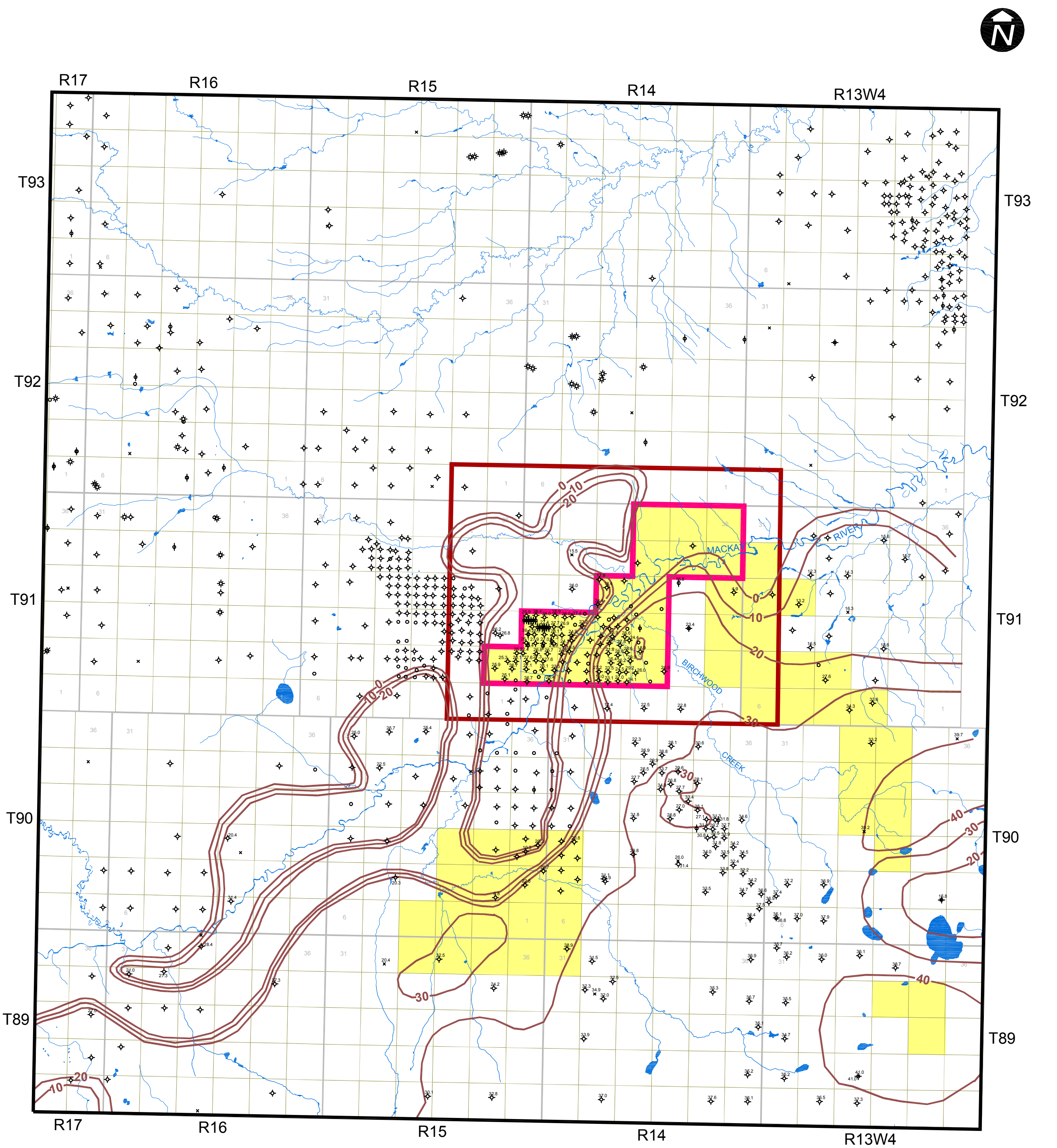
Back Main Menu Search Main TOC



Legend

- Well Symbol
- HLSA
- Project Area
- Isopach Contour (10m Interval)
- STP Oil Sands Leases

0 2.5 5 10km

Scale 1 : 250 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Grand Rapids 5 Isopach Map

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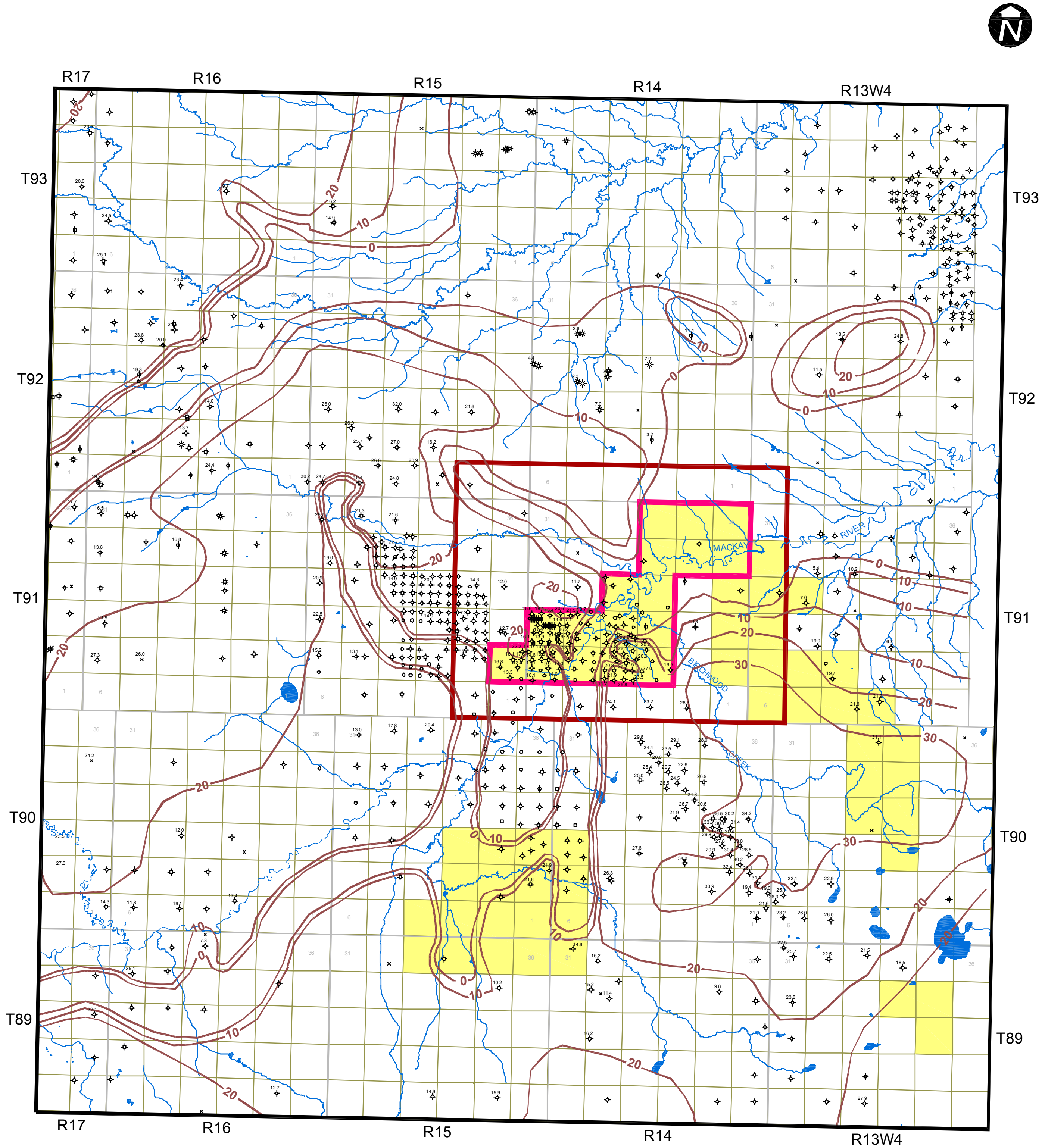
PROJECT: 10-037	

Back Main Menu Search Main TOC



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- Well Symbol
- HLSA
- Project Area
- Isopach Contour (10m Interval)
- STP Oil Sands Leases

0 2.5 5 10km

Scale 1 : 250 000

REF: Southern Pacific Resource Corp., Oct 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Grand Rapids 4 Isopach Map

FILE: ...Final Docs\GW\Geology Maps_250K.dwg

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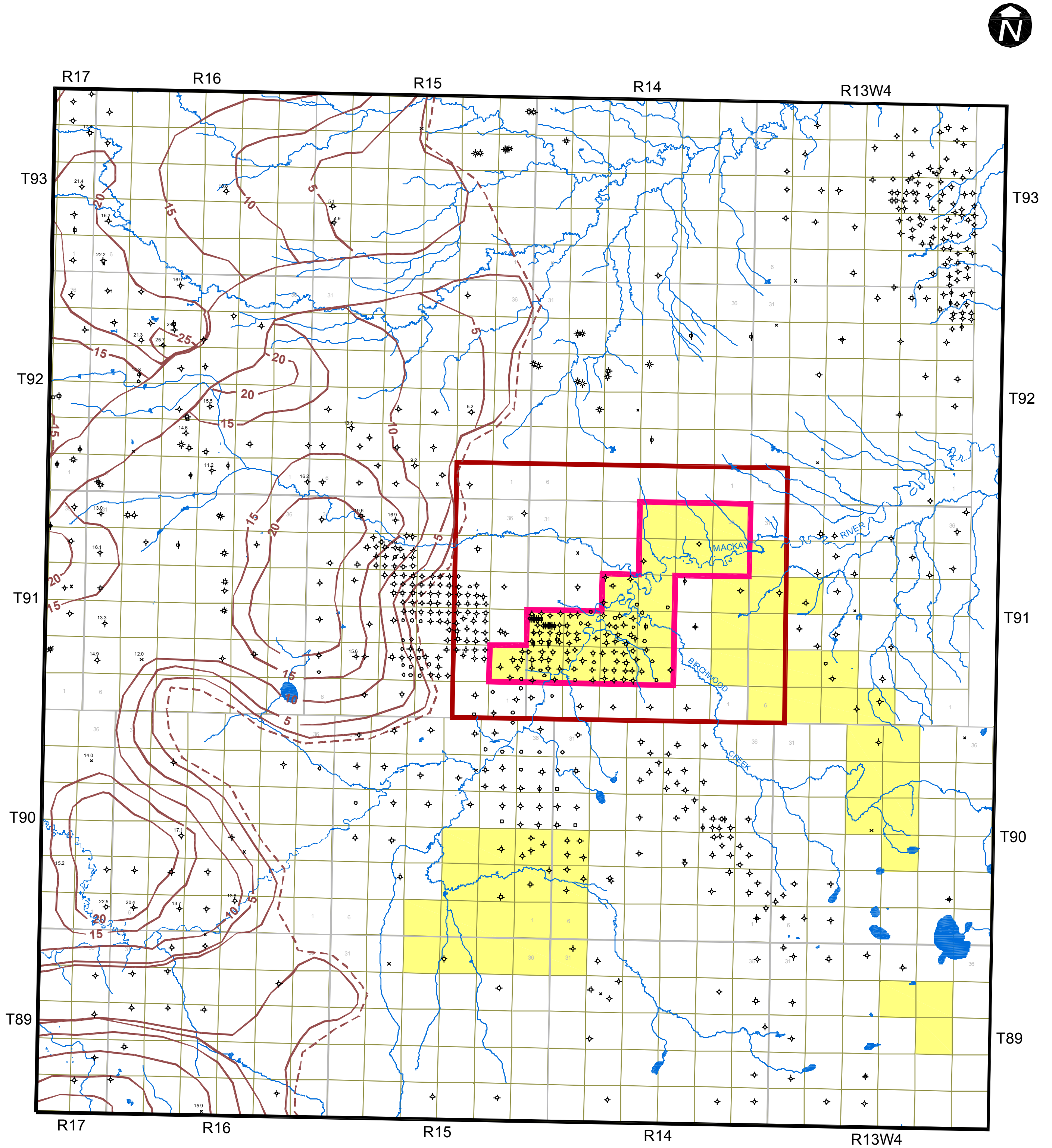
DATE: Oct 25/11

PROJECT: 10-037

FIGURE: 13

Back Main Menu Search Main TOC



Legend

- Well Symbol
- HLSA
- Project Area
- Isopach Contour (5m Interval)
- STP Oil Sands Leases

0 2.5 5 10km

Scale 1 : 250 000

REF: Southern Pacific Resource Corp., Oct. 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Grand Rapids 3 Isopach Map

FILE: ...Final Docs\GW\Geology Maps_250K.dwg		
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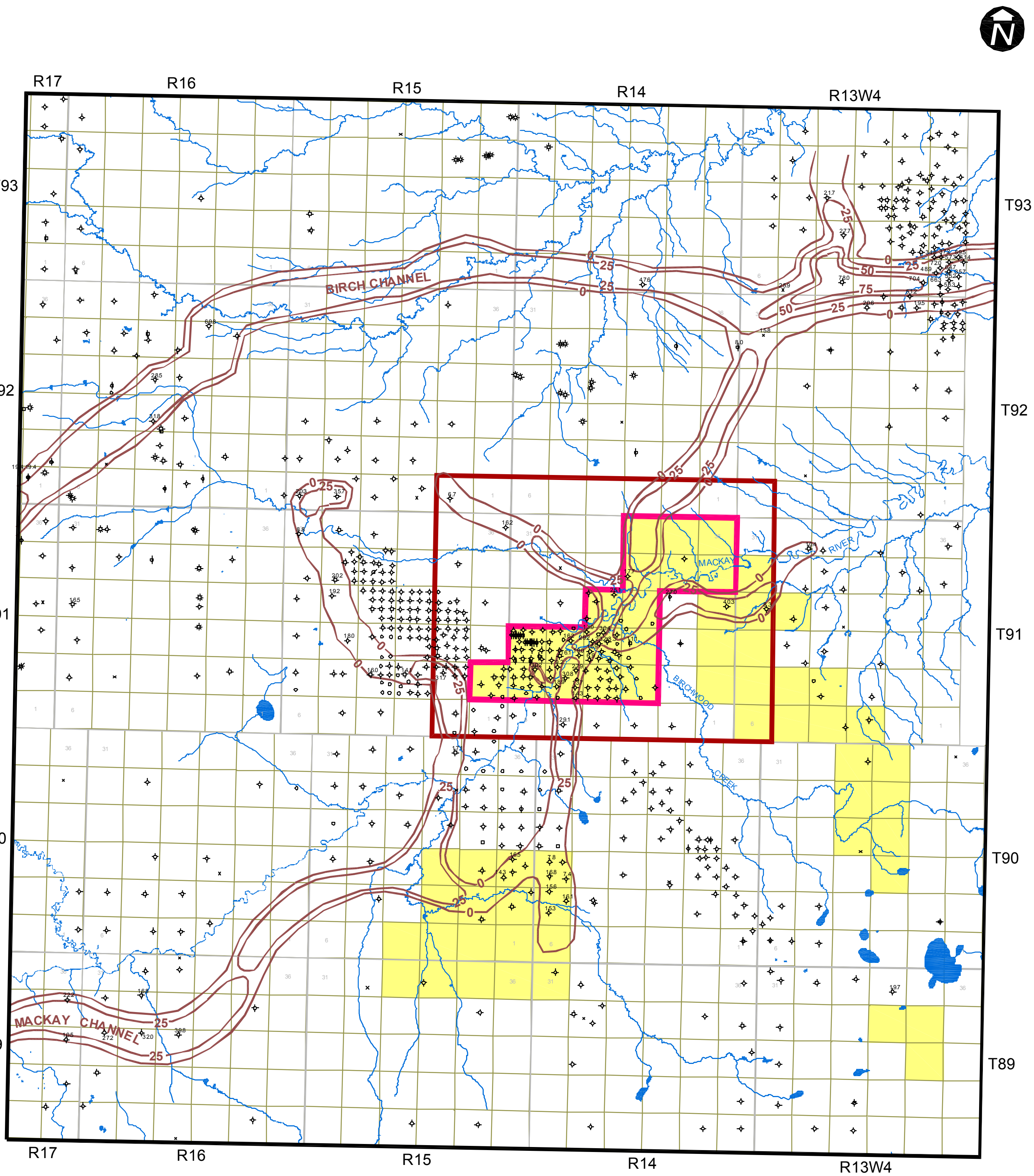
PROJECT:	10-037	



Legend

- Well Symbol
- HLSA
- Project Area
- Isopach Contour (25m Interval)
- STP Oil Sands Leases

0 2.5 5 10km

Scale 1 : 250 000

REF: Southern Pacific Resource Corp., Oct 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Undifferentiated Empress Formation Isopach Map

FILE: ...Final Docs\GW\Geology Maps_250K.dwg

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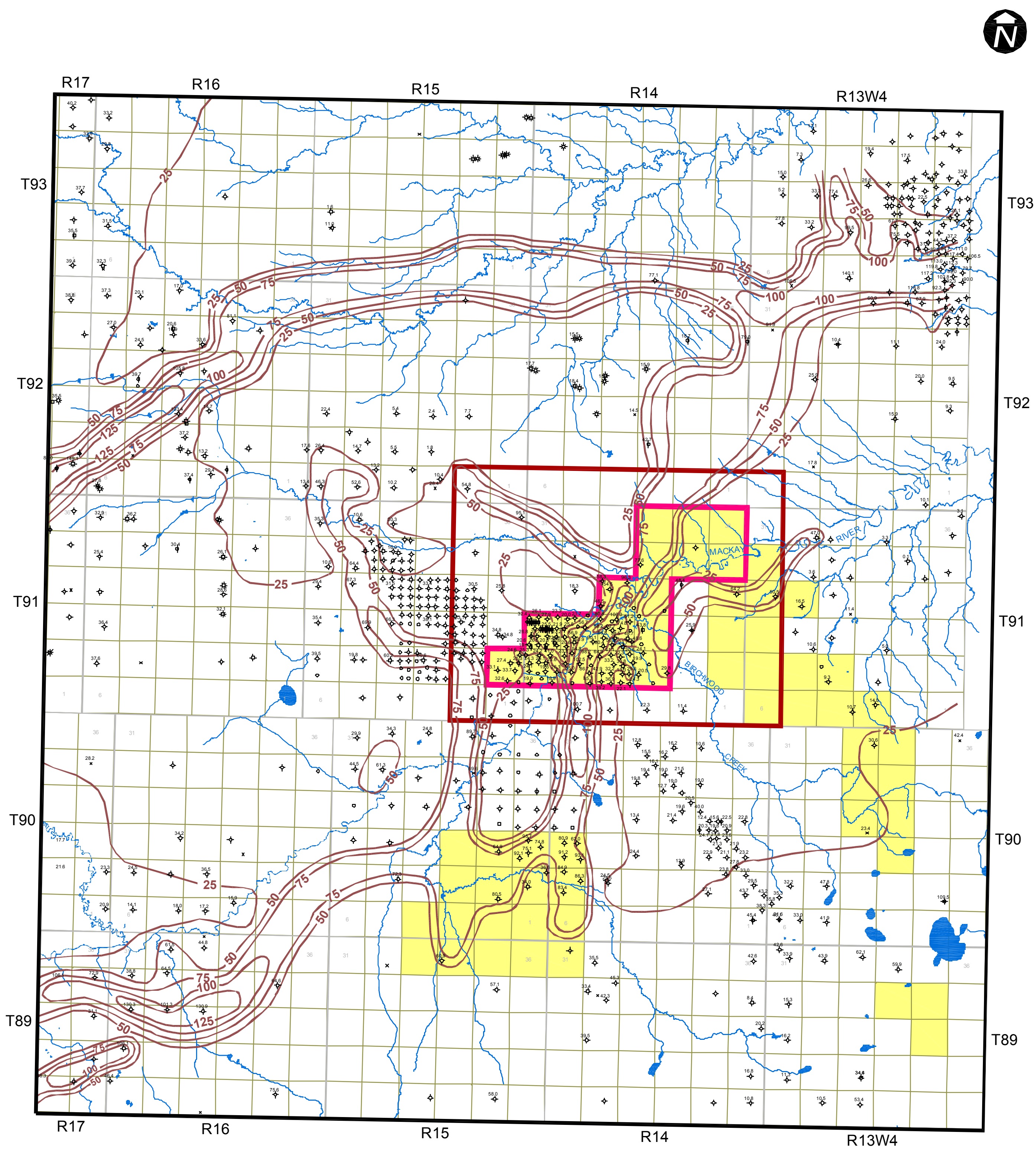
PROJECT: 10-037	



Legend

- Well Symbol
- HLSA
- Project Area
- Isopach Contour (25m Interval)
- STP Oil Sands Leases

0 2.5 5 10km

Scale 1 : 250 000

REF: Southern Pacific Resource Corp., Oct 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Quaternary Deposits Isopach Map

FILE: ...Final Docs\GW\Geology Maps_250K.dwg

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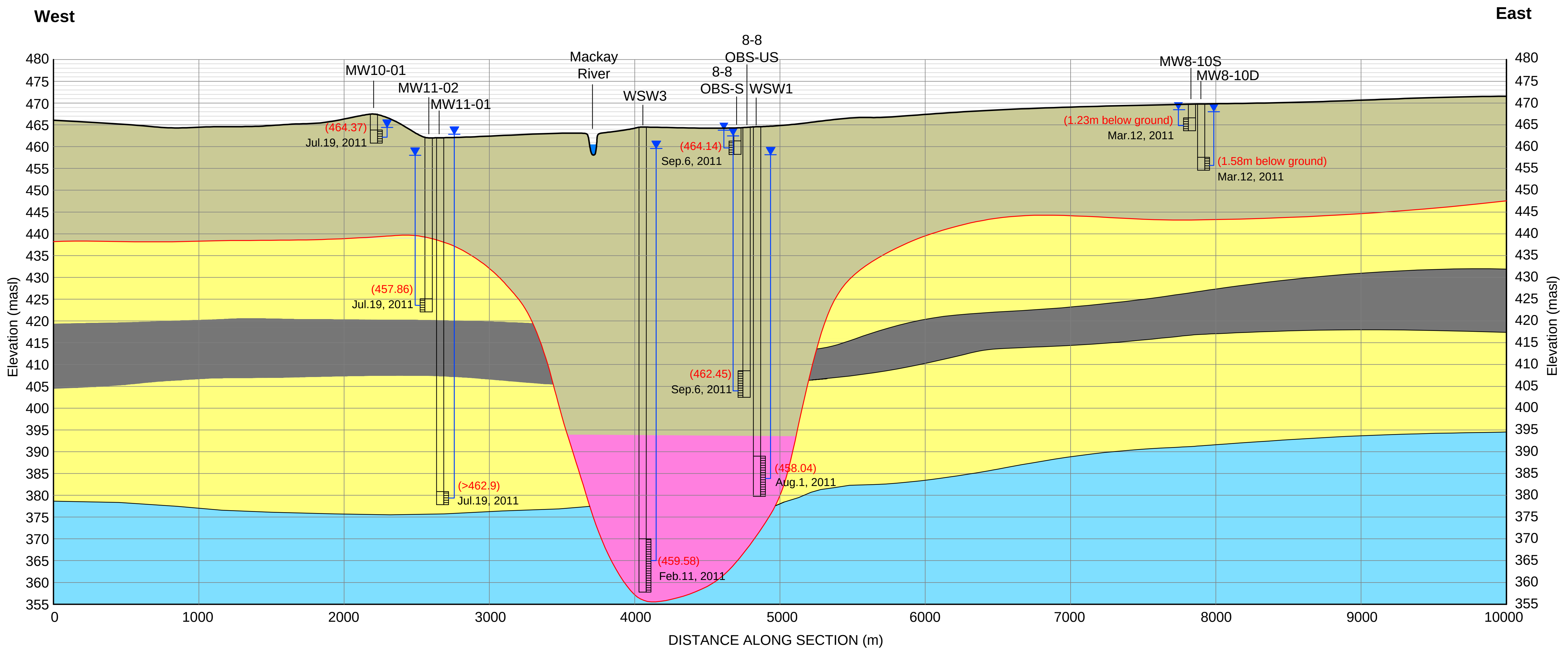
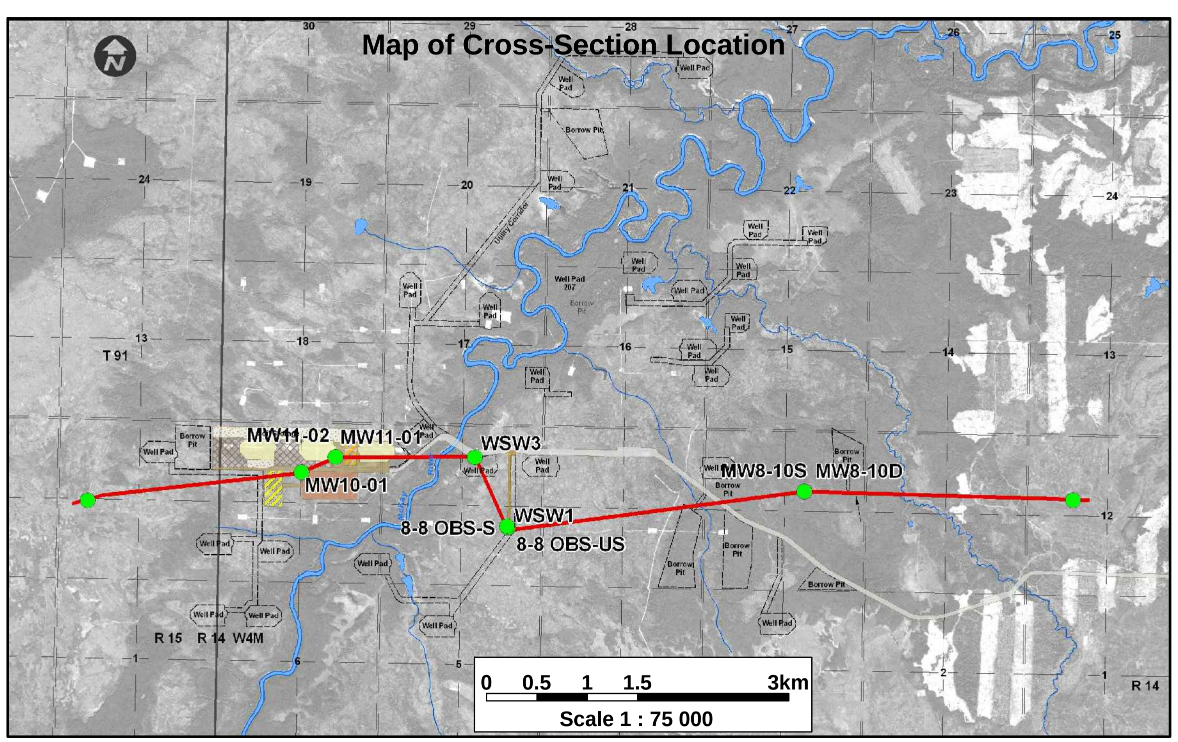
CHECKED: NG

DATE: Oct 25/11

PROJECT: 10-037

FIGURE: 16





Horizontal Scale

0 0.2 0.4 1km

Scale 1 : 30 000

Vertical Exaggeration 30X

Legend

- QUATERNARY (DRIFT AND CHANNEL FILL)
- GRAND RAPIDS (SANDSTONE)
- GRAND RAPIDS (SHALE AND SILTSTONE)
- EMPRESS (SAND AND GRAVEL)
- CLEARWATER (SHALE)
- 458.04 SCREENED INTERVAL AND GROUNDWATER ELEVATION

REF: Elevation data from Lidar.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay SAGD Project

Millennium EMS Solutions Ltd.

TITLE:

Hydrogeological Cross-Section within LSA

FILE: Fig 16 Hydrogeological XS.dwg

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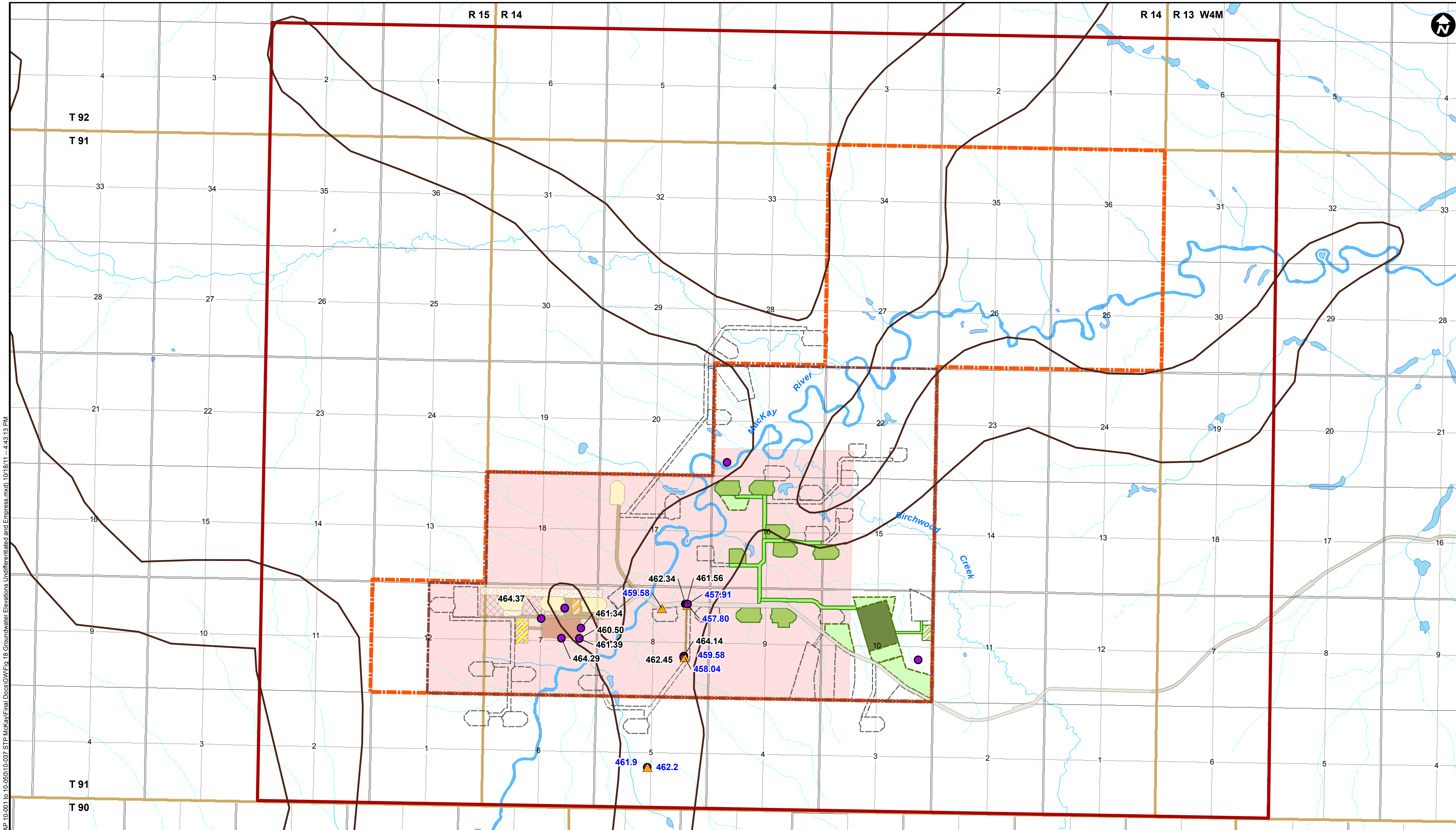
DATE: Oct 13/11
PROJECT: 10-037

FIGURE: **17**



Legend

- HLSA
- Groundwater Monitoring Well
- Water Source Well
- MacKay Channel

464.14 Groundwater Elevation (masl) in Undifferentiated Drift
461.9 Groundwater Elevation (masl) in Empress Formation

Existing Phase 1 Development

- Approved Project Area
- CPF
- Well Pad
- Utility Corridor
- Borrow Pit
- Construction Camp
- Operations Camp
- Soil Storage
- Access Road
- Water Source Well

Proposed Phase 2 Development

- CPF
- Operations Camp
- Utility Corridor
- Well Pad
- Borrow Pit
- Proposed Project Area
- Proposed Development Area
- Future Development

0 0.5 1 2
Kilometres

REF:David Loucks Consulting Drifter Projects Ltd., 2011; NHC (Hydrology) 2010.

Map Document: (K:\Active Projects 2010\AP 10-001 to 10-050\10-037 STP McKay\Final Docs\GW\Fig 18 Groundwater Elevations Undifferentiated and Empress.mxd) 10/18/11 -- 4:43:13 PM

SOUTHERN PACIFIC RESOURCE CORP.

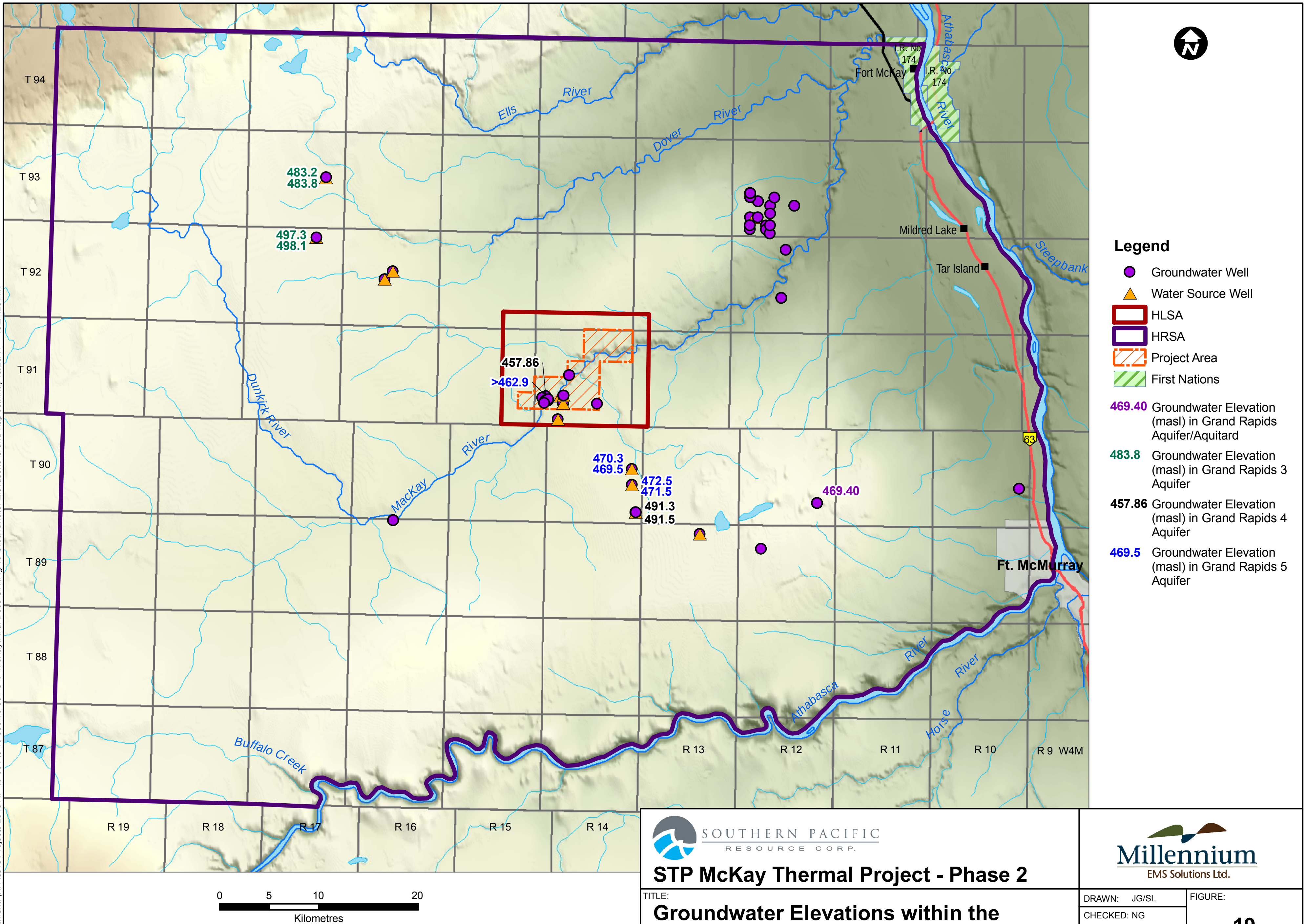
STP McKay Thermal Project - Phase 2

TITLE:

Groundwater Elevations within the Undifferentiated Drift and Empress Formation

Millennium EMS Solutions Ltd.

DRAWN: JG/SL	FIGURE:
CHECKED: NG	18
DATE: Oct 26/11	
PROJECT: 10-037	



SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

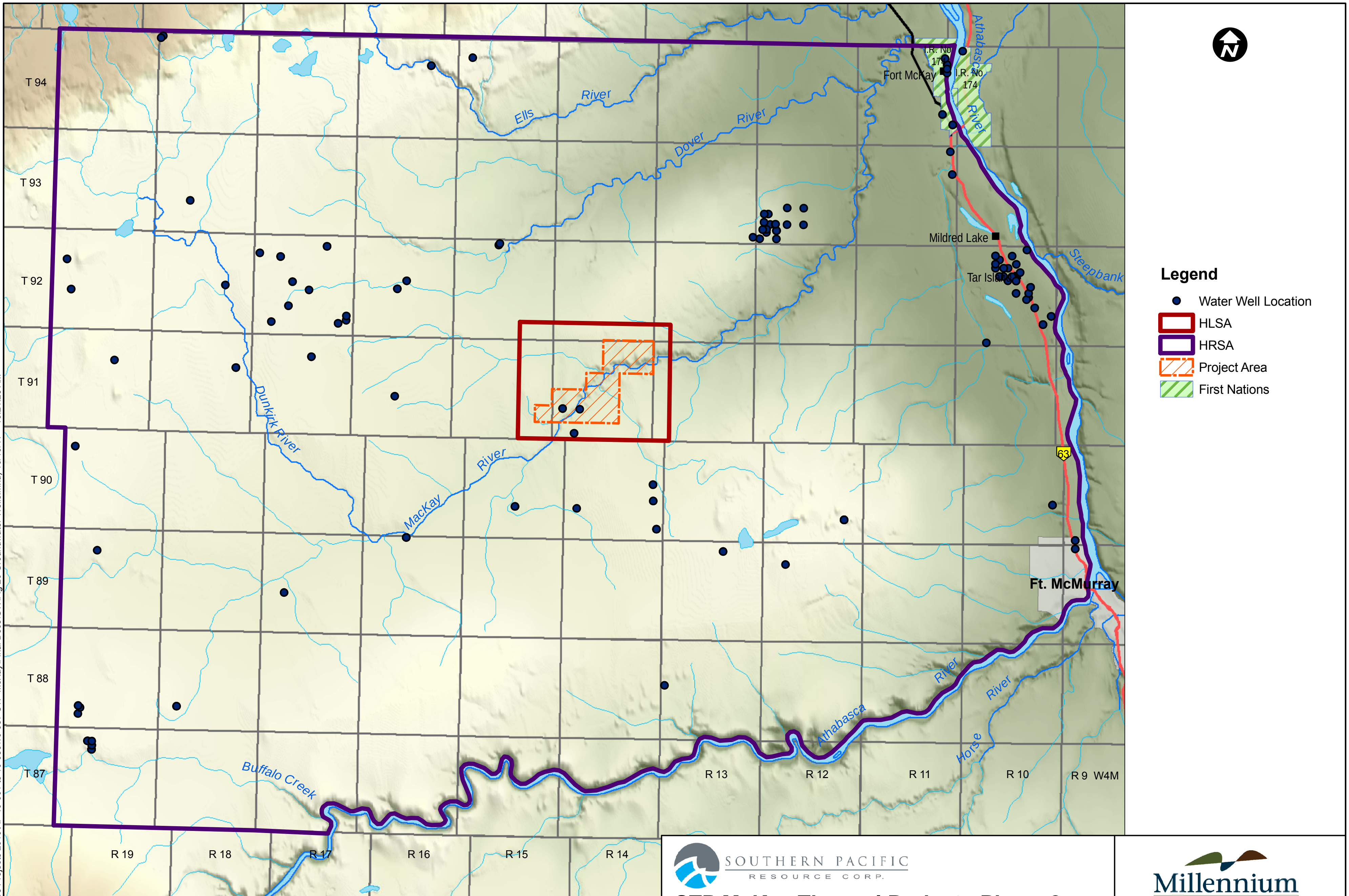
Groundwater Elevations within the Grand Rapids Aquifer/Aquitard

DRAWN: JG/SL
CHECKED: NG
DATE: Oct 26/11
PROJECT: 10-037

FIGURE: 19

REF: Geobase, 2011; Water wells from Alberta Environment, http://www.envinfo.gov.ab.ca/GroundWater, Oct 18, 2011.

Map Document: (K:\Active Projects 2010\AP 10-001 to 10-050\10-037 STP McKay\Final Docs\GW\Fig 19 Groundwater Elevations Grand Rapids.mxd) 10/26/11 -- 10:21:23 AM



REF: Geobase, 2011; Water wells from Alberta Environment, http://www.envinfo.gov.ab.ca/GroundWater, Oct 18, 2011.

Map Document: (K:\Active Projects 2010\AP 10-001 to 10-050\10-037 STP McKay\Final Docs\GW\Fig 20 Groundwater Wells.mxd) 10/19/11 -- 10:21:23 AM

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

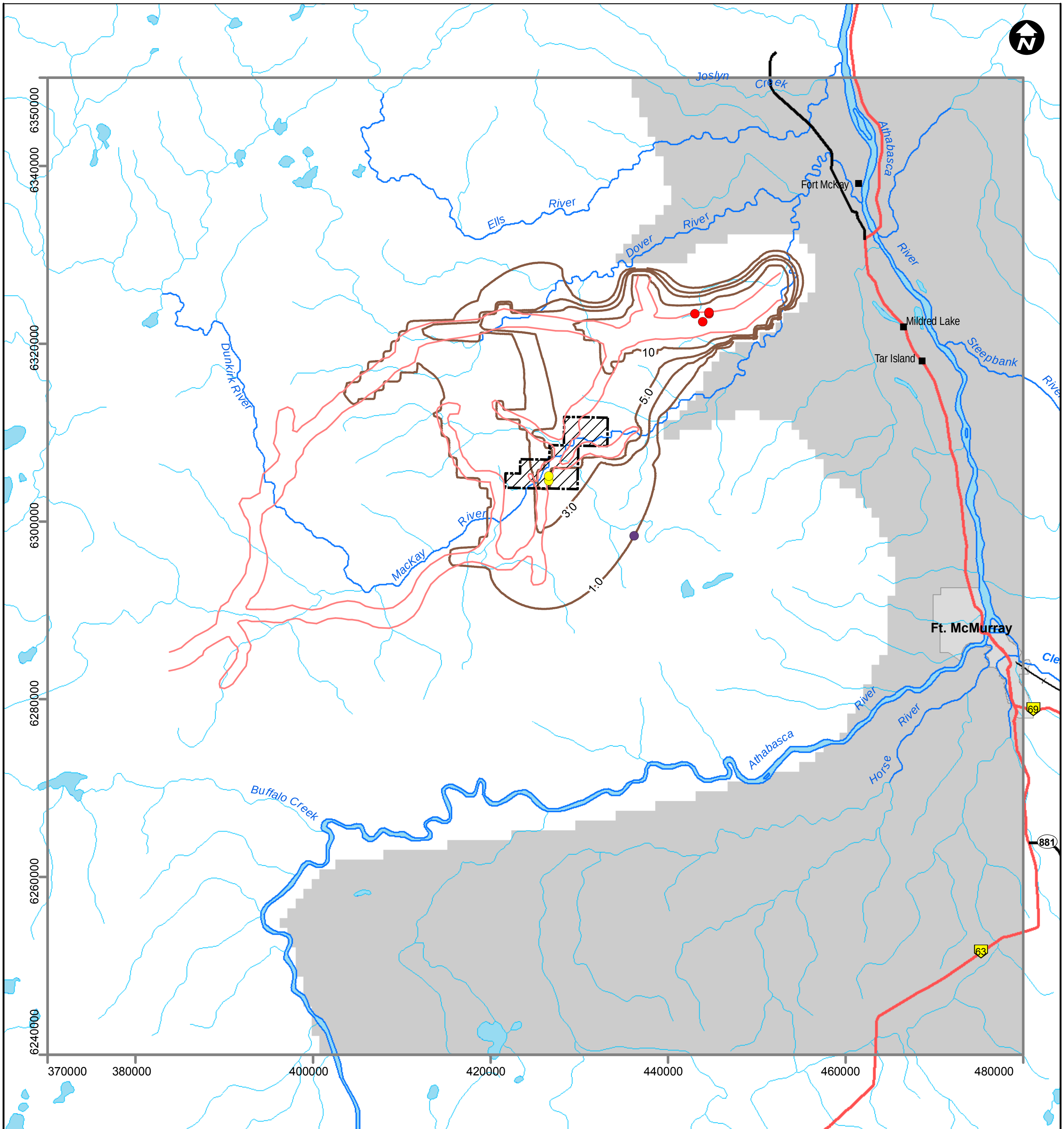
TITLE:

Locations of Groundwater Wells

Millennium EMS Solutions Ltd.

DRAWN: JG/SL	FIGURE: 20
CHECKED: NG	
DATE: Oct 26/11	
PROJECT: 10-037	

Back Main Menu Search Main TOC



Legend

Project Area

Model Domain

Channel

Predicted Drawdown (m)

1;3;5;10

Well (Owner)

AOSC

STP

Suncor

0 5 10 20

Kilometres

REF: Geobase, 2011.

SOUTHERN PACIFIC RESOURCE CORP.

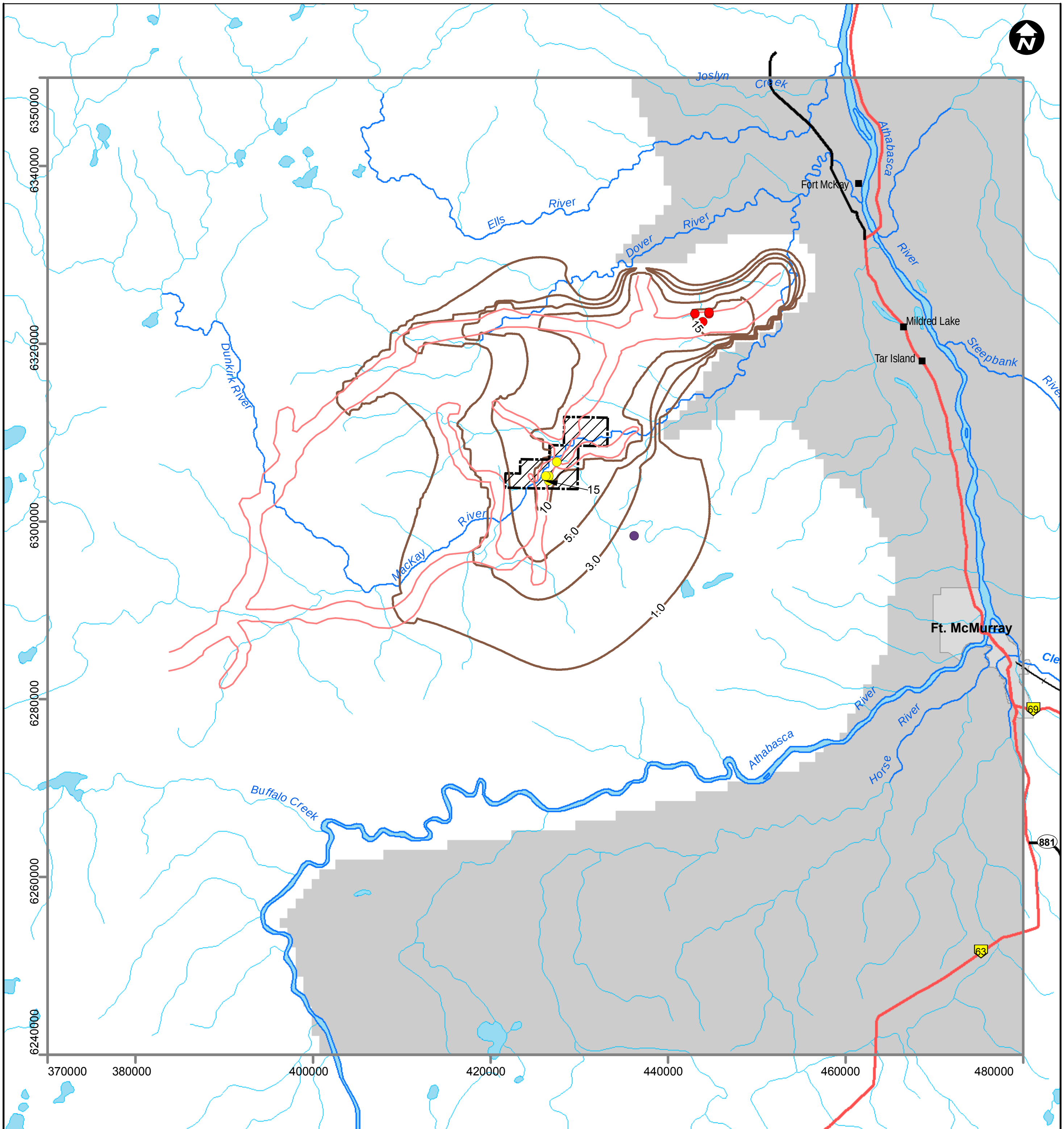
STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Baseline Case Predicted Maximum Drawdown (March 2035)

DRAWN: PS	FIGURE:
CHECKED: AuK	21
DATE: Nov 8/11	
PROJECT: 10-037	



Legend

Project Area

Model Domain

Channel

Predicted Drawdown (m)

1;3;5;10;15

Well (Owner)

AOSC

STP

Suncor

0 5 10 20

Kilometres

SOUTHERN PACIFIC
RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium
EMS Solutions Ltd.

TITLE:

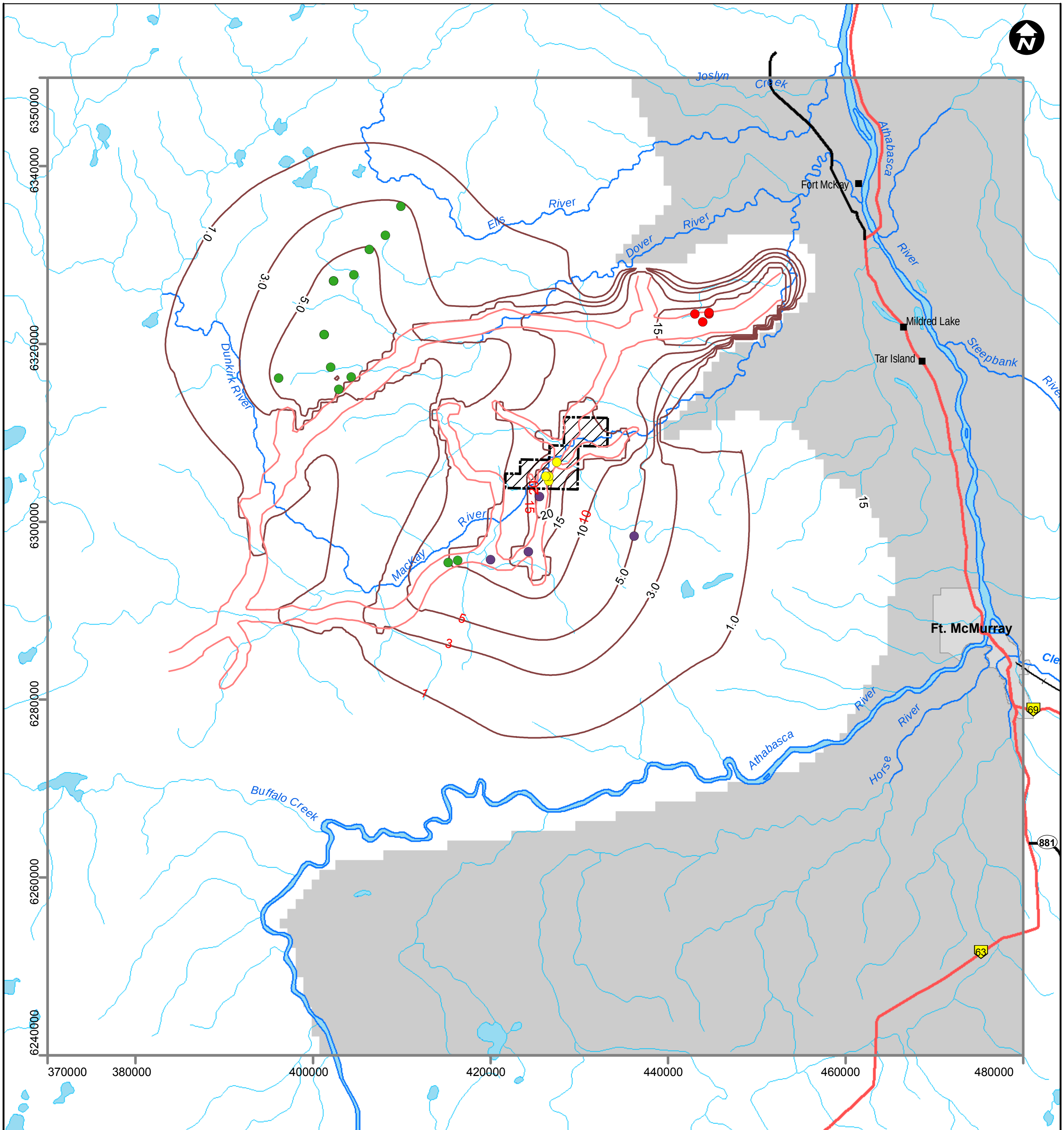
Application Case Predicted Maximum Drawdown (March 2035)

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 8/11
PROJECT:	10-037

FIGURE:

22

REF: Geobase, 2011.



Legend

Project Area

Model Domain

Clean Channel

Predicted Drawdown (m)

1;3;5;10;15,20,25

Well (Owner)

AOSC

Dover

STP

Suncor

0 5 10 20
Kilometres

REF: Geobase, 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:
Planned Case Predicted Maximum Drawdown (March 2035)

DRAWN: PS
CHECKED: AuK
DATE: Nov 8/11
PROJECT: 10-037

FIGURE:
23

APPENDIX B: TABLES

Table B1: Well Completion Details, Groundwater Elevations and Hydraulic Conductivities

Well ID	Project/Reference	Location					UTM Easting (NAD 83)	UTM Northing (NAD 83)	Ground Elevation (masl)	Stickup (m)	Well Depth (mbgs)	Screened Interval (mbgs)	Date Measured	Water Level		Hydraulic Conductivity	Lithology
		LSD	Sec	Twp	Rge	Mer								(mbgs)	(masl)	(m/s)	
Undifferentiated Glacial Drift Aquifer/Aquitard																	
MW4-24	This assessment	4	21	91	14	4	-	-	-	1.00	6.7	3.7 - 6.7	12-Mar-11	5.50	-	2.3×10^{-7}	clay till
MW8-10S	This assessment	8	10	91	14	4	-	-	-	0.90	6.1	3.1 - 6.1	12-Mar-11	1.23	-	4.3×10^{-5}	clay till and sand
MW8-10D	This assessment	8	10	91	14	4	-	-	-	0.60	15.2	12.2 - 15.2	12-Mar-11	1.58	-	3.3×10^{-8}	sandy clay till
MW10-01	This assessment	10	7	91	14	4	424080	6304915	465.49	0.99	6.7	3.7 - 6.7	10-Feb-10	3.17	462.32	3.6×10^{-8}	clay till
													31-May-10	0.31	465.18		
													24-Aug-10	0.40	465.09		
													4-Oct-10	0.37	465.12		
													12-Mar-11	Frozen	Frozen		
													12-Jun-11	-0.56	466.05		
													19-Jul-11	1.12	464.37		
MW10-02	This assessment	10	7	91	14	4	424375	6304630	464.14	0.94	3.9	2.4 - 3.9	10-Feb-10	2.37	461.77	1.3×10^{-6}	sand
													31-May-10	-0.03	464.17		
													24-Aug-10	0.11	464.03		
													4-Oct-10	0.10	464.04		
													12-Mar-11	Frozen	Frozen		
													12-Jun-11	0.20	463.94		
													19-Jul-11	-0.15	464.29		
MW10-03S	This assessment	9	7	91	14	4	424638	6304625	463.32	1.04	3.8	2.3 - 3.8	10-Feb-10	2.44	460.88	1.5×10^{-6}	silty sand
													31-May-10	1.78	461.54		
													24-Aug-10	1.33	461.99		
													4-Oct-10	1.20	462.12		
													12-Mar-11	2.45	460.87		
													12-Jun-11	2.75	461.39		
MW10-03D	This assessment	9	7	91	14	4	424639	6304626	463.34	0.97	9.8	6.8 - 9.8	10-Feb-10	3.28	460.06	2.4×10^{-5}	clay till and silty sand
													31-May-10	3.05	460.29		
													24-Aug-10	2.84	460.50		
													4-Oct-10	Damaged	Damaged		
MW10-03D (replacement)	This assessment		7	91	14	4			-	1.00	8.5	5.5 - 8.5	12-Mar-11	2.81	-		clay till and silty sand
													12-Jun-11	2.97	-		
													19-Jul-11	3.29	-		
MW10-04	This assessment	9	7	91	14	4	424661	6304776	463.90	1.01	4.6	1.5 - 4.6	10-Feb-10	3.29	460.61	1.8×10^{-5}	clay, sand and clay till
													31-May-10	3.26	460.64		
													24-Aug-10	2.87	461.03		
													4-Oct-10	2.52	461.38		
													12-Mar-11	3.02	460.88		
													12-Jun-11	3.02	460.88		
													19-Jul-11	2.56	461.34		
8-8 OBS-US	STP 2009	8	8	91	14	4	426161	6304344	464.60	1.00	61.9	55.8 - 61.9	17-Feb-09	2.09	462.51	1.9×10^{-5}	sandy clay
													2-May-11	2.08	462.52		
													6-Jun-11	2.12	462.48		
													4-Jul-11	2.16	462.44		
													1-Aug-11	2.13	462.47		
													6-Sep-11	2.15	462.45		
8-8 OBS-S	STP 2009	8	8	91	14	4	426160	6304370	464.50	0.90	6.1	3.0 - 6.1	17-Feb-09	0.43	464.07	6.7×10^{-6}	sand
													2-May-11	0.18	464.32		
													6-Jun-11	0.33	464.17		
													4-Jul-11	0.33	464.17		
													1-Aug-11	0.30	464.20		
													6-Sep-11	0.36	464.14		

Table B1: Well Completion Details, Groundwater Elevations and Hydraulic Conductivities

Well ID	Project/Reference	Location					UTM Easting (NAD 83)	UTM Northing (NAD 83)	Ground Elevation (masl)	Stickup (m)	Well Depth (mbgs)	Screened Interval (mbgs)	Date Measured	Water Level		Hydraulic Conductivity	Lithology
		LSD	Sec	Twp	Rge	Mer								(mbgs)	(masl)	(m/s)	
16-8 OBS-US	STP 2009	16	8	91	14	4	426200	6305126	463.70	0.75	30.5	27.4 - 30.5	8-Feb-09	2.93	460.77	6.5×10^{-6}	sand
													2-May-11	2.34	461.37		
													6-Jun-11	2.35	461.36		
													4-Jul-11	2.32	461.39		
													1-Aug-11	2.15	461.56		
													6-Sep-11	2.15	461.56		
16-8 OBS-S	STP 2009	16	8	91	14	4	426183	6305126	463.60	0.86	8.4	5.3 - 8.4	8-Feb-09	1.86	461.74	5.3×10^{-5}	sand
													2-May-11	1.71	461.89		
													4-Jul-11	1.14	462.46		
													1-Aug-11	1.05	462.55		
													6-Sep-11	1.26	462.34		
98-1A	Petro Canada 2005	2	17	93	12	4	-	-	-	-	4 to 18	-	2004	-	409.12	3.5×10^{-8}	till
98-1B	Petro Canada 2005	2	17	93	12	4	-	-	-	-		-	2004	-	403.21		till
98-2A	Petro Canada 2005	3	4	93	12	4	-	-	-	-		-	2004	-	388.15		till
98-2B	Petro Canada 2005	3	4	93	12	4	-	-	-	-		-	2004	-	388.11		till
98-5A	Petro Canada 2005	7	16	93	12	4	-	-	-	-		-	2004	-	371.13		till
98-6B	Petro Canada 2005	14	9	93	12	4	-	-	-	-		-	2004	-	385.64		till
P00-SW3	Petro Canada 2005	12	17	93	12	4	-	-	-	-		-	2004	-	408.31		till
P01-25A	Petro Canada 2005	5	17	93	12	4	-	-	-	-		-	2004	-	414.69		till
P01-27A	Petro Canada 2005	12	17	93	12	4	-	-	-	-		-	2004	-	409.20		till
P01-28A	Petro Canada 2005	5	17	93	12	4	-	-	-	-		-	2004	-	412.90		till
P01-29A	Petro Canada 2005	12	17	93	12	4	-	-	-	-		-	2004	-	410.91		till
P02-21A	Petro Canada 2005	12	4	93	12	4	-	-	-	-		-	2004	-	391.52		till
P02-23A	Petro Canada 2005	11	4	93	12	4	-	-	-	-		-	2004	-	388.96		till
P02-24A	Petro Canada 2005	11	4	93	12	4	-	-	-	-		-	2004	-	387.43		till
13 - 70	Hackbarth & Nastasa 1979	8	11	90	12	4	-	-	533.4	0.48	18.9	14.9 - 16.5	7-Feb-76	12.25	521.12	-	silt, sand and gravel
13 - 230	Hackbarth & Nastasa 1979	8	11	90	12	4	-	-	533.1	0.54	67.7	61.6 - 66.1	17-Jan-76	23.07	510.00	6.1×10^{-8}	
14 - 31	Hackbarth & Nastasa 1979	4	15	92	12	4	-	-	372	0.47	9.4	6.4 - 7.9	4-Feb-76	1.68	370.77	3.0×10^{-6}	clay
15 - 53	Hackbarth & Nastasa 1979	15	33	89	16	4	-	-	480	0.47	13.7	10.7 - 12.2	26-Jan-76	2.41	477.32	1.8×10^{-6}	
15 - 135	Hackbarth & Nastasa 1979	15	33	89	16	4	-	-	480	0.20	38.7	35.7 - 37.2	26-Jan-76	13.78	466.26	1.8×10^{-7}	undifferentiated drift
16 - 55	Hackbarth & Nastasa 1979	6	13	90	10	4	-	-	480	-	16.8	-	-	-	-	-	sand and gravel
Empress Aquifer																	
WSW1	STP 2009	8	8	91	14	4	426174	6304352	464.35	0.80	84.8	75.6 - 84.8	17-Feb-09	5.00	459.35	4.8×10^{-5}	sand
													6-Jun-11	6.74	457.61		
													4-Jul-11	6.35	458.00		
													1-Aug-11	6.31	458.04		
WSW2	STP 2009	16	8	91	14	4	426212	6305111	463.50	0.74	103.7	92.4 - 103.7	8-Feb-09	4.58	458.92	1.2×10^{-4}	sand and gravel
													2-May-11	5.04	458.46		
													6-Jun-11	6.35	457.15		
													4-Jul-11	5.66	457.84		
													1-Aug-11	5.66	457.84		
													6-Sep-11	5.70	457.80		

Table B1: Well Completion Details, Groundwater Elevations and Hydraulic Conductivities

Well ID	Project/Reference	Location					UTM Easting (NAD 83)	UTM Northing (NAD 83)	Ground Elevation (masl)	Stickup (m)	Well Depth (mbgs)	Screened Interval (mbgs)	Date Measured	Water Level		Hydraulic Conductivity	Lithology
		LSD	Sec	Twp	Rge	Mer								(mbgs)	(masl)	(m/s)	
WSW3	This assessment	15	8	91	14	4	425839	6305065	464.40	0.50	106.7	94.5 - 106.7	11-Feb-11	4.82	459.58	5.0×10^{-4}	sand and gravel
8-8 OBS-LS	STP 2009	8	8	91	14	4	426159	6304355	464.50	0.90	86.9	80.8 - 86.9	8-Feb-09	4.15	460.35	-	sand
													17-Feb-09	4.89	459.61		
													2-May-11	4.41	460.09		
													6-Jun-11	5.24	459.26		
													4-Jul-11	4.88	459.62		
													1-Aug-11	4.85	459.65		
													6-Sep-11	4.92	459.58		
16-8 OBS-LS	STP 2009	16	8	91	14	4	426216	6305126	463.80	0.80	103.7	97.6 - 103.7	8-Feb-09	4.62	459.18	-	gravel
													17-Feb-09	5.42	458.38		
													2-May-11	6.22	457.58		
													6-Jun-11	6.50	457.30		
													4-Jul-11	5.89	457.91		
													1-Aug-11	6.24	457.56		
													6-Sep-11	5.89	457.91		
5-22 OBS EMP	AOSC 2009	5	22	92	16	4	409027	6317662	483.7	-	141.2	84.2 - 86.2	-	1.5	482.2	4.9×10^{-5}	
5-22 WSW EMP	AOSC 2009	5	22	92	16	4	409027	6317662	483.7	-	116.7	66.4 - 113.7	-	1.5	482.2	4.9×10^{-5}	
7-34 OBS EMP	AOSC 2009	7	34	89	13	4	439928	6291161	512.3	-	131.0	55.0 - 57.0	-	19.5	492.8	1.3×10^{-4}	
7-34 WSW EMP	AOSC 2009	7	34	89	13	4	439928	6291161	512.3	-	69.4	40.8 - 65.3	-	19.3	493.0	1.3×10^{-4}	
6-05 OBS EMP	AOSC 2009	6	5	91	14	4	425628	6302751	465.1	-	127.0	101.8 - 103.8	-	3.2	461.9	3.2×10^{-4}	
6-05 WSW EMP	AOSC 2009	6	5	91	14	4	425628	6302751	465.1	-	112.3	72.2 - 109.0	-	2.9	462.2	3.2×10^{-4}	
15-16 OBS EMP	AOSC 2009	15	16	92	22	4	408199	6316855	485.1	-	112.9	90.4- 92.4	-	1.7	483.4	7.8×10^{-5}	
15-16 WSW EMP	AOSC 2009	15	16	92	22	4	408199	6316855	485.1	-	120.4	97.2 - 118.2	-	1.6	483.5	6.0×10^{-5}	
P02-9B	Petro Canada 2005	5	5	93	12	4	-	-	-	-		-	2004	-	400.59		
P02-10B	Petro Canada 2005	5	5	93	12	4	-	-	-	-		-	2004	-	399.26		
P02-12B	Petro Canada 2005	12	5	93	12	4	-	-	-	-		-	2004	-	395.12		
P02-18A	Petro Canada 2005	6	9	93	12	4	-	-	-	-		-	2004	-	389.50		
P02-20D	Petro Canada 2005	4	8	93	12	4	-	-	-	-	5 to 85	-	2004	-	395.62	7.2×10^{-5} to 7.8×10^{-4}	
P04-11B	Petro Canada 2005	12	5	93	12	4	-	-	-	-		-	2004	-	394.88		
02-08-93-12 WSTO	Petro Canada 2005	2	8	93	12	4	-	-	-	-		-	2004	-	391.71		
WSW 2	Petro Canada 2005	3	8	93	12	4	-	-	-	-		-	2004	-	395		
Grand Rapids Aquifer/Aquitard																	
13 - 460	Hackbarth & Nastasa 1979	8	11	90	12	4	-	-	533.07	0.72	137.8	131.7 - 136.2	13-Jan-76	63.67	469.40	1×10^{-4}	sandstone
Grand Rapids 3 Aquifer																	
1-23 OBS GR3	AOSC 2009	1	23	93	17	4	402304	6327142	499.80	-	100.4	88.4 - 90.4	12-Feb-09	16.6	483.2	1.3×10^{-5}	
1-23 WSW GR3	AOSC 2009	1	23	93	17	4	402286	6327108	499.80	-	100.4	77.5 - 98.9	3-Nov-08	16.1	483.8	9.7×10^{-6}	
6-35 OBS GR3	AOSC 2009	6	35	92	17	4	401331	6321077	505.80	-	112.4	87.4 - 89.4	10-Mar-09	8.5	497.3	1.5×10^{-5}	
6-35 WSW GR3	AOSC 2009	6	35	92	17	4	401313	6321067	505.80	-	103.9	80.4 - 99.4	7-Mar-09	7.7	498.1	1.7×10^{-5}	
Grand Rapids 4 Aquifer																	
MW11-02	This assessment	15	7	91	14	4	424424	6305068	461.90	0.89	39.9	36.9 - 39.9	12-Mar-11	4.03	457.77	5.7×10^{-5}	sand
													12-Jun-11	4.07	457.73		
													19-Jul-11	3.94	457.86		

Table B1: Well Completion Details, Groundwater Elevations and Hydraulic Conductivities

Well ID	Project/Reference	Location					UTM Easting (NAD 83)	UTM Northing (NAD 83)	Ground Elevation (masl)	Stickup (m)	Well Depth (mbgs)	Screened Interval (mbgs)	Date Measured	Water Level		Hydraulic Conductivity	Lithology
		LSD	Sec	Twp	Rge	Mer								(mbgs)	(masl)	(m/s)	
10-01 OBS GR4	AOSC 2009	10	1	90	14	4	433488	6293351	497.90	-	119.5	57.5 - 59.5	20-Feb-09	6.6	491.3	7.1×10^{-6}	
10-01 WSW GR4	AOSC 2009	10	1	90	14	4	433468	6293352	497.90	-	67.5	47.6 - 66.2	11-Feb-09	6.4	491.5	7.0×10^{-6}	
Grand Rapids 5 Aquifer																	
MW11-01	This assessment	15	7	91	14	4	424423	6305063	461.80	0.88	84.1	81.1 - 84.1	12-Mar-11 12-Jun-11 19-Jul-11	>-0.88 >-0.88 >-0.88	>462.9 >462.9 >462.9	-	sand
6-13 OBS GR5	AOSC 2009	6	13	90	14	4	433094	6296133	484.50	-	97.3	63.3 - 75.3	1-Feb-09	13.0	471.5	9.8×10^{-7}	
6-13 WSW GR5	AOSC 2009	6	13	90	14	4	433109	6296149	484.50	-	84.1	61.3 - 82.3	1-Feb-09	12.0	472.5	9.8×10^{-7}	
6-24 OBS GR5	AOSC 2009	6	24	90	14	4	433095	6297718	481.20	-	104.5	64.5 - 66.5	20-Feb-09	11.7	469.5	7.5×10^{-6}	
6-24 WSW GR5	AOSC 2009	6	24	90	14	4	433097	6297758	481.20	-	90.2	60.1 - 88.6	8-Feb-09	10.9	470.3	7.6×10^{-6}	
Clearwater Aquitard																	
98-1C	Petro Canada 2005	2	17	93	12	4	-	-	-	-		-	2004	-	397.82		
98-3A	Petro Canada 2005	16	10	93	12	4	-	-	-	-		-	2004	-	359.44		
98-3B	Petro Canada 2005	16	10	93	12	4	-	-	-	-		-	2004	-	359.65		
98-5B	Petro Canada 2005	7	16	93	12	4	-	-	-	-		-	2004	-	370.92		
P00-DW3	Petro Canada 2005	12	17	93	12	4	-	-	-	-	5 to 18	-	2004	-	408.33	5×10^{-9}	
P01-25B	Petro Canada 2005	5	17	93	12	4	-	-	-	-		-	2004	-	410.48		
P01-28B	Petro Canada 2005	5	17	93	12	4	-	-	-	-		-	2004	-	410.55		
P01-29B	Petro Canada 2005	12	17	93	12	4	-	-	-	-		-	2004	-	408.67		
P02-22A	Petro Canada 2005	5	4	93	12	4	-	-	-	-		-	2004	-	388.66		
14 - 119	Hackbarth & Nastasa 1981	4	15	92	12	4	-	-	373	0.46	33.8	27.7 - 32.3	17-Feb-76	19.96	352.79	3.3×10^{-7}	sandstone
15 - 477	Hackbarth & Nastasa 1982	15	33	89	16	4	-	-	480	0.48	142.9	136.8 - 141.4	5-Feb-76	4.63	475.71	5.4×10^{-7}	sandstone
Wabiskaw/McMurray Aquitard																	
03-04-93-12	Petro Canada 2005	3	4	93	12	4	-	-	-	-	55 to 95	-	2004	-	334.90	2.5×10^{-6} to 3.7×10^{-5}	
03-34-92-12	Petro Canada 2005	3	34	92	12	4	-	-	-	-		-	2004	-	320.58		
16-10-93-12	Petro Canada 2005	16	10	93	12	4	-	-	-	-		-	2004	-	314.70		
13 - 770	Hackbarth & Nastasa 1979	8	11	90	12	4	-	-	532.76	0.46	232.2	227.7 - 230.7	11-Feb-76	220.05	312.71	-	shale and sandstone
14 - 247	Hackbarth & Nastasa 1981	4	15	92	12	4	-	-	373.06	0.62	72.5	66.7 - 71.3	23-Nov-76	60.84	312.22	-	sandstone
15 - 750	Hackbarth & Nastasa 1982	15	33	89	16	4	-	-	480.04	0.50	226.2	221.6 - 224.6	28-Jan-76	133.10	346.94	2.0×10^{-7}	sandstone
16 - 165	Hackbarth & Nastasa 1982	6	13	90	10	4	-	-	480	-	-	-	-	-	dry	-	sandstone
Basal McMurray Aquifer																	
03-34-92-12B	Petro Canada 2005	3	34	92	12	4	-	-	369	-	110	-	2004	-	319.65	-	
10-01 WDW MCMR	AOSC 2009	10	1	90	14	4	433454	6293353	497.9	-	220.2	210.7 - 218.2	14-Feb-09	177.40	302.60	-	
11-29 WDW MCMR	AOSC 2009	11	29	89	12	4	446077	6289662	521.1	-	220.4	209.6 - 218.8	16-Feb-09	208.40	312.60	-	
13 - 872	Hackbarth & Nastasa 1980	8	11	90	12	4	-	-	532.76	0.61	265.8	258.8 - 261.8	11-Feb-76	219.29	313.47	-	shale and sandstone
16 - 325	Hackbarth & Nastasa 1982	6	13	90	10	4	-	-	480.0	-	-	94.5 - 97.5	-	-	-	7.6×10^{-7}	sandstone
Beaverhill Lake Aquifer/Aquitard																	
13-1230	Hackbarth & Nastasa 1979	8	11	90	12	4	-	-	533.37	0.70	372.4	334.0 - 372.4	11-Feb-76	188.72	344.65	4.9×10^{-9}	limestone
14 - 699	Hackbarth & Nastasa 1980	4	15	92	12	4	-	-	372.45	0.44	201.5	115.2 - 201.5	7-Feb-76	180.00	192.45	4.5×10^{-9}	limestone
15 - 997	Hackbarth & Nastasa 1981	15	33	89	16	4	-	-	480.04	0.51	301.4	243.2 - 301.4	20-Dec-76	126.88	353.15	1×10^{-10}	limestone

Table B1: Well Completion Details, Groundwater Elevations and Hydraulic Conductivities

Well ID	Project/Reference	Location					UTM Easting (NAD 83)	UTM Northing (NAD 83)	Ground Elevation (masl)	Stickup (m)	Well Depth (mbgs)	Screened Interval (mbgs)	Date Measured	Water Level		Hydraulic Conductivity	Lithology
		LSD	Sec	Twp	Rge	Mer								(mbgs)	(masl)	(m/s)	
16 - 550	Hackbarth & Nastasa 1981	6	13	90	10	4	-	-	480	-	-	-	-	-	-	-	limestone

Notes:

mbgs = meters below ground surface

masl = meters above sea level

m/s = meters per second

"-" = indicates not available/not measured

Table B2: Groundwater Chemistry Summary of General and Major Ion Parameters

Well ID	Project	Location					Sampling Date	General Chemistry					Major Ions and Ion Balance										
		LSD	Sec	Twp	Rge	Mer		pH	Electrical Conductivity	Total Dissolved Solids	Total Alkalinity	Hardness	Bicarbonate	Carbonate	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulphate	Nitrate - N	Nitrite - N	Ion Balance
							Units		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%
Undifferentiated Glacial Drift Aquifer/Aquitard																							
MW4-24	This assessment	4	21	91	14	4	12-Mar-11	7.9	998	577	534	525	652	<5	142	41.3	14.5	6.9	3	49	<0.113	<0.015	-
MW8-10S	This assessment	8	10	91	14	4	12-Mar-11	7.9	768	432	434	329	530	<5	91.5	24.5	37.0	3.4	2	13	<0.113	<0.015	-
MW8-10D	This assessment	8	10	91	14	4	12-Mar-11	7.8	1440	855	391	452	477	<5	134	28.6	132.0	9	86	230	0.136	<0.015	-
MW10-01	This assessment	10	7	91	14	4	10-Feb-10	7.45	1000	640	550	510	670	<0.5	130	44	53	5.1	2	66	0.06	<0.003	-
							31-May-10	7.52	1000	591	530	491	640	<0.5	130	42	37	4.7	2	60	0.039	<0.003	-
							24-Aug-10	7.58	1000	551	510	453	620	<0.5	120	40	38	4.1	1	46	0.058	<0.003	-
							4-Oct-10	7.60	1000	635	560	570	680	<0.5	150	48	39	14	2	42	0.38	0.007	-
							12-Mar-11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
							22-Jun-11	7.70	1030	636	570	582	695	<5	150	50.4	41.6	4.4	2	45	<0.113	<0.015	-
							19-Jul-11	7.80	1020	632	549	576	670	<5	148	50.2	36.8	3.8	2	62	<0.113	<0.015	-
MW10-02	This assessment	10	7	91	14	4	10-Feb-10	6.9	380	230	220	210	270	<0.5	60	14	7.5	0.6	2	<1	0.019	<0.003	-
							31-May-10	6.85	280	156	140	150	170	<0.5	40	12	7.6	0.4	2	4.7	0.009	<0.003	-
							24-Aug-10	6.68	270	137	130	133	160	<0.5	35	11	7.9	0.5	<1	<1	0.050	<0.003	-
							4-Oct-10	6.75	290	155	150	147	180	<0.5	40	12	7.8	0.8	2	<1	0.007	<0.003	-
							12-Mar-11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
							22-Jun-11	7.20	300	170	158	164	193	<5	43.9	13.2	8.2	0.6	1	8	<0.113	<0.015	-
							19-Jul-11	7.50	331	187	181	185	221	<5	50.6	14.2	9.8	<0.6	<1	4	<0.113	<0.015	-
MW10-03 S	This assessment	9	7	91	14	4	9-Feb-10	7.72	560	310	300	320	370	<0.5	85	25	6.4	0.8	2	12	0.035	<0.003	-
							31-May-10	7.8	550	295	290	303	350	<0.5	81	24	6	0.8	<1	9	0.022	<0.003	-
							24-Aug-10	7.72	550	277	280	271	340	<0.5	71	23	6.2	0.7	<1	7	0.20	0.007	-
							4-Oct-10	7.54	590	320	310	327	380	<0.5	89	25	6.2	1.0	1	9	0.064	<0.003	-
							12-Mar-11	8	549	299	312	285	380	<5	77.1	22.5	5.5	<0.6	<1	6	<0.113	<0.015	-
							22-Jun-11	8.00	668	402	302	319	369	<5	86.2	25.2	33.2	0.9	3	71	0.248	<0.015	-
MW10-03 D	This assessment	9	7	91	14	4	9-Feb-10	7.47	600	360	310	290	370	<0.5	78	23	28	4.3	2	32	0.029	0.007	-
							31-May-10	7.91	610	338	310	257	370	<0.5	68	21	36	2.1	2	23	0.005	<0.003	-
							24-Aug-10	7.68	610	349	290	283	350	<0.5	74	24	36	3.3	1	32	0.056	<0.003	-
							4-Oct-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
							12-Mar-11	7.9	915	569	282	231	344	<5	69.1	14.2	106	3.2	13	194	<0.113	<0.015	-
							22-Jun-11	8.00	1130	762	310	309	378	<5	88.4	21.5	175	3.4	18	269	<0.113	<0.015	-
							19-Jul-11	8.10	1040	690	316	288	386	<5	83.2	19.6	151	3.2	15	228	<0.113	<0.015	-
MW10-04	This assessment	9	7	91	14	4	10-Feb-10	7.58	720	430	360	350	430	<0.5	90	30	31	1.6	3	60	1	0.004	-
							31-May-10	7.83	1000	596	370	263	450	<0.5	66	24	120	1.6	4	160	0.33	0.007	-
							24-Aug-10	7.70	830	492	340	322	420	<0.5	80	30	80	1.6	2	92	0.006	<0.003	-
							4-Oct-10	7.62	560	314	300	328	360	<0.5	82	30	8.0	1.0	1	10	0.48	<0.003	-
							12-Mar-11	8.1	584	318	315	282	384	<5	70.6	25.6	9.2	0.9	<1	20	0.52	<0.015	-
							22-Jun-11	8.00	658	397	334	330	407	<5	82.6	30	38.4	1.4	1	42	0.203	<0.015	-
							19-Jul-11	8.10	650	377	353	354	431	<5	88.3	32.4	17.8	0.7	1	22	0.497	<0.015	-

Table B2: Groundwater Chemistry Summary of General and Major Ion Parameters

Well ID	Project	Location					Sampling Date	General Chemistry					Major Ions and Ion Balance										
								pH	Electrical Conductivity	Total Dissolved Solids	Total Alkalinity	Hardness	Bicarbonate	Carbonate	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulphate	Nitrate - N	Nitrite - N	Ion Balance
		LSD	Sec	Twp	Rge	Mer	Units		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%
13 - 70	Hackbarth & Nastasa 1979	8	11	90	12	4	20-Feb-76	7.3	410	216	-	-	232	-	37	13	27.5	3	22	6.7	0.2	-	-
13 - 230	Hackbarth & Nastasa 1979	8	11	90	12	4	19-Jul-76	10.1	1000	508	-	-	39	130	2.2	-	198	10.2	120	43	0.9	-	-
14 - 31	Hackbarth & Nastasa 1979	4	15	92	12	4	7-Jul-77	7.7	1900	1218	-	-	603	-	131	64	214	5.9	38	562.8		-	-
15 - 53	Hackbarth & Nastasa 1979	15	33	89	16	4	7-Jul-77	7.4	1950	1610	-	-	373	-	231	99	96	7.3	20	981	1	-	-
15 - 135	Hackbarth & Nastasa 1979	15	33	89	16	4	7-Jul-77	7.7	2200	1610	-	-	61	-	109	80	241	22.5	104	965	0.3	-	-
16 - 55	Hackbarth & Nastasa 1979	6	13	90	10	4	8-Jul-77	7.3	550	372	-	-	244	-	34	36	25	2.1	30	54	1.5	-	-
14 wells	Petro Canada 2005			93	12	4	2004	6.8 to 8.4 *	599 to 9250	412 to 8330	-	36 to 1190	-	-	5 to 206	3 to 163	15 to 2500	-	<1 to 300	80 to 5000	-	-	-
Empress Aquifer																							
WSW1	STP 2009	8	8	91	14	4	17-Feb-09	7.89	1200	780	420	350	520	<0.5	82	34	150	4.7	4	250	<0.003	<0.003	97
							18-Feb-09	7.89	1200	790	430	340	520	<0.5	80	34	150	4.7	4	260	<0.003	<0.003	96
WSW2	STP 2009	16	8	91	14	4	8-Feb-09	8.3	1600	920	600	130	730	0.6	29	14	250	3.6	24	240	<0.003	<0.003	77
							11-Feb-09	8.3	1600	910	590	130	730	<0.5	28	14	250	3.3	21	240	<0.003	<0.003	77
							18-Mar-11	8.3	1580	992	606	164	730	<5	33.2	19.6	310	4.1	18	243	<0.5	<0.015	96
WSW3	This assessment	15	8	91	14	4	11-Mar-11	8.4	1780	1160	650	263	766	13	53.4	31.6	307	5.7	23	350	<0.5	<0.015	90
5-22 WSW EMP	AOSC 2009	5	22	90	16	4	1-Mar-09	8.0	983	597	496	228	605	<5	57.9	20.3	141	6.1	2	72	<0.1	<0.05	-
06-05 WSW EMP	AOSC 2009	6	5	91	14	4	5-Mar-09	8.2	1450	986	560	249	683	<5	56.0	26.5	283	4.6	16	264	<0.1	<0.05	-
07-34 WSW EMP	AOSC 2009	7	34	89	13	4	24-Feb-09	8.3	876	508	479	584	584	584	24.8	7.8	172	3.5	1	11	<0.1	<0.05	-
15-16 WSW EMP	AOSC 2009	15	16	90	16	4	31-Jan-09	8.0	1140	689	540	310	658	<5	76.4	27.4	131	5.8	4	107	<0.1	<0.05	-
11 wells	Petro Canada 2005			93	12	4	2004	6.5 to 7.9*	210 to 1545*	112 to 1140	-	74 to 550	-	-	19 to 162	5 to 79	4 to 350	-	<1 to 60	4 to 260	-	-	-
Grand Rapids Aquifer/Aquitard																							
13 - 460	Hackbarth & Nastasa 1979	8	11	90	12	4	15-Jan-76	8.8	1600	952	-	-	776	43	1	0.5	398	2.14	22	31.5	1.2	-	-
Grand Rapids 3 Aquifer																							
1-23 WSW GR3	AOSC 2009	1	23	93	17	4	22-Jan-09	8.8	2040	1340	-	8	887	60	1.7	1	470	3.4	20	267	-	-	-
6-35 OBS GR3	AOSC 2009	6	35	92	17	4	9-Mar-09	8.0	1000	612	-	373	596	<5	95.3	32.8	91	5.5	2	93	-	-	-
Grand Rapids 4 Aquifer																							
MW11-02	This assessment	15	7	91	14	4	12-Mar-11	8.6	1850	1180	720	29	832	<5	6.8	3	436	4.1	20	275	<0.113	<0.015	-
							22-Jun-11	8.6	1840	1160	711	38	822	22	8.7	3.9	433	3.7	20	262	<0.113	<0.015	-
							19-Jul-11	8.7	1830	1180	721	38	818	31	8.5	4	453	3.7	19	256	<0.113	<0.015	-
10-01 WSW GR4	AOSC 2009	10	1	90	14	4	16-Feb-09	8.1	971	560	-	129	612	<5	27.3	14.8	169	4.6	1	42	-	-	-
Grand Rapids 5 Aquifer																							
MW11-01	This assessment	15	7	91	14	4	12-Mar-11	8.4	3500	2100	1540	22	1860	8	3.9	2.9	823	5.0	293	45	<0.113	<0.015	-
							22-Jun-11	8.6	3390	2090	51	45	1520	1730	9.3	5.2	844	5.2	247	62	<0.113	<0.015	-
							19-Jul-11	8.7	3600	2250	1580	20	1770	78	3	3	943	5.2	297	52	<0.113	<0.015	-
6-13 WSW GR5	AOSC 2009	6	13	90	14	4	8-Feb-09	8.8	1910	1110	-	9	866	54	2.0	1.0	423	2.1	79	119	-	-	-

Table B2: Groundwater Chemistry Summary of General and Major Ion Parameters

Well ID	Project	Location					Sampling Date	General Chemistry					Major Ions and Ion Balance										
								pH	Electrical Conductivity	Total Dissolved Solids	Total Alkalinity	Hardness	Bicarbonate	Carbonate	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulphate	Nitrate - N	Nitrite - N	Ion Balance
		LSD	Sec	Twp	Rge	Mer	Units		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%
6-24 WSW GR5	AOSC 2009	6	24	90	14	4	13-Feb-09	8.8	1840	1100	-	12	871	58	2.8	1.1	422	2.1	35	149	-	-	-
Clearwater Aquitard																							
11 wells	Petro Canada 2005						2004	-	-	700 to 5500	-	23 to 621	-	-	-	-	30 to 2100	-	1 to 460	80 to 2800	-	-	-
14 - 119	Hackbarth & Nastasa 1979	4	15	92	12	4	7-Jul-77	9.4	5000	2472	-	-	1274	209	2.9	3.6	1038	9	821	14.5	-	-	-
15-477	Hackbarth & Nastasa 1979	15	33	89	16	4	7-Jul-77	9.4	4800	2654	-	-	1149	278	1.9	3.7	1125	11.6	659	85.1	0.3	-	-
Wabiskaw/McMurray Aquitard																							
3 wells	Petro Canada 2005						2004	6.8 to 7.2*	22900 to 37200*	13800 to 24200	-	≤ 1690	-	-	-	-	5040 to 9230	-	7730 to 14500	0.3 to <50	-	-	-
13 - 770	Hackbarth & Nastasa 1979	8	11	90	12	4	11-Jul-77	11.3	1730	704	-	-	-	43	65	-	198	13.6	268	69.1	0.7	-	-
14-247	Hackbarth & Nastasa 1979	4	15	92	12	4	11-Jul-77	7.4	78000	10420	-	-	1891	-	109	75	4038	32.8	3024	16.9	1	-	-
15-750	Hackbarth & Nastasa 1979	15	33	89	16	4	7-Jul-77	8.4	8000	9712	-	-	2106	14.4	15.2	59	3700	30.7	4887	7.3	-	-	-
Basal McMurray Aquifer																							
03-34-92-12B	Petro Canada 2005	3	34	92	12	4	2004	7 to 8*	51000 to 55000*	32000 to 36500	-	≤ 2600	-	-	-	-	11500 to 13200	-	19600 to 21600	-	-	-	-
10-01 WDW MCMR	AOSC 2009	10	1	90	14	4	14-Feb-09	8.2	12300	6930	-	244	2180	<5	38.8	35.7	2530	20.6	3180	47	-	-	-
11-29 WDW MCMR	AOSC 2009	11	29	89	12	4	16-Feb-09	8.5	9880	5480	-	221	1540	48	48.0	24.6	1980	12.3	2570	38	-	-	-
13 - 872	Hackbarth & Nastasa 1979	8	11	90	12	4	11-Jul-77	9.8	8000	6900	-	-	444	312	3.6	9.7	2675	20.1	3525	111.2	0.1	-	-
16 - 325	Hackbarth & Nastasa 1979	6	13	90	10	4	8-Jul-77	9.4	8000	5596	-	-	632	185	2.4	14	2138	42.0	3505	45.9	0.3	-	-
Beaverhill Lake Aquifer/Aquitard																							
13 - 1230	Hackbarth & Nastasa 1979	8	11	90	12	4	11-Jul-77	8.3	8000	8656	-	-	83	-	69	46	3019	27.3	4326	1068	0.1	-	-
14 - 699	Hackbarth & Nastasa 1979	4	15	92	12	4	7-Jul-77	7.6	8000	8704	-	-	537	-	113	65	3013	20.9	3856	1612	0.5	-	-
15 - 997	Hackbarth & Nastasa 1979	15	33	89	16	4	7-Jul-77	9.3	8000	7004	-	-	1027	228	4.7	40	2638	88	28660	37.6	0.2	-	-
16 - 550	Hackbarth & Nastasa 1979	6	13	90	10	4	7-Jul-77	8.1	7000	3520	-	-	127	-	42	14	1450	27.7	1923	477.7	2.7	-	-

Notes:

* Field measurements

"-" = indicates not available/not measured

Table B3: Groundwater Chemistry Summary of Dissolved Metals Parameters

Well ID	Project	Location					Sampling Date	Aluminum	Antimony	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Selenium	Silver	Uranium	Zinc
		LSD	Sec	Twp	Rge	Mer	Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Undifferentiated Glacial Drift Aquifer/Aquitard																							
MW4-24	This assessment	4	21	91	14	4	12-Mar-11	0.114	<0.001	<0.001	0.09	0.16	0.00002	0.003	0.002	0.2	<0.001	0.143	0.014	0.002	<0.0001	0.01	0.006
MW8-10S	This assessment	8	10	91	14	4	12-Mar-11	0.085	<0.001	0.009	0.2	0.09	0.000041	0.002	<0.002	2.5	<0.001	0.8	0.007	<0.001	0.0001	0.003	0.008
MW8-10D	This assessment	8	10	91	14	4	12-Mar-11	0.096	<0.001	0.007	0.13	0.18	0.00004	0.004	0.003	1.3	<0.001	1.02	0.01	0.005	<0.0001	0.013	0.009
MW10-01	This assessment	10	7	91	14	4	10-Feb-10	0.005	0.0003	0.0034	0.07	0.38	0.000064	<0.001	0.0014	0.88	<0.0002	0.80	0.0028	0.0002	<0.0001	0.0026	0.015
							31-May-10	0.096	<0.0002	0.0023	0.08	0.34	0.000037	<0.001	0.0095	0.99	<0.0002	1.30	0.0058	<0.0002	<0.0001	0.0031	0.082
							24-Aug-10	0.055	<0.0002	0.0039	0.08	0.30	0.026	<0.001	0.0005	1.1	0.0002	1.3	0.0057	<0.0002	<0.0001	0.0024	0.004
							4-Oct-10	1.4	0.0019	0.0038	0.11	0.33	<0.000005	0.003	0.0031	3.0	0.0017	1.40	0.0085	<0.0002	<0.0001	0.0033	0.044
							22-Jun-11	0.006	<0.001	0.002	0.09	0.35	0.000034	<0.001	<0.002	1.1	<0.001	1.00	0.007	<0.001	<0.0001	0.003	0.012
							19-Jul-11	<0.002	<0.001	<0.001	0.11	0.30	0.000019	<0.001	<0.002	<0.1	<0.001	1.08	0.010	<0.001	<0.0001	0.004	0.012
MW10-02	This assessment	10	7	91	14	4	10-Feb-10	0.46	<0.001	0.004	0.04	0.04	0.00014	<0.005	0.002	8.9	0.002	0.81	0.009	<0.001	<0.0005	0.0008	<0.02
							31-May-10	0.25	<0.0002	0.0017	0.03	0.06	0.000008	0.002	0.0005	6.8	0.0005	0.76	0.0084	0.0009	<0.0001	0.0002	0.007
							24-Aug-10	0.26	<0.0002	0.0011	0.03	0.04	<0.03	0.001	0.0006	4.8	0.0003	0.65	0.0053	0.0009	<0.0001	0.0003	0.005
							4-Oct-10	0.25	0.0017	0.0036	0.03	0.04	<0.000005	0.001	0.001	5.2	0.0004	0.70	0.0067	0.0008	<0.0001	0.0002	0.022
							22-Jun-11	0.441	0.001	0.003	<0.05	0.08	0.000027	0.002	<0.002	10.0	<0.001	1.07	0.009	<0.001	0.0003	<0.001	0.011
							19-Jul-11	0.111	<0.001	0.002	<0.05	0.04	0.000019	0.002	0.003	1.2	<0.001	0.926	0.008	<0.001	<0.0001	<0.001	0.004
MW10-03S	This assessment	9	7	91	14	4	9-Feb-10	0.11	<0.0002	<0.0002	0.10	0.05	0.000035	<0.001	0.0011	0.25	0.0004	0.062	0.0021	<0.0002	<0.0001	0.0006	<0.003
							31-May-10	0.36	<0.0002	0.0005	0.11	0.06	0.000068	<0.001	0.0031	0.69	0.0009	0.16	0.0058	<0.0002	<0.0001	0.0008	0.005
							24-Aug-10	0.021	<0.0002	<0.0002	0.10	0.05	0.035	<0.001	0.0013	<0.06	<0.0002	0.040	0.0023	<0.0002	<0.0001	0.0006	<0.003
							4-Oct-10	0.005	0.0012	0.0003	0.12	0.06	<0.000005	<0.001	0.0015	<0.06	<0.0002	0.39	0.0038	0.0003	<0.0001	0.0006	0.015
							12-Mar-11	0.008	<0.001	<0.001	0.10	0.05	0.00002	<0.001	0.002	<0.1	<0.001	0.029	0.005	<0.001	<0.0001	<0.001	0.006
							22-Jun-11	1.1	<0.001	0.001	0.17	0.07	0.000111	0.002	0.004	2.7	0.003	0.56	0.01	0.002	<0.0001	0.002	0.013
MW10-03D	This assessment	9	7	91	14	4	9-Feb-10	0.027	<0.0002	0.0008	0.07	0.21	0.000053	<0.001	0.0006	2.5	<0.0002	0.35	0.0037	<0.0002	<0.0001	0.0003	0.004
							31-May-10	0.022	<0.0002	0.0005	0.07	0.15	0.000012	<0.001	0.0005	2	<0.0002	0.38	0.0015	<0.0002	<0.0001	0.0013	<0.003
							24-Aug-10	0.036	<0.0002	0.0004	0.05	0.23	0.018	<0.001	0.0006	3.7	<0.0002	0.23	0.0011	<0.0002	<0.0001	0.0003	0.003
							12-Mar-11	0.024	<0.001	0.001	0.11	0.12	0.000017	<0.001	0.003	0.8	<0.001	0.581	0.007	0.001	<0.0001	0.003	0.008
							22-Jun-11	0.556	<0.001	0.002	0.16	0.2	0.000054	0.001	0.003	4.4	0.002	2.43	0.009	<0.001	<0.0001	0.004	0.014
							19-Jul-11	0.012	<0.001	0.002	0.19	0.16	<0.000017	0.001	0.003	<0.1	<0.001	1.77	0.009	<0.001	<0.0001	0.004	0.008
MW10-04	This assessment	9	7	91	14	4	10-Feb-10	0.003	0.0002	0.0007	0.09	0.05	0.0001	<0.001	0.0012	<0.06	<0.0002	0.41	0.014	0.0016	<0.0001	0.0025	<0.003
							31-May-10	0.008	<0.0002	0.0006	0.09	0.05	0.000048	<0.001	0.0012	<0.06	<0.0002	0.41	0.0097	0.0006	<0.0001	0.009	<0.003
							24-Aug-10	0.22	<0.0002	0.0008	0.09	0.05	0.088	<0.001	0.0021	0.96	0.0008	0.39	0.0082	<0.0002	<0.0001	0.0059	0.006
							4-Oct-10	0.37	0.0014	0.0008	0.08	0.04	0.00054	0.001	0.0025	0.99	0.0014	0.096	0.0073	0.0008	<0.0001	0.0013	0.035
							12-Mar-11	0.011	<0.001	<0.001	0.08	0.04	0.000029	<0.001	0.002	<0.1	<0.001	<0.005	0.005	<0.001	<0.0001	0.001	0.005
							22-Jun-11	0.33	<0.001	<0.001	0.1	0.06	0.000086	<0.001	0.003	0.9	0.001	0.11	0.007	<0.001	<0.0001	0.003	0.007
							19-Jul-11	<0.002	<0.001	<0.001	0.12	0.03	0.000040	<0.001	<0.002	<0.1	<0.001	0.023	0.006	<0.001	0.0002	0.002	0.003
Empress Aquifer																							
WSW1	STP 2009	8	8	91	14	4	17-Feb-09	0.003	<0.0002	0.0055	0.02	0.66	<0.0002	<0.001	<0.0002	<0.06	<0.0002	0.088	<0.0005	<0.0002	<0.0001	0.0001	<0.003
							18-Feb-09	0.001	<0.0002	0.0056	0.02	0.67	<0.0002	<0.001	<0.0002	0.34	<0.0002	0.088	0.0006	<0.0002	<0.0001	0.0001	<0.003
WSW2	STP 2009	16	8	91	14	4	8-Feb-09	0.003	<0.0002	<0.0002	<0.01	0.98	<0.0002	<0.001	<0.0002	1.1	<0.0002	0.02	<0.0005	<0.0002	<0.0001	0.0002	<0.003
							11-Feb-09	0.002	<0.0002	<0.0002	<0.01	0.98	<0.0002	<0.001	<0.0002	1.1	<0.0002	0.02	<0.0005	<0.0002	<0.0001	0.0002	<0.003

Table B3: Groundwater Chemistry Summary of Dissolved Metals Parameters

Well ID	Project	Location					Sampling Date	Aluminum	Antimony	Arsenic	Barium	Boron	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Nickel	Selenium	Silver	Uranium	Zinc
		LSD	Sec	Twp	Rge	Mer	Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
							18-Mar-11	0.005	<0.001	<0.001	<0.05	1.55	<0.000016	0.001	0.005	<0.1	<0.001	0.028	<0.01	<0.001	<0.00005	<0.001	0.005
WSW3	This assessment	15	8	91	14	4	11-Mar-11	0.018	<0.001	<0.001	<0.05	1.16	0.00005	0.002	0.006	0.6	<0.001	0.036	<0.01	<0.001	<0.00005	<0.001	0.006
5-22 WSW EMP[1]	AOSC 2009	5	22	90	16	4	1-Mar-09	<0.02	<0.0004	0.0015	0.0279	0.83	<0.0002	<0.0008	<0.001	2.66	0.0001	0.047	0.0015	<0.0004	<0.0004	<0.0001	0.011
5-22 WSW EMP	AOSC 2009	5	22	90	16	4	1-Mar-09	<0.01	<0.0004	0.0011	0.0162	0.76	<0.0001	<0.0004	<0.0006	0.01	<0.0001	0.045	0.0012	<0.0004	<0.0002	<0.0001	0.009
06-05 WSW EMP[1]	AOSC 2009	6	5	91	14	4	5-Mar-09	<0.02	<0.0004	0.0088	0.111	0.69	<0.0002	<0.0008	0.001	0.8	0.0002	0.021	0.0007	<0.0004	<0.0004	0.0001	0.021
06-05 WSW EMP	AOSC 2009	6	5	91	14	4	5-Mar-09	<0.01	<0.0004	0.0078	0.106	0.67	<0.0001	0.0009	0.0008	0.81	0.0002	0.021	0.0005	<0.0004	<0.0002	0.0001	0.019
07-34 WSW EMP[1]	AOSC 2009	7	34	89	13	4	24-Feb-09	<0.02	<0.0004	0.0046	0.025	0.98	<0.0002	0.0017	0.001	3.02	0.0001	0.049	0.0008	<0.0004	<0.0004	0.0002	0.013
07-34 WSW EMP	AOSC 2009	7	34	89	13	4	24-Feb-09	<0.01	<0.0004	0.0043	0.022	0.98	<0.0001	<0.002	0.0014	<0.05	<0.0001	0.05	0.0007	<0.0004	<0.0002	0.0003	0.013
15-16 WSW EMP[1]	AOSC 2009	15	16	90	16	4	31-Jan-09	<0.01	<0.0004	0.0009	0.023	0.71	<0.0002	<0.005	<0.001	0.9	0.0003	0.031	0.008	<0.0004	<0.0004	0.0001	0.007
15-16 WSW EMP	AOSC 2009	15	16	90	16	4	31-Jan-09	0.006	<0.0004	0.0008	0.024	0.72	<0.0001	<0.005	0.001	0.82	0.0001	0.031	0.008	0.0004	<0.0001	0.0001	0.012
Grand Rapids 3 Aquifer																							
1-23 WSW GR3[1]	AOSC 2009	1	23	93	17	4	22-Jan-09	0.16	<0.0004	0.0004	0.105	3.77	<0.0002	<0.005	0.002	0.41	0.0052	<0.005	0.002	0.001	0.0006	0.0002	0.009
1-23 WSW GR3	AOSC 2009	1	23	93	17	4	22-Jan-09	<0.005	<0.0004	0.0005	0.089	3.91	<0.0001	<0.005	<0.001	0.04	<0.0001	<0.005	<0.002	0.0007	<0.0001	<0.0001	0.005
6-35 OBS GR3[1]	AOSC 2009	6	35	92	17	4	9-Mar-09	0.1	<0.0004	<0.0004	0.0233	0.54	<0.0002	0.0009	<0.001	2.71	0.0002	0.027	0.0100	<0.0004	<0.0004	<0.0001	0.005
6-35 OBS GR3	AOSC 2009	6	35	92	17	4	9-Mar-09	<0.01	<0.0004	<0.0004	0.0192	0.57	<0.0001	<0.0004	0.0008	2.57	<0.0001	0.026	0.0015	<0.0004	<0.0002	<0.0001	0.004
Grand Rapids 4 Aquifer																							
MW11-02	This assessment	15	7	91	14	4	12-Mar-11 22-Jun-11 19-Jul-11	0.045 0.033 0.144	<0.001 <0.001 <0.001	0.002 0.001 0.001	<0.05 <0.05 <0.05	2.46 2.63 2.72	0.000023 0.000040 <0.000017	0.002 0.001 0.002	0.01 0.005 0.007	<0.1 0.1 <0.1	<0.001 <0.001 <0.001	0.012 0.089 0.116	<0.003 <0.003 <0.003	<0.001 <0.001 <0.001	<0.0001 <0.0001 <0.0001	<0.001 <0.001 <0.001	0.013 0.013 <0.003
10-01 WSW GR4[1]	AOSC 2009	10	1	90	14	4	16-Feb-09	<0.02	<0.0004	<0.0004	0.0618	1.00	<0.0002	0.0028	0.002	0.51	0.0004	0.030	0.0007	<0.0004	<0.0004	<0.0001	0.013
10-01 WSW GR4	AOSC 2009	10	1	90	14	4	16-Feb-09	<0.01	<0.0004	<0.0004	0.0604	0.96	<0.0001	0.0026	0.002	0.39	<0.0001	0.030	0.0006	<0.0004	0.0002	<0.0001	0.013
Grand Rapids 5 Aquifer																							
MW11-01	This assessment	15	7	91	14	4	12-Mar-11 22-Jun-11 19-Jul-11	0.003 1.85 <0.002	<0.001 <0.001 <0.001	<0.001 0.001 <0.001	0.22 0.29 0.28	3.07 3.48 3.73	<0.000017 0.000081 <0.000017	0.009 0.009 0.007	0.016 0.012 0.013	<0.1 11.0 <0.1	<0.001 0.006 <0.001	0.009 0.204 <0.005	<0.003 0.005 <0.003	0.004 0.002 0.003	<0.0001 <0.0001 <0.0001	<0.001 <0.001 <0.001	0.004 0.027 <0.003
6-13 WSW GR5[1]	AOSC 2009	6	13	90	14	4	8-Feb-09	0.41	<0.0004	0.0007	0.102	3.23	<0.0002	0.002	0.002	1.15	0.0022	0.027	0.0019	0.001	<0.0004	0.0001	0.008
6-13 WSW GR5	AOSC 2009	6	13	90	14	4	8-Feb-09	<0.01	<0.0004	0.0005	0.0656	3.25	<0.0001	0.001	0.001	0.22	0.0002	0.008	0.0005	0.001	<0.0002	<0.0001	0.004
6-24 WSW GR5[1]	AOSC 2009	6	24	90	14	4	13-Feb-09	0.88	<0.0004	0.0007	0.0690	1.52	<0.0002	0.005	0.028	4.79	0.0057	0.064	0.0056	<0.0004	<0.0004	0.0003	0.036
6-24 WSW GR5	AOSC 2009	6	24	90	14	4	13-Feb-09	<0.01	<0.0004	<0.0004	0.0434	1.62	<0.0001	0.003	0.001	0.03	<0.0001	0.004	0.0002	<0.0004	<0.0002	0.0002	0.003
Basal McMurray Aquifer																							
03-34-92-12B	Petro Canada 2005	3	34	92	12	4	2004	0.013 to 0.27	-	<0.005 to 0.033	1.29 to 10.0	-	-	-	-	0.08 to 3.3	-	0.256 to 0.412	-	-	-	-	-
10-01 WDW MCMR[1]	AOSC 2009	10	1	90	14	4	14-Feb-09	0.5	<0.008	0.024	0.127	4.7	<0.004	<0.02	<0.02	12.4	0.011	0.24	0.018	0.015	<0.008	<0.002	0.93
10-01 WDW MCMR	AOSC 2009	10	1	90	14	4	14-Feb-09	<0.2	<0.008	0.018	0.098	4.71	<0.002	<0.04	<0.01	1.71	<0.002	0.14	0.007	0.02	<0.004	<0.002	0.13
11-29 WDW MCMR[1]	AOSC 2009	11	29	89	12	4	16-Feb-09	43.3	<0.008	0.056	2.8	3.5	<0.004	0.15	0.29	129	0.175	1.36	0.188	0.024	<0.008	0.012	2.57
11-29 WDW MCMR	AOSC 2009	11	29	89	12	4	16-Feb-09	<0.2	<0.008	0.018	1.22	3.52	<0.002	<0.04	<0.01	0.03	<0.002	0.076	0.004	0.016	<0.004	0.004	<0.02

Notes:

[1] Total metals

"-" = indicates not available/not measured

Table B4: Groundwater Chemistry Summary of Organic Parameters

Well ID	Project	Location					Sample Date	Petroleum Hydrocarbons						Naphthenic Acids	Phenols
								Benzene	Toluene	Ethylbenzene	Xylene	F1 (C6-C10) - BTEX	F2 (C10-C16 Hydrocarbons)		
		LSD	Sec	Twp	Rge	Mer	Units	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L	mg/L
Undifferentiated Glacial Drift Aquifer/Aquitard															
MW4-24	This assessment	4	21	91	14	4	12-Mar-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	0.1	<0.2	0.006
MW8-10S	This assessment	8	10	91	14	4	12-Mar-11	<0.0005	<0.0005	<0.0005	0.0018	<0.1	<0.1	<0.2	0.007
MW8-10D	This assessment	8	10	91	14	4	12-Mar-11	<0.0005	<0.0005	<0.0005	0.001	<0.1	<0.1	<0.2	0.009
MW10-01	This assessment	10	7	91	14	4	10-Feb-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	<0.002
							31-May-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.009
							24-Aug-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.002
							4-Oct-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.003
							12-Mar-11	-	-	-	-	-	-	-	-
							22-Jun-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.008
							19-Jul-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
MW10-02	This assessment	10	7	91	14	4	10-Feb-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	<0.002
							31-May-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.01
							24-Aug-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	<0.002
							4-Oct-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.002
							12-Mar-11	-	-	-	-	-	-	-	-
							22-Jun-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.009
							19-Jul-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.003
MW10-03S	This assessment	9	7	91	14	4	9-Feb-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	<0.002
							31-May-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.006
							24-Aug-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	<0.002
							4-Oct-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.002
							12-Mar-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
							22-Jun-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.002
MW10-03D	This assessment	9	7	91	14	4	9-Feb-10	<0.4	<0.4	<0.4	<0.8	<100	0.1	<1.0	<0.002
							31-May-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.006
							24-Aug-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	<0.002
							12-Mar-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	0.1	<0.2	<0.002
							22-Jun-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.004
							19-Jul-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.003
MW10-04	This assessment	9	7	91	14	4	10-Feb-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	<0.002
							31-May-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.004
							24-Aug-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.002
							4-Oct-10	<0.4	<0.4	<0.4	<0.8	<100	<0.1	<1.0	0.003
							12-Mar-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
							22-Jun-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.003
							19-Jul-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
14 wells	Petro Canada 2005			93	12	4	2004	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.05	<1 to 3	<0.001 to 0.003
Empress Aquifer															
WSW1	STP 2009	8	8	91	14	4	18-Feb-09	<0.0004	<0.0004	<0.0004	<0.0008	-	-	-	<0.002
WSW2	STP 2009	16	8	91	14	4	11-Feb-09	<0.0004	<0.0004	<0.0004	<0.0008	-	-	-	<0.002
							18-Mar-11	<0.0005	<0.0005	<0.0005	<0.001	-	-	-	<0.005
WSW3	This assessment	15	8	91	14	4	11-Mar-11	<0.0005	<0.0005	<0.0005	<0.001	-	-	-	<0.005
5-22 WSW EMP	AOSC 2009	5	22	90	16	4	1-Mar-09	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.05	-	0.003
06-05 WSW EMP	AOSC 2009	6	5	91	14	4	5-Mar-09	<0.0005	<0.00075	<0.0005	<0.0005	<0.1	<0.05	-	<0.002
07-34 WSW EMP	AOSC 2009	7	34	89	13	4	24-Feb-09	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.05	-	0.003
15-16 WSW EMP	AOSC 2009	15	16	90	16	4	31-Jan-09	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.05	-	<0.001
11 wells	Petro Canada 2005			93	12	4	2004	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.05 to 21	<1 to 2	<0.001 to 0.034
Grand Rapids 4 Aquifer															
MW11-02	This assessment	15	7	91	14	4	12-Mar-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
							22-Jun-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.005
							19-Jul-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
Grand Rapids 5 Aquifer															
MW11-01	This assessment	15	7	91	14	4	12-Mar-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
							22-Jun-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	0.002
							19-Jul-11	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.1	<0.2	<0.002
Clearwater Aquitard															
11 wells	Petro Canada 2005						2004	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.05	1 to 2	<0.001
Wabiskaw/McMurray Aquitard															
3 wells	Petro Canada 2005						2004	<0.0005	<0.0005	<0.0005	<0.0005	<0.1	<0.05 to 2.7	4 to 5	0.019 to 0.059
Basal McMurray Aquifer															
03-34-92-12B	Petro Canada 2005	3	34	92	12	4	2004	-	-	-	-	-	-	5 to 7	-

Notes:

"-" = indicates not available/not measured

Table B5: AENV Water Well Records within the HRSA

Well ID	Location					Latitude	Longitude	Elevation (masl)	Well Depth (m)	Owner	Type of Work	Use	Date of Information	Completion Interval (m)	Water Level		Test Rate (L/min)	Bedrock Depth (m)	Lithology	Hydrostratigraphic Unit
	LSD	Sec	Twp	Rge	Mer										(mbgs)	(masl)				
279610	12	28	87	19	4	56.575	-112.979	-	30.5	Union Oil Co.	New Well	Industrial	14-Jan-82	22.56 - 25.60	6.10	-	-	NE	Sand & gravel	Undifferentiated drift
279618	12	28	87	19	4	56.575	-112.979	-	30.5	Union Oil Co.	New Well	omestic & Industr	11-Jan-82	24.99 - 25.60	6.10	-	-	NE	Sand	Undifferentiated drift
279622	12	28	87	19	4	56.575	-112.979	-	36.6	Union Oil Co.	New Well	Industrial	22-Feb-82	32.0 - 35.05	9.14	-	331.86	35.97	Sandstone	
279624	12	28	87	19	4	56.575	-112.979	-	36.6	Union Oil Co.	New Well	Industrial	25-Feb-82	30.48 - 35.05	9.14	-	-	NE	Sand & gravel	Undifferentiated drift
279626	13	28	87	19	4	56.579	-112.979	-	30.5	Union Oil Co.	New Well	Domestic	13-Jan-82	24.99 - 26.52	7.62	-	27.28	NE	Sand	Undifferentiated drift
279677	13	28	87	19	4	56.579	-112.979	-	21.3	Union Oil Co.	New Well	Industrial	17-Jun-82	10.06 - 11.58	-	-	-	21.34	Sand & gravel	Undifferentiated drift
279679	13	28	87	19	4	56.579	-112.979	-	48.8	Union Oil Co.	New Well	Industrial	1-Jan-82	36.58 - 41.15	4.57	-	136.38	23.77	Sandstone	
279680	13	28	87	19	4	56.579	-112.979	-	61.0	Union Oil Co.	New Well	Industrial	6-Feb-82	32.61 - 35.66	9.14	-	363.69	56.39	Sand & gravel	Undifferentiated drift
279681	1	32	87	19	4	56.583	-112.986	-	41.5	Union Oil Co.	New Well	Domestic	8-Feb-82	38.40 - 41.45	9.45	-	136.38	NE	Sand & gravel	Undifferentiated drift
279682	1	32	87	19	4	56.583	-112.986	-	68.3	Union Oil Co.	New Well	Domestic	5-Jan-82	37.80 - 39.32	12.19	-	-	NE	Clay	Undifferentiated drift
279742	SW	19	88	13	4	56.642	-112.072	-	-	Mariana Lakes Lodge	Chemistry	Domestic	21-Feb-86	-	-	-	-	-	-	-
279743	5	8	88	18	4	56.615	-112.846	-	17.7	Coseka Res.	New Well	Domestic	24-Jan-86	16.46 - 17.68	-	-	59.10	NE	Sand	Undifferentiated drift
279744	5	8	88	18	4	56.615	-112.846	-	24.4	Coseka Res.	Chemistry	Industrial	31-Mar-87	-	-	-	-	-	-	-
279745	NW	5	88	19	4	56.606	-113.003	-	19.8	Union Oil Co.	New Well	Industrial	17-Feb-78	12.80 - 19.81	-	-	-	NE	Clay and sand	Undifferentiated drift
279746	SW	8	88	19	4	56.613	-113.003	519.99	61.0	Union Oil Co.	New Well	Industrial	17-Feb-78	30.78 - 37.80	24.38	495.61	90.92	NE	Sand	Undifferentiated drift
279747	SW	8	88	19	4	56.613	-113.003	519.99	39.6	Union Oil Co.	New Well	Industrial	17-Feb-78	30.78 - 37.49	25.91	494.08	136.38	NE	Sand	Undifferentiated drift
279748	3	8	88	19	4	56.612	-112.999	-	42.7	Union Oil Co.	New Well	Industrial	31-Jan-82	38.10 - 41.15	18.29	-	-	NE	Sand & gravel	Undifferentiated drift
279808	NE	31	89	9	4	56.766	-111.421	-	12.2	Blish Concrete Products Ltd.	New Well	Industrial	22-Oct-89	-	2.74	-	90.92	10.06	Shale	-
2099021	11	29	89	12	4	56.751	-111.883	-	244.0	Athabasca Oil Sands Corp.	New Well	Industrial	13-Feb-09	213.5 - 222.5	212.0	-	<4.5	54.0	Sandstone	Basal McMurray Aquifer
2065010	7	34	89	13	4	56.761	-111.982	512.30	72.4	Athabasca Oil Sands Corp.	New Well	Industrial	17-Feb-09	43.80 - 63.80*	19.42	492.88	1111.20	70.0	Gravel	Empress
233683	15	33	89	16	4	56.768	-112.488	479.76	16.2	Alberta Research Council 15-53	New Well	Observation	1-Dec-75	13.11 - 14.63	-	-	-	-	-	Undifferentiated drift
233685	15	33	89	16	4	56.768	-112.488	480.06	41.2	Alberta Research Council 15-135	New Well	Observation	2-Dec-75	38.10 - 39.62	-	-	-	-	-	Undifferentiated drift
233686	15	33	89	16	4	56.768	-112.488	480.36	145.4	Alberta Research Council 15-477	New Well	Observation	29-Jan-76	139.29 -	-	-	-	-	-	Clearwater Aquitard
233687	15	33	89	16	4	56.768	-112.488	480.36	228.6	Alberta Research Council 15-750	New Well	Observation	29-Jan-76	224.03 - 227.08	-	-	-	-	-	Wabiskaw/McMurray Aquitard
233688	15	33	89	16	4	56.768	-112.488	480.06	303.9	Alberta Research Council	New Well	Observation	29-Jan-76	-	-	-	-	-	-	Beaverhill Lake Aquifer/Aquitard
92590	6	17	89	17	4	56.717	-112.680	466.34	53.3	Richfield Oil Corp.	Chemistry	Industrial	23-Feb-59	-	-	-	-	-	-	-
279825	12	28	89	19	4	56.750	-112.979	-	61.0	Union Oil Co.	New Well	Industrial	28-Feb-82	49.07 - 52.12	9.14	-	227.30	59.4	Sand	Undifferentiated drift
1270000	SE	6	90	9	4	56.773	-111.421	244.45	10.7	Diversified Transportation Ltd.	New Well	Industrial	6-Jul-01	7.62 - 9.14	3.60	240.85	113.65	9.45	Sand & gravel	Undifferentiated drift
1270147	SE	6	90	9	4	56.773	-111.421	244.75	-	Diversified Transportation Ltd.	Piezometer	Observation	3-Jul-01	3.35 - 6.40	3.19	241.56	-	6.10	Sand & gravel	Undifferentiated drift
1270148	SE	6	90	9	4	56.773	-111.421	245.06	-	Diversified Transportation Ltd.	New Well	Industrial	4-Jul-01	6.40 - 7.92	3.44	241.62	113.65	7.92	Sand & gravel	Undifferentiated drift
1270150	SE	6	90	9	4	56.773	-111.421	244.45	-	Diversified Transportation Ltd.	New Well	Industrial	5-Jul-01	6.40 - 9.45	5.64	238.81	170.48	7.62	Gravel	-
233392	6	13	90	10	4	56.804	-111.457	341.99	99.1	Alberta Research Council 16-325	New Well	Observation	-	94.49 - 97.54	-	-	18.64	-	-	Basal McMurray Aquifer

Table B5: AENV Water Well Records within the HRSA

Well ID	Location					Latitude	Longitude	Elevation (masl)	Well Depth (m)	Owner	Type of Work	Use	Date of Information	Completion Interval (m)	Water Level		Test Rate (L/min)	Bedrock Depth (m)	Lithology	Hydrostratigraphic Unit
	LSD	Sec	Twp	Rge	Mer										(mbgs)	(masl)				
233689	6	13	90	10	4	56.804	-111.457	341.99	16.8	Alberta Research Council 16-55	New Well	Observation	-	10.67 - 15.24	-	-	-	-	-	Undifferentiated drift
233690	6	13	90	10	4	56.804	-111.457	341.99	50.3	Alberta Research Council 16-165	New Well	Observation	-	45.72 - 48.77	-	-	-	-	-	Wabiskaw/McMurray Aquitard
233696	6	13	90	10	4	56.804	-111.457	341.99	167.6	Alberta Research Council	New Well	Observation	-	-	-	-	-	-	-	Beaverhill Lake Aquifer/Aquitard
233698	8	11	90	12	4	56.790	-111.790	532.79	265.8	Alberta Research Council13-872	New Well	Observation	-	261.26 - 264.26	-	-	-	-	-	Basal McMurray Aquifer
233701	8	11	90	12	4	56.790	-111.790	533.40	374.9	Alberta Research Council	New Well	Observation	-	-	31.70	343.20	-	-	-	Beaverhill Lake Aquifer/Aquitard
233703	8	11	90	12	4	56.790	-111.790	533.40	21.3	Alberta Research Council 13-70	New Well	Observation	-	17.37 - 18.90	-	-	-	-	-	Undifferentiated drift
233706	8	11	90	12	4	56.790	-111.790	533.10	70.1	Alberta Research Council 13-230	New Well	Observation	-	64.01 - 68.58	-	-	-	-	-	Undifferentiated drift
233707	8	11	90	12	4	56.790	-111.790	533.10	140.2	Alberta Research Council	New Well	Observation	-	134.11 - 138.68	-	-	-	-	-	Grand Rapids Aquifer/Aquitard
233708	8	11	90	12	4	56.790	-111.790	532.79	234.7	Alberta Research Council 13-770	New Well	Observation	-	230.12 - 233.17	-	-	-	-	-	Wabiskaw/McMurray Aquitard
288023	8	11	90	12	4	56.790	-111.790	-	265.8	Alberta Research Council	Chemistry	Observation	26-Sep-84	-	-	-	-	-	-	-
288024	8	11	90	12	4	56.790	-111.790	-	374.9	Alberta Research Council	Chemistry	Observation	26-Sep-84	-	-	-	-	-	-	-
288025	8	11	90	12	4	56.790	-111.790	533.40	374.9	Alberta Research Council	Chemistry	Observation	16-Oct-84	-	-	-	-	-	-	-
288026	8	11	90	12	4	56.790	-111.790	-	265.8	Alberta Research Council	Chemistry	Observation	16-Oct-84	-	-	-	-	-	-	-
288027	8	11	90	12	4	56.790	-111.790	-	140.2	Alberta Research Council	Chemistry	Observation	16-Oct-84	-	-	-	-	-	-	-
2065009	6	24	90	14	4	56.819	-112.096	481.20	93.2	Athabasca Oil Sands Corp.	New Well	Industrial	28-Feb-09	64.10 - 91.60*	10.86	470.34	194.50	48.0	Sandstone	-
2065011	10	1	90	14	4	56.779	-112.089	487.50	70.0	Athabasca Oil Sands Corp.	New Well	Industrial	11-Feb-09	50.60 - 69.20	6.53	480.97	97.20	50.0	Sandstone	Grand Rapids 4 Sand
2065044	16	7	90	14	4	56.797	-112.212	475.90	130.0	Dover Operating Corp.	New Well	Observation	19-Jan-11	75.0 - 86.0	1.90	474.00	-	86.0	Sand	-
2099020	10	1	90	14	4	56.779	-112.089	-	223.5	Athabasca Oil Sands Corp.	New Well	Industrial	6-Feb-09	214.2 - 221.7	195.0	-	5.60	65.0	Tarsand	Basal McMurray
2099025	6	13	90	14	4	56.804	-112.095	-	87.8	Athabasca Oil Sands Corp.	New Well	Industrial	30-Jan-09	65.0 - 86.0*	19.00	-	27.8	51.0	Sandstone	-
2065028	13	10	9	15	4	56.797	-112.316	142.97	119.2	Dover Operating Corp.	New Well	Other	25-Jan-11	78.60 - 116.60*	Artesian	-	-	NE	Sand & gravel	
2065046	13	10	9	15	4	56.797	-112.316	468.0	117.5	Dover Operating Corp.	New Well	Observation	22-Jan-11	81.0 - 117.50	Artesian	-	-	132.5	Sand & gravel	
160331	15	30	90	19	4	56.841	-113.019	-	15.2	Paramount Res.	New Well	Domestic	28-Dec-86	9.45 - 15.24	10.85	-	27.28	NE	Sand	Undifferentiated drift
160331	15	30	90	19	4	56.841	-113.019	-	15.2	Paramount Res.	New Well	Domestic	28-Dec-86	9.45 - 15.24	10.85	-	27.28	NE	Sand	Undifferentiated drift
279836	15	30	90	19	4	56.841	-113.019	-	11.3	Paramount Res.	Chemistry	Domestic	4-Feb-87	-	-	-	-	-	-	-
1421128	15	8	91	14	4	56.885	-112.215	-	115.8	Southern Pacific Resources Corp.	New Well	Industrial	11-Mar-11	92.05 - 106.68	5.72	-	863.76	106.7	Sand & gravel	Empress
1421129	15	7	91	14	4	56.885	-112.242	-	83.8	Southern Pacific Resources Corp.	New Well	Observation	9-Mar-11	80.77 - 83.82	Artesian	-	-	40.2	Sandstone	Grand Rapids 5 Sand
1421130	15	7	91	14	4	56.885	-112.242	-	36.6	Southern Pacific Resources Corp.	New Well	Observation	10-Mar-11	-	-	-	-	40.2	Sandstone	Grand Rapids 4 Sand
2065008	6	5	91	14	4	56.863	-112.220	464.90	115.5	Athabasca Oil Sands Corp.	New Well	Industrial	25-Feb-09	75.4 - 112.2	-	-	-	112.0	Sand & gravel	Empress
1911911	7	16	91	16	4	56.892	-112.510	-	89.3	CNRL	New Well	Domestic	24-Jan-06	85.34 - 88.39	7.27	-	54.55	23.2	Sandstone	-
2065050	10	27	91	17	4	56.924	-112.645	499.60	147.5	Dover Operating Corp.	New Well	Observation	9-Feb-11	-	-	-	-	-	-	-
2065058	10	27	91	17	4	56.924	-112.644	499.60	153.0	Dover Operating Corp.	New Well	Industrial	2-Mar-11	108.0 - 153.0	-	-	-	-	-	-
287116	13	24	91	18	4	56.913	-112.766	-	73.2	Rio Alta Expl.	New Well	Domestic	17-Feb-97	23.16 - 24.69	2.13	-	81.83	59.4	Sand	-
1911910	13	24	91	18	4	56.914	-112.765	-	67.1	CNRL	New Well	Domestic	28-Jan-06	60.96 - 64.01	2.34	-	54.55	65.8	Sand	-
292382	1	27	91	19	4	56.917	-112.961	-	35.1	Rio Alta Expl.	New Well	Domestic	26-Feb-99	28.65 - 30.18	5.49	-	68.19	NE	Sand & gravel	-
279860	1	5	92	10	4	56.946	-111.565	-	19.2	GCOS #P19	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
150376	SW	12	92	10	4	56.963	-111.474	-	20.1	Carbovan	New Well	Industrial	6-Mar-90	10.67 - 15.24	4.27	-	168.21	NE	Sand	Undifferentiated drift
151049	SW	12	92	10	4	56.963	-111.474	-	109.7	Carbovan	New Well	Industrial	31-Mar-90	14.94 - 19.51	20.70	-	254.58	103.6	Gravel	
151051	SW	12	92	10	4	56.963	-111.474	-	31.1	Carbovan	New Well	Industrial	30-Apr-90	9.45 - 14.02	8.72	-	54.55	NE	Sand	
152514	SW	12	92	10	4	56.963	-111.474	-	30.5	Carbovan Well #4	New Well	Industrial	10-Jul-90	13.11 - 17.68	8.84	-	68.19	27.1	Sand	
152515	SW	12	92	10	4	56.963	-111.474	-	105.2	Carbovan Well #3	New Well	Industrial	8-Jul-90	12.50 - 17.07	8.23	-	159.11	66.5	Gravel	

Table B5: AENV Water Well Records within the HRSA

Well ID	Location					Latitude	Longitude	Elevation (masl)	Well Depth (m)	Owner	Type of Work	Use	Date of Information	Completion Interval (m)	Water Level		Test Rate (L/min)	Bedrock Depth (m)	Lithology	Hydrostratigraphic Unit
	LSD	Sec	Twp	Rge	Mer										(mbgs)	(masl)				
296250	SW	12	92	10	4	56.963	-111.474	-	17.1	Graham Construction & Eng.	New Well	Industrial	7-Dec-00	12.19 - 15.24	2.74	-	272.77	NE	Sand & gravel	Undifferentiated drift
296251	NE	12	92	10	4	56.970	-111.461	-	12.2	Midstream Joint Venture #3	New Well	Industrial	8-May-01	7.32 - 10.36	3.96	-	54.55	NE	Gravel	Undifferentiated drift
1827822	SE	14	92	10	4	56.977	-111.488	-	8.5	Alberta Environment	New Well	Monitoring	30-Sep-94	-	-	-	-	-	-	-
1827856	SE	14	92	10	4	56.977	-111.488	-	8.5	Alberta Environment	New Well	Monitoring	20-Jul-94	-	-	-	-	-	-	-
279861	NW	14	92	10	4	56.984	-111.501	-	13.7	GCOS #CH 117	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279862	14	14	92	10	4	56.986	-111.498	-	13.7	GCOS #OBS 1	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279863	14	14	92	10	4	56.986	-111.498	-	13.7	GCOS #OBS 2	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279864	2	22	92	10	4	56.990	-111.518	-	13.4	GCOS #P49	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279865	2	22	92	10	4	56.990	-111.518	-	15.2	GCOS #P48	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279866	13	22	92	10	4	57.001	-111.531	-	19.5	ARC #K17	Chemistry	Unknown	-	-	-	-	-	-	-	-
279867	15	22	92	10	4	57.001	-111.518	-	3.1	GCOS #P51	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279868	15	22	92	10	4	57.001	-111.518	-	3.1	GCOS #P29	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279869	15	22	92	10	4	57.001	-111.518	-	12.2	GCOS #P55	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279870	0	23	92	10	4	56.995	-111.495	-	-	GCOS	Chemistry	Unknown	12-Jun-69	-	-	-	-	-	-	-
279871	0	23	92	10	4	56.995	-111.495	-	-	GCOS #TS6	Chemistry	Unknown	12-Jun-69	-	-	-	-	-	-	-
279872	0	23	92	10	4	56.995	-111.495	-	-	GCOS #TS7	Chemistry	Unknown	12-Jun-68	-	-	-	-	-	-	-
279873	3	23	92	10	4	56.990	-111.498	-	12.2	GCOS	Chemistry	Unknown	30-Jul-68	-	-	-	-	-	-	-
279875	8	27	92	10	4	57.008	-111.512	-	12.2	GCOS #K3	Chemistry	Unknown	-	-	-	-	-	-	-	-
279876	3	27	92	10	4	57.005	-111.525	-	11.6	GCOS #K4	Chemistry	Unknown	-	-	-	-	-	-	-	-
279877	12	27	92	10	4	57.012	-111.531	-	17.4	GCOS #P57	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279878	15	27	92	10	4	57.015	-111.518	-	5.8	GCOS #P39	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279879	1	28	92	10	4	57.005	-111.538	-	17.7	GCOS #P58	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279880	2	28	92	10	4	57.005	-111.545	-	10.7	GCOS #K18	Chemistry	Unknown	-	-	-	-	-	-	-	-
279881	11	28	92	10	4	57.012	-111.552	-	16.5	GCOS #K15	Chemistry	Unknown	-	-	-	-	-	-	-	-
279882	14	28	92	10	4	57.015	-111.552	-	17.7	GCOS #K16	Chemistry	Unknown	-	-	-	-	-	-	-	-
279883	9	28	92	10	4	57.012	-111.538	-	8.2	GCOS #P56	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279884	9	28	92	10	4	57.012	-111.538	-	14.3	GCOS #P54	Piezometer	Dewatering	1-Oct-71	-	-	-	-	-	-	-
279885	2	33	92	10	4	57.019	-111.545	-	12.2	GCOS #K14	Chemistry	Unknown	-	-	-	-	-	-	-	-
279886	6	33	92	10	4	57.023	-111.552	-	11.6	GCOS #K9	Chemistry	Unknown	-	-	-	-	-	-	-	-
279888	6	34	92	10	4	57.023	-111.525	-	8.5	GCOS #K6	Chemistry	Unknown	-	-	-	-	-	-	-	-
279889	NW	35	92	10	4	57.028	-111.501	270.49	12.2	Syncrude Canada Ltd.	Chemistry	Domestic	14-Aug-72	-	-	-	-	-	-	-
233709	4	15	92	12	4	56.975	-111.853	373.08	75.3	Alberta Research Council 14-247	New Well	Observation	-	69.19 - 73.76	-	-	-	-	-	Wabiskaw/McMurray Aquitard
233710	4	15	92	12	4	56.975	-111.853	372.77	484.6	Alberta Research Council	New Well	Observation	-	-	-	-	-	-	-	-
233711	4	15	92	12	4	56.975	-111.853	372.47	11.9	Alberta Research Council 14-31	New Well	Observation	-	8.84 - 10.36	-	-	-	-	-	Undifferentiated drift
233713	4	15	92	12	4	56.975	-111.853	372.77	36.3	Alberta Research Council 14-119	New Well	Observation	-	30.18 - 34.75	-	-	-	-	-	Clearwater Aquitard
233714	4	15	92	12	4	56.975	-111.853	372.47	213.1	Alberta Research Council 14-699	New Well	Observation	-	-	-	-	-	-	-	Beaverhill Lake Aquifer/Aquitard
2065043	10	33	92	15	4	57.026	-112.350	479.54	63.0	Dover Operating Corp.	New Well	Monitoring	8-Jan-11	42.0 - 63.0	9.00	470.54	-	NE	Sand & gravel	-
2065045	NE	33	92	15	4	57.028	-112.347	479.54	64.4	Dover Operating Corp.	New Well	Industrial	15-Jan-11	41.86 - 64.41	8.90	470.64	-	NE	Sand & gravel	-
2099017	15	16	92	16	4	56.986	-112.511	-	124.0	Athabasca Oil Sands Corp.	New Well	Industrial	21-Jan-09	101.2 - 122.20	7.00	-	-	NE	Sand	
2099019	5	22	92	16	4	56.995	-112.497	-	120.5	Athabasca Oil Sands Corp.	New Well	Industrial	21-Feb-09	70.20 - 117.50	6.00	-	-	NE	Sand	Empress
2065047	12	1	92	17	4	56.955	-112.104	498.80	161.7	Dover Operating Corp.	New Well	Observation	3-Feb-11	-	-	-	-	-	-	-
296254	15	1	92	17	4	56.957	-112.592	-	27.4	Paramount Res.	New Well	Domestic	7-Mar-01	18.59 - 20.12	2.13	-	90.92	9.1	Sandstone	-
2065048	12	1	92	17	4	56.955	-112.604	498.80	77.4	Dover Operating Corp.	New Well	Industrial	5-Feb-11	50.37 - 77.37	-	-	-	NE	Sand & gravel	-
2065057	12	5	92	17	4	56.953	-112.710	512.70	46.0	Dover Operating Corp.	New Well	Observation	25-Feb-11	-	-	-	-	-	-	-
2065051	12	9	92	17	4	56.968	-112.685	510.48	102.0	Dover Operating Corp.	New Well	Observation	10-Feb-11	-	-	-	-	-	-	-
2065052	12	9	92	17	4	56.968	-112.687	510.25	98.5	Dover Operating Corp.	New Well	Industrial	15-Feb-11	65.50 - 98.50	-	-	-	-	-	-
2065049	2	12	92	17	4	56.961	-112.590	496.50	110.1	Dover Operating Corp.	New Well	Observation	7-Feb-11	-	-	-	-	-	-	-

Table B5: AENV Water Well Records within the HRSA

Well ID	Location					Latitude	Longitude	Elevation (masl)	Well Depth (m)	Owner	Type of Work	Use	Date of Information	Completion Interval (m)	Water Level		Test Rate (L/min)	Bedrock Depth (m)	Lithology	Hydrostratigraphic Unit
	LSD	Sec	Twp	Rge	Mer										(mbgs)	(masl)				
2065056	11	15	92	17	4	56.982	-112.655	503.86	85.0	Dover Operating Corp.	New Well	Observation	25-Feb-11	-	-	-	-	-	-	-
2065054	3	21	92	17	4	56.989	-112.680	508.00	70.0	Dover Operating Corp.	New Well	Observation	19-Feb-11	-	-	-	-	-	-	-
2065055	3	21	92	17	4	56.989	-112.680	508.00	72.0	Dover Operating Corp.	New Well	Industrial	23-Feb-11	43.0 - 70.0	-	-	-	-	-	-
243283	10	29	92	17	4	57.012	-112.699	-	102.7	EBA Engineering	New Well	Industrial	9-Mar-81	80.77 - 100.58	12.95	-	340.96	48.8	Sandstone	-
279904	10	29	92	17	4	57.012	-112.699	498.35	105.5	EBA Engineering	New Well	Industrial	24-Feb-81	98.76 - 104.85	13.78	484.57	113.65	65.5	Sandstone	-
2065053	14	30	92	17	4	57.015	-112.730	514.40	77.0	Dover Operating Corp.	New Well	Observation	17-Feb-11	-	-	-	-	-	-	-
2099026	6	35	92	17	4	57.022	-112.626	-	107.5	Athabasca Oil Sands Corp.	New Well	Industrial	20-Feb-09	84.0 - 103.0	12.00	-	-	72.0	Sandstone	Grand Rapids 3 Sand
2065036	14	14	92	18	4	56.986	-112.788	514.42	114.0	Athabasca Oil Sands Corp.	New Well	Observation	21-Feb-11	95.60 - 114.00	-	-	-	114.5	Sand	-
292384	1	30	92	19	4	57.004	-113.041	-	73.2	Paramount Res.	New Well	Domestic	26-Feb-99	68.58 - 71.63	10.45	-	68.19	66.5	Sandstone	-
1501742	5	17	92	19	4	56.979	-113.035	-	140.2	Athabasca Oil Sands Corp.	New Well	Observation	26-Feb-10	83.21 - 131.98	-	-	-	-	Sand	-
2065035	5	17	92	19	4	56.979	-113.035	528.00	141.8	Athabasca Oil Sands Corp.	New Well	Other	19-Feb-11	81.8 - 141.30	9.50	518.50	-	141.0	Sand	-
235184	10	36	93	11	4	57.113	-111.625	-	-	-	Spring	Unknown	-	-	-	-	-	-	-	-
1827859	SE	25	93	11	4	57.094	-111.622	-	7.0	Alberta Environment	New Well	Monitoring	20-Jul-94	-	-	-	-	-	-	-
42469	SW	5	93	12	4	57.035	-111.904	-	56.7	PTI Camp SVC	New Well	Other	23-Nov-00	46.33 - 50.90	30.72	-	113.65	54.0	Sand	Undifferentiated drift
258339	NW	5	93	12	4	57.043	-111.904	-	68.3	-	New Well	Unknown	31-Jan-84	64.01 - 65.53	-	-	-	-	-	-
299208	NW	5	93	12	4	57.043	-111.904	-	57.9	Petro Canada	New Well	Domestic	24-May-01	49.38 - 52.43	30.48	-	386.42	53.6	Gravel	-
1501015	NW	5	93	12	4	57.043	-111.904	-	40.2	Petro Canada	New Well	Monitoring	30-Apr-04	36.58 - 39.62	-	-	-	NE	Sand & gravel	-
1501016	NW	5	93	12	4	57.043	-111.904	-	40.2	Petro Canada	New Well	Monitoring	1-May-04	32.00 - 35.05	-	-	-	NE	Sand	-
1501017	NW	5	93	12	4	57.043	-111.904	-	39.9	Petro Canada	New Well	Monitoring	1-May-04	36.58 - 39.62	-	-	-	NE	Sand	-
1501018	NW	5	93	12	4	57.043	-111.904	-	40.2	Petro Canada	New Well	Monitoring	30-Apr-04	33.53 - 36.58	-	-	-	NE	Sand	-
1501039	NW	5	93	12	4	57.043	-111.904	-	56.4	Petro Canada	New Well	Monitoring	13-Dec-03	41.15 - 53.34	30.48	-	204.57	53.3	Sand & gravel	-
258340	SW	6	93	12	4	57.035	-111.930	-	67.7	-	New Well	Unknown	31-Jan-84	61.87 - 63.70	-	-	-	-	-	-
1421009	9	6	93	12	4	57.041	-111.913	-	33.5	Enbridge Pipelines	New Well	Observation	9-Jul-10	27.13 - 33.22	30.50	-	-	NE	Sand	-
1501144	14	6	93	12	4	57.044	-111.929	-	94.2	Petro Canada	New Well	Industrial	24-Feb-07	60.97 - 79.88	37.00	-	1363.83	89.0	Sand	-
1501145	14	6	93	12	4	57.044	-111.929	-	82.0	Petro Canada	New Well	Industrial	26-Feb-07	59.84 - 82.00	38.00	-	1363.83	106.7	Sand	-
1501146	15	6	93	12	4	57.044	-111.919	-	75.2	Petro Canada	New Well	Industrial	23-Feb-07	56.40 - 75.15	35.98	-	1363.83	91.4	Sand & gravel	-
168219	SE	7	93	12	4	57.050	-111.924	-	94.8	A.O.S.T.R.A. UTF Site	New Well	Industrial	29-Jul-92	60.66 - 69.80	33.16	-	968.95	NE	Sand	-
235185	NH	7	93	12	4	57.057	-111.924	-	-	A.O.S.T.R.A.	Chemistry	Domestic	-	-	-	-	-	-	-	-
286009	1	7	93	12	4	57.048	-111.914	-	93.0	Gibson Petroleum Co. Ltd.	New Well	Industrial	9-Feb-96	66.75 - 76.81	34.14	-	909.22	NE	Sand & gravel	-
42470	4	8	93	12	4	57.048	-111.906	-	91.4	Petro Canada WSW#3	New Well	Industrial	18-Feb-01	57.91 - 76.20	-	-	-	NE	Sand & gravel	-
42471	4	8	93	12	4	57.048	-111.906	-	86.0	Petro Canada WSW#2	New Well	Industrial	15-Feb-02	60.96 - 82.30	-	-	-	NE	Sand & gravel	-
42472	4	8	93	12	4	57.048	-111.906	-	85.3	Petro Canada	New Well	Observation	15-Feb-02	66.45 - 78.64	-	-	-	NE	Sand & gravel	-
1501399	4	8	93	12	4	57.048	-111.906	-	89.9	Petro Canada	New Well	Industrial	12-Dec-05	62.18 - 83.52*	-	-	1363.83	83.5	Sand & gravel	-
1501400	4	8	93	12	4	57.048	-111.906	-	88.4	Petro Canada	New Well	Industrial	10-Dec-05	60.96 - 81.38*	-	-	1136.52	82.3	Sand	-
150681	13	9	93	18	4	57.059	-112.846	-	67.1	Petro Canada	New Well	Domestic	10-Feb-90	31.70 - 33.22	1.89	-	159.11	62.8	Sand	-
233809	13	12	94	11	4	57.146	-111.639	262.43	61.0	Alberta Research Council	New Well	Observation	-	-	-	-	-	12.2	-	-
233810	13	12	94	11	4	57.146	-111.639	262.43	13.7	Alberta Research Council 17-45	New Well	Observation	-	7.62 - 12.19	-	-	-	-	Sand	Undifferentiated drift
235255	6	25	94	11	4	57.183	-111.632	-	-	-	Spring	Unknown	-	-	-	-	-	-	-	-
235257	14	25	94	11	4	57.190	-111.632	243.84	-	-	Well Inventory	Unknown	-	-	-	-	-	-	-	-
235261	SW	36	94	11	4	57.195	-111.636	268.22	-	Alberta Forestry Ranger Station	Chemistry	Domestic	-	-	-	-	-	-	-	-
92630	16	30	94	15	4	57.190	-112.397	-	231.7	-	Chemistry	Industrial	-	-	-	-	-	-	-	-
1420724	6	26	94	16	4	57.183	-112.465	-	117.3	Chevron Canada Resources	New Well	Observation	20-Jan-08	105.10 - 117.30	62.51	-	-	61.5	Sandstone	-
1420749	6	26	94	16	4	57.183	-112.465	-	131.1	Chevron Canada Resources	New Well	Other	18-Jan-08	97.53 - 118.87	62.14	-	120.02	54.3	Sandstone	-
279598	NW	31	94	18	4	57.202	-112.897	-	30.1	Paramount Res.	Chemistry	Domestic	-	-	-	-	-	-	-	-
293907	12	31	94	18	4	57.201	-112.900	-	39.6	Paramount Res.	New Well	Domestic	9-Feb-00	26.82 - 28.35	3.66	-	22.73	26.8	Sandstone	-

Notes:

mbgs = meters below ground surface

Table B5: AENV Water Well Records within the HRSA

Well ID	Location					Latitude	Longitude	Elevation (masl)	Well Depth (m)	Owner	Type of Work	Use	Date of Information	Completion Interval (m)	Water Level		Test Rate (L/min)	Bedrock Depth (m)	Lithology	Hydrostratigraphic Unit
	LSD	Sec	Twp	Rge	Mer										(mbgs)	(masl)				

masl = meters above sea level

m/s = meters per second

"-" = indicates not available/not measured

Table B6 Groundwater Licenses within the HRSA (October 27, 2011)

Approval ID	Company	Purpose	Expiry Date	Source	Maximum Annual Withdrawal (m3)	Average Daily Production (m3/day)	Lsd	Sec	Twp	Rng	Mer	Latitude	Longitude	Maximum Pump Rate (m3/day)	Upper Production Interval (m)	Lower Production Interval (m)
26507	Canadian Natural Resources Ltd.	Camp (Domestic)	-	-	1,230	3	13	9	93	18	4	57.058	-112.846	72.01	31.6	33.2
70286	PTI Group Inc.	Camp (Domestic)	-	Undifferentiated Drift	38,254	105	NE	32	94	10	4	57.129	-111.345	235.4	3.9	7
151264	Williams Energy (Canada), Inc.	Camp (Fire Supply/ Utility)	15-Jul-21	Undifferentiated Drift	1,660	5	NE	12	92	10	4	56.970	-111.461	4.5	7.3	10.4
188229	Suncor Energy Inc.	Industrial (Injection)	10-Aug-12	Birch Channel (Empress)	511,000	1400	13	5	93	12	4	57.043	-111.904	450	30.6	52.4
							4	8	93	12	4	57.050	-111.904	1368	60.9	82.2
							4	8	93	12	4	57.050	-111.904	1411	57.9	73.1
239110	Suncor Energy Inc.	Drainage and Flow control/ Industrial	12-Aug-17	Aquifers contributing or adjacent to the Athabasca River	1,000,000	2740	NW	25	91	10	4	56.927	-111.474	0		
							N	26	91	10	4	56.927	-111.495	0		
							NE	34	91	10	4	56.941	-111.515	0		
								35	91	10	4	56.938	-111.495	0		
							W	36	91	10	4	56.938	-111.474	0		
							W	1	92	10	4	56.952	-111.474	0		
								2	92	10	4	56.952	-111.495	0		
							E	3	92	10	4	56.952	-111.515	0		
								10	92	10	4	56.967	-111.521	0		
								11	92	10	4	56.967	-111.495	0		
							S	12	92	10	4	56.963	-111.468	0		
							S	14	92	10	4	56.978	-111.495	0		
							S	15	92	10	4	56.978	-111.521	0		
239114	Suncor Energy Inc.	Drainage and Flow control/ Industrial	12-Aug-17	Aquifers contributing or adjacent to the Steepbank River	380,000	1041	NE	20	92	9	4	57.000	-111.408	0		
								21	92	9	4	56.997	-111.387	0		
								22	92	9	4	56.997	-111.360	0		
								23	92	9	4	56.997	-111.334	0		
								24	92	9	4	56.997	-111.307	0		
								25	92	9	4	57.010	-111.307	0		
								26	92	9	4	57.010	-111.334	0		
								27	92	9	4	57.010	-111.360	0		
								28	92	9	4	57.010	-111.387	0		
								29	92	9	4	57.010	-111.414	0		
							E	30	92	9	4	57.010	-111.434	0		
								31	92	9	4	57.025	-111.441	0		
								32	92	9	4	57.025	-111.414	0		
								33	92	9	4	57.025	-111.387	0		
								34	92	9	4	57.025	-111.360	0		
								35	92	9	4	57.025	-111.334	0		
								36	92	9	4	57.025	-111.307	0		
							S	3	93	9	4	57.036	-111.360	0		
							S	4	93	9	4	57.036	-111.387	0		
							S	5	93	9	4	57.036	-111.414	0		
							SE	6	93	9	4	57.036	-111.434	0		
							NW	30	92	9	4	57.014	-111.448	0		

Approval ID	Company	Purpose	Expiry Date	Source	Maximum Annual Withdrawal (m3)	Average Daily Production (m3/day)	Lsd	Sec	Twp	Rng	Mer	Latitude	Longitude	Maximum Pump Rate (m3/day)	Upper Production Interval (m)	Lower Production Interval (m)
235309	Syncrude Canada Ltd.	Channel Dewatering/ Processing	14-Feb-17	-	6,448	18	SW	5	93	11	4	57.036	-111.743	19.6	39.6	44.2
					8,600	24	NW	32	92	11	4	57.028	-111.743	26.2	25.9	29
					71,683	196	SE	31	92	11	4	57.021	-111.756	196.4	8.5	15.9
					584,000	1600	SW	5	93	11	4	57.036	-111.743	1600	37.5	40
					584,000	1600	NW	32	92	11	4	57.028	-111.743	1600	12	21
251163	Suncor Energy Inc.	Oilfield Injection	14-Dec-13	Birch Channel (Empress)	677,354	1856	SE	7	93	12	4	57.050	-111.917	5656	67.8	77.2
249470	Suncor Energy Inc.	Industrial (camp, project administration and operation buildings)	22-Jul-13	Birch Channel (Empress)	25,550	70	13	5	93	12	4	57.043	-111.904	160	46.3	56.7
253181	Perpetual Energy Operating Corp.	Industrial (gas plant operation)	10-Feb-29	-	2,500	7	5	8	88	18	4	56.614	-112.843	27	16.4	17.6
262149	Southern Pacific Resource Corp.	Industrial (SAGD)	05-Dec-12	MacKay Channel (Empress)	419,750	1150	8	8	91	14	4	56.876	-112.212	853	75.6	84.4
							16	8	91	14	4	56.883	-112.212	1223	92.4	102.4
288314	Marathon Oil Canada Inc	Industrial (Camp water)	31-Mar-13	-	3,650	10	12	24	91	15	4	56.912	-112.279	57	48.8	50.3
288464	Southern Pacific Resource Corp.	Code of Practice Hydrostatic Testing	03-Mar-12	-	1,845	5	E	8	91	14	4	56.879	-112.212	1140		

APPENDIX C: DESCRIPTION OF NUMERICAL GROUNDWATER FLOW MODEL

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1.0 MODEL OVERVIEW

1.1 Model Software Selection

A three-dimensional (3-D) numerical flow model was created to assist in determining the potential effects of the Southern Pacific (STP) McKay Thermal Project – Phase 2 (the Project) on the regional groundwater flow regime. The model focuses on the major stratigraphic units, including the Grand Rapids and the Empress Formations.

The model was developed using the finite difference code of United States Geological Survey (USGS) MODFLOW (McDonald and Harbaugh 1988) and the Visual MODFLOW interface developed by Schlumberger Water Services (2010). The input parameters were based on site specific determinations as well as the following previous model data in the public domain:

- Suncor Model (Petro Canada 2005)
- Dover Model (Dover 2010)
- AOSC Model (AOSC 2009)

The primary goal of the model was to help predict the potential drawdown in groundwater elevation due to the proposed pumping schedule. Other goals included the study of impacts to other users as defined in Baseline, Application and Planned scenarios.

1.2 Model Domain

The groundwater model was created to capture the entire area of potential groundwater elevation drawdown caused by the pumping wells within the Project. This domain includes existing and planned projects in the area, especially projects using water from the Empress Formation, which is the main aquifer of interest for the Project. The model is 110 km by 110 km and is large enough to accommodate the entire Birch and MacKay channel system.

In addition, the size of the model domain was defined such that imposed boundary conditions do not directly influence drawdown predictions. Figure C1 presents a schematic of the model domain.

The vertical distribution of parameters within the model sought to represent the known stratigraphy underlying the area. The drift layer was removed in order to keep the model saturated at all times and avoid problems associated with dry cells (Waterloo Hydrogeologic 2011). This was a reasonable assumption since shallow drift aquifers are regionally discontinuous and the overall deposit is not an aquifer. Six layers with varying hydraulic parameters were defined to represent:

- Layers 1, 3 and 5:
    - sandstone of the Grand Rapids Formation (GR), including the Grand Rapids 3, 4 and 5 sand Aquifers (referred to herein as GR3, GR4 and GR5, respectively); and

    - fill deposits and Empress Formation in the McKay and Birch Channels.
- Layers 2 and 4:
    - shale aquitards of the GR; and
    - fill deposits and Empress Formation in the McKay and Birch Channels.
- Layer 6:
    - shale and siltstone of the Clearwater Formation; and
    - Empress Formation in the McKay and Birch Channels.

All the layers were assigned as confined layer in the model to represent the confined conditions present at STP and other projects within the model domain.

Layer thickness varied according to the thickness of the respective geologic units represented by the model layers. Cell discretization in the x- and y- direction was uniformly set at a 910 m interval with local refinements around the STP Plant site for a total of 466,466 model cells.

The initial assignment of the hydraulic parameters including initial heads, hydraulic conductivity and storage within the layers was based on available site specific data and parameter estimation but was ultimately chosen through the calibration procedures described in Section 2.

1.3 Model Boundaries

The model boundary conditions control the sources and sinks of water within the model and therefore they control how the model is interacting with the surrounding environment. The vertical flow between hydrodynamic units, the presence of pumping or injection wells, or the horizontal recharge from precipitation are only a few examples of boundary conditions that can be encountered. The types of boundary conditions used in the present groundwater numerical model are presented on Figure C1 and summarized below:

- the base of the model was defined by a no-flow boundary;
- the north and south boundaries were defined as no-flow boundaries;
- the west and northwest boundary was defined as constant head boundaries that were interpolated from observed head values and topography; and
- the east boundary was defined as a drain to represent the Grand Rapids subcrop west of the incised Athabasca River.

1.3.1 Top and Bottom Boundary Conditions

Recharge is often assigned to the top layer of a model that is concerned with shallow groundwater flow regimes. This can represent an average percentage of the total annual precipitation in the area. The model for this Project has omitted the surficial drift as it is does not represent a regional aquifer (average hydraulic conductivity measurements are 10^{-7} m/s or less) and is generally greater than

15 m thick over the majority of the model domain. The upper most layer represented in the Project model is the GR3. The effective infiltration through the drift into the GR3 is interpreted as negligible over the majority of the model domain, so no recharge was assigned above the Site.

Recharge was assigned above the Suncor site as numerous wetlands are present in the area (Petro Canada 2005), so that recharge is not only due to precipitation but also to surface water bodies. In this area, the Birch Channel is shallower (*i.e.,* the drift is thinner) and the hydraulic conductivity of the drift is higher, so recharge from the surface is a considerable source of water locally.

No significant groundwater is expected to enter the system from below the base of the model through the Clearwater Formation, which forms a regional aquitard, so a no-flow boundary was assigned.

1.3.2 West and East Boundary Conditions

The average distance of the west and east model boundary to the planned STP water source wells is greater than 10 km. Accounting for topography and interpolating from available heads, constant head boundaries were assigned along the west and northwest edges of the model.

Drain boundary were assigned along the east to represent the discharge of the Grand Rapids aquifers along the drop in topography towards the Athabasca River. This corresponds to the Grand Rapids subcrop as mapped by the Alberta Geological Survey (Hamilton et al. 1999). In each layer that represents an aquifer, the initial water elevation of the drains was set 0.1 m above the bottom of the cell.

East of the subcrop and the corresponding drain boundaries, model cells were defined as inactive as groundwater flow in this area is not physically connected to the groundwater west of the Athabasca River.

1.3.3 North and South Boundary Conditions

Groundwater flow is predominantly from the west to the east due to the topographic features of the Birch Mountains to the northwest and the Athabasca River to the east. The Thickwood Hills are located to the south. Groundwater naturally flows from the topographic highs to the topographic lows. Because of this natural flow control, a no-flow boundary was assigned to the north and south as these areas are generally parallel to the direction of groundwater flow and negligible water is expected to contribute to the general flow.

1.3.4 Pumping Wells

Water supply wells were entered into the model to represent the baseline, application and planned scenarios. The locations of the wells include AOSC's MacKay River Commercial Project, Suncor's Petro-Canada McKay River Commercial Project, Dover's Commercial Project, and STP's Project. The schedule of pumping is presented in Table 1.1.

Table 1.1 Summary of Groundwater Use within the HRSA

Project		**Suncor Dover and MacKay**	**AOSC MacKay River Pilot Project**	**AOSC MacKay River Commercial Project**	**STP - Phase 1**	**STP - Phase 2**	**AOSC Dover Central Pilot Project**	
Aquifer Unit		Empress	GR4 and GR5	Empress	Empress	Empress	GR3	Empress
Case	Baseline	✓	✓		✓			
	Application	✓	✓		✓	✓		
	Planned	✓	✓	✓	✓	✓	✓	✓
Start Date	End Date							
1-Oct-84	30-Sep-92	212						
1-Oct-92	30-Sep-95	907						
1-Oct-95	30-Sep-00	1487						
1-Oct-00	30-Sep-02	480						
1-Oct-02	30-Sep-06	1480						
1-Oct-06	30-Sep-09	1735						
1-Oct-09	31-Mar-10	5200						
1-Apr-10	31-Dec-10	4000	65					
1-Jan-11	31-Dec-11	4000	245					
1-Jan-12	31-Dec-12	4000	218	320	1060			
1-Jan-13	31-Aug-13	4000	201	320	882		541	
1-Sep-13	31-Dec-13	4000	201	1955	882		541	
1-Jan-14	30-Jun-14	4000	180	1955	596	4000	541	
1-Jul-14	31-Dec-14	4000	180	5800	596	4000	541	
1-Jan-15	31-May-15	4000		4800	596	4000	541	
1-Jun-15	30-Jun-15	4000		4800	596	4000	3382	4559
1-Jul-15	30-Nov-15	4000		3500	596	4000	3382	4559
1-Dec-15	31-Dec-15	4000		3500	596	4000	3382	1266
1-Jan-16	30-May-16	4000		3500	596	1708	3382	1266
1-Jun-16	31-Mar-35	4000		3500	596	1708	3382	
1-Apr-35	31-Dec-38			3500	596	1708	3382	
1-Jan-39	31-Dec-41			3500	596		3382	
1-Jan-42	31-Dec-43			3500	202		3382	
1-Jan-44	31-Dec-46			3500	202		3382	
1-Jan-47	31-Dec-48			3500			3382	
1-Jan-49	30-Jun-59			3500			3382	
1-Jul-59	30-Jun-63						3382	

Long term pumping well data and recovery data was available for three wells (including one pumping well and 2 observation wells).

2.0 MODEL CALIBRATION

The model was calibrated to regional water elevation measurements, historical groundwater models in the region that are within the public domain and to a pump test that was conducted on the STP Project site. The parameters that were altered during the calibration process included the hydraulic conductivity (K) and specific storage (S) of the hydrogeologic bodies within the model. In order to match observed head or drawdown during a pumping test, K and S were iteratively modified until a satisfactory output was reached. The initial properties were based on site specific hydraulic tests and available data from other projects.

2.1 Initial Properties

Site specific data from hydraulic tests, including slug tests and pumping tests, as reported in Table B1 (Appendix B) of the main report were input as preliminary values in the model. As a range of values was available for most of the units (*i.e.,* GR3, GR4, GR5, aquitards and Clearwater), the mean values were initially assigned. Input values were then modified within their observed ranges to calibrate the initial heads in the model.

All layers must be continuous throughout the entire model in MODFLOW. As a result, a subcrop or the pinching of a layer is physically input into the model by defining different hydraulic parameters at the subcrop interface. This strategy was used to represent the pinching of the GR3, GR4 and GR5 to the east and of the GR5 to the north. A lower conductivity material was input to physically represent the disappearance of the aquifers into a less permeable material. The hydraulic conductivity of this material was defined by regional measurements in the drift deposits.

2.2 Head Observation Wells

Groundwater level elevations within the model were calibrated to 15 groundwater monitoring wells installed in the GR3, GR5 and the Empress Formations. The baseline measurements from these locations were input to calibrate the model in steady-state condition as a preliminary calibration before running the model in transient conditions. The location of these observation points is shown on Figure C1. The resulting calibration head contours in the layer representing the GR5 and the chart for simulated versus measured heads are included as Figure C8 and C9.

2.3 Short term Pumping Tests

At the Site, WSW2 (screened in the Empress Formation) was pump tested (MEMS 2009). This test was used to help calibrate the hydraulic conductivity and storage. Head values at observation wells were input at the location of WSW2-OBS-LS and at WSW1, both also screened within the Empress aquifer. WSW2 was pumped at an average of 1,223 m^3/d for 72 hours. Figure C10 presents a comparison of observed (field) and simulated (calculated) drawdown at both wells.

A good match was obtained between field observations and calculated drawdown at WSW2-OBS-LS; however, the match was not as close at WSW1. The difference in match is mainly due to discrete heterogeneities in the channel that are not possible to reproduce in the regional model. Hydraulic conductivity at WSW1 was field estimated to be lower than in the thalweg of the channel, and was thus inputted lower in the model, but localized heterogeneities could not be accounted for in the model. As a result, the calculated drawdown at this location was less than observed in the field. During the calibration process it was decided to keep hydraulic values in the regional model as close to the values calculated in the field tests rather than changing values by up to an order of magnitude to calibrate localized differences.

2.4 Selection of Hydraulic Parameters

Project specific field data, previously published reports and the model calibration process all assisted in the selection of the hydraulic parameters that were used for the different hydraulic bodies within the model. These parameters have been applied for predicting the drawdown to the pumping scenarios going forward (Section 3.1) and are presented in Figures C2 to C7. An anisotropic ratio of 0.1 between horizontal and vertical hydraulic conductivities was applied throughout the model.

3.0 MODEL OUTPUTS

3.1 Scenarios

The calibrated model was run under three different groundwater pumping scenarios:

- Baseline Case: all existing projects including the approved STP MacKay Thermal Project – Phase 1.
- Application Case: same as Baseline but including the Project pumping schedule.
- Planned Case: same as Application but including the proposed pumping schedules from planned projects that are not yet approved.

Tables 2 and 4 in the main report details further the different scenarios, including time period and rate for each user in each scenario.

Critical time steps for the outputs include:

- December 2012 – corresponding to the end of the first year of pumping at STP.
- November 2015 – corresponding to the time period when all projects will pump at the maximum rate.
- March 2035 – corresponding to the end of the pumping in the Birch Channel at Suncor.

3.2 Influence of Model Domain

The constant head boundary conditions defined along the west and northwest edge of the model domain have the potential to artificially influence the predicted drawdown from pumping at the various projects in the model. These boundary conditions can theoretically provide an infinite source of water that is not representative of the natural hydrogeologic setting. To insure that these boundary conditions were defined far enough away from the hydrodynamic stresses induced on the model through pumping wells, a zone budget was defined directly east of the constant heads.

The zone budget allows for the calculation of the volume and rate of water flowing into the model from the constant heads. During each model scenario presented in Sections 3.3 through 3.5 below, the output of the zone budget was compared to the steady-state scenario, when no pumping was active. The results of this analysis demonstrate that the drawdown predicted during the pumping scenarios is not artificially influenced by the constant heads, as the rate of inflow into the model increased by a maximum of 6.6 % relative to steady-state conditions.

3.3 Baseline Case

The baseline case includes only the current pumping of the Birch Channel occurring at Suncor with the pumping schedule in the MacKay Channel for the STP Mackay Thermal Project – Phase 1. Drawdown contours at various times are presented on Figures C11 to C14.

The total available head in the Empress Formation is approximately 69 m around the Project. At the STP lease the drawdown is estimated at 6 m around WSW1 in March 2035. The extent of the drawdown cone is very limited for the first years of pumping then increases until reaching the drawdown cone at Suncor to the north and 10 km to the south. At first the drawdown is strictly limited to the channel, but with time the cone eventually spreads into the Grand Rapids aquifers surrounding the channel.

At Suncor the maximum drawdown is estimated at 13 m.

3.4 Application case

The application case corresponds to the baseline case plus the Project application of water demand. Drawdown contours at various times are presented on Figures C15 to C18.

There is no noteworthy difference in the extent of the drawdown between the baseline case and the application case; however the depth of drawdown is increased. At STP in the Empress Aquifer the maximum drawdown observed during the application case is 16 m in March 2035. At Suncor the drawdown is estimated at 15 m.

3.5 Planned Case

The planned case includes all pumping schedules from the application case as well as other planned projects. These projects include AOSC MacKay River Commercial Projects and Dover Central Pilot and Commercial Projects. Drawdown contours at various times are presented on Figures C19 to C21.

The maximum drawdown at STP is estimated at 25 m in December 2038. At Suncor the maximum drawdown is estimated at 16 m. The extent of the drawdown is increased in comparison to the two previous cases, extending across most of the Mackay Channel and almost reaching the Birch Channel at its southwestern termination. Drawdown cones present in the northwest around the Dover pumping wells are not influence by the STP projects and are the result of the GR3 being pumped by Dover.

In all three scenarios the maximum drawdown predicted occurs in December 2035 at the Project Site. A discussion regarding the maximum drawdown expected and Project impacts is presented in the main report.

4.0 SENSITIVITYANALYSIS

A sensitivity analysis is conducted to assess the weight of parameters in the overall model output. Although the model has been calibrated to all available data, inherent uncertainties still remain due to the overall size of the model domain and limited information. In general, only hydraulic conductivity and storage are subject to a sensitivity analysis as they are the parameters with the most uncertainty (limited hydraulic test data compared to the extent of the aquifer).

The application case was selected as the model to be tested for this analysis. The output looked at during the sensitivity analysis was the drawdown. Typically, higher values of storage or conductivity will result in more water available and thus in less drawdown when pumping. As a result, the sensitivity analysis was limited to a decrease of the hydraulic parameters. In the Project model, the two hydrogeostratigraphic units with the most influence to the drawdown are the Empress Formation, which is the pumped aquifer, and the GR5, which is in direct connection to the Empress (see cross-section shown in Figure 17 in the main report).

A total of four sensitivity analysis scenarios were run as presented in Table 4.1. The changes consisted of lowering the hydraulic conductivity or the storage by one order of magnitude.

Table 4.1 Sensitivity Analysis Scenarios

Scenario	Empress K (m/s)	Empress S (1/m)	GR5 K (m/s)	GR5 S (1/m)	Max. Original DD (m)	Max. Sensitivity DD (m)
Actual Model	2.2E-4	2.2E-4	5.0E-6	7.0E-6	16 m	-
1	2.2E-5	2.2E-4	5.0E-6	7.0E-6	16 m	27 m
2	2.2E-4	2.2E-5	5.0E-6	7.0E-6	16 m	16 m
3	2.2E-4	2.2E-4	5.0E-7	7.0E-6	16 m	17 m
4	2.2E-4	2.2E-4	5.0E-6	1.0E-6	16 m	16 m

The model seems to have little sensitivity to the storage, as decreasing the value by an order of magnitude did not impact the maximum drawdown interpolated. The model is more sensitive to hydraulic conductivity, specifically in the Empress channel. This is not unexpected as the channel is of limited width, extent and thickness and thus a change of one order of magnitude on the hydraulic conductivity will have a significant impact on the transmissivity of water available to pumping. In addition, all the pumping wells are screened directly in this aquifer contrary to the GR5. As a result, the immediate sensitivity is confined to the Empress and the effect on the GR5 is less direct.

The hydraulic conductivity of the Empress Formation in the McKay and Birch channels is the most instrumented unit in the model domain. Several projects are relying on this unit to provide source water supplies and the related field testing is well understood. As a result, the hydraulic conductivity of the Empress Formation used within the Project model is deemed to be representative of the real-world setting as are the predictions presented in Sections 3.3 to 3.5. The sensitivity analysis performed herein demonstrates that general variations in input parameters are insignificant with the exception of the hydraulic conductivity of the Empress Formation; however, even reducing this parameter by an order of magnitude results in a maximum drawdown of less than 25% of available head.

5.0 REFERENCES

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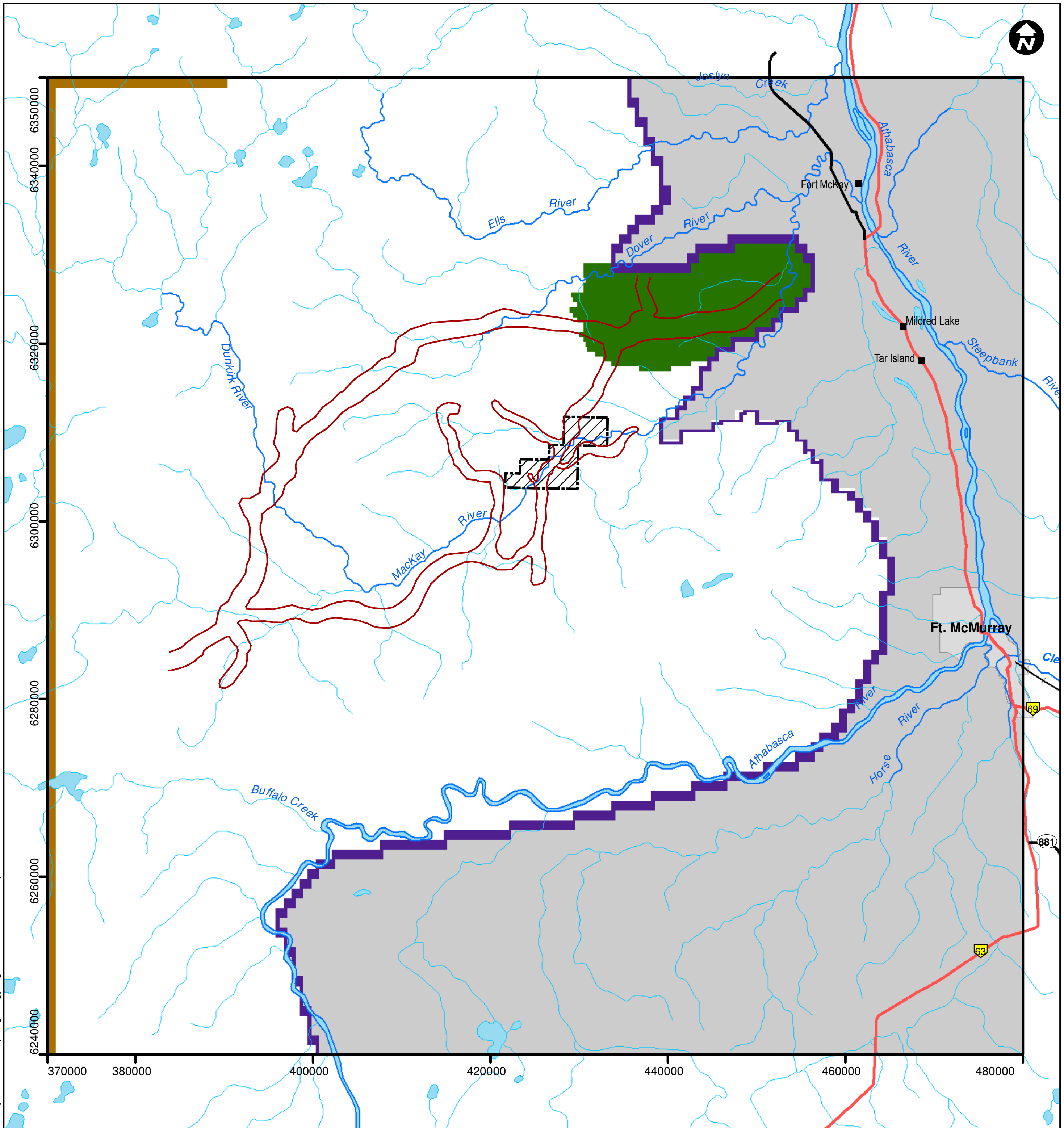
FIGURES



Legend

- Project Area
- Model Domain
- Channel (Birch & MacKay)
- No Recharge Applied
- Recharge
- Drain
- Constant Head
- Inactive Flow

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Model Domain and Boundary Conditions

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE: **C1**

Map Document: (K:\Active Projects 2010\AP 10-001 to 10-050\10-037 STP McKay\Final Docs\Hydrogeology\Fig 1 Model Domain.mxd) 11/03/11 -- 9:30:23 AM

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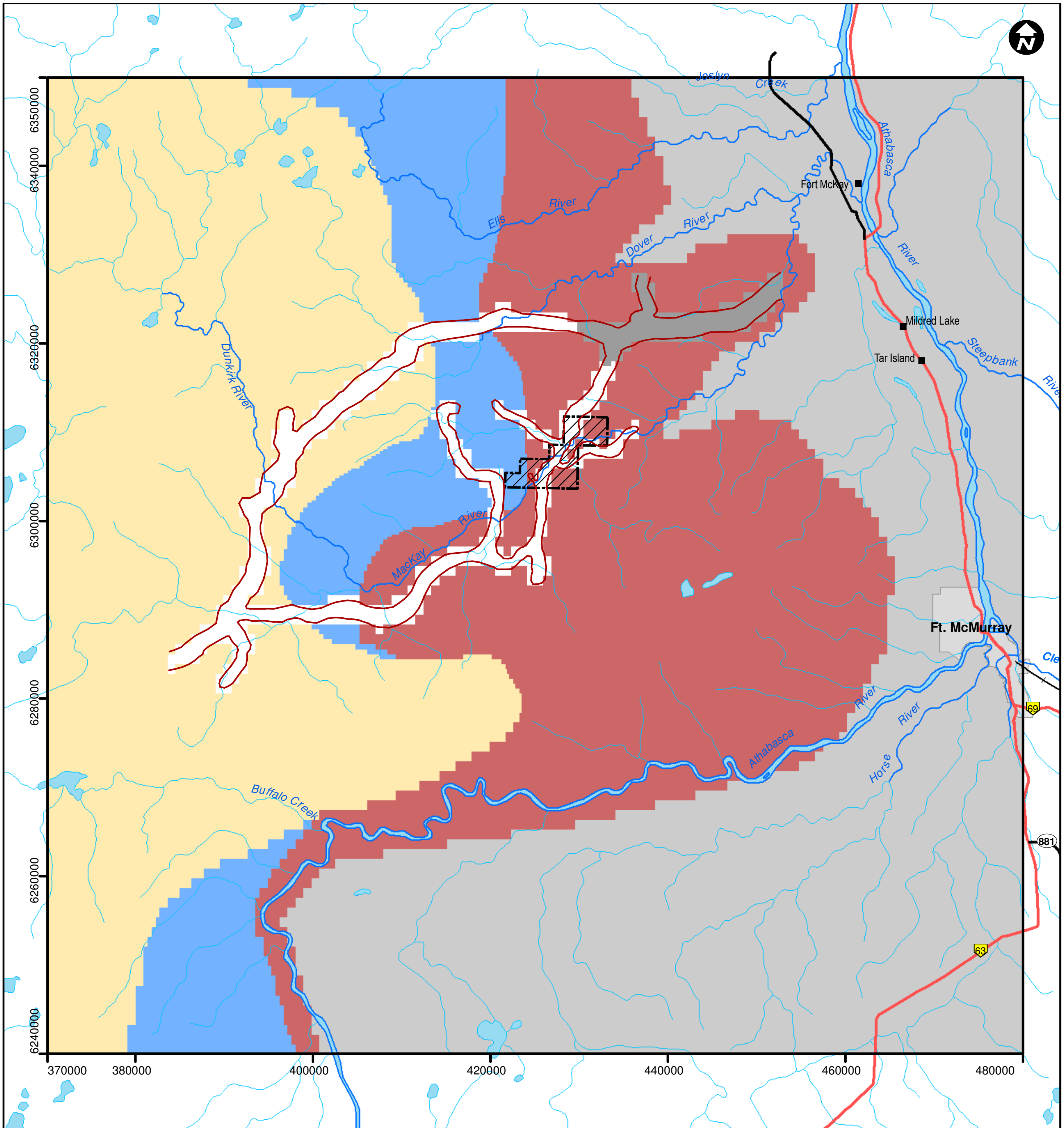


Legend

	K: m/s	S: 1/m
(yellow)	2.0E-05	2.0E-04
(red)	4.0E-08	1.0E-06
(blue)	1.2E-05	2.0E-04
(dark grey)	5.0E-07	8.0E-06
(white)	1.0E-08	4.5E-06
(light grey)	Inactive Flow	

Project Area
Model Domain
Channel

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

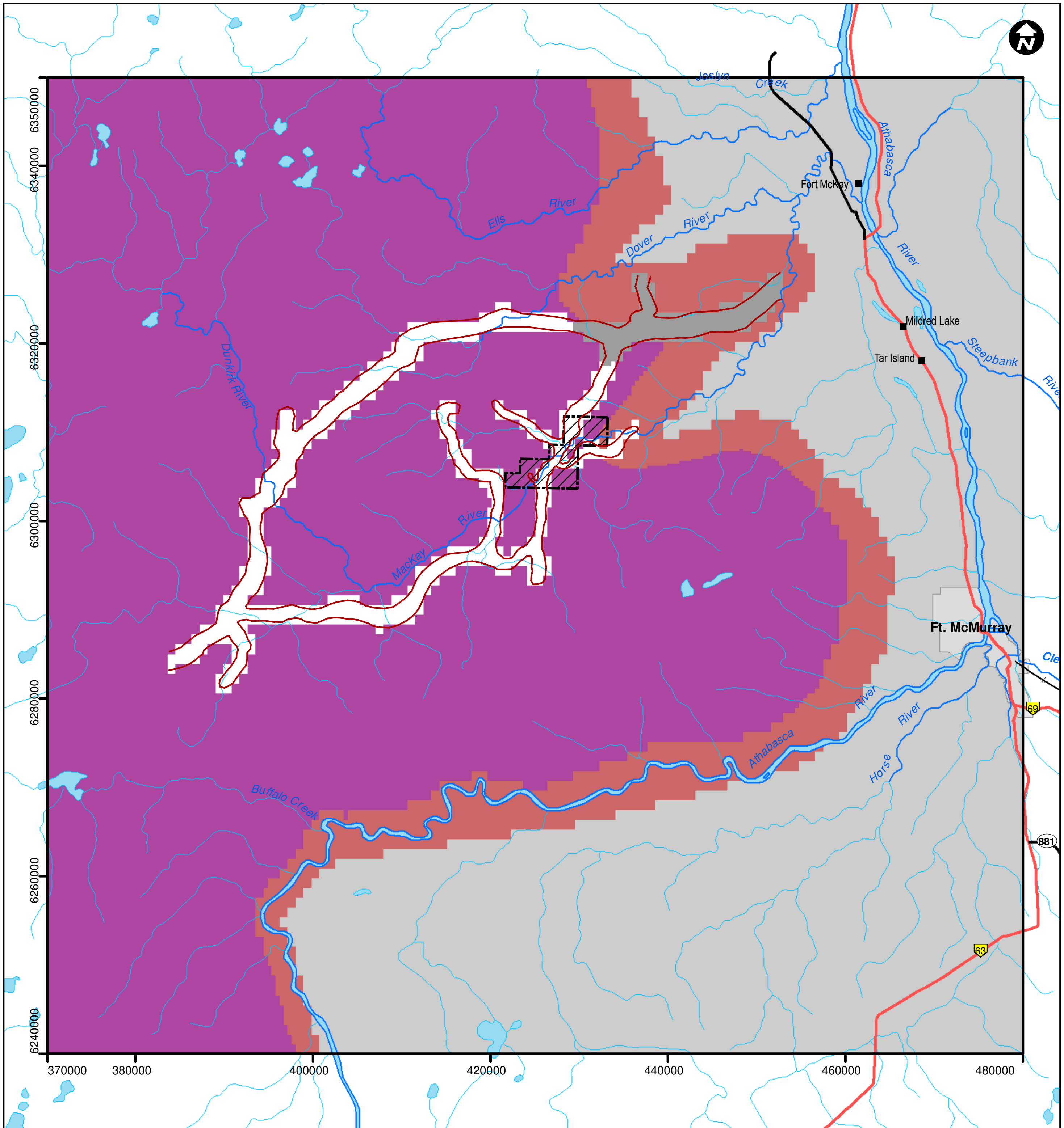
Millennium EMS Solutions Ltd.

TITLE:
Conductivity and Storage Zones, Layer 1 Grand Rapids 3

DRAWN: PS
CHECKED: AuK
DATE: Nov 3/11
PROJECT: 10-037

FIGURE: **C2**

REF: Geobase, 2011.



Legend

	K: m/s	S: 1/m
(red)	4.0E-08	1.0E-06
(purple)	1.0E-08	1.0E-06
(dark grey)	5.0E-07	8.0E-06
(white)	1.0E-08	4.5E-06
(light grey)	Inactive Flow	

Project Area
Model Domain
Channel

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

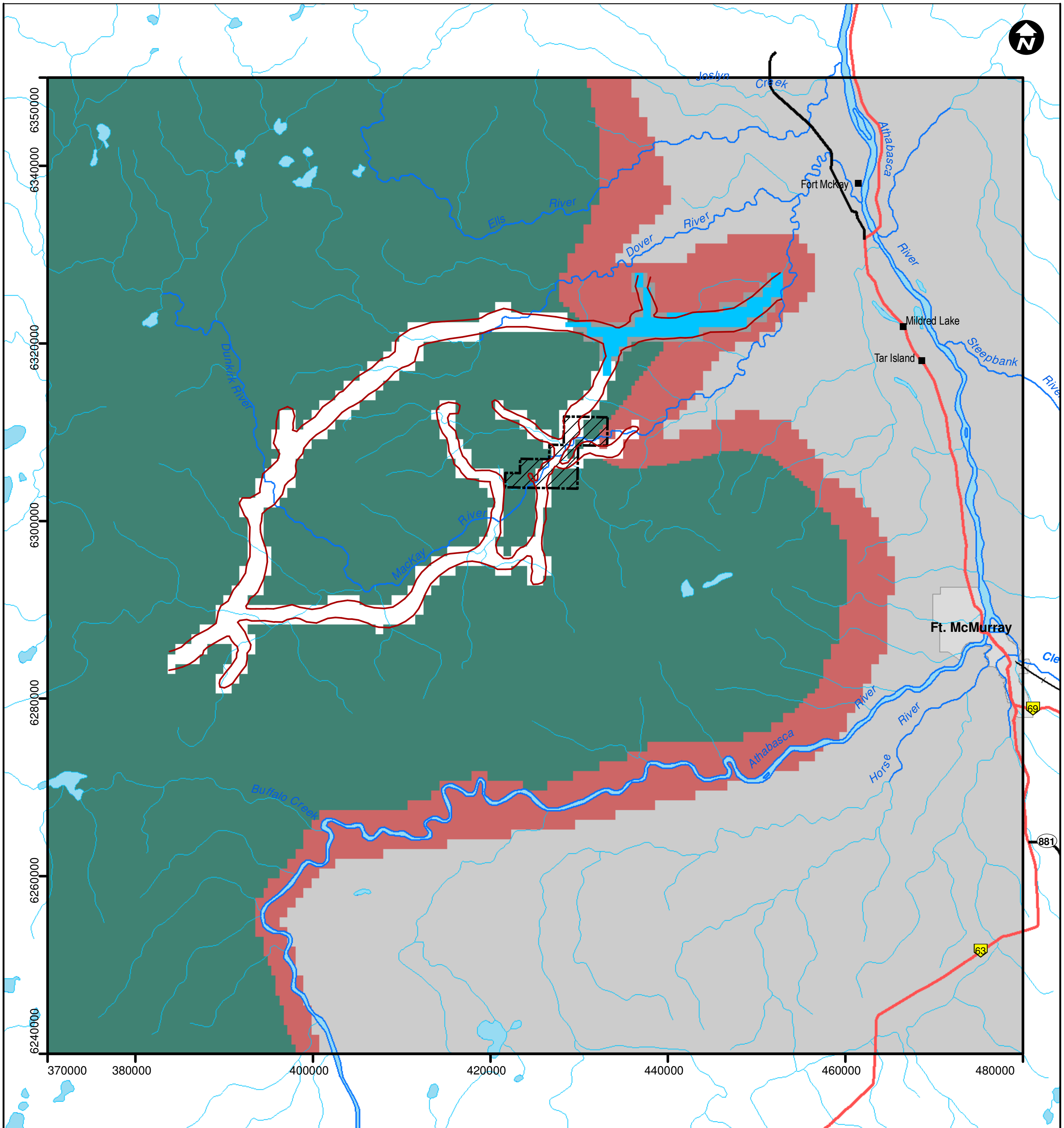
Millennium EMS Solutions Ltd.

TITLE:
Conductivity and Storage Zones, Layer 2 Aquitard

DRAWN: PS
CHECKED: AuK
DATE: Nov 3/11
PROJECT: 10-037

FIGURE: **C3**

REF: Geobase, 2011.



Legend

	K: m/s	S: 1/m
	4.0E-08	1.0E-06
	3.0E-05	2.5E-04
	2.2E-04	2.2E-04
	5.0E-07	8.0E-06
	4.4E-04	2.0E-04
	1.0E-08	4.5E-06

Inactive Flow

Project Area
Model Domain
Channel

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

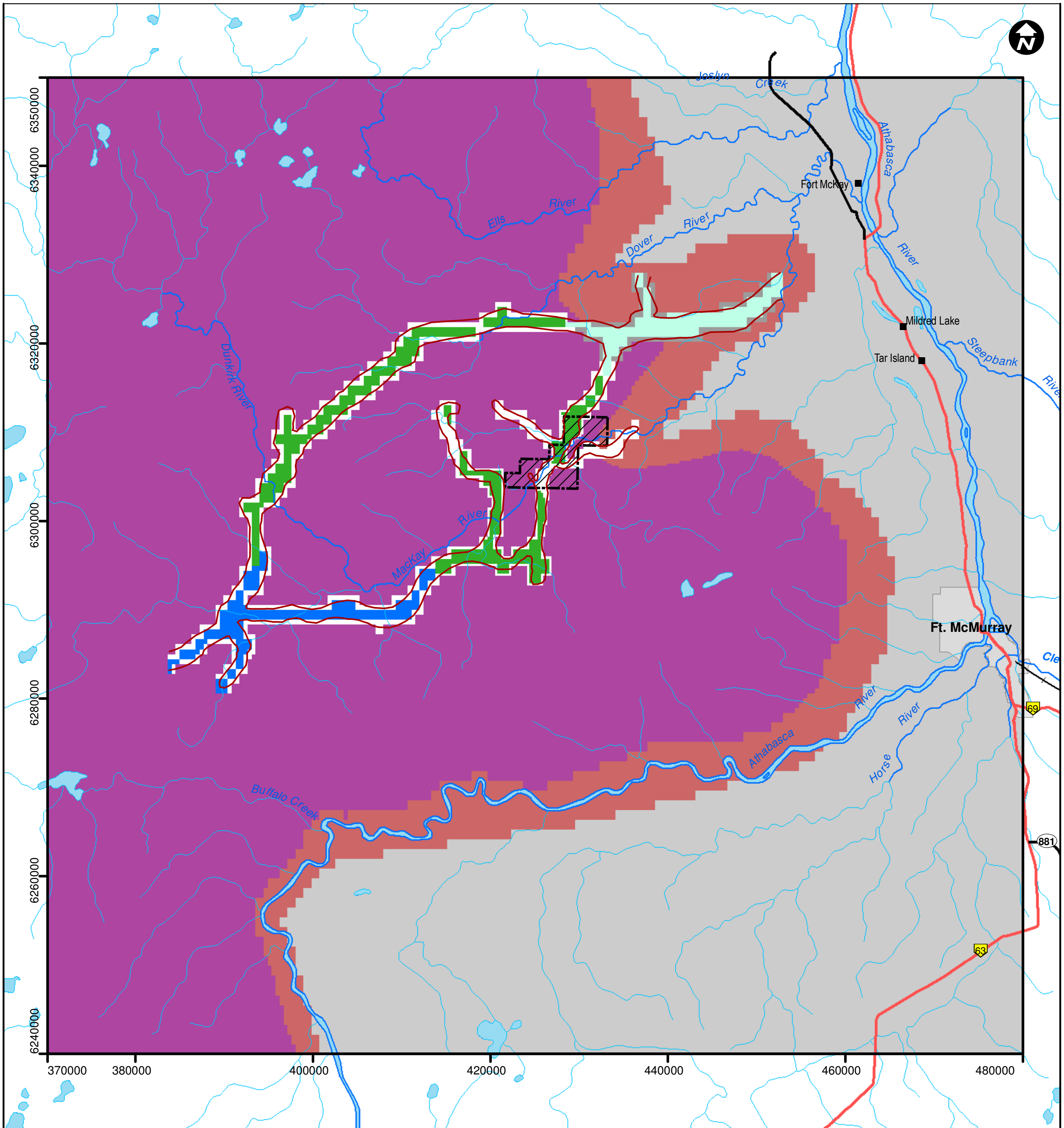
Millennium EMS Solutions Ltd.

TITLE:
Conductivity and Storage Zones, Layer 4 Grand Rapids 4

DRAWN: PS
CHECKED: AuK
DATE: Nov 3/11
PROJECT: 10-037

FIGURE: C4

REF: Geobase, 2011.



Legend

	K: m/s	S: 1/m
(red)	4.0E-08	1.0E-06
(purple)	1.0E-08	1.0E-06
(blue)	9.0E-05	2.2E-04
(green)	2.2E-04	2.2E-04
(grey)	5.0E-07	8.0E-06
(light cyan)	4.4E-04	2.0E-04
(white)	1.0E-08	4.5E-06
(light grey)	Inactive Flow	

Project Area
Model Domain
Clean Channel

0 5 10 20
Kilometres

SOUTHERN PACIFIC
RESOURCE CORP.

STP McKay Thermal Project - Phase 2

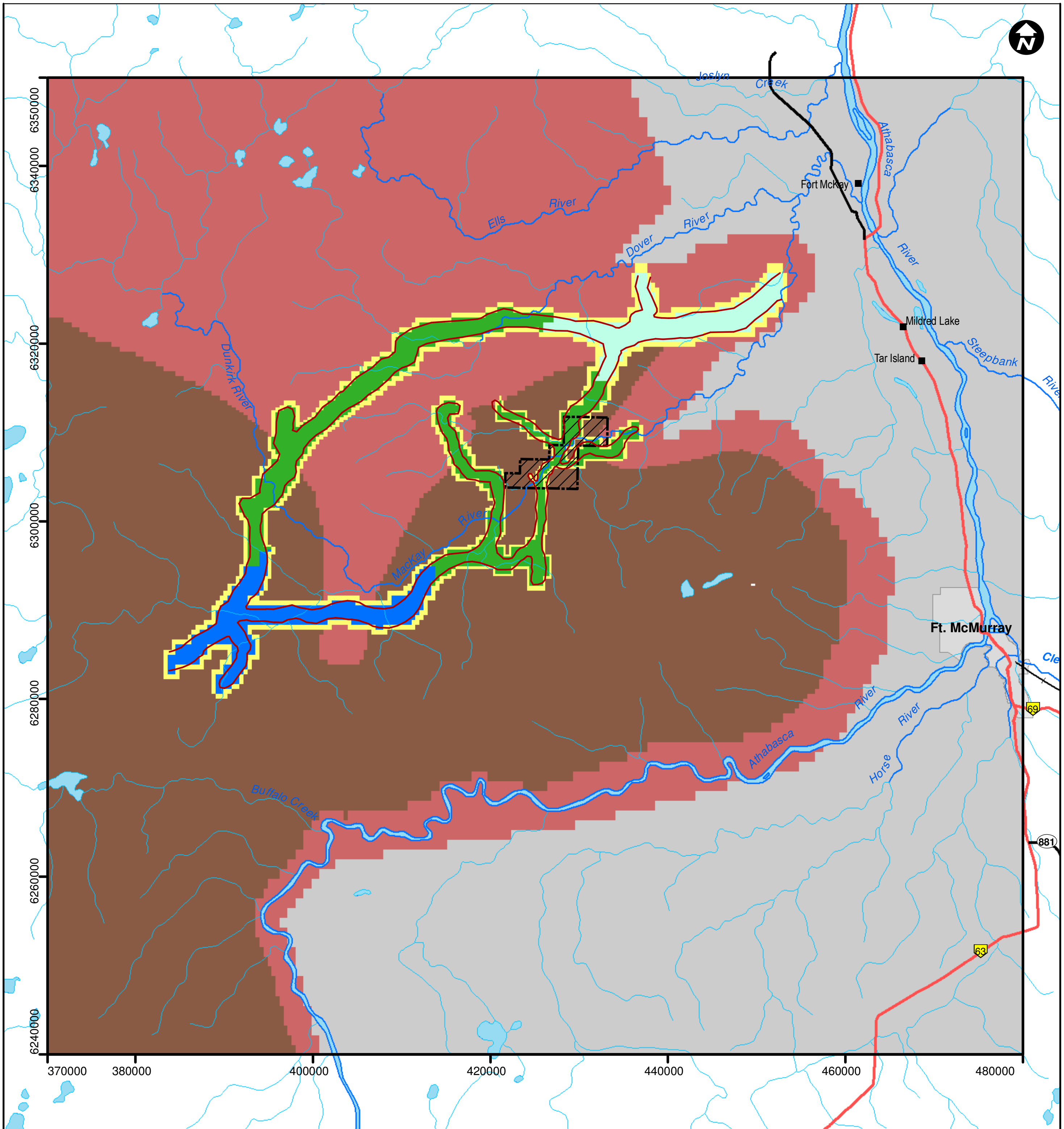
Millennium
EMS Solutions Ltd.

TITLE:
Conductivity and Storage Zones, Layer 5 Aquitard

DRAWN: PS
CHECKED: AuK
DATE: Nov 3/11
PROJECT: 10-037

FIGURE:
C5

REF: Geobase, 2011.



Legend

	K: m/s	S: 1/m
(red)	4.0E-08	1.0E-06
(yellow)	3.0E-05	1.5E-05
(blue)	9.0E-05	2.2E-04
(green)	2.2E-04	2.2E-04
(brown)	5.0E-06	7.0E-06
(light green)	4.4E-04	2.0E-04
(grey)	Inactive Flow	

Project Area
Model Domain
Channel

0 5 10 20
Kilometres

SOUTHERN PACIFIC
RESOURCE CORP.

STP McKay Thermal Project - Phase 2

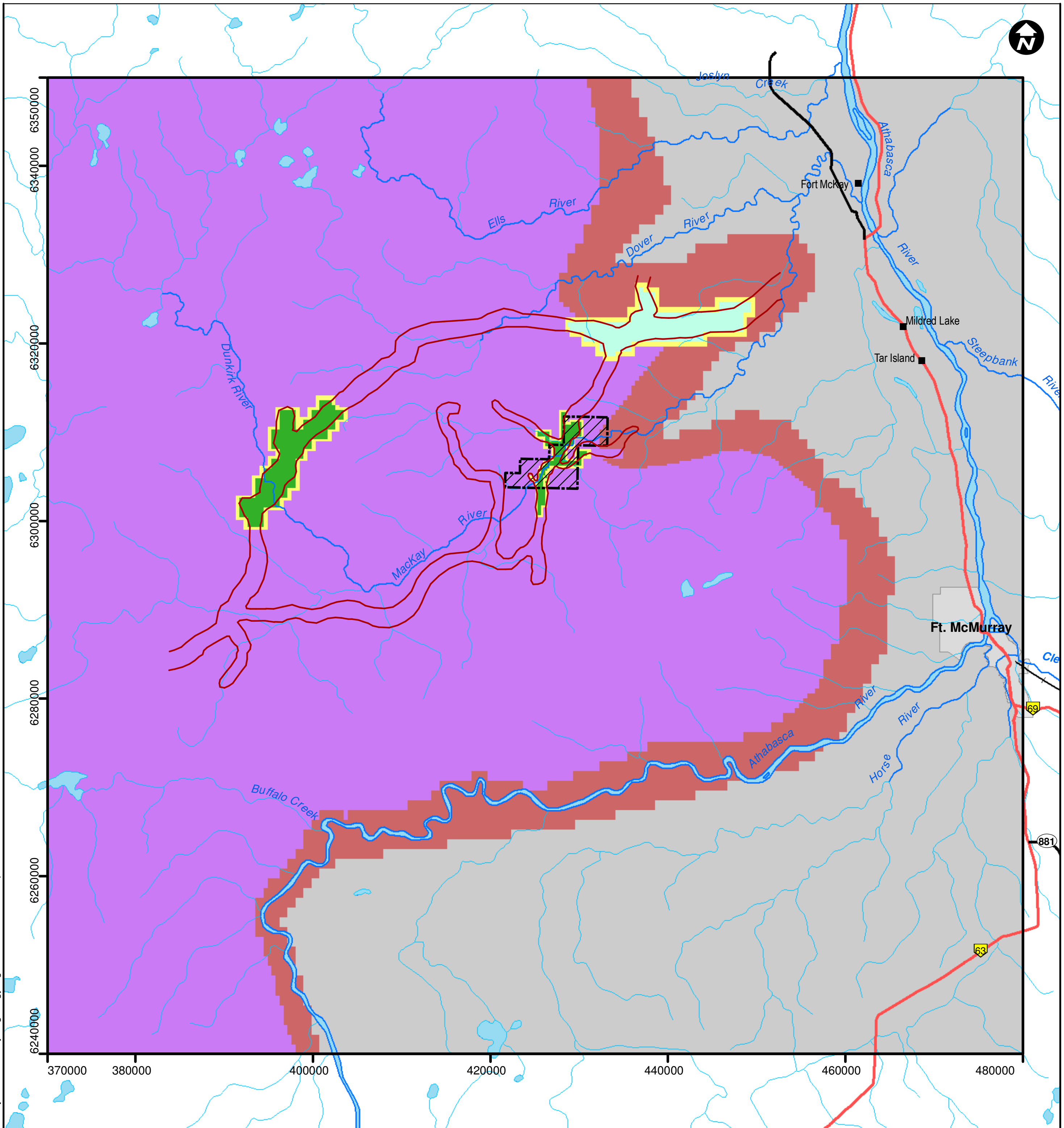
Millennium
EMS Solutions Ltd.

TITLE:
Conductivity and Storage Zones, Layer 6 Grand Rapids 5

DRAWN: PS
CHECKED: AuK
DATE: Nov 3/11
PROJECT: 10-037

FIGURE:
C6

REF: Geobase, 2011.



Legend

	K: m/s	S: 1/m
(red)	4.0E-08	1.0E-06
(yellow)	3.0E-05	1.5E-05
(purple)	5.0E-08	1.0E-06
(green)	2.2E-04	2.2E-04
(light green)	4.4E-04	2.0E-04
(grey)	Inactive Flow	

Project Area
Model Domain
Channel

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:
Conductivity and Storage Zones, Layer 7 Clearwater

DRAWN: PS
CHECKED: AuK
DATE: Nov 3/11
PROJECT: 10-037

FIGURE:
C7

Map Document: (K:\Active Projects 2010\AP 10-001 to 10-050\10-037 STP McKay\Final Docs\Hydrogeology\Fig 1 Model Domain.mxd) 11/03/11 -- 9:30:23 AM

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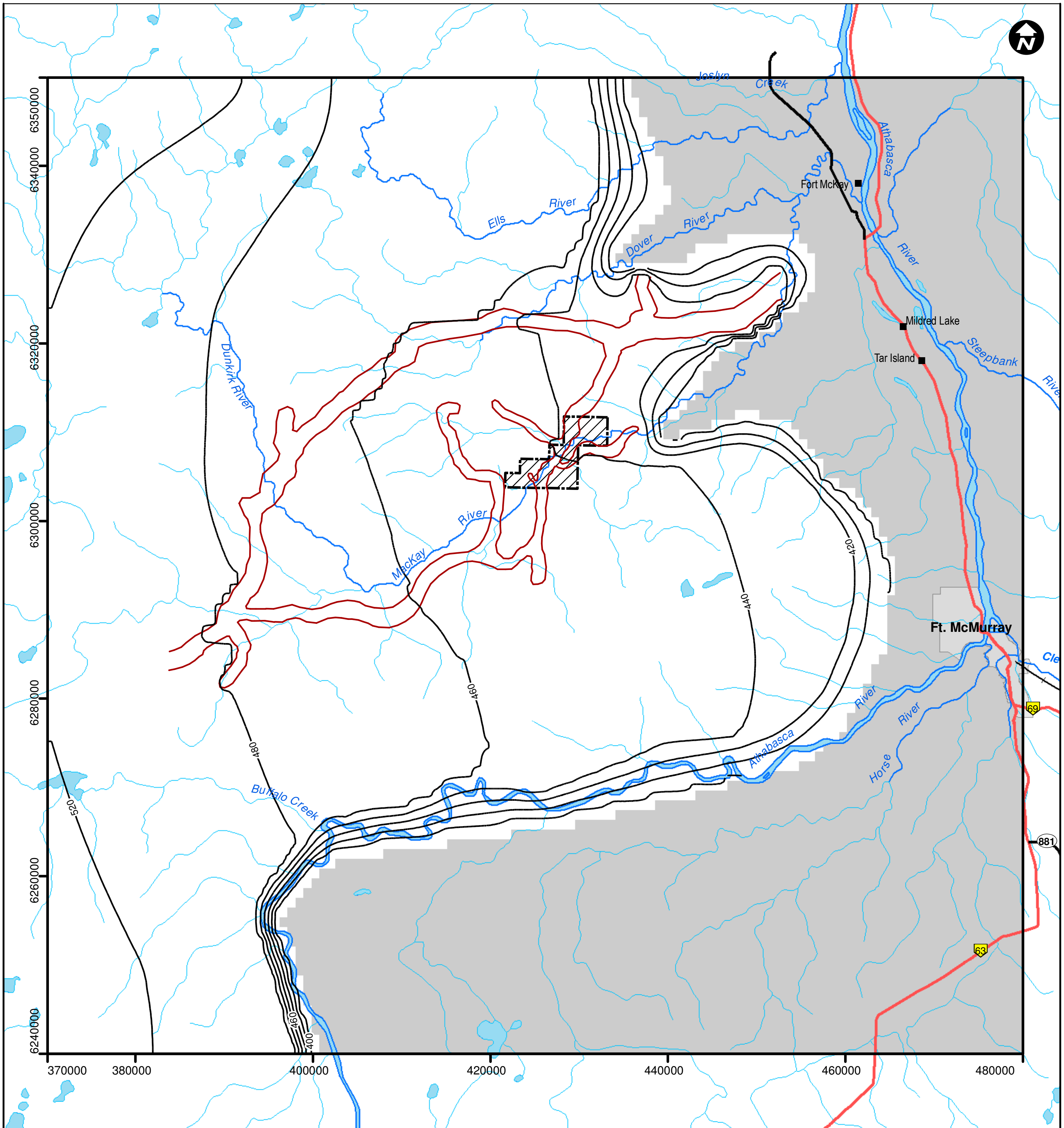


Legend

Project Area

Model Domain

Channel

Equipotential (20m interval)

Time: 9804 Days (End of 2011)

0 5 10 20

Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Static Hydraulic Heads (Calibrated)

DRAWN: PS

CHECKED: AuK

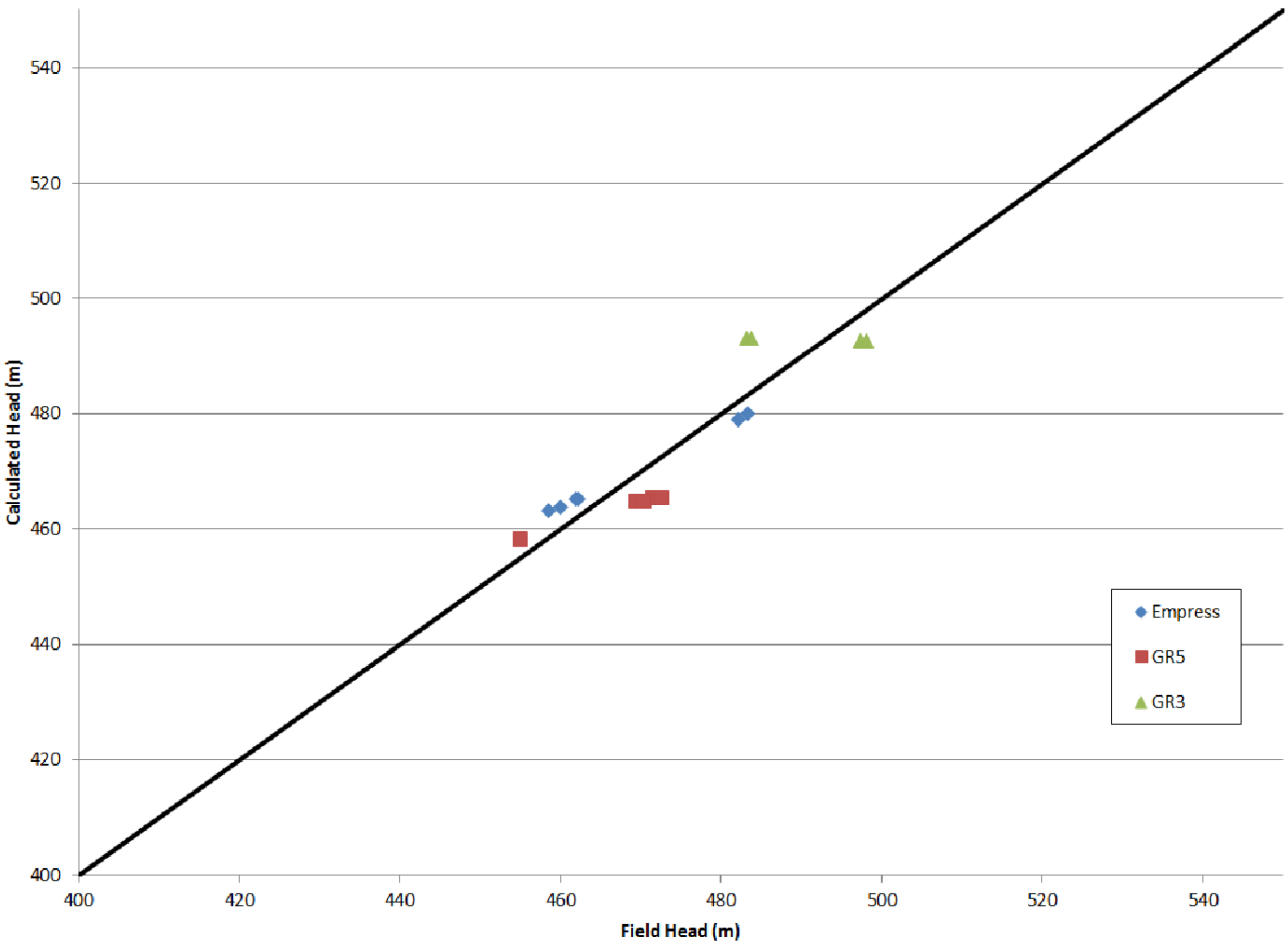
DATE: Nov 3/11

PROJECT: 10-037

FIGURE:

C8

REF: Geobase, 2011.



SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

TITLE:

Observed vs Interpolated Heads

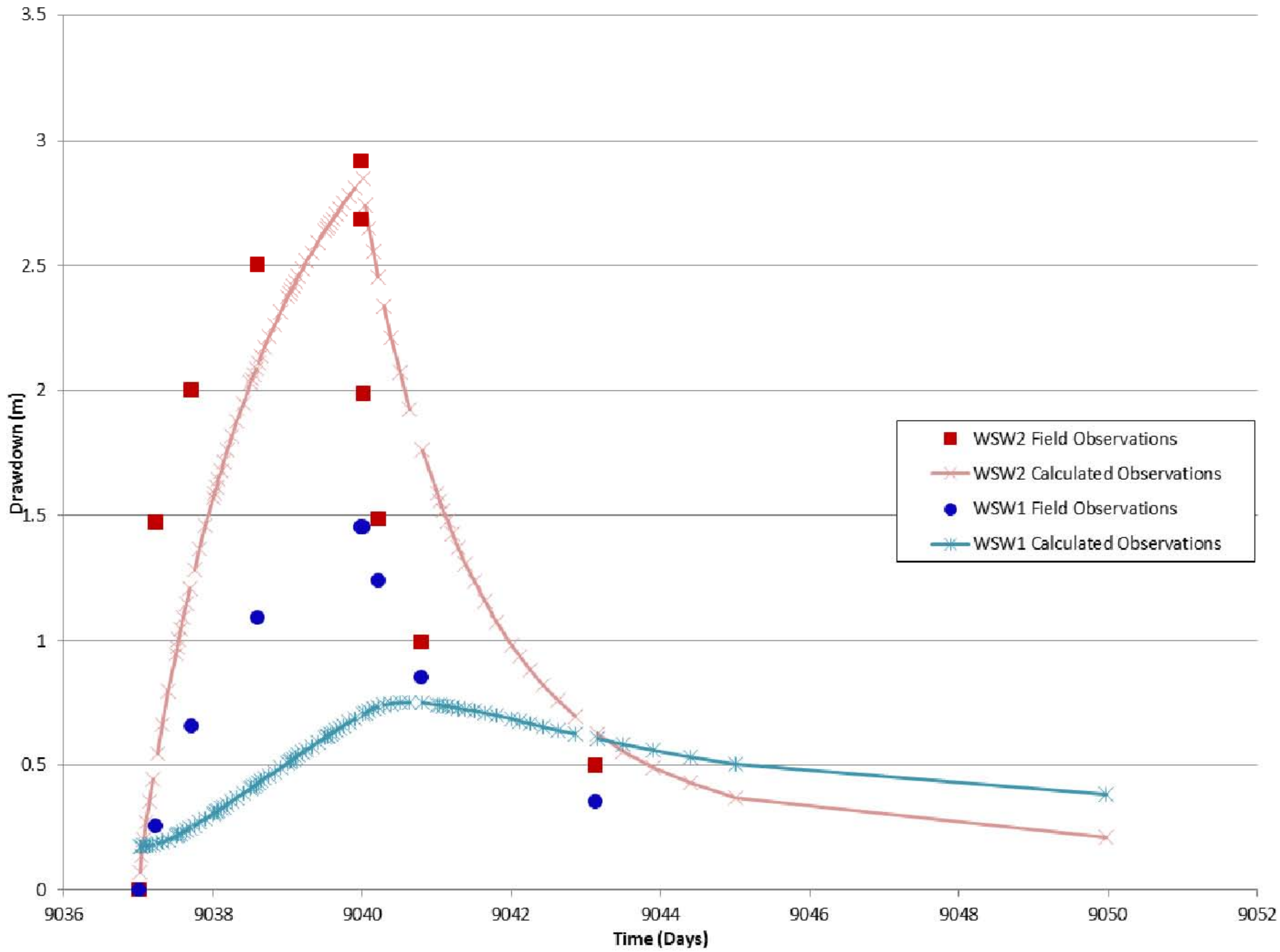
Millennium EMS Solutions Ltd.

FILE: ...Final Docs\Hydrogeology\Hydrology_Figs.dwg

DRAWN: JG
CHECKED: AuK
DATE: Nov 8/11
PROJECT: 10-037

FIGURE: C9

REF: Geobase,2011.



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SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

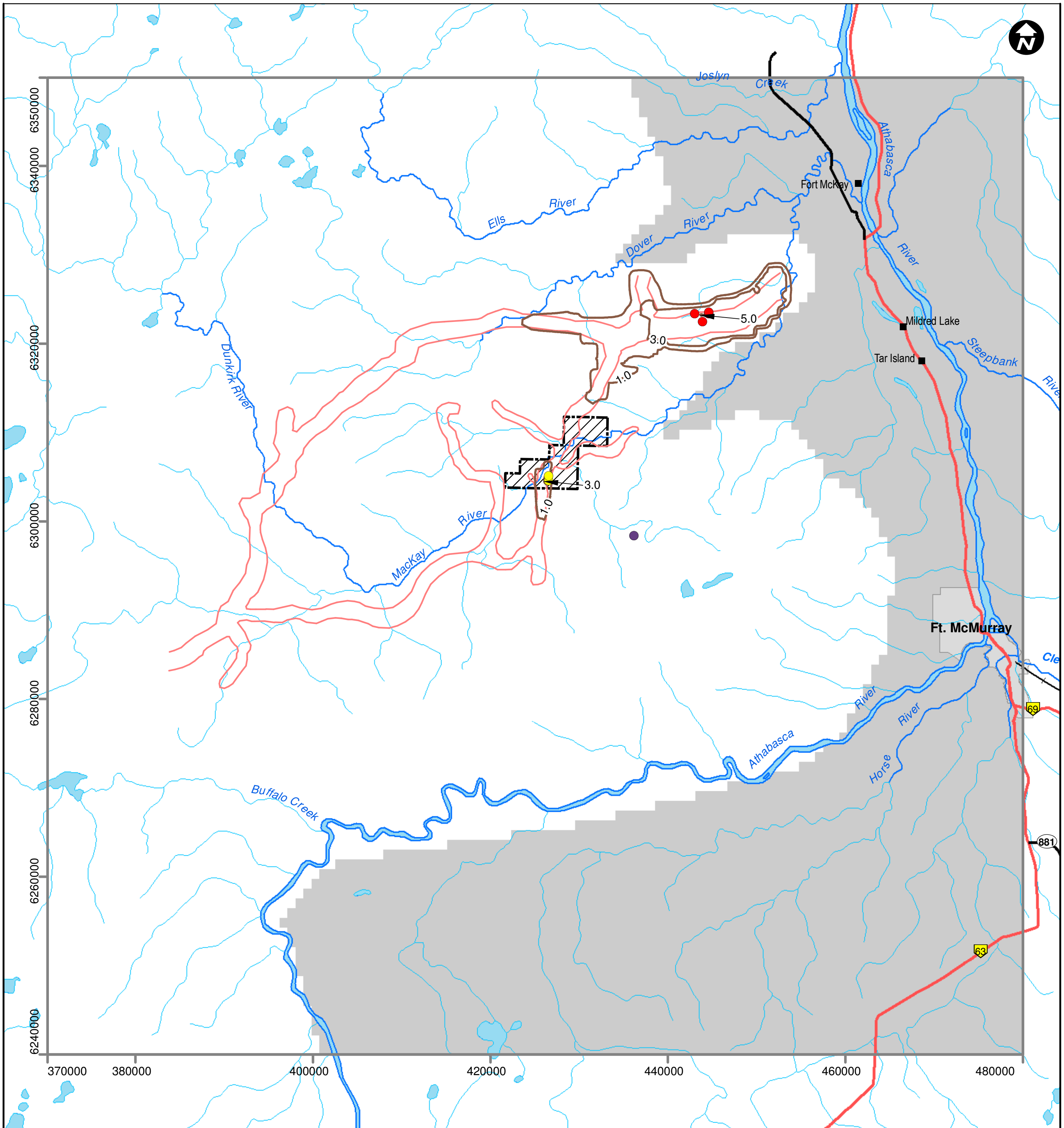
Millennium EMS Solutions Ltd.

TITLE:

Calibrated Drawdown

FILE: ...Final Docs\Hydrogeology\Hydrology_Figs.dwg

DRAWN: JG		FIGURE:
CHECKED: AuK		C10
DATE: Nov 8/11		
PROJECT: 10-037		



Legend

- Project Area
- Model Domain
- Channel

Predicted Drawdown (m)

- 1;3;5

Well (Owner)

- AOSC
- STP
- Suncor

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

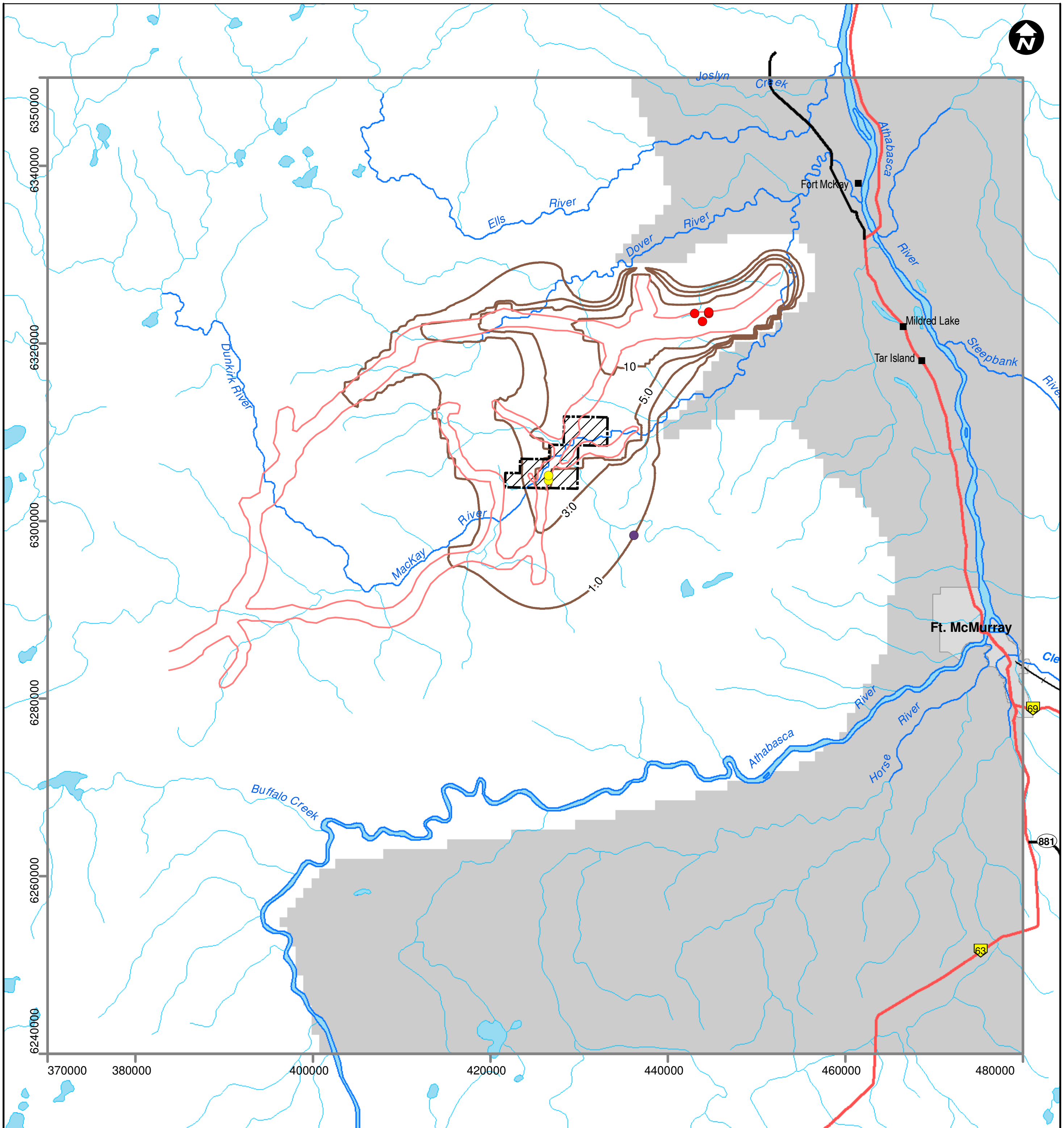
TITLE:
Baseline Case Predicted Drawdown in December 2012 (1 Year)

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE: **C11**

REF: Geobase, 2011.

Back Main Menu Search Main TOC



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SOUTHERN PACIFIC RESOURCE CORP.

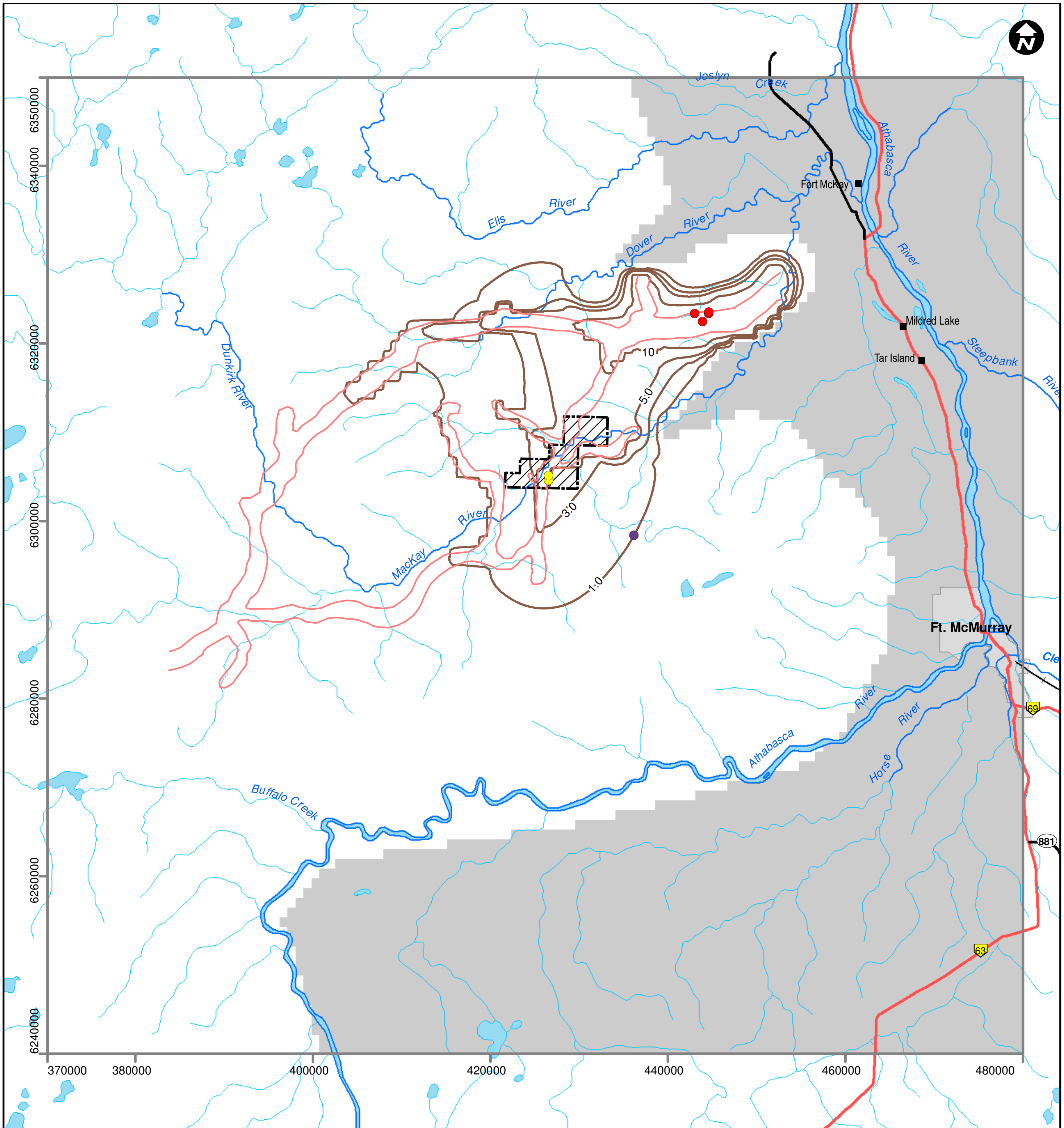
STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Baseline Case Predicted Drawdown in March 2035 (23 Years)

DRAWN: PS	FIGURE: C12
CHECKED: AuK	
DATE: Nov 3/11	
PROJECT: 10-037	



Legend

- Project Area
- Model Domain
- Channel

Predicted Drawdown (m)

- 1;3;5;10

Well (Owner)

- AOSC
- STP
- Suncor

0 5 10 20
Kilometres

SOUTHERN PACIFIC
RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium
EMS Solutions Ltd.

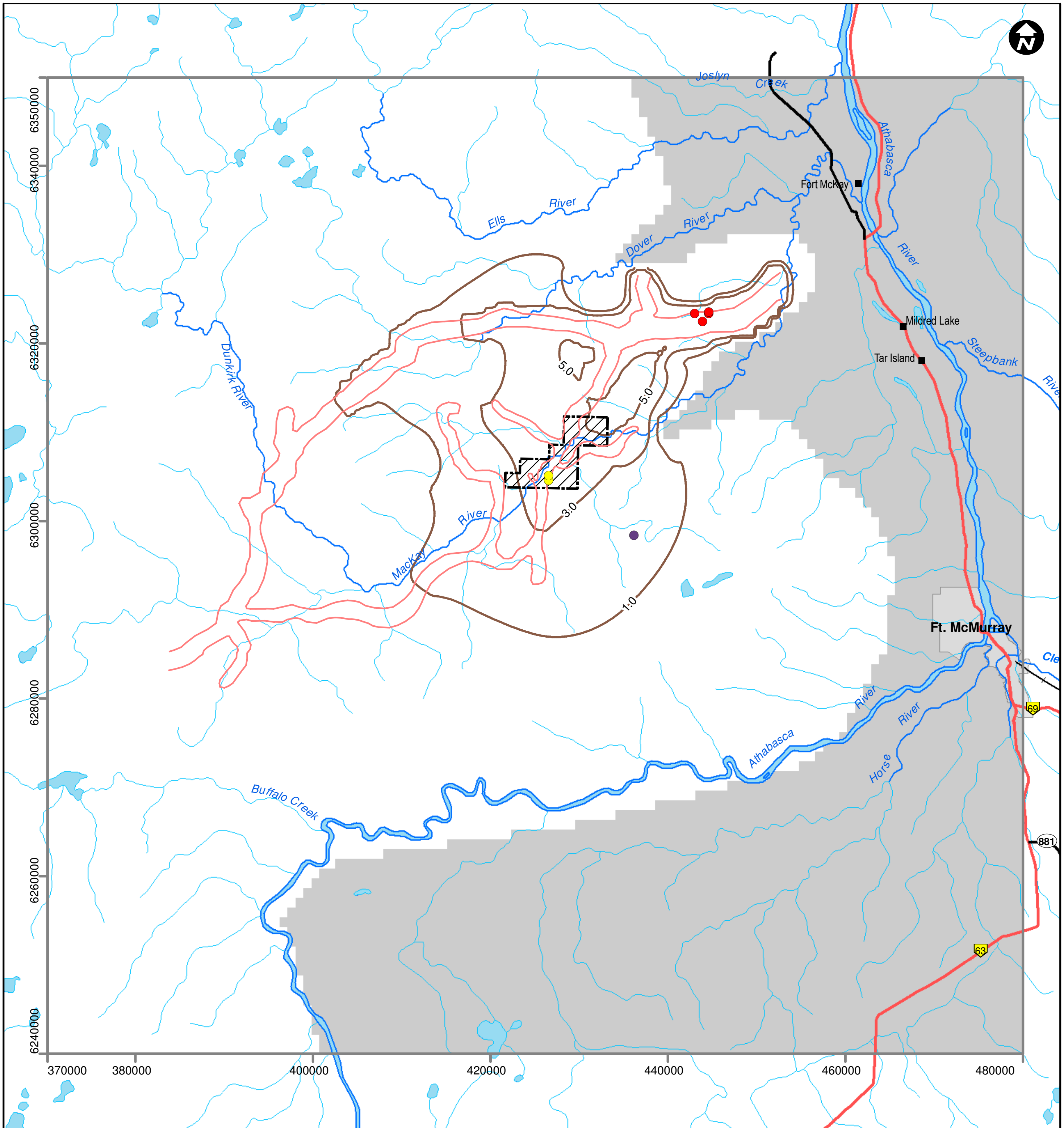
TITLE:
Baseline Case Predicted Drawdown in March 2035 (23 Years) Layer 1

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE:
C13

REF: Geobase, 2011.

Back Main Menu Search Main TOC



Legend

Project Area

Model Domain

Channel

Predicted Drawdown (m)

1;3;5

Well (Owner)

AOSC

STP

Suncor

0 5 10 20

Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

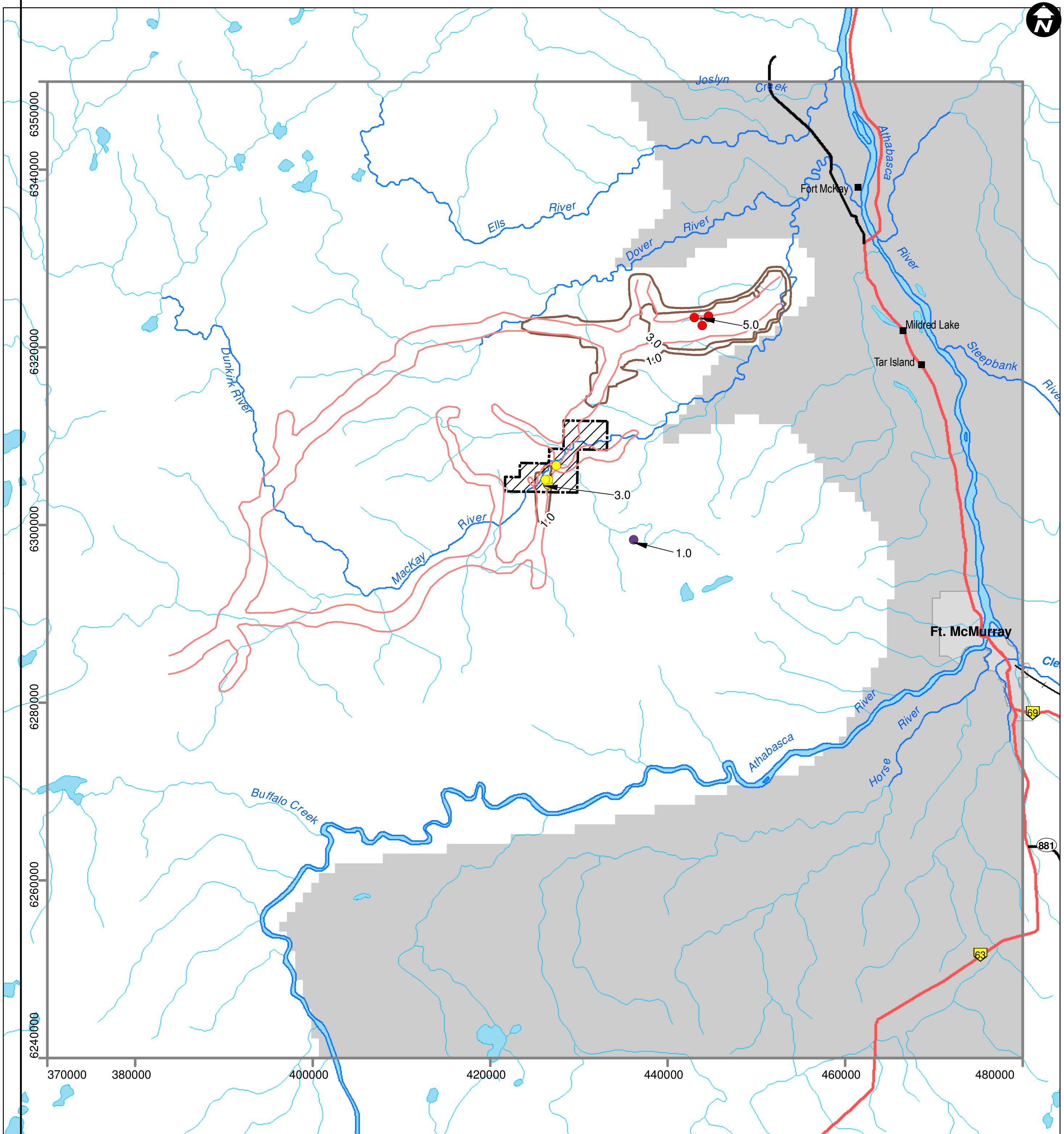
TITLE:

Baseline Case Predicted Drawdown in December 2046 (35 Years)

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE: **C14**

REF: Geobase, 2011.



Legend

- Project Area
- Model Domain
- Channel

Predicted Drawdown (m)

- 1;3;5

Well (Owner)

- AOSC
- STP
- Suncor

0 5 10 20
Kilometres

REF: Geobase, 2011.

SOUTHERN PACIFIC RESOURCE CORP.

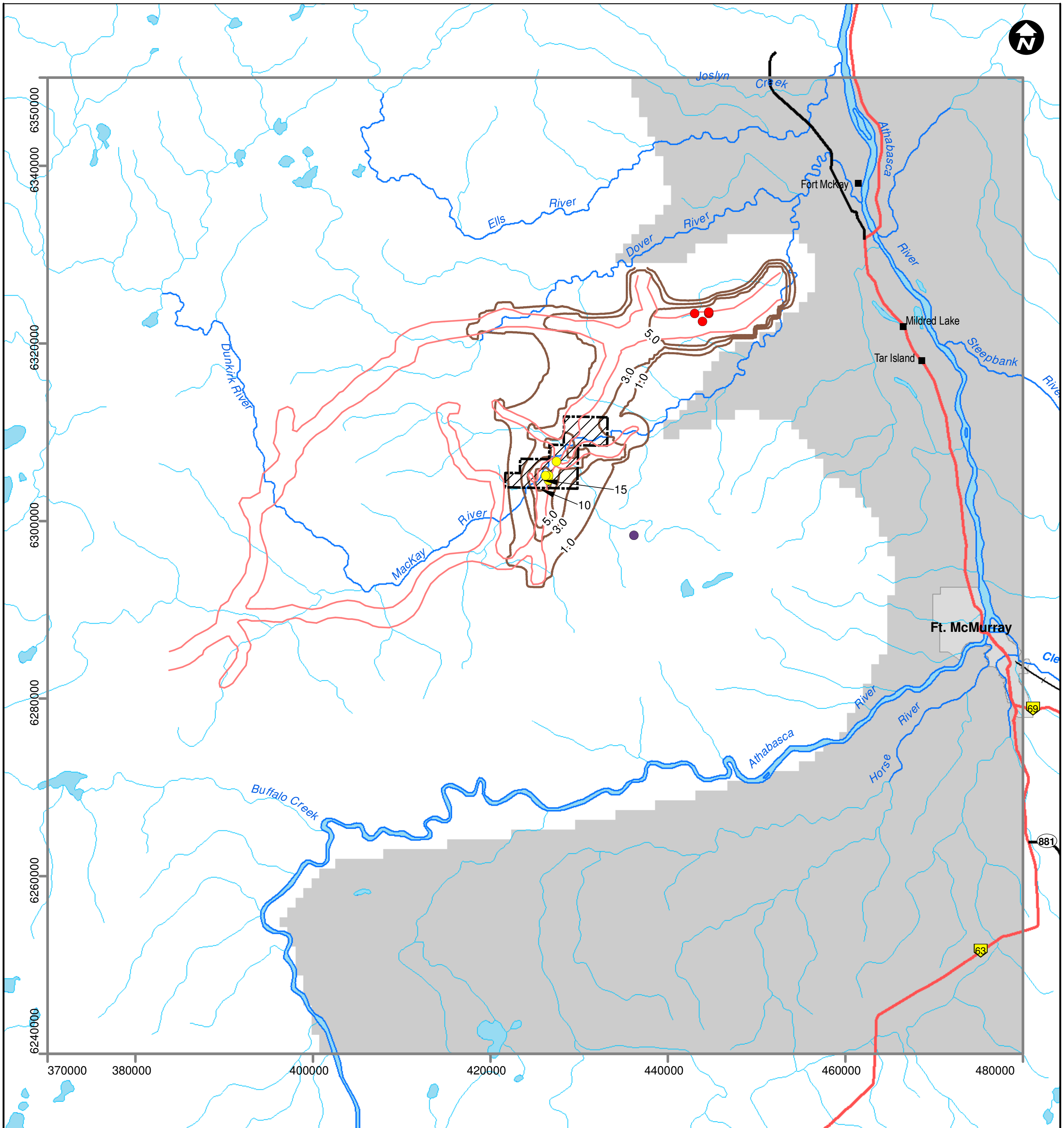
STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

TITLE:

Application Case Predicted Drawdown in December 2012 (1 Year)

DRAWN: PS	FIGURE:
CHECKED: AuK	**C15**
DATE: Nov 3/11	
PROJECT: 10-037	



Legend

Project Area

Model Domain

Clean Channel

Predicted Drawdown (m)

1;3;5;10;15

Well (Owner)

AOSC

STP

Suncor

0 5 10 20

Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

TITLE:

Application Case Predicted Drawdown in November 2015 (4 Year)

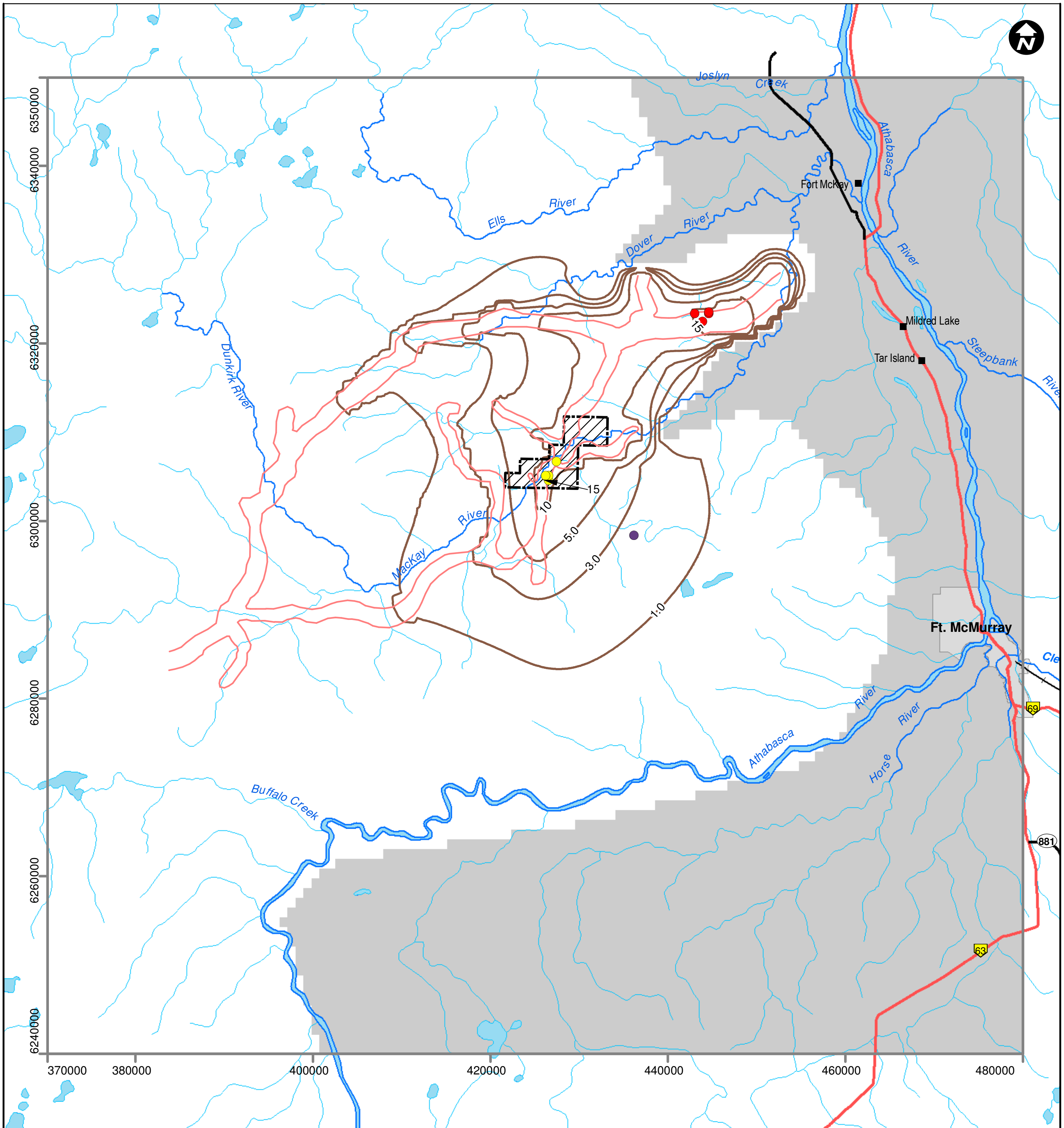
Millennium EMS Solutions Ltd.

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE:

C16

REF: Geobase, 2011.



Legend

- Project Area
- Model Domain
- Channel

Predicted Drawdown (m)

- 1;3;5;10;15

Well (Owner)

- AOSC
- STP
- Suncor

0 5 10 20
Kilometres

REF: Geobase, 2011.

SOUTHERN PACIFIC RESOURCE CORP.

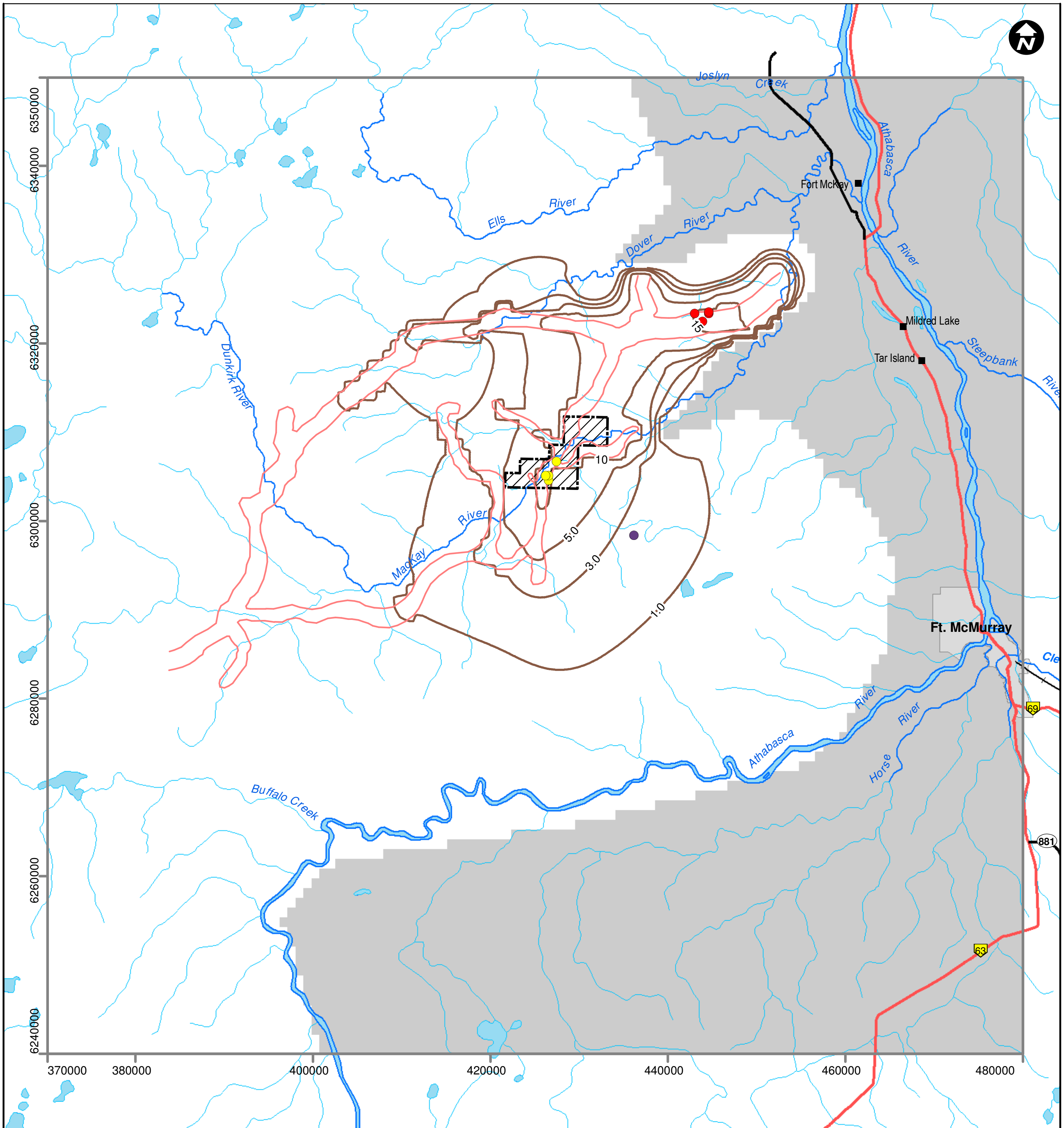
STP McKay Thermal Project - Phase 2

TITLE:

Application Case Predicted Drawdown in March 2035 (23 Years)

Millennium EMS Solutions Ltd.

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037
FIGURE:	C17



Legend

- Project Area
- Model Domain
- Channel

Predicted Drawdown (m)

- 1;3;5;10;15

Well (Owner)

- AOSC
- STP
- Suncor

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

Millennium EMS Solutions Ltd.

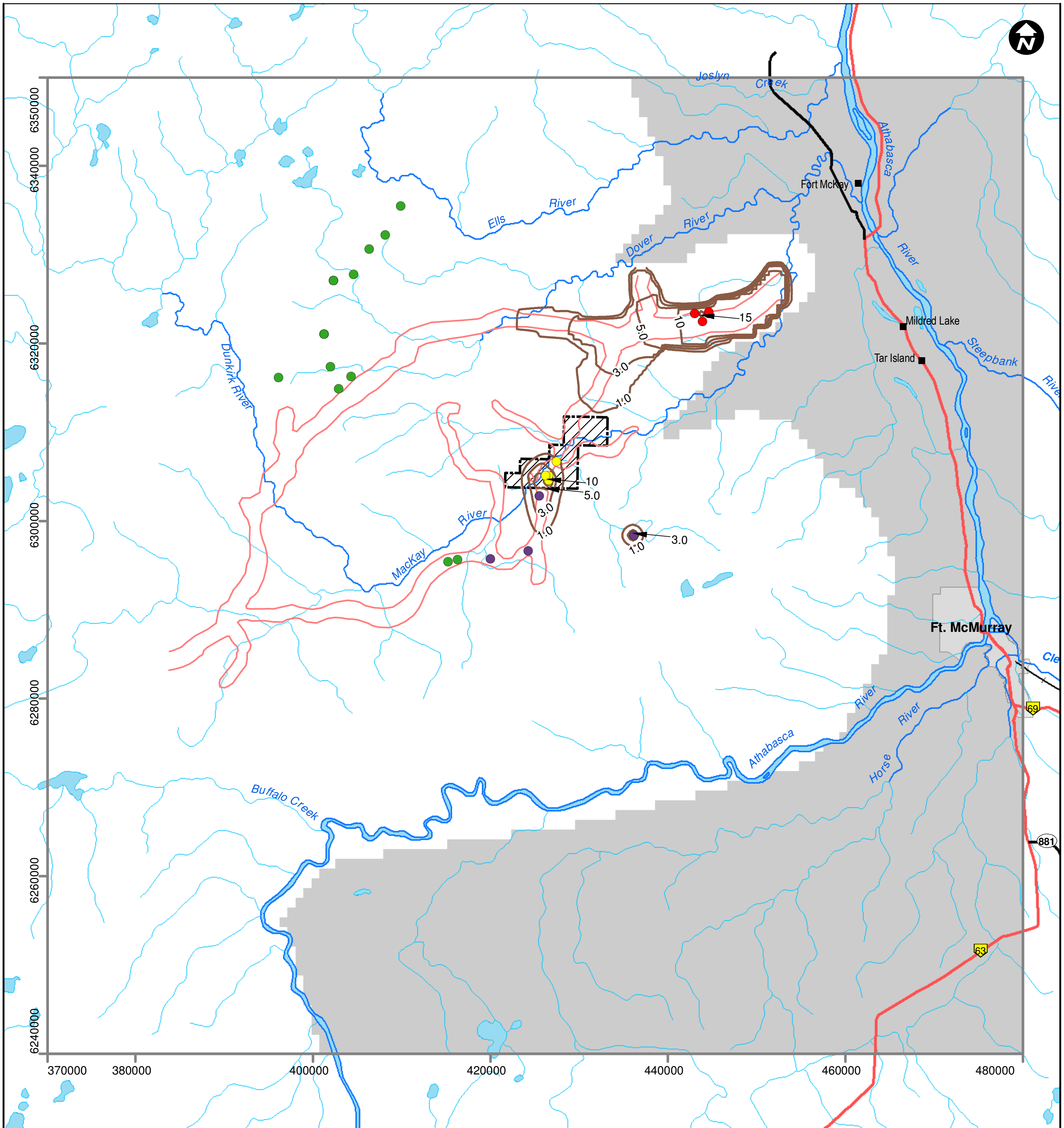
TITLE:

Application Case Predicted Drawdown in March 2035 (23 Years) Layer 1

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE: **C18**

REF: Geobase, 2011.



Legend

- Project Area
- Model Domain
- Channel

Predicted Drawdown (m)

- 1;3;5;10;15

Well (Owner)

- AOSC
- Dover
- STP
- Suncor

0 5 10 20
Kilometres

REF: Geobase, 2011.

SOUTHERN PACIFIC RESOURCE CORP.

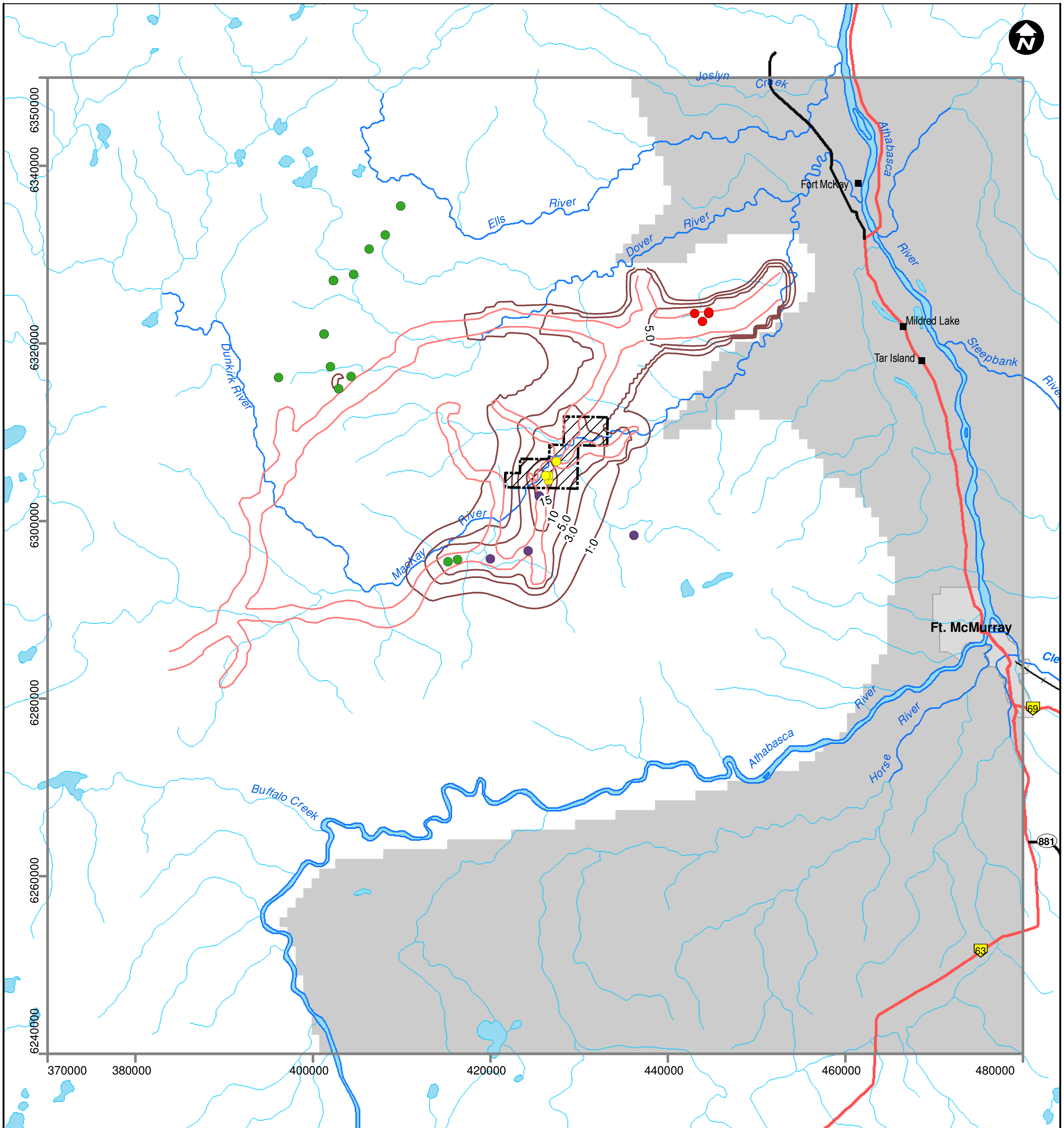
STP McKay Thermal Project - Phase 2

TITLE:
Planned Case Predicted Drawdown in December 2012 (1 Year)

Millennium EMS Solutions Ltd.

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE:
C19



Legend

- Project Area
- Model Domain
- Channel

Predicted Drawdown (m)

- 1;3;5;10;15

Well (Owner)

- AOSC
- Dover
- STP
- Suncor

0 5 10 20
Kilometres

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

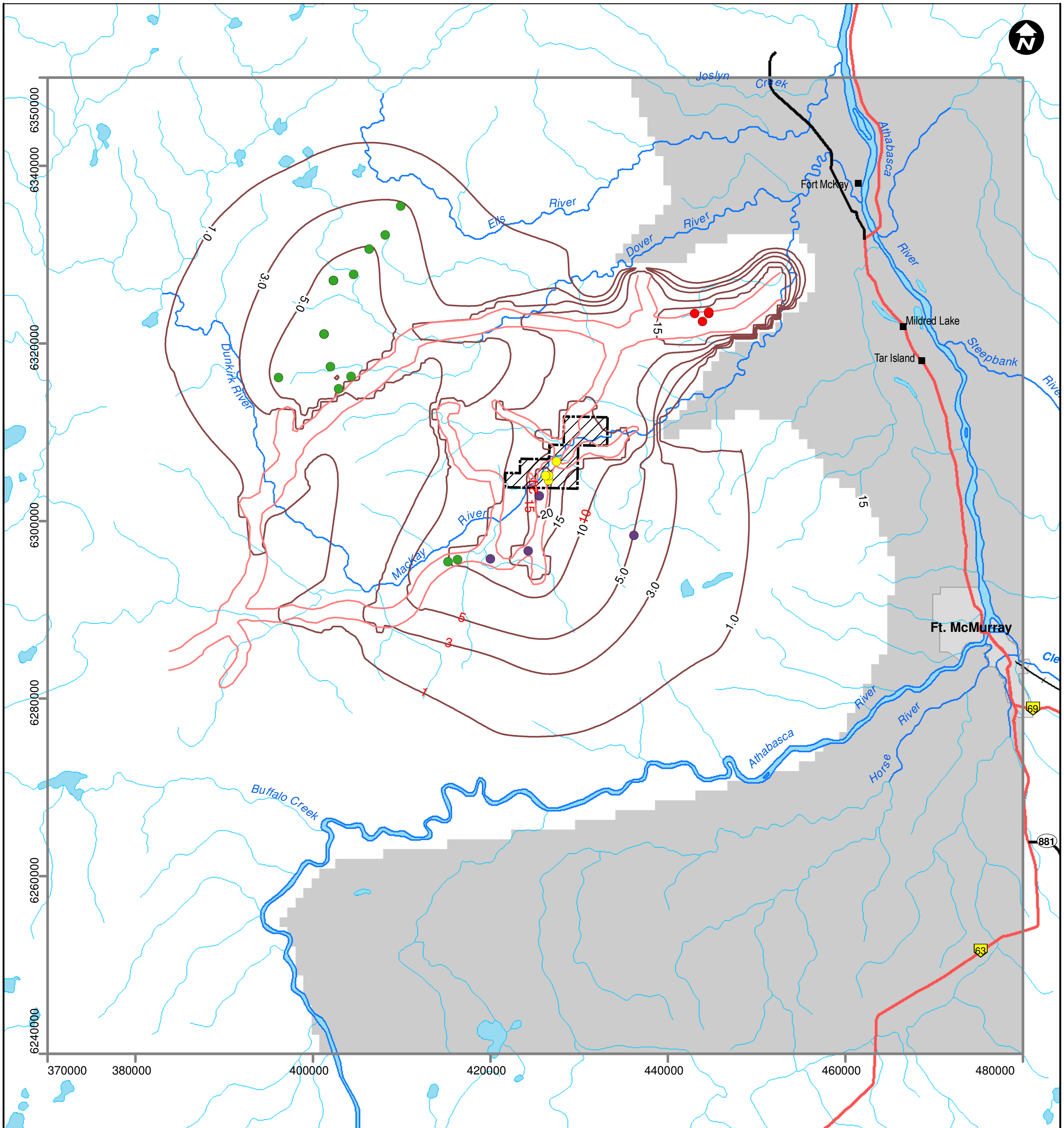
Millennium EMS Solutions Ltd.

TITLE:
Planned Case Predicted Drawdown in November 2015 (4 Years)

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE: **C20**

REF: Geobase, 2011.



Legend

- Project Area
- Model Domain
- Clean Channel

Predicted Drawdown (m)

- 1;3;5;10;15,20,25

Well (Owner)

- AOSC
- Dover
- STP
- Suncor

0 5 10 20
Kilometres

REF: Geobase, 2011.

SOUTHERN PACIFIC RESOURCE CORP.

STP McKay Thermal Project - Phase 2

TITLE:

Planned Case Predicted Drawdown in March 2035 (23 Years)

Millennium EMS Solutions Ltd.

DRAWN:	PS
CHECKED:	AuK
DATE:	Nov 3/11
PROJECT:	10-037

FIGURE: **C21**

APPENDIX D: AUTHENTICATION

AUTHENTICATION

Form: MEMS-APEGGA-BS

The Engineering, Geological and Geophysical Professions Act (the Act) of Alberta requires that engineering, geological or geophysical work be authenticated by the application of:

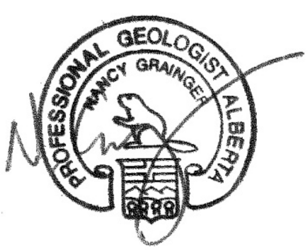
- The professional seal or stamp of the individual member responsible for preparing the work **and**
- The corporate permit number or stamp of the company employing the responsible individual member.

This section identifies those portions of this report that fall under the Act and will be authenticated in compliance with the Act.

The report entitled:

STP McKay Thermal Project – Phase 2
Hydrogeology

meets the definition of engineering or geology within the Act and is authenticated with APEGGA Permit to Practice Number P07002 and the professional stamp applied below:



Millennium EMS Solutions Ltd. provides the same level of quality assurance to our clients throughout this report.