CAMPBELL WATER WELL COMPLAINT REVIEW

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EXECUTIVE SUMMARY

In March 2006 Mr. Shawn and Mrs. Ronalie Campbell initiated a complaint about increased gas in their Well (Campbell Well 1). Several Energy companies that have energy wells in the area (i.e. Penn West Petroleum, Real Resources and Encana). AENV initiated a well investigation. In November, 2007, Alberta Research Council (ARC) was contracted by AENV to critically review the scientific and technical data contained in the AENV Campbell water well complaint file. In addition, ARC was asked to do an independent review of all relevant data, including new data that has become available through Directive 35 (Standard Baseline Water-Well Testing for CBM/NGC Operations) and other information in the EUB files.

ARC's independent review and evaluation involved the examination of all the data contained in the AENV file and the following additional lines of evidence:

- Review of the local and regional geology and hydrostratigraphy.
- Calculation of hydraulic gradients between the Aquifer 3 in the Paskapoo Formation, (which Campbell Well 1 utilizes), and deeper formations that contain nearby gas and oil energy wells.
- A theoretical review of the potential of methane migration along a fracture (potentially induced by well stimulation) between the Aquifer 3 in the Paskapoo Formation and deeper formations that contain nearby gas and oil energy wells using the observed pressure gradients.
- An estimation of the change in dissolved methane concentrations in the Campbell well related to the fluctuations in water level observed in the Campbell well.
- A graphical and statistical approach to the evaluation of data on major ions, bacteria, gas and isotope chemistry of the Campbell well, 30 additional water wells, 154 AENV D35 database wells and 17 Energy wells in the area.

Alberta Research Council's overall conclusion of the evidence from the review of the AENV and AEUB files, along with a new review and evaluation of addition data and aspects, is that the Campbell Well 1 appears to be impacted by a deep gas source. Additional work need to be done to identify whether the source of contamination is a leaking resource well or a natural pathway such as a fault.

Alberta Research Council's review of the AENV Campbell complaint file and AEUB data, and independent review of additional data and aspects of the complaint, provides the following recommendations:

- The cement integrity of energy well 00/02-18-043-27 W4M should be further investigated.
- The cement integrity of energy well 00/05-18-043-27 W4M should be further investigated.

- The cement integrity of energy well 00/14-07-043-27 W4M should be further investigated.
- Three Mannville wells in 05-18-043-27 W4M (00, 02 and 03) should be sampled for gas composition and carbon isotopes.
- A study could be conducted, using seismic data from energy companies, to try to identify fault structures in the area that could be conducting deep (Viking or Mannville) fluids to the overlying Paskapoo aquifer.

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1 INTRODUCTION

Alberta Research Council (ARC) was contracted by Alberta Environment (AENV) to conduct a review of the technical and scientific data on the subject of a Fall 2005 complaint placed by landowner Mr. Shawn and Mrs. Ronalie Campbell (located SE1/4-18-043-27 W4M, in the FerryBank area of Ponoka County, Alberta) (Figure 1). Several energy companies that have energy wells in the area (i.e. Penn West Petroleum, Real Resources and Encana). The Campbell's have two water wells (Campbell Well 1 and 2), both in the Paskapoo Formation. In the Fall of 2005, Well 1 which had previously used as a stock well became the domestic supply source. The Campbells noted gas in their plumbing that they indicated had not been there prior to their domestic use of the well. The complaint concerned whether energy activities in the area have increased the amount of methane in the Campbell well. Historically, methane has been observed in water wells in the Ferrybank area. This is not an unexpected occurrence because many water wells in the area are completed in water bearing zones in the Paskapoo that have been noted to produce methane.

ARC undertook this review to assess whether the evidence suggests that energy resource extraction operations have impacted the water quality on the landowner's property through the migration of methane from energy wells to the water well. ARC agreed to work under contract to AENV to independently assess the situation and provide conclusions identifying whether or not the AENV investigation suggests groundwater has been impacted by CBM and/or conventional oil/gas extraction activities in the area.

This report summarizes ARC's independent conclusions based on scientific and technical data surrounding the investigation of the complaint. The review is based primarily on the collected information in AENV's water well complaint file. Available scientific and technical data include groundwater quality data, water well construction characteristics, oil and gas production activities, and local groundwater gas characteristics. The information in the AENV files sent to ARC included: AENV correspondence from March 2006 to June 2007, including results from their sampling of the Campbell Water Well 1 in May 2007, and various consultants reports including two Matrix Solutions Inc. reports (February 2007, retained by three energy companies with wells in the area (EnCana Corporation (Encana), Real Resources (Real) and Canetic Resources Trust (Canetic) to summarize the hydrogeology in the Ponoka County; and October 2007 retained by Tristar Oil and Gas Resources (Tristar) (formerly Real Resources) and Canetic to investigate the geochemistry of gas samples in the vicinity of the Campbell property).

In addition, ARC endeavoured to compile, review and assess supplementary information not included within the complaint file. This supplementary information includes results of an evaluation of CBM Baseline water well testing data (D35 database) in the general area (provided by AENV), EUB information on energy wells, and deep geological cross sections of the area constructed by ARC.

2 REGIONAL GEOLOGIC AND HYDROGEOLOGIC SETTING

2.1 Stratigraphy and Energy Development

The study area is found within Central Alberta within the Western Sedimentary Basin. A complete review of the geology of the basin is provided in Mossop and Shetsen (1994). A brief overview is given below. The Alberta Basin originated in the late Proterozoic by rifting of the North American craton and early sedimentary deposition was dominated by carbonates, evaporates and shale. Uplift of the Rocky Mountains in the early Cretaceous deposited fluvial sandstones and shales into the developing foreland basin. The changing sea levels during the middle to late Cretaceous resulted in deposition of marine shale and coal-bearing fluvial sandstone. The bedrock underneath the area consists of the Tertiary aged Paskapoo Formation where the majority of water wells are located. Underlying the Paskapoo is the Upper Cretaceous Edmonton and Belly River Groups, which are underlain by the Colorado Group. The Colorado Group unconformably overlies the Early Cretaceous Mannville Group. Key points relevant to the water well complaint of these formations with respect to stratigraphy and energy activities are provided here. More detailed geologic descriptions are provided in the Matrix February 2007 report.

In this area, the Paskapoo is generally less than 500 m thick and consists of the Dalehurst, Lacombe and Haynes Members. Within these members there are occurrences of coal which could be sources of methane in water wells. Two prominent coals zones within the uppermost Dalehurst member, which is reported to have thicknesses of up to 220 m, are the Obed-Marsh Coal (up to 30 m thick) and the Lower Dalehurst Coal (up to 50 m thick). These two zones are reported not to be well utilized for water supplies within the County. Within the up to 245 m thick underlying Lacombe Member, there are thin units of coal with in sandstone and shale with a zone of up to 5 m thick with the Lower Lacombe Member. The deeper Haynes member has some coal layers within the 50 m or less thick unit. The many coals seams within the Scollard Formation of the Edmonton Group, including the Ardley coal, are economic targets for CBM.

Coals seams contained in the Horseshoe Canyon Formation have been produced for CBM with the majority at depths of 700 to 1000 m. The underlying Belly River and Lea Park Formations consist of a series of coarsening upward cycles and the boundary between these two formations is transitional. These sequences are usually referred to as the “Basal Belly River Sands” where the majority of the oil and gas development in Ponoka County targeted this zone at depths of approximately 1000 m. Within the deeper Colorado Group, the Viking Formation is a hydrocarbon-producing unit. It can be expected to be 40-50 m thick and is found at a depth of approximately 1500 m. The deepest Cretaceous unit of interest is the Mannville Group where there are known oil and gas reserves at depths of approximately 1800 m.

Oil and gas activity has been occurring in the Ponoka County area since the early 1950s. Energy Wells were drilled during these early times into the Lower Paskapoo. These wells are reported not to have been used and were abandoned. There were also some wells drilled in the

1970's targeting the Viking or Lower Mannville Formations at depths of approximately 1700 masl. The majority of the energy wells were drilled in the late 1980s and typically completed in the Basal Belly River Sands (Belly River and Lea Park Formations) noted above. These wells mostly produce crude oil and some have associated gas. In the early 1990's a water flood/pressure-maintenance program was initiated as part of enhanced oil recovery in the county. The groundwater was sourced from the same township as the Campbell well is located (43-28 W4M). In 2003-2005, an estimated 12 oil and gas wells were drilled within the country targeting the Viking and Mannville Formations at depths of approximately 1800 m. About half were drilled in section 18-043-27-W4M. CBM reserves may be found in conjunction with coal seams that occur in the upper geologic formations, including the OBED Coal (in the Paskapoo), the Ardley, Scollard, and Horseshoe Canyon Formations (Edmonton Group) and the Belly River Formation. Since 2005 there has been CBM activity in the Horseshoe Canyon with one well located within 1.5 km of the Campbell Well 1.

2.2 Regional Stress Regime

The stress regime of Cretaceous – Tertiary strata in Alberta has a strong correlation to permeability and fracture directions. This in turn has a strong control on the direction that "fluids" (both gas and water) tend to migrate in these strata. Rock mechanics theory and field measurements shows that fractures trend in a direction normal to the least compressive stress. Horizontal stress orientations in Alberta have been measured using well breakout analyses (i.e. damage to boreholes caused by stresses acting on the rock) (Bachu and Michael 2002). Based on breakout analysis the most likely azimuth (orientation) of fractures and face cleats in the formations would be about 060°E of N of the Campbell Well 1. Two energy wells (00/02-18-043-W4M and 00/14-07-043-27 W4M) line up roughly along this orientation from the Campbell Well 1. The implications of this alignment along this fracture orientation are discussed in section 4.

An additional structural feature has been observed in the area during the pumping of the Pan Canadian 1-88 well (and also seen in observation well 1-89) for the water flood/maintenance program. A north-west elliptical drawdown cone was observed with this pumping whose orientation is not what is expected for the regional stress field. This orientation may be due to a fault and associated fracturing. Whether there is any connection to this structure and the extensive pumping (e.g. 130,000 cubic metres per year for the first four years, 1991 to 1994 (HCL 2003) is discussed in Section 4.

2.3 Hydrostratigraphy, Groundwater Flow and Gradients and Water Wells

Large scale regional flow systems across the Alberta Basin are controlled in part by major recharge areas along the Rocky Mountain front in western Alberta. Regional flow within the basin is northeast towards the basin edge (Hitchon 1969a,b). Bachu (1999) recognised that flow in the northern part of the basin was driven by topography north-eastward. Within Ponoka County, regional groundwater flow is interpreted to flow from southwest to the northeast (HCL, 1995). A more local northwest to southeast trend in groundwater flow direction was observed from the Campbell Well towards an observation well (1-89) used for the water flood/pressure program, noted above, from 1991 to 1998 in the same aquifer as the Campbell Well 1. HCL (1995) noted that the northwest to southeast trending cone of depression, parallel to major fracture lineation in Ponoka County, developed when water was produced from Aquifer 3.

The water producing zones within the Paskapoo Formation have been designated as three aquifers (Aquifers 1-3) in previous assessments (reported in Matrix 2007a). Campbell Well 1 (refer to section 4 for additional information on the Campbell water wells) is reported to be in the Aquifer 3. Aquifer 3 occurs at elevations of approximately 780 to 820 masl (Lower Paskapoo) and has large regional extent and transmissivity values of up to 20 m^2/day. According to HCL (1995), the Aquifer 3 dips to the west resulting in deeper water wells in the area to the west of Campbell Well 1. This aquifer typically has sodium bicarbonate type groundwater with TDS values of less than 600 mg/L (Matrix, 2007a).

Large downward vertical gradients between the Aquifer 3 of the Paskapoo Formation (where the Campbell Water Well 1 is completed) and the various deeper zones where the energy wells are located (see section 4.4.2 for estimated values). The whole Cretaceous succession of rocks are underpressured (or lower) with respect to predicted hydraulic gradients based on elevation differences. These lower pressures have been interpreted to be due to erosional rebound caused by stripping of up to 3800m of sediments (Parks. and Tóth, 1995; Bachu 1999).

Information from Matrix (2007a) reported 105 wells in Ponoka County and 10 water well users within section 18. The majority of these water wells tap the Aquifer 1 and 2 of the Paskapoo Formation. Some wells, including the Campbell well and water supply wells for energy companies (e.g. EnCana 1-88) do tap the deeper Aquifer 3 of the Paskapoo Formation.

3 ENERGY WELL INFORMATION

ARC located energy wells of interest roughly within a 1.6 km radius of the Campbell property from the EUB data base (Figure 2). There is one CBM well and the rest are conventional oil and gas.

A summary of drilling and completions reports (based on the tour reports) provided by Brenda Austin of the AEUB are found in (Table 1). All depths on the table are mKb (metres from the Kelly bushing which is usually 3 to 4 metres above ground surface). The report of 02-18-043-27-W4M has no information on cement returns for either the surface or production casings and no cement bond log. This means that there is no confirmation of the integrity of either casing seals. This well is located in the Belly River Sands, separated horizontally by about 400 m SW from Campbell Well 1 and vertically approximately 926 m deeper (from bottom of the water well to top of the perforation of the energy well. The oil/gas well 00/14-07-043-27 W4M (located approximately 1 km to the southwest of Campbell Well 1) had remedial cement work done to stop a vent flow. This well previously produced from the Viking and Mannville Formations. This well continues to have hydrocarbon gases in the surface casing vent that have a thermogenic isotope signature. While 00/05-18-043-27-W4M had good cement returns on both the surface and production casing, no bond log was done. While bond logs are not usually to be run on wells with good cement returns, it would be useful to confirm an adequate casing seal because it is located within one potential source of gas, the Ellerslie Formation of the Mannville Group (depth around 1750 m). The compositional and/or isotopic data that was available for some of the energy wells in the vicinity of the Campbell well, including the 00/02-18-043-27 W4M and 00/05-18-043-27 W4M wells. This data will be discussed in section 4 of this report.

4 CAMPBELL WATER WELL INFORMATION

4.1 Initiation of Well Complaint

The water well complaint by the Campbells was originally made in the September 2005 to Penn West Petroleum which had the closest operational energy well to in their Well 1. This company contracted a consultant to sample their well. Additional investigations were also conducted by consultants hired by Encana, Real Resources and Canetic Resources Trust.

4.2 Well Design, Construction and Maintenance

There are two water wells on the Campbell property. The Campbell Well 1 record, available through the AENV Groundwater Information Centre (GIC) (Well ID #0078001, is included in Appendix A). The well was drilled and completed by Finn Drilling Ltd. on November 28, 1980. There is a clear lithology log and it indicates that this well is completed in Aquifer 3 of the Paskapoo Formation. Details provided on the well construction included the depth of the well at 67.1 m, a 141 mm diameter casing set at 23.8 m, and a screen interval from 54.9 to 67.1 m. A steel liner was used. No information on the sealing method was provided so it is unknown if the existing seal provides adequate protection against contamination of water from ground surface or other aquifers entering the well. Campbell Well 1 is reported to have been drilled as a stock well but was switched to use for domestic purposes in 2005 because of reported poor production and water quality in Campbell Well 2 which was 42.7 m deep and apparently completed in Aquifer 2 (Matrix 2007a).

A short term pump test on Campbell Well 1 is reported in the well record. It was tested at 15 imperial gallons per minute for two hours and had a drawdown of almost 16 m. This indicates that a much lower pump rate should be used. In 1991, Campbell Well 1 had water quantity problems. There were two groundwater diversion programs noted in the files that were ongoing at this time (PanCanadian and Union Pacific Resources Inc.). It was noted in Matrix 2007a that the Campbells were reported to be concerned that groundwater diversion programs were affecting their Well 1 (which was a stock supply at that time). As part of the investigation by PanCanadian's consultants, a new liner was installed in the well. The large fluctuations in water levels were reported to decline with this change. However, the investigation did conclude that the measured drawdown in the well of 4m over 3 years was due to the PanCanadian groundwater diversion program where the supply well was also located in Aquifer 3.

There was no indication in the AENV complaint file whether the Well 1 undergoes regular shock chlorination. A correspondence from the Campbell's (November 3, 2005) indicated that they did have their well shock chlorinated shortly after it was switched to a domestic supply. The bacterial analyses (Table 1) indicate that iron related bacteria (IRB) and sulphur reducing bacteria (SRB) are present in the well water which suggests irregular well maintenance.

4.3 Stratigraphy

Two geologic cross sections through the Campbell residence were constructed using lithology information from Campbell well, and surrounding energy wells (Figure 3a roughly north-south and Figure 3b roughly east-west). The cross-sections illustrates that the Campbell Well 1 is completed in Aquifer 3 of the Paskapoo Formation within a groundwater bearing zone in a sandstone unit from approximately 60-67 m (MASL). These figures are drawn as deep geologic cross sections to illustrate the possible sources of gases from energy wells in the vicinity of the Campbell Well 1. These wells finished in the Belly River Basal Sands, the Viking or the Mannville Formations are discussed in the following sections.

4.4 Hydrogeology

4.4.1 General Groundwater flow directions

In the Campbell Well 1, the deeper confined groundwater flow within the Aquifer 3 of the Paskapoo bedrock is part of the regional groundwater flow system flow directed to the northeast (Bachu and Michael 2002). A more local northwest to southeast trend in groundwater flow direction was observed for drawdown from the Pan-Canadian water-flood program that ran from 1991 to 1998. The Paskapoo/Scollard Formations act as a separate groundwater flow system isolated from the Horseshoe Canyon Formation by the Battle and Whitemud aquitards and from the Belly River Aquifer by the Bearpaw aquitard. The Mannville aquifer is separated from shallower aquifers by the Colorado aquitard. This is supported by the presence trapped gas in the Horseshoe Canyon, Belly River, Viking and Mannville Formations and the underpressured nature of the Horseshoe Canyon and Belly River Formations (Parks and Tóth, 1995; Bachu 1999). Under natural conditions, flow between water saturated sandstone in the Paskapoo (where water wells are completed) and energy well zones is expected to be very limited.

4.4.2 Vertical Hydraulic Gradient

An estimation was made of the vertical hydraulic gradient between the middle of screened zone of the Campbell Well 1 (Aquifer 3) and that of several energy wells where pressure data is available. An example calculation is shown below. Table 3 lists the energy well location, the formation the pressure test was completed in and the calculated vertical gradient between the Campbell Well 1 and the tested formation. The downward vertical gradient between the Campbell Well 1 and the producing energy zones ranges from 0.21 to 0.39.

Elevation of the middle of the aquifer in Campbell Well 1 = 835.14 MASL.

Elevation of the middle of the tested formation in energy well 102/10-18-043-27W4M = -619.75 MASL.

Elevation of the head of water in the Campbell Well 1 = 861.09 MASL.

A shut-in pressure of 4678 KPa was measured in the Viking Formation of energy well 102/10-18-043-27W4M (equivalent to 477.8 m of water).

Therefore the equivalent head of water in the energy well = 456.7 MASL assuming density of 1000 kg/m^3 (fresh water).

The vertical gradient is estimated from = $\Delta h/\Delta l$ = (861.09 - 456.7) / (835.14 – (-619.75) = 0.28. This suggests a large downward vertical gradient. If these zones become connected, groundwater would flow down into the energy well. The rate of flow however, is going to be controlled by the hydraulic conductivity along the flow path. For example, if a fracture connects an energy well to an overlying aquifer, the amount of groundwater produced could be significant, but will controlled by the fracture aperture.

4.4.3 Water levels and methane saturation

Water levels from the Campbell Well 1 from the water monitoring done for the PanCanadian water flood/pressure maintenance program are available for years 1989 to 2003 as a hydrograph in HCL (2003). The pumping well (1-89) is located 3.3 km northwest also operated in Aquifer 3. Over the 7 years (1991 to 1998) of pumping, the maximum drawdown measured in the Campbell's Well 1 was approximately 4 m. After five years of recovery the well was 1.5 m less than the pre-diversion level. Using the maximum difference in water levels (i.e. 4 m), this corresponds to a pressure difference of 0.39 Atm (5.7 PSI). A drop in pressure is expected to decrease the solubility of methane in the water and cause an increase in the amount of methane coming out of the water. This is similar to the case where pressure is decreased in a carbonated drink (by opening the top) and CO_2 bubbles out of solution. An estimation of the concentration of methane in water (in the Campbell Well 1) at saturation can be done using the head (height) of water above the coal zone to calculate water pressure and then to use the Henry's Law equilibrium equation to relate water pressure to methane solubility:

Head of water above aquifer on January 6, 1988 = 25.95 m or 2.51 Atm

Head of water above aquifer in 1998 = 21.95 m or 2.12 Atm

Henry's constant for methane = 1.4×10^{-3} Moles/Atm (at 25 °C or 298.15 °K)

A temperature correction needs to be done to the Henry's constant to account for the observed temperature of 281.15 °K (8 °C) in the Campbell Well 1:

Henry's constant for methane in water at 8 °C = 1.0×10^{-3} Moles/Atm

Concentration methane in water = Henry's constant x pressure

Therefore, based on this equation, the concentration of methane in water is calculated to be 2.54×10^{-3} Moles/kg of water at saturation for the January 6, 1988 water level and 2.14×10^{-3} Moles/kg of water at saturation for the approximate lowest static water level in 1998. This illustrates that with lower water levels or lower pressures, the solubility decreases and this could explain an increase in the amount of methane coming out of the water. However, it does not explain the source of the methane.

4.4.4 Potential for Methane Gas Migration

In order to estimate methane gas migration potential from an active CBM site to an overlying water supply aquifer, an assessment of the forces controlling the methane gas bubble migration is helpful. If an aquifer overlying a CBM zone was connected to the CBM zone through and induced fracture (from well stimulation) methane bubbles would tend to rise in the fracture due to buoyancy forces. Groundwater flow downward in the fracture would tend to counteract the buoyancy force and prevent the bubble from rising. Appendix B provides a discussion on how those forces are determined and presents simplified calculations (personal communication with Dr. J, Jones, PhD., University of Waterloo) that determine what kinds of flow conditions prevent methane gas bubble migration into an overlying water supply.

An example of the application of this approach for the case of an induced fracture connecting a CMB zone with an overlying aquifer (e.g. either in the geological medium or in a casing annulus) provides some estimates of groundwater flow in the fractures (under the observed gradients at the site) were compared to the terminal velocity (maximum velocity the bubble can reach given the density and viscosity of the fluids involved) of methane bubbles. For a 100 μm fracture, the flow velocity in the aperture would stop a methane bubble of 122 μm or less from rising into an overlying aquifer. In coal fracturing operations the intended fracture apertures are in the order of 1000 μm (1 mm) (personal communication with Paul Smolarchuk, Canadian Spirit Energy). An estimation of a downward groundwater flow velocity for the hydraulic gradient in the area in a 1 mm fracture indicates that a bubble of 1.2 mm or less would be stopped from rising. This kind of assessment suggests that if an induced connection existed between an energy well and the Campbell Well 1, methane bubbles would not tend to rise in these smaller fracture expected from fracturing because of the downward groundwater flow (based on the hydraulic gradient estimated for the local area).

4.5 Water and Gas Chemistry

This section presents the results of ARC's compilation, review and assessment of water and gas chemistry data from the AENV and AEUB files (Campbell Well 1 complaint file and energy well data). These data include sampling results from various consultants' reports for 30 water wells within 18-43-28-W4M and adjacent sections (7-43-27-W4M, 23-43-28-W4M, 12-43-28-W4M, 15-43-28-W4M) and the 154 D35 data from Ponoka and Wetaskiwin areas. Note that 55 wells of the D35 wells have gas/isotope analyses. The new D35 AENV database and other water wells are compared here with the Campbell Well 1 and the Energy wells. An analysis of this new chemistry data is organized into major ion chemistry, gas chemistry and isotope geochemistry. The Campbell Well 1 chemistry results are summarized in Table 2 and analytical reports are provided in Appendix C.

4.5.1 Major Ions, Metals and Bacterial Chemistry

One historical water quality analyses was available for the Campbell Well 1 prior to the initiation of the complaint (June 5 1991). In addition to the one historic water analysis from the Campbell Well 1, four additional water samples were collected after the complaint, including one by AENV. These analyses have ion balances of 10% which is an acceptable value. It is not possible for ARC to comment on the field QA/QC as this type of information was not available.

Time inorganic sequence results (1991 to 2007) show similar values, e.g. TDS values of between 700-800 mg/L, and sulphate slightly greater than 100 mg/L and sodium bicarbonate type waters. Although there was a decrease of TDS and sulphate in some water samples they had slight change in water type to more calcium rich. The results indicate that the Campbell Well 1 consistently exceeds the aesthetic objectives for total dissolved solids (TDS) and sometimes for sodium, iron, and manganese. Bacterial analyses related to indicators of health risks (e.g. coliforms and E.Coli) were not detected in the Campbell Well 1 samples.

The major ion chemistry of the D35 water wells, the Campbell Well 1 and other water wells is presented on Figure 4. The major ion chemistry in the water wells group into sodium-carbonate with some chloride to more calcium rich carbonates with some chloride type. Although there is not a strong correlation of specific water types in the area with methane concentration, sodium-bicarbonate/chloride ($Na\text{-}HCO_{3}\text{-}Cl$) waters seem to correlate more with those wells with methane. This correlation relates to the reducing conditions, found where methane occurs in coal zones, that likely result in the biochemical reduction of dissolved sulphate, resulting in decreased sulphate. Bicarbonate, on the other hand, likely tends to be enriched in the coals as a result of carbonate dissolution by oxygenated recharge water and by sulphate reduction and methane production (fermentation). Calcium and magnesium tend to be reduced by inorganic precipitation of calcite due to reduced solubility in the presence of elevated bicarbonate (Van Voast 2003).

The major ion chemistry is presented on Schoeller plots (Figure 5 and 6). Most of the wells with methane have decreased calcium, magnesium and sulphate. Again, these wells show a trend where the water wells with methane tends to have sodium-bicarbonate (Na-HCO3) or sodium-bicarbonate-chloride (Na-HCO3-Cl) type waters. The Campbell Well 1 has a chemistry that does not consistently correlate well to this trend.

4.5.2 Dissolved Organic Chemistry

The one BTEX sample did not detect any of these compounds.

Dissolved methane was measured in samples with concentrations of 5140 and 2170 ug/L. These results are significantly lower than the solubility of methane (approximately 30,000 ug/L).

4.5.3 Atmospheric Elements and Hydrocarbon Gas Chemistry

Several free gas analysis are available for the Campbell Well 1 (Table 2). Two samples (labelled hydrant and well) from the Wiebe (2005) report were air contaminated with almost no hydrocarbons. These results could be due to pump cavitation, improper field collection or laboratory errors. These results were not used in ARC's analysis. The most recent gas sample taken by AENV (June 5, 2007) sat for several weeks before being submitted for analysis (personal communication with AENV). Methane gas concentrations are anomalously low and it appears that there may have been preferential leakage from the Tedlar bag. The best quality analyses appear to be the two taken in 2006. The remaining gas samples contain 45,800 to 223,500 ppm methane, <100 to 1400 ppm ethane, 42 to 300 ppm propane and 3 to 100 ppm butane. There is a risk that methane can form an explosive mixture with air. In addition to the Campbell Well 1, 55 water wells from the D35 database and 7 additional water wells have gas chemistry. The average methane concentrations of surrounding water wells are higher than those measured in the Campbell well. The average ethane concentrations of the Campbell Well 1 are higher than those measured in the surrounding water wells. A more rigorous, statistical approach to differentiate gas characteristics is presented at the end of this section. Analysis of hydrocarbon gas from the Campbell Well 1 also detected the presence of propane, n-butane and i-butane in low concentrations. These compounds are indicative of a thermogenic gas as they are not known to form at the low temperatures where biogenic gas is expected to form.

4.5.4 Stable Carbon Isotope Chemistry on Hydrocarbon Gas

Stable carbon isotopes sometimes can be used to help in the identification of the origin of gas in water wells. Four carbon isotope analyses on hydrocarbon gas were available for the Campbell Well 1 (Table 2). In addition to the Campbell Well 1, 49 area water wells from the D35 database have carbon isotope analyses on the hydrocarbon gases and on the carbon dioxide gas. Carbon isotope analyses for hydrocarbons and CO_2 were also available for the 7 water wells sampled by Matrix (2007b).

The most recent isotopic results from the Campbell Well 1 were performed by the Applied Geochemistry group at the University of Calgary using a gas chromatograph coupled to a Finnigan MAT delta plus XL mass spectrometer (3 kV). This analytical setup requires at least 500 ppm methane, 300 ppm ethane and 200 ppm propane in the injected gas to stay in the linear range of the mass spectrometer (Dr. Bernhard Mayer, personal communication). The reported $\delta^{13}C$ values have a precision of +-0.5 per mil. The analytical technique used for gas isotope results of the D35 samples and earlier Campbell Well 1 samples is not known. The most recent gas sample taken by AENV (June 5, 2007) sat for several weeks before being submitted for analysis (personal communication with AENV). The hydrocarbon gas analyses appear to be anomalously less depleted (less negative) and are likely not valid, especially when compared to the consistent isotope results previously obtained (Table 2).

A histogram of the carbon isotope values of methane from the Campbell Well 1, the surrounding D35 water wells, additional water wells (Matrix 2007b) and energy wells is presented in Figure

7. The methane values for the Campbell Well 1 have a biogenic carbon isotope signature but fall on the less depleted (less negative) side of the peak of the distribution for methane values for water wells. A statistical analysis of the mean isotopic compositions is presented at the end of this section. From a visual observation of the plot, it is observed that the energy wells have a less depleted (less negative) methane isotope signature. The D35 wells and Campbell Well 1 have methane isotope signatures that fall within the range typical of biogenic methane (Schoell 1980; Whiticar et al. 1986; Rice 1993).

A histogram of the carbon isotope values of ethane from the D35 water wells, the Campbell Well 1, the additional water wells and energy wells is presented in Figure 8. The Campbell Well 1 has ethane isotope signatures that are similar to the energy wells and less depleted than the local water wells. One additional water well (Pan Canadian Petroleum 1-89) also has an ethane signature similar to the energy wells. The source of ethane is not clear but possible sources could be a leak from a poor cement job in an energy well or natural leakage through a fault. The energy wells (Viking and Basal Belly River Formations) have much less depleted ethane isotope signatures.

A plot of the methane concentration versus the methane carbon isotope signature ($\delta^{13}C_{Methane}$) is presented on Figure 9. Below the line at -60 ‰ typically represents a biogenic (bacterial) origin for methane (Schoell 1980 and 1983; Whiticar et al 1986; Rice 1993). The energy wells have $\delta^{13}C_{Methane}$ values that are less enriched than the typical range of biogenic methane. These values represent thermogenic and mixed thermogenic/biogenic origin. The water well data, including the Campbell Well 1, all have $\delta^{13}C_{Methane}$ values that are predominantly biogenic.

A plot of the ethane concentration versus the ethane carbon isotope signature ($\delta^{13}C_{Ethane}$) is presented on Figure 10. Most of the surrounding water wells have ethane concentrations below the lab detection limit (which was as high as 100 ppm for some analyses). The Campbell Well 1 has 1130 ppm ethane (average of 3 analyses), about 25 times less than observed in the local energy wells. Of the D35 wells with detectable ethane, concentrations are about 85 times less than that observed in the energy wells in the area. This suggests a different source for the ethane or a small proportion of mixing (discussed later). The Campbell Well 1 has ethane isotope signatures that are similar to the energy wells and less depleted than the local water wells. A more rigorous statistical approach for mean isotope values with more detailed interpretations is presented at the end of this section.

A plot of the methane carbon isotope signature ($\delta^{13}C_{Methane}$) versus the ethane carbon isotope signature ($\delta^{13}C_{Ethane}$) is presented on Figure 11. The $\delta^{13}C_{Methane}$ and $\delta^{13}C_{Ethane}$ values of the energy wells are less depleted than most of the water wells. The $\delta^{13}C_{Ethane}$ values of the Campbell Well 1 are less depleted than the D35 wells, and are similar to the energy wells.

Both the hydrocarbon gas composition and the isotopic signatures can be a result of mixing between different sources of gases (such as biogenic methane with thermogenic methane). These hypothetical mixing curves (Figures 12, 13 and 14) can be calculated using the equations of Jenden et al. (1993).

In Figure 12 the carbon isotope ratio of methane is plotted against the ratio of methane to higher order hydrocarbons (C1/C2+C3+C4), sometimes referred to as the “wetness” of the gas. For this mixing calculation three different end member gases were considered: the average concentration biogenic methane gas in the area (from the D35 wells), a gas with an isotopic signature similar to the Campbell Well 1, and a thermogenic gas from local energy wells.

The first mixing scenario (curve 1) was the average biogenic methane gas found in the D35 water well ([Methane=648500 ppm], $\delta^{13}C_{methane}$=-63 ‰) mixed with a thermogenic methane gas from an energy well ([Methane=785600 ppm], $\delta^{13}C_{methane}$= -48‰). The Campbell Well 1 does not fall on this curve. The carbon isotopic signature of the methane in the Campbell Well 1 is too enriched to represent a mixture of the local biogenic methane with thermogenic gas in the area.

The second scenario (curve 2) started with a methane concentration similar to biogenic gas in the area [Methane=648500 ppm] with a methane carbon isotopic signature ($\delta^{13}C_{methane}$=-59 ‰) chosen so the Campbell Well 1 would fall on the curve, mixed with thermogenic methane from local energy wells ([Methane=785600 ppm], $\delta^{13}C_{methane}$= -48‰).. The tick marks on the curves represent mixtures of thermogenic gas with the gas from water wells, ranging from 0% to 100% in 5% intervals. The Campbell Well 1 mixing curve 2 shows a potential 5% mixture of the thermogenic with a biogenic end-member (chosen to fall though the well).

In Figure 13 the carbon isotope ratio of ethane is plotted against the ratio of methane to higher order hydrocarbons (C1/C2+C3+C4). For this mixing calculation the average concentration biogenic ethane gas in the area (from the D35 wells) and a thermogenic gas from local energy wells was used. The mixing scenario (curve 1) was the estimated average biogenic ethane gas found in the D35 water well ([Ethane=10 ppm], $\delta^{13}C_{methane}$=-57 ‰) mixed with a thermogenic ethane gas from an energy well ([Ethane=100000 ppm], $\delta^{13}C_{methane}$= -31‰). The ethane concentration of the local water wells was estimated to be 1/10th the detection limit from a few high precision ethane analyses. Detection limits for ethane in the D35 water well data were poor, with most analyses being <100 ppm. The ethane concentration of ethane in the energy wells used to calculate the mixing curve was higher than actually measured in the wells, to account for higher order hydrocarbons (propane, n-butane and i-butane). The carbon isotopic signature of the ethane in the Campbell (mixing curve 1) shows a potential 5% mixture of the thermogenic gas with a biogenic end-member.

In Figure 14 the carbon isotope ratio of methane is plotted against the carbon isotope ratio of ethane. The mixing scenario (curve 1) uses the same concentration and isotopic characteristics used in the Matrix (2007b) report. A biogenic gas found in the additional water wells ([Methane=950000], [Ethane=100 ppm], $\delta^{13}C_{methane}$=-63 ‰ and $\delta^{13}C_{ethane}$=-57 ‰) mixed with a thermogenic ethane gas from an energy well ([Methane=870000], [Ethane=50000 ppm], $\delta^{13}C_{methane}$= -50‰ and $\delta^{13}C_{ethane}$= -31‰). The carbon isotopic signature of the ethane in the Campbell (mixing curve 1) shows a potential 45% mixture of the thermogenic gas with a biogenic end-member. This does not seem reasonable. This shows how sensitive these mixing calculations are to the choice of end member gases. When the gas concentrations are not constrained on the plot, the mixing ratio for an isotopic fit through both methane and ethane of the Campbell Well 1 produces and unreasonable fit. By plotting the ethane and isotopes separately and constraining the gas concentration ratios (Figures 12 and 13) a consistent (and more reasonable) mixture of 5% thermogenic gas with biogenic gas is estimated.

4.5.5 Statistical Analysis

A statistical analysis was performed on gas concentration and gas carbon isotope data. The concentration of methane, ethane and propane along with the carbon isotope values of methane and ethane from water wells containing methane were compared to the Campbell Well 1 and the area energy wells (Table 4). Hydrocarbon gases were detected in 52 of 185 (28%) of the wells in the Ponoka/Wetaskiwin area.

Hydrocarbon Gas concentrations

Student T-Tests were used to compare methane concentrations in the Campbell Well 1 with the surrounding water wells. T-Tests are based on a t-distribution, which is similar to a normal distribution, but is dependent upon the number of samples measured. There is a significant difference between the mean methane concentrations in the Campbell Well 1 with that of the water wells (5% level of significance). Student T-Tests also indicate there is a significant difference between the mean methane concentrations in the Campbell well with that of the surrounding energy wells (5% level of significance). This statistically validates the contention that the methane concentrations in the Campbell Well 1 are lower than that of surrounding water wells and energy wells.

Ethane gas concentrations were detected by gas chromatography in 13 of 185 (7%) water wells tested. Of these thirteen wells, the average concentration was 310 ppm as compared to 26765 ppm in the energy wells and 1130 ppm in the Campbell Well 1. Propane and butane were detected (by gas chromatography) in the Campbell Well 1 (average 177 ppm and 71 ppm respectively). Propane was detected in the Pan Canadian 1-89 observation well (~100 ppm). Propane and butane were detected in the energy wells (average 22340 ppm and 4763 ppm respectively). These results indicate a different source for these higher order hydrocarbons or a mixture between biogenic and thermogenic gas.

Methane carbon Isotopic Signatures

Student T-Tests were used to compare mean methane carbon isotope value in the Campbell Well 1 with the surrounding water wells and the energy wells. There is a significant difference between the mean methane carbon isotope values in the Campbell Well 1 with that of the water wells (5% level of significance). This statistically validates the observation that the carbon isotope value of the methane in the Campbell Well 1 is less depleted (less negative) than the methane isotope signature of the surrounding water wells.

There is a statistically significant difference between the mean methane carbon isotope values in the water wells with that of the energy wells (5% level of significance). This statistically validates the observation that the mean carbon isotope value of the methane in the energy wells is less depleted than the methane isotope signature of the surrounding water wells
.
There is also a statistically significant difference between the mean methane carbon isotope values in the Campbell Well 1 with that of the energy wells (5% level of significance). This statistically validates the observation that the carbon isotope values of the methane in the energy wells is less depleted than the methane isotope signature of the Campbell Well 1.

Ethane Isotopic Signatures

Student T-Tests were used to compare mean ethane carbon isotope value in the water wells and the energy wells. There is a statistically significant difference between the mean ethane carbon isotope values in the wells with that of the Campbell Well 1 (5% level of significance). This statistically validates the observation that the carbon isotope values of the ethane in the Campbell Well 1 is less depleted (less negative) than the ethane isotope signatures of the surrounding water wells.

There is a statistically significant difference between the mean ethane carbon isotope value in the surrounding water wells with that of the energy wells (5% level of significance). This statistically validates the observation that the carbon isotope value of the ethane in the energy wells is less depleted than the ethane isotope signature of the surrounding water wells.

There is no statistically significant difference between the mean ethane carbon isotope values in the Campbell Well 1 with that of the energy wells (5% level of significance). This statistically validates the observation that the carbon isotope values of the ethane in the Campbell Well 1 are similar to the ethane isotope signature of the energy wells.

5 SUMMARY AND CONCLUSIONS

Alberta Research Council's review of the AENV Campbell complaint file and AEUB data, and independent review of additional data and aspects of the complaint, provides the following conclusions:

- The Campbell water Well 1 is completed in what previous authors refer to as Aquifer 3 of the Paskapoo Formation. Some local water wells appear to be predominantly completed in the same aquifer although most utilize shallower zones in the Paskapoo.
- The Paskapoo/Scollard Formations act as a separate groundwater flow system isolated from the Horseshoe Canyon Formation by the Battle and Whitemud aquitards and from the Belly River Aquifer by the Bearpaw aquitard. The Mannville aquifer is separated from shallower aquifers by the Colorado aquitard. This is supported by the presence trapped gas in the Horseshoe Canyon, Belly River, Viking and Mannville Formations and the

underpressured nature of the Horseshoe Canyon and Belly River Formations (Parks. and Tóth, 1995; Bachu 1999). Under natural conditions, flow between water saturated sandstone in the Paskapoo (where water wells are completed) and energy well zones is expected to be very limited.

- A local stress analysis indicates the most likely azimuth (orientation) of fractures and face cleats in the coal would be about 060° east of north (Bachu and Michael 2002). Several energy wells (within 1 km) line up on the 060° azimuth to the Campbell Water 1.
- Three energy wells in the vicinity (within 1.6 km) of the Campbell Well 1 have drilling and construction issues that need to be investigated:
- The oil well 00/02-18-043-27 W4M, located about 400 m south west of the Campbell Well 1, producing from the Basal Belly River Sands had no reported cement tops for either the surface or production casings. No cement bond logs were run.
- The oil/gas well 00/14-07-043-27 W4M (located approximately 1 km southwest of Campbell Well1) had remedial cement work done to stop a vent flow. This well produced from the Viking and Mannville Formation and continues to have hydrocarbon gases in the surface casing vent that have a thermogenic isotope signature.
- The oil well 00/5-18-043-27 W4M located approximately 1 km northwest, producing from the Mannville Formation, has reported cement returns but no bond log.
- The ethane and propane carbon isotope signatures of the Campbell Well 1 gas have been postulated to be deep Viking or Mannville in origin. Three Mannville wells in 05-18-043-27 W4M (00, 02 and 03) are located about 800 m to the north-west.
- An estimate of downward vertical gradient between the Campbell Well 1 and the producing energy zones ranges from 0.21 to 0.39. This represents a large downward vertical gradient. If these water well zone and the deeper energy zones become connected, water would flow downwards towards the deeper energy zone rather than up into the Campbell Well 1.
- A theoretical evaluation of the potential migration of methane as bubbles from the energy wells to the Campbell Well 1 (through an induced fracture) suggests that the downward flow of groundwater in the fracture would stop the upward migration of methane bubbles.
- The fluctuation in static water level observed in the Campbell Well 1, and corresponding drop in pressure on the aquifer, can be shown to contribute to the increase in amount of methane dissolved in the groundwater. This effect would be even greater during regular pumping of this well where the water level drops much more significantly.
- The water well major ion chemistry for the Campbell Well 1 is sodium bicarbonate (Na-HCO_3) or sodium calcium bicarbonate (Na-Ca-HCO_3) type water. The analyses show the Campbell Well 1 consistently exceeds the aesthetic objectives for total dissolved solids (TDS) and occasionally exceeds the aesthetic objective for sodium. This water chemistry is typical of water wells in the area.
- For all the D35 wells in the area sodium-bicarbonate (Na-HCO_3) and sodium-bicarbonate-chloride (Na-HCO_3-Cl) type waters are associated with the presence of methane in the water. The Campbell Well 1 has a chemistry that does not consistently correlate well to these trends but falls within the range of D35 chemistry results.

- The methane carbon isotope values for the Campbell Well 1 generally fall within the histogram distribution peak for methane values for all D35 wells in the area, but are on the less depleted (less negative) side.
- The energy wells in the area have $\delta^{13}C$ methane values that are less depleted than the typical range for biogenic methane. This range represents thermogenic and mixed thermogenic/biogenic origin.
- The water well data, including the Campbell Well 1, all have $\delta^{13}C$ methane values that are predominantly biogenic. This means the majority of the methane likely formed at a shallow depth.
- The ethane carbon isotope values for the energy wells in the area fall outside the histogram distribution peak for ethane values for all water wells in the area. They are less depleted an indicate a thermogenic origin.
- The $\delta^{13}C$ ethane values of the Campbell Well 1 are similar to the values of the energy wells and are less depleted (less negative) than the surrounding water wells.
- The hydrocarbon gas composition and isotopic values can be modified by mixing between different sources of gases. Hypothetical mixing of 5 % energy well gas with a biogenic end-member could produce results similar to the Campbell Well 1.
- The Pan Canadian observation well 1-89 (located approximately 3 km northwest of Campbell Well 1) also has a less depleted ethane value (-31.42 per mil) and is similar to the Campbell Well 1. These wells are hydraulically connected as water withdrawals from the Pan Canadian 1-88 water supply well were shown to have caused about 4 m of drawdown in the Campbell Well 1. The north-west elongation of the drawdown cone is not consistent with the predicted fracture orientation from the regional stress regime. It is possible that there is a structural control (such as a regional fault) that affects gas leakage from a deep source. Alternatively, the heavy water production from 1-88 that had a drawdown cone incorporating the Campbell Well 1 could also have captured gas from a leaking well near the Campbell Well 1).
- Student T-Tests statistically validate the observation that the carbon isotope signature of the methane in the Campbell Well 1 is different from the methane isotope signature of the surrounding D35 water wells and energy wells.
- Student T-Tests statistically validate the observation that the carbon isotope value of the ethane in the Campbell Well 1 is the same as the ethane isotope signature of the energy wells and different than the surrounding water wells.

Alberta Research Council's review of the AENV Campbell complaint file and AEUB data, and independent review of additional data and aspects of the complaint, provides the following recommendations:

- The cement integrity of energy well 00/02-18-043-27 W4M should be further investigated.
- The cement integrity of energy well 00/05-18-043-27 W4M should be further investigated.
- The cement integrity of energy well 00/14-07-043-27 W4M should be further investigated.

- Three Mannville wells in 05-18-043-27 W4M (00, 02 and 03) should be sampled for gas composition and carbon isotopes.
- A study could be conducted, using seismic data from energy companies, to try to identify fault structures in the area that could be conducting deep (Viking or Mannville) fluids to the overlying Paskapoo aquifer.

Overall Conclusion

Alberta Research Council's overall conclusion of the evidence from the review of the AENV and AEUB files, along with a new review and evaluation of addition data and aspects, is that the Campbell Well 1 appears to be impacted by a deep gas source. Additional work need to be done to identify whether the source of contamination is a leaking resource well or a natural pathway such as a fault.

6 CLOSURE

This report details a thorough review of the AENV well complaint file for Ms. Campbell regarding Coal Bed Methane (CBM) and conventional gas activities undertaken by energy companies in the area and the subsequent perceived decrease in water quality of the Campbell well.

This work was carried out in accordance with accepted hydrogeological practices.

Respectfully submitted,
Alberta Research Council
Permit to Practice P03619

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Table 1 AEUB Review of Energy Wells Near the Campbell residence

Well Location	Spud date/FDD/On Production	Surface Casing. (m)	Total Depth (m)	Perforation Depths (m) and Dates	Fracture Depths (m) and Dates	Comments
F1/03-07-043-27W4	16 Nov 90 17 Nov 90 No info.	30.8	54.0	Liner from 28.8 to 54.0		Water Well Surface Casing cemented full length – reported
F4/03-07-043-27W4	13 Nov 90 13 Nov 90 1 Apr 91	92.5	135.0	Open hole from 92.5 to 135.0		Water Well Surface Casing cemented full length - reported
00/11-07-43-27W4	07 Dec 05 08Dec 05 Not on production	100.0	678.0	All on 24 Jan 06 530.0 – 531.0, 424.0 – 425.0 379.0 – 380.0, 281.0 – 282.0 254.0 – 255.0, 222.0 – 223.0 208.0 - 209.0 (Edmonton/Belly River)	All perforations fractured on 30 Jan 06	No lost circulation reported Good cement returns on surface and production casing reported No cement bond log
00/14-07-043-27W4	02 Aug 85 09 Aug 85 01 Nov 85 (Basal Belly River)	203.0	1765.0	1739.0-1740.0 / 02 Oct 85 (Ellerslie) 1714.0-1717.0 / 10 Oct 85 (Glauconitic) 989.7- 990.0 / 15 Oct 85 (Remedial cementing) 954.7-955.0 / 17 Oct 85 (Remedial cementing) 968.0-971.0 / 22 Oct 85 (Basal Belly River – oil) 1714.0-1717.0 / 20 Jul 03 (Glauconitic) 1713.5-1717.0 / 21 Jul 03 (Glauconitic) 1537.0-1538.3 / 17 Sep 03 (Viking - gas)	1739.0-1740.0 / 5 Oct 85 968.0-971.0 / 23 Oct 85 1713.5-1717.0 / 24 Jul 03 1537.0-1538.3 / 21 Sep 03	No lost circulation reported Good cement returns on surface casing Bridge plugs: 1728.0-1736.0 / 10 Oct 85 1702.0-1710.0 / 15 Oct 85 Production casing cement top @ 1015 m. from cement bond log. Remedial cementing through perfs @ 989.7-990.0 & 954.7-955.0 to remediate vent flow. Cement squeezed perfs @ 968.0-971.0 / 17 Jul 03 Bridge plugs: 1734.0 / 21 Jul 03 1708.0-1710.0/ 28 Jul 03

Well Location	Spud date/FDD/On Production	Surface Casing. (m)	Total Depth (m)	Perforation Depths (m) and Dates	Fracture Depths (m) and Dates	Comments
00/16-07-043-27W4 *surface casing vent flow present – non-serious classification	05 Sep 87 09 Sep 87 03 Oct 87	200.0	1010.0	957.0-960.5 / 24 Sep 87 (Basal Belly River – oil)	957.0-960.5 / 25 Sep 87	No lost circulation reported Good cement returns on surface casing reported No information on production casing cement top in Tour Reports. Cement bond log indicates production casing cement top at 511.0 metres.
W0/13-08-43-27W4	30 Jan 53 30 Jan 53	N/A	208.0	N/A		Structure test hole – no tour report. Drilled and abandoned without casing
00/02-18-043-27W4 Directional well	18 Jun 88 24 Jun 88 18 Sep 88	202.0	1045.0 (TVD = 1006.4)	993.0-1001.0 / 10 Aug 88 (Basal Belly River – oil)	993.0-1001.0 / 11 & 12 Aug 88	Lost circulation @ 68 m and regained @ 168.0 m prior to setting and cementing surface casing. No information on cement returns for either casing string in Tour Reports. No cement bond log
00/05-18-43-27W4	13 May 03 16 May 03 03 Aug 03	211.0	1800.0	1754.0-1755.8 / 26 May 03 (Ellerslie – oil)	1754.0-1755.8 / 08 Jun 03	No lost circulation reported Good cement returns on surface and production casing reported.
02/05-18-043-27W4	18 Jun 04 24 Jun 04 29 Jul 04	236.0	1636.5	1597.0-1599.0 / 08 Jul 04 (Upper Mannville – gas)	1597.0-1599.0 / 19 Jul 04	No lost circulation reported Good cement returns on surface and production casing reported Cement bond log confirms cement to surface on production casing

Well Location	Spud date/FDD/On Production	Surface Casing. (m)	Total Depth (m)	Perforation Depths (m) and Dates	Fracture Depths (m) and Dates	Comments
03/05-18-043-27W4	23 Jul 05 27 Jul 05 02 Sep 05	372.0	1793.0	1759.5-1761.0 / 08 Aug 05 (Ellerslie – oil)	1759.5-1761.0 12 Aug 05	No lost circulation reported Good cement returns on surface and production casing reported Cement bond log confirms cement top on production casing above base of surface casing.
00/07-18-043-27W4	20 Nov 03 24 Nov 03 02 Oct 06	240.0	1770.0	1537.0-1539.0 / 13 Dec 03 (Viking) 973.5 – 976.0 / 27 May 06 (Basal Belly River – oil)	1537.0-1539.0 / 21 Jan 04 973.5-976.0 / 28 May 06	Bridge plug @ 1522.0 – 1530.0 / 27 May 06 No lost circulation reported Cement returns on surface casing not reported Good cement returns on production casing reported, and confirmed by cement bond log.
00/08-18-043-27W4	03 Jul 88 06 Jul 88 05 Sep 90	209.5	1033.0	985.5-991.0 / 26 Aug 88 (Basal Belly River – oil)	985.5-991.0 / 28 Aug 88	No lost circulation reported Cement returns on surface and production casing not reported. Cement bond log indicates production casing cemented full length
02/10-18-043-27W4 +production events	06 Jun 03 09 Jun 03 15 Feb 04+ 23 Jun 06+	213.0	1790.0	1753.0-1756.0 / 14 Jun 03 (Ellerslie – gas cap to oil pool) 1597.5-1603.0 / 13 Jul 03 (Upper Mannville – gas) 1553.5 – 1555.0 / 14 Jun 06 (Viking - gas)	1597.5-1603.0 / 19 Jul 03 1553.5-1555.0 / 19 Jun 06	Lost circulation @ 100 m – controlled with sawdust Good cement returns on surface and production casing reported Cement bond log appears to confirm production casing cement. Poor digital log quality. Packer at 1745.9 separating lower zone from upper two zones. Upper two zones are commingled.

Table 2 Summary of Chemical Analyses for the Campbell Water Well

Parameter	Units	Campbell Well 1									GCDWQ Recommended Limit	
Date	dd/mm/yyyy	05/06/1991	22/09/2005	26/09/2005	15/06/2006	21/07/2006	21/07/2006	05/06/2007	05/06/2007	05/06/2007	AO	MAC
Consultant		HCL	Wiebe	Wiebe	Chinook Environmental Services Ltd.	Golder	GCHEM Ltd.	Aenv	Aenv	Aenv		
Laboratory		Western Industrial	Maxxam	Maxxam	NorWest Labs	NorWest Labs	GCHEM Ltd.	ALS Labs	ARC	U of C		
pH	units	8.4	8.22	---	8.33	7.84	---	8.4	---	---	6.5 - 8.5	---
EC	μS/cm	1275	910	---	1220	908	---	1200	---	---	---	---
TDS-calculated	mg/L	**823**	**547**	---	**785**	**534**	---	**769**	---	---	500	---
Total Alk. as CaCO3	mg/L	583	---	---	561	465	---	582	---	---	---	---
Sodium	mg/L	**278**	125	---	**264**	107	---	**265**	---	---	200	---
Potassium	mg/L	---	2.8	---	1.8	3.4	---	1.9	---	---	---	---
Calcium	mg/L	28	55.2	---	28.2	66.4	---	19.2	---	---	---	---
Magnesium	mg/L	11	20.9	---	10.9	29.2	---	9.8	---	---	---	---
Iron	mg/L	---	---	---	<0.01	**0.38**	---	<0.05	---	---	0.3	---
Iron (total)	mg/L	**0.34**	0.3	---	0.2	0.3	---	0.038	---	---	---	---
Manganese	mg/L	---	**0.059**	---	<0.01	**0.084**	---	<0.01	---	---	0.05	---
Manganese (total)	mg/L	---	---	---	0.025	**0.078**	---	0.016	---	---	---	---
Chloride	mg/L	7	13.3	---	10	11.8	---	7	---	---	250	---
Fluoride	mg/L	0.7	---	---	0.56	0.2	---	---	---	---	---	1.5
Sulphate	mg/L	121	27.7	---	132	37.4	---	117	---	---	500	---
Carbonate	mg/L	50	nd	---	6	<6	---	15	---	---	---	---
Bicarbonate	mg/L	610	613	---	672	567	---	679	---	---	---	---
NO3 as N	mg/L	---	---	---	<0.01	<0.01	---	<0.1	---	---	---	10
NO2 as N	mg/L	---	---	---	<0.005	<0.005	---	<0.05	---	---	---	1
NO2+NO3 as N	mg/L	<0.002	nd	---	<0.02	<0.02	---	<0.1	---	---	---	10
Ion Balance %	%	0.08	4.83	---	2.32	0.73	---	3.35	---	---	---	---
Bacteria												
Total Coliforms	cfu/100mL	---	---	---	---	<1	---	---	---	---	---	0
Total Coliforms	mpn/100mL	---	---	---	---	---	---	---	---	---	---	0
Escherichia Coli	cfu/100mL	---	---	---	---	<1	---	---	---	---	---	0
Escherichia Coli	mpn/100mL	---	---	---	---	---	---	---	---	---	---	0
S Reducing Bacteria	cfu/100mL	---	---	---	---	9	---	Aerobic and Anaerobic	---	---	---	---
S Reducing Bacteria	MPN/mL	---	---	---	---	<0.3	---	---	---	---	---	---
Iron Related Bacteria	cfu/100mL	---	---	---	---	9000	---	Absent	---	---	---	---
Dissolved Hydrocarbons												
Benzene	mg/L	---	nd	---	---	---	---	0	---	---	---	0.005
Toluene	mg/L	---	nd	---	---	---	---	0	---	---	0.024	---
EthylBenzene	mg/L	---	nd	---	---	---	---	0	---	---	0.0024	---
Xylenes	mg/L	---	nd	---	---	---	---	0	---	---	0.3	---
F1(C6-C10) - BTEX	mg/L	---	nd	---	---	---	---	---	---	---	---	---
F2 (C10-C16)	mg/L	---	nd	---	---	---	---	---	---	---	---	---
F3(C16-C34)	mg/L	---	---	---	---	---	---	---	---	---	---	---
F4(C34-C50)	mg/L	---	---	---	---	---	---	---	---	---	---	---
Dissolved Gas Analysis												
Nitrogen	mg/L	---	---	---	---	---	---	---	24.7	---	---	---
Carbon Dioxide	mg/L	---	---	---	---	---	---	---	9.22	---	---	---
Oxygen	mg/L	---	---	---	---	---	---	---	---	---	---	---
Methane	μg/L	---	---	---	---	5140	---	---	2170	---	---	---
Ethane	μg/L	---	---	---	---	---	---	---	127	---	---	---
Propane	μg/L	---	---	---	---	---	---	---	5.36	---	---	---
n-Butane	μg/L	---	---	---	---	---	---	---	0.66	---	---	---
i-Butane	μg/L	---	---	---	---	---	---	---	3.15	---	---	---
δ13C Methane	‰ PDB	---	---	---	---	---	---	---	---	---	---	---
Free Gas Analysis												
Nitrogen	ppm	---	---	674200*	---	721400	---	---	819000	---	---	---
Carbon Dioxide	ppm	---	---	574100	---	24400	---	---	4190	---	---	---
Oxygen	ppm	---	---	174500	---	---	---	---	---	---	---	---
Methane	ppm	---	---	45800*	---	223500	153185	---	67900	---	---	---
Ethane	ppm	---	---	trace	---	1200	789	---	1400	---	---	---
Propane	ppm	---	---	nd	---	300	188	---	41.9	---	---	---
n-Butane	ppm	---	---	nd	---	<100	14	---	2.95	---	---	---
i-Butane	ppm	---	---	nd	---	100	90	---	24.4	---	---	---
δ13C CO2	‰ PDB	---	---	-22.38	---	-24.17	-28.27	---	---	-21.4	---	---
δ13C Methane	‰ PDB	---	---	-58.35	---	-57.5	-58.37	---	---	-41.6	---	---
δ13C Ethane	‰ PDB	---	---	-31.19	---	-30.75	-31.46	---	---	-29.3	---	---
δ13C Propane	‰ PDB	---	---	-26.58	---	-26.48	-27.11	---	---	---	---	---
δ13C n-Butane	‰ PDB	---	---	-25.86	---	-24.75	-27.43	---	---	---	---	---
δ13C i-Butane	‰ PDB	---	---	-27.85	---	-25.62	-22.12	---	---	---	---	---

GCDWQ - Health Canada Guidelines for Canadian Drinking Water Quality (2007)
AO - Aesthetic objective
MAC - Maximum acceptable concentration
* - Results reissued by lab April 11, 2006
nd - not detected
--- not analyzed
Bold font denotes exceedence of GCDWQ limit

Table 3 Gradient between Campbell Well and selected energy well formations.

Well	Formation Name	Gradient
102/10-18-43-27W4M/3	Viking	0.28
102/12-18-043-27W4/00	Ellerslie	0.39
103/08-13-043-28W4/00	Horseshoe Canyon	0.21
100/02-24-043-28W4/0	Horseshoe Canyon	0.29
100/08-24-043-28W4/2	Horseshoe Canyon	0.21
103/03-24-043-28W4/0	Horseshoe Canyon	0.30

Table 4. Statistical values and T-Tests of the gas and isotope data.

Water Wells			
	[Methane] (ppm)	$\delta^{13}C_{Methane}$ (‰)	$\delta^{13}C_{Ethane}$ (‰)
n	52	56	48
Min	1812	-75.38	-75.38
Max	972000	-45.16	-75.38
Mean	648499	-64.83	-50.00
Std.	303032	5.73	6.69

Campbell Well 1			
	[Methane] (ppm)	$\delta^{13}C_{Methane}$ (‰)	$\delta^{13}C_{Ethane}$ (‰)
n	4	3	3
Min	67900	-58.37	-31.46
Max	251400	-57.50	-30.75
Mean	173996	-58.07	-31.13
Std.	81918	0.05	0.36

Energy Wells			
	[Methane] (ppm)	$\delta^{13}C_{Methane}$ (‰)	$\delta^{13}C_{Ethane}$ (‰)
n	11	7	7
Min	150200	-60.12	-41.71
Max	916700	-48.00	-30.13
Mean	788345	-51.91	-32.87
Std.	219219	3.95	4.00

T-Test	T-Test	Degees of Freedom	5% level of significance
Mean [Methane] D 35 and Campbell	3.099	54	**significant difference**
Mean $\delta^{13}C_{Methane}$ D 35 and Campbell	-2.026	57	**significant difference**
Mean $\delta^{13}C_{Ethane}$ D 35 and Campbell	-4.836	49	**significant difference**
Mean [Methane] D 35 and Energy Wells	1.448	61	no significant difference
Mean $\delta^{13}C_{Methane}$ D 35 and Energy Wells	-5.775	61	**significant difference**
Mean $\delta^{13}C_{Ethane}$ D 35 and Energy Wells	-6.571	53	**significant difference**
Mean [Methane] Campbell and Energy Wells	-5.361	13	**significant difference**
Mean $\delta^{13}C_{Methane}$ Campbell and Energy Wells	-2.611	8	**significant difference**
Mean $\delta^{13}C_{Ethane}$ Campbell and Energy Wells	0.725	8	no significant difference

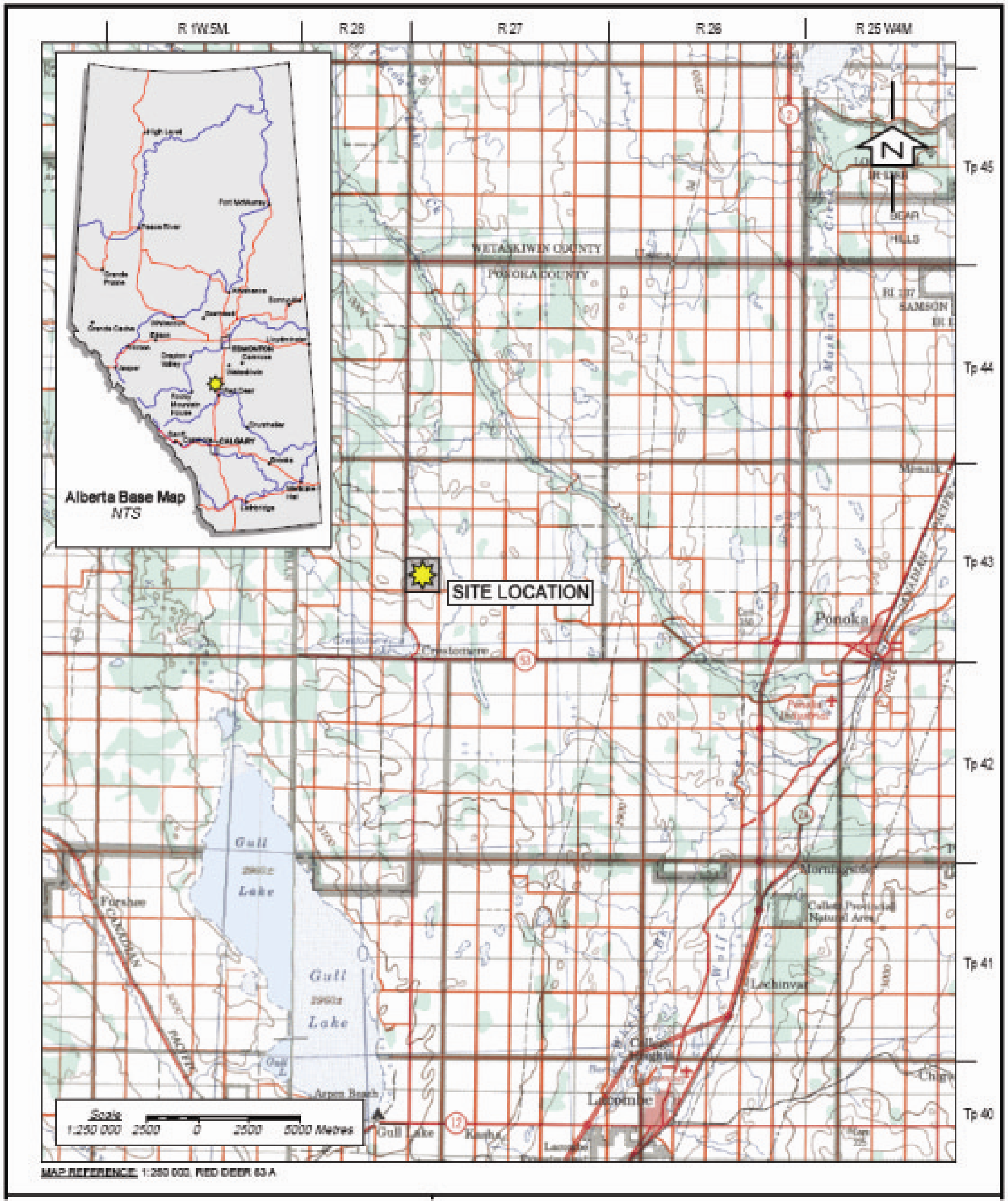

Figure 1 Campbell Well Location Map

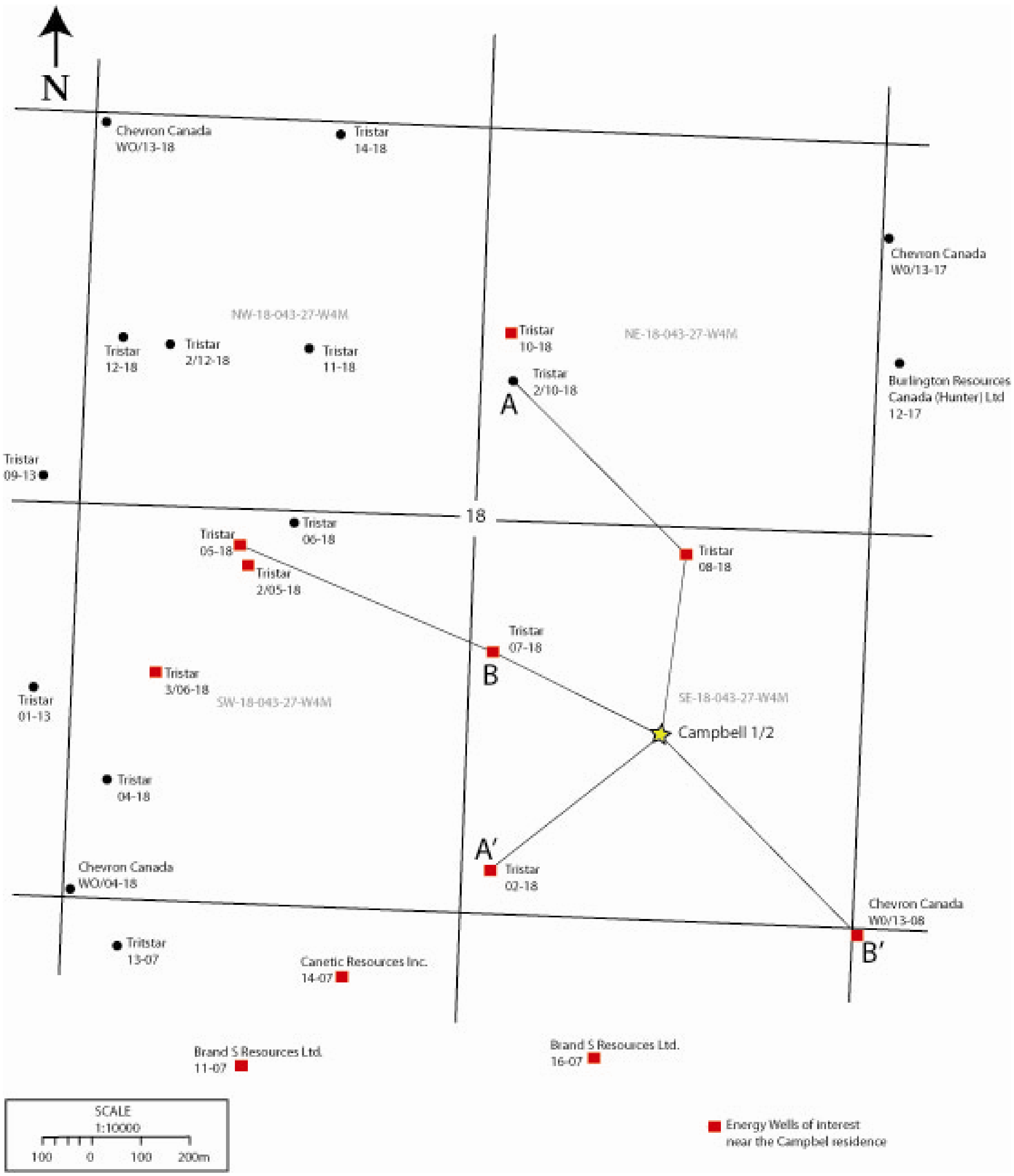

Figure 2 Energy wells Near the Campbell Residence and Location of Geologic Cross Sections

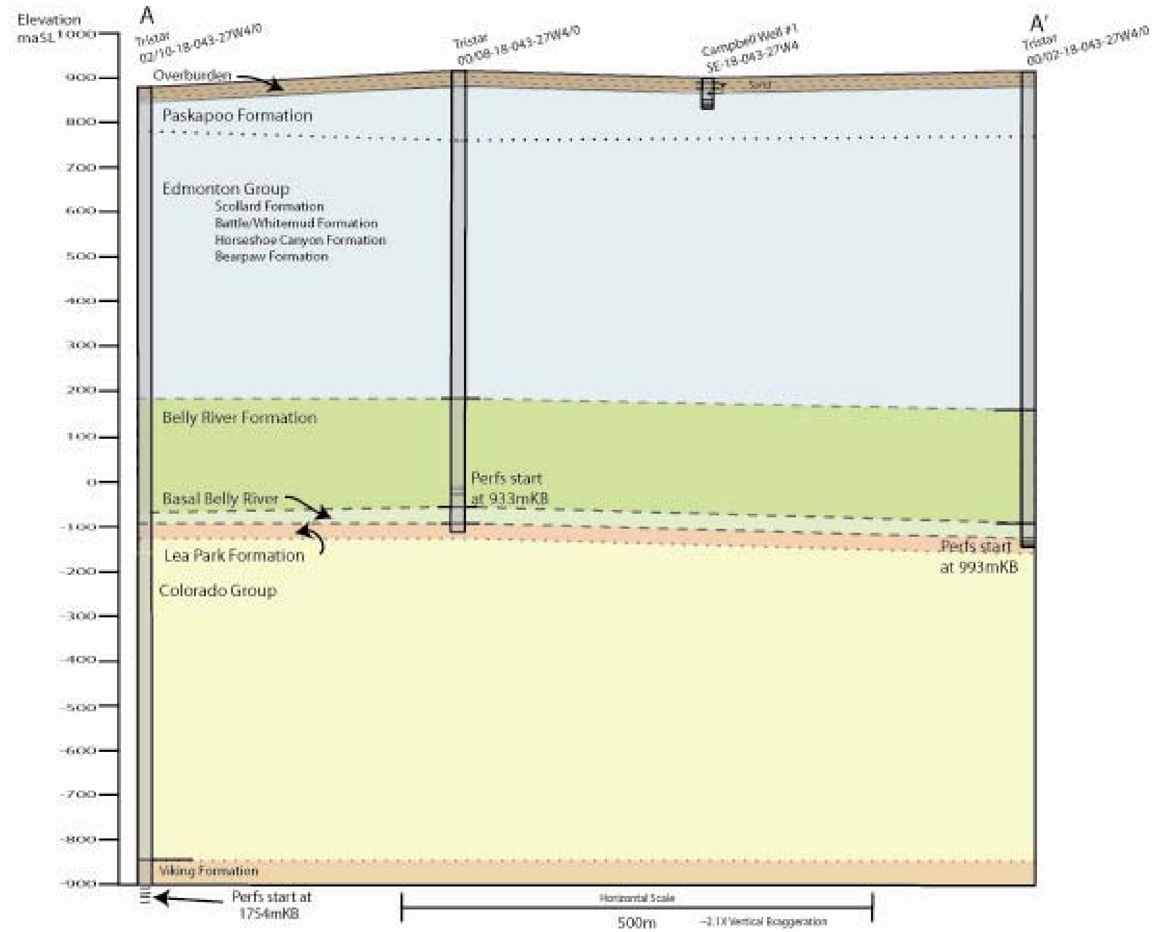

Figure 3a Geologic Cross-Sections A-A'

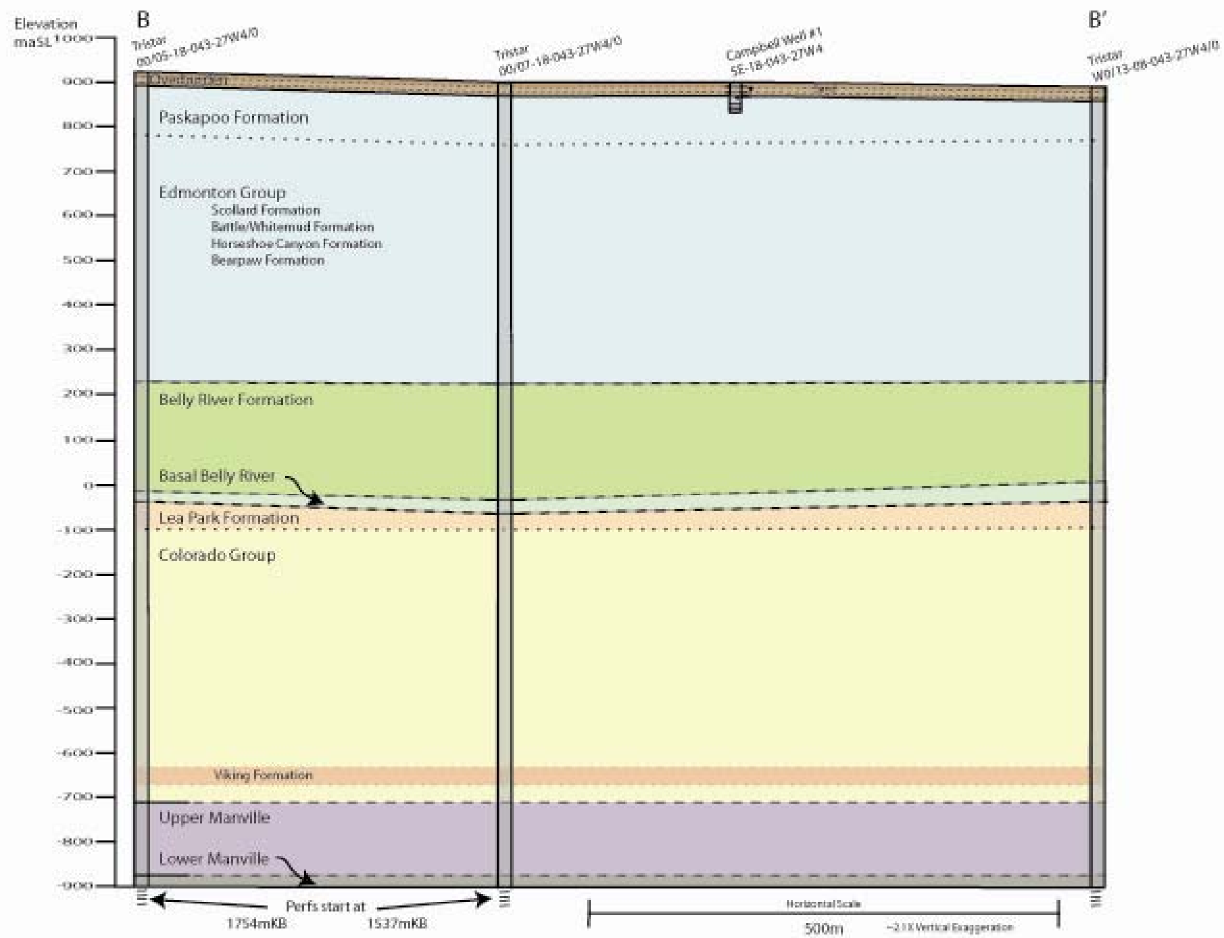

Figure 3b Geologic Cross-Sections B-B'

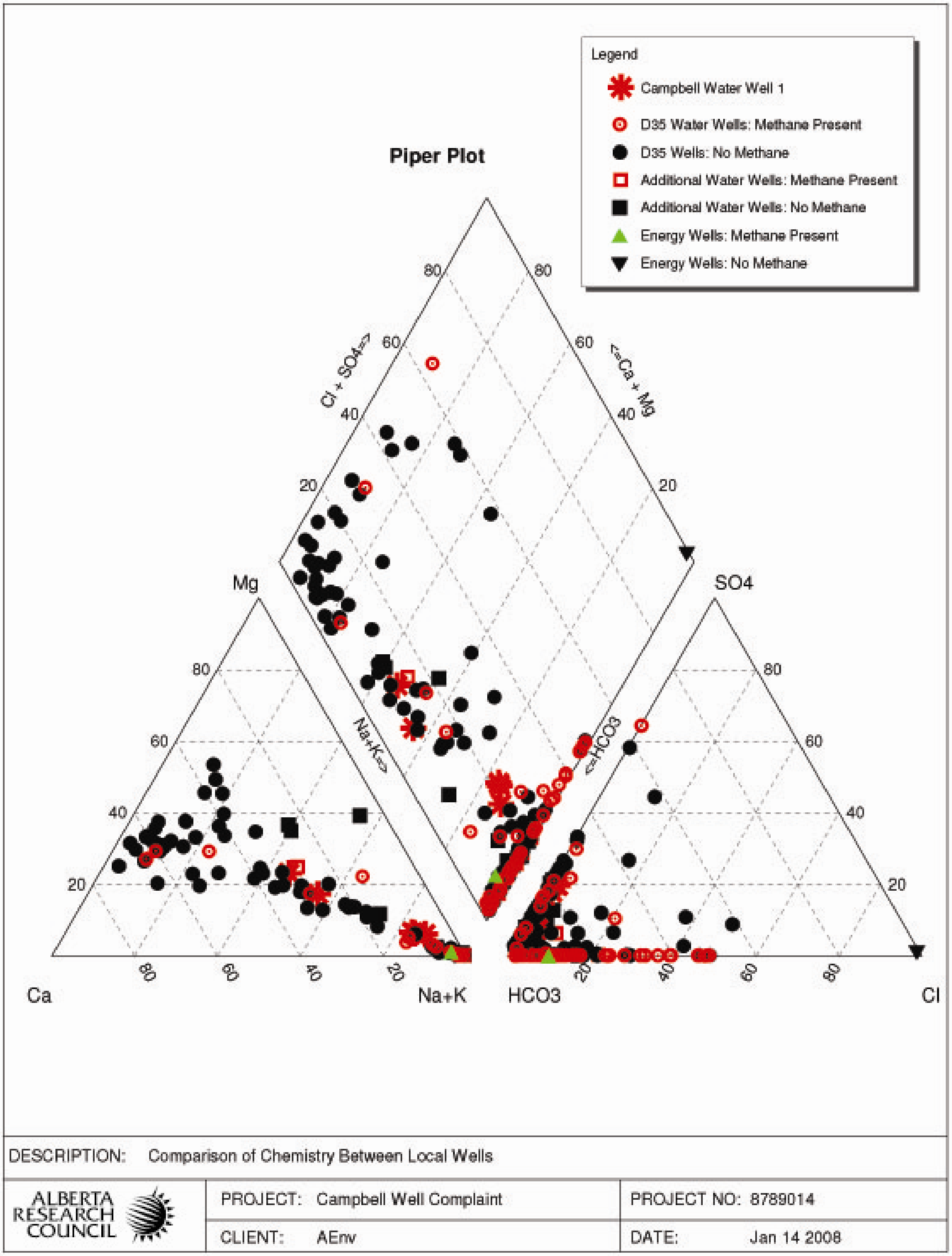

Figure 4. Piper plot of water chemistry from the Campbell well, Surrounding D35 and other water wells.

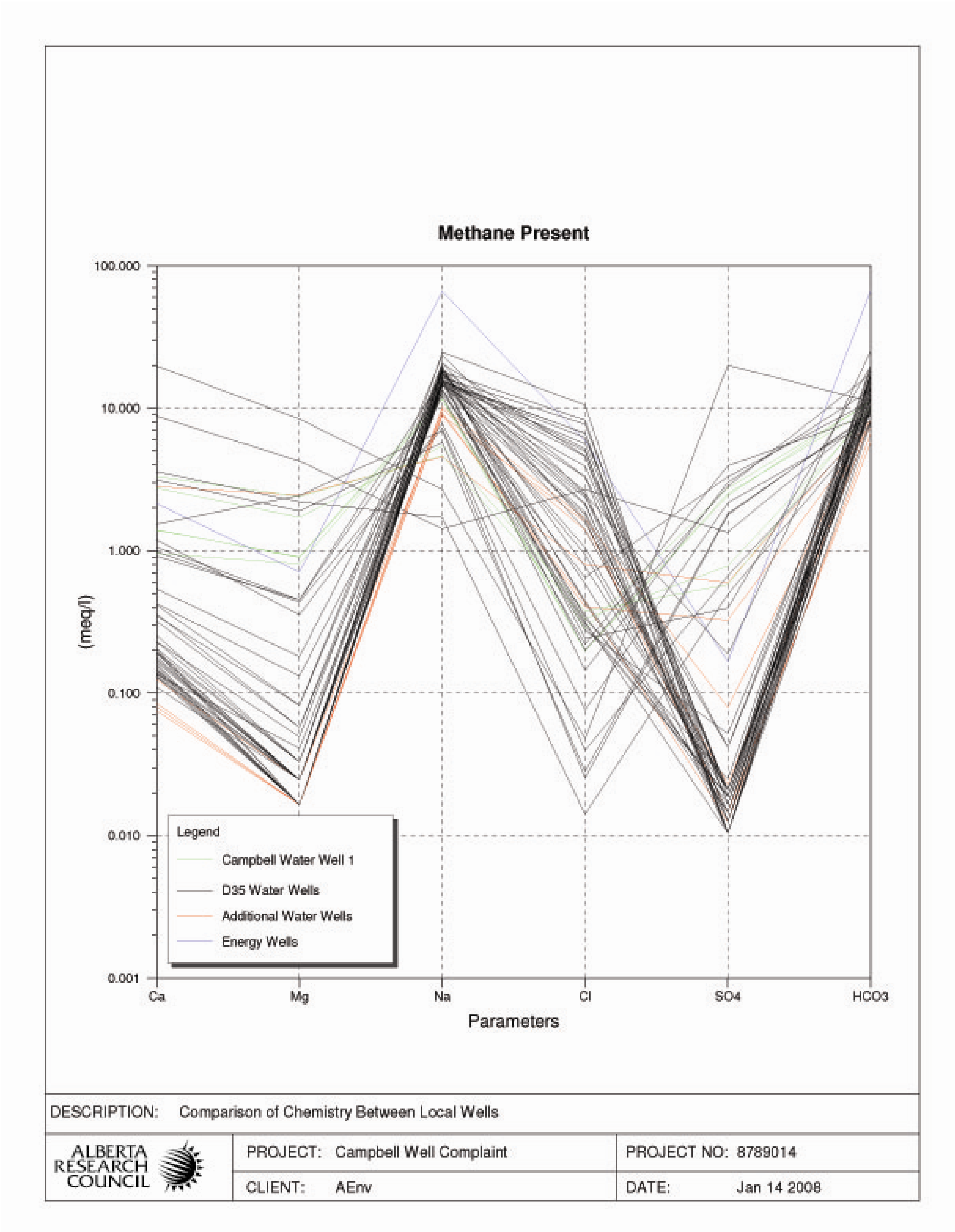

Figure 5 Schoeller plot of water wells with methane present.

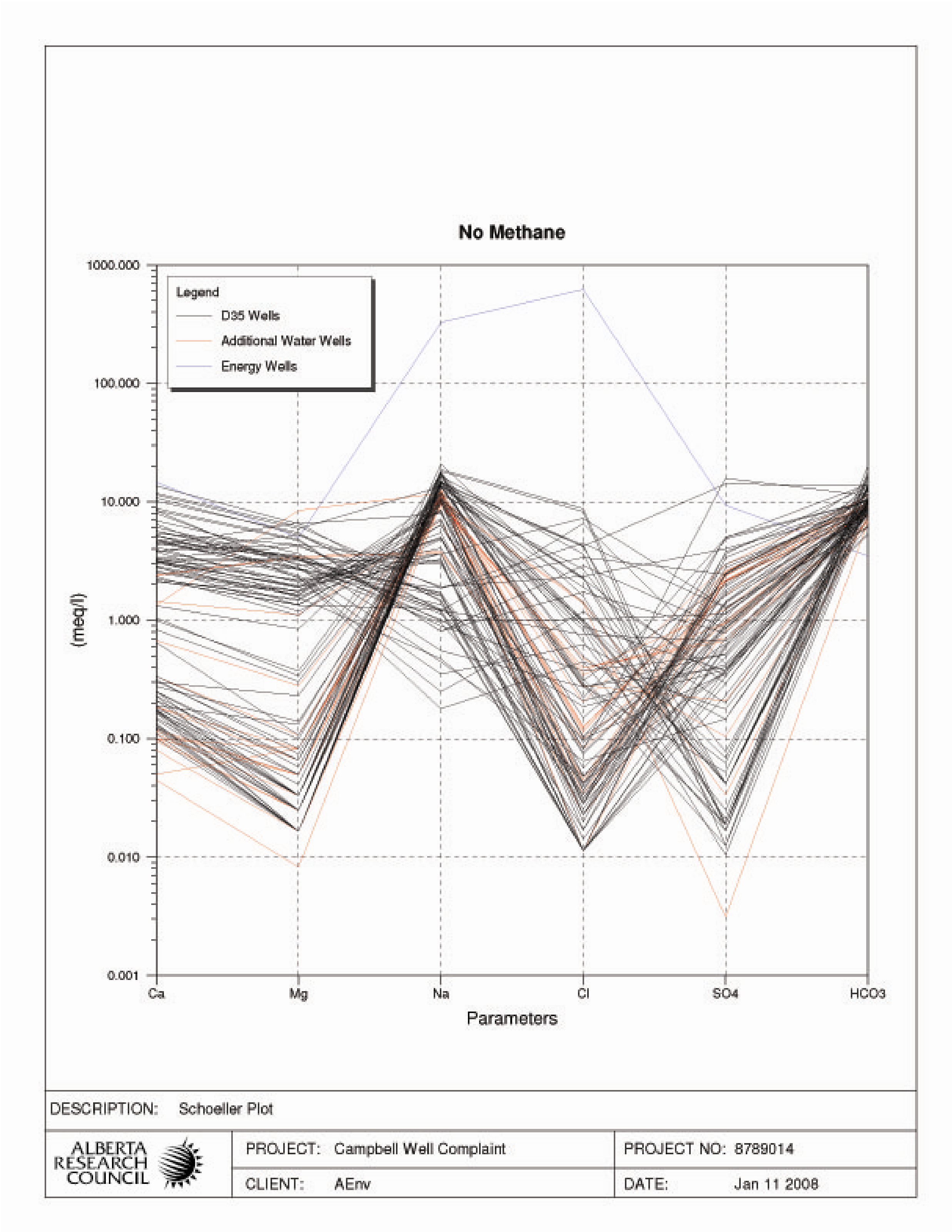

Figure 6 Schoeller plot of water wells with no methane.

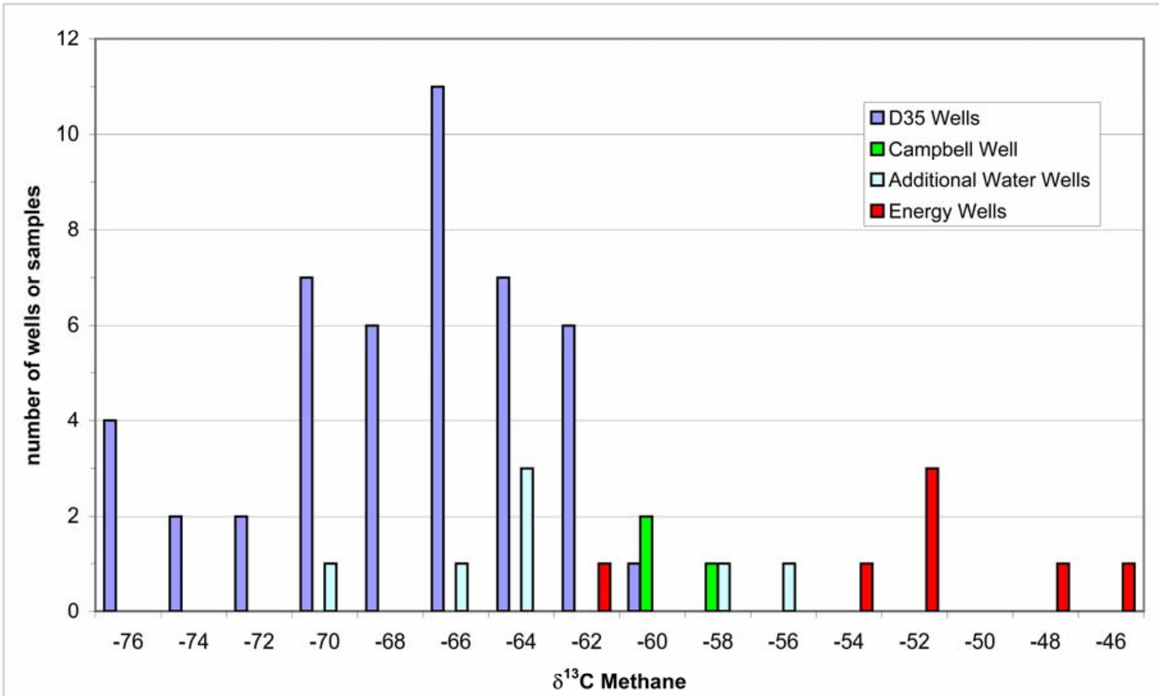

Figure 7 Histogram of the carbon isotope values of methane in all water wells and Energy wells.

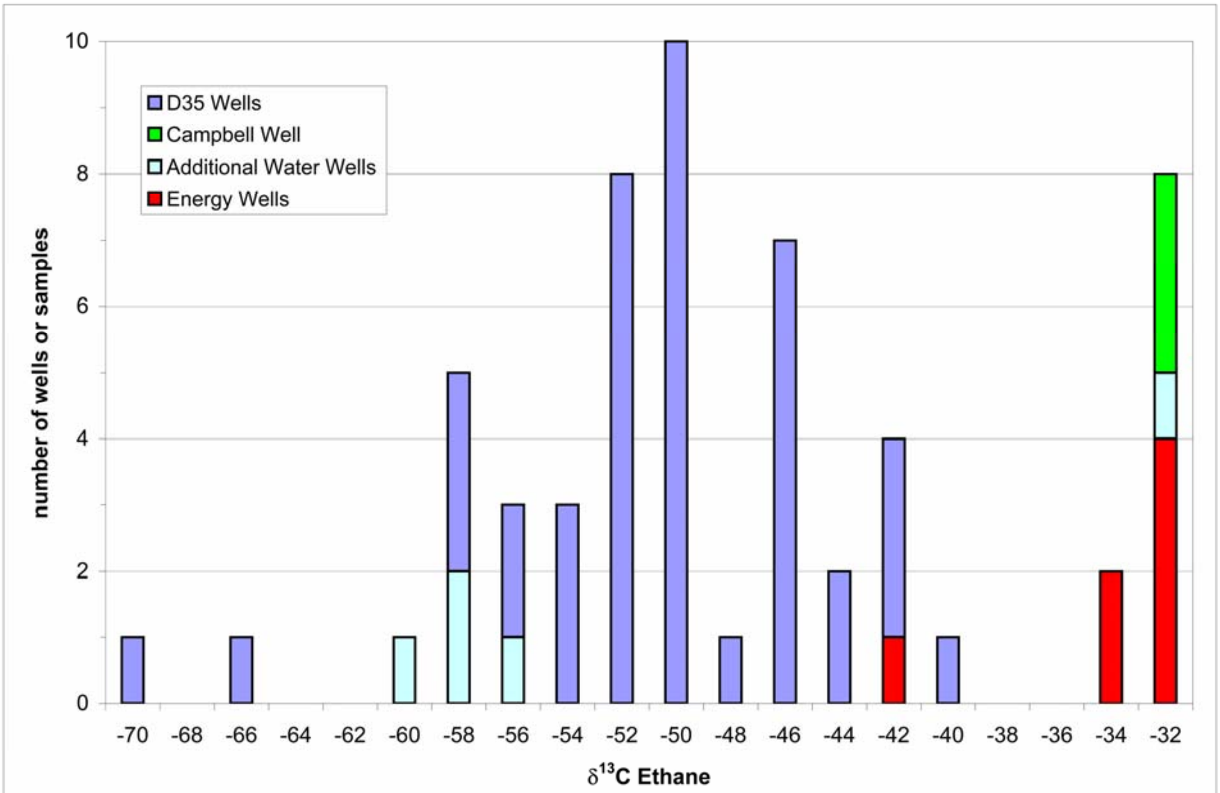

Figure 8 Histogram of the carbon isotope values of ethane in all water wells and energy wells.

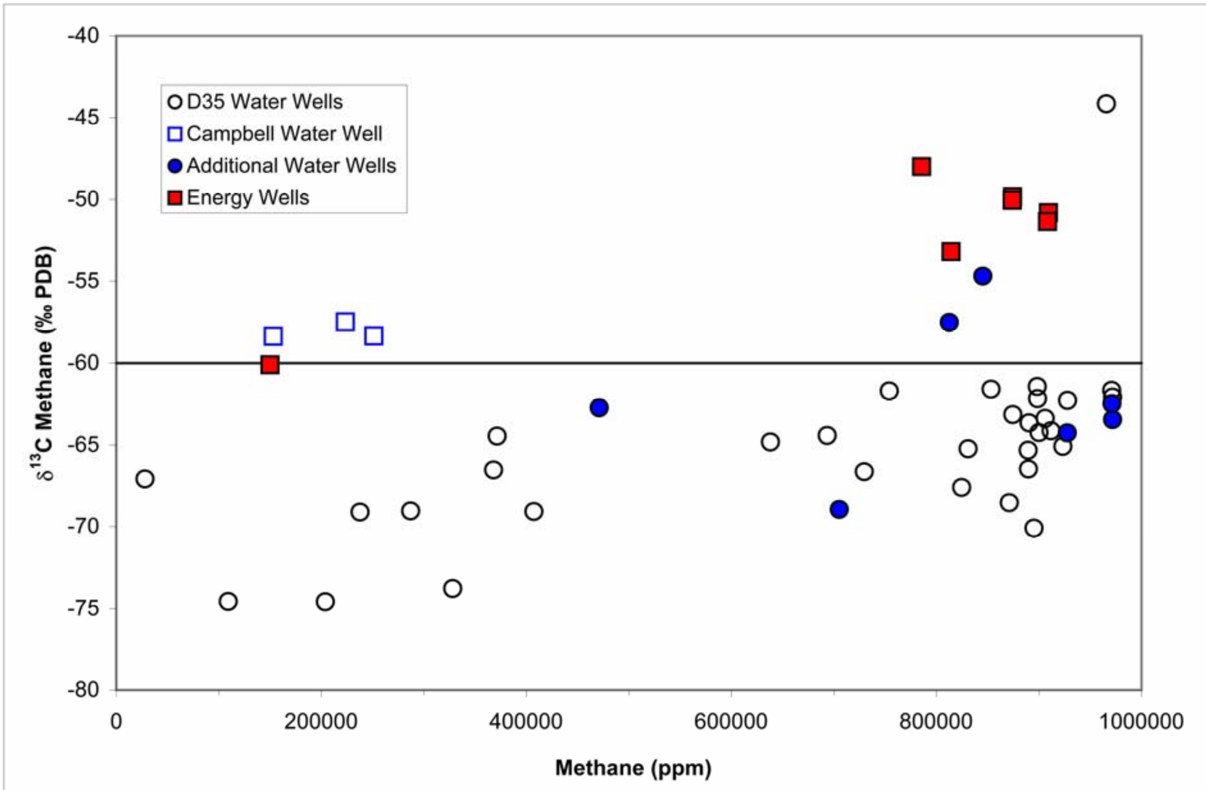

Figure 9 Methane concentration versus $\delta^{13}C$ of methane.

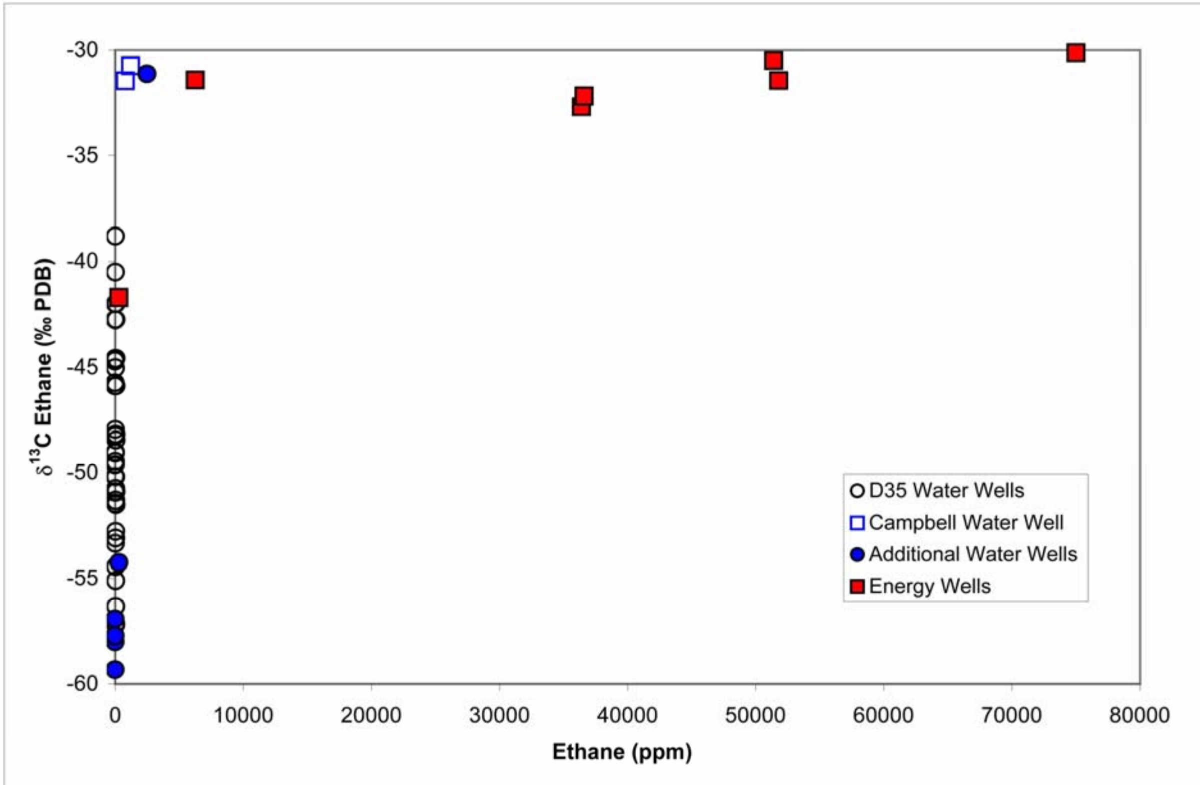

Figure 10 Ethane concentration versus $\delta^{13}C$ of ethane.

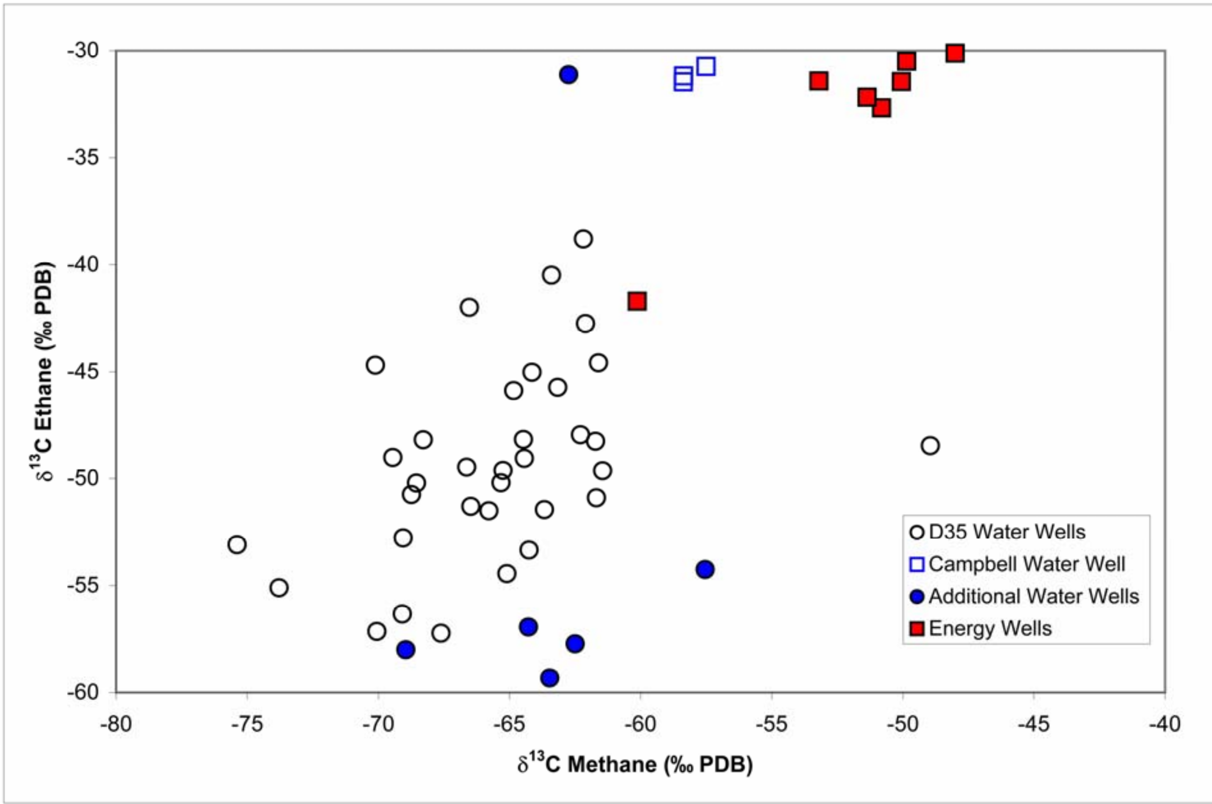

Figure 11 $\delta^{13}C$ Methane versus $\delta^{13}C$ Ethane.

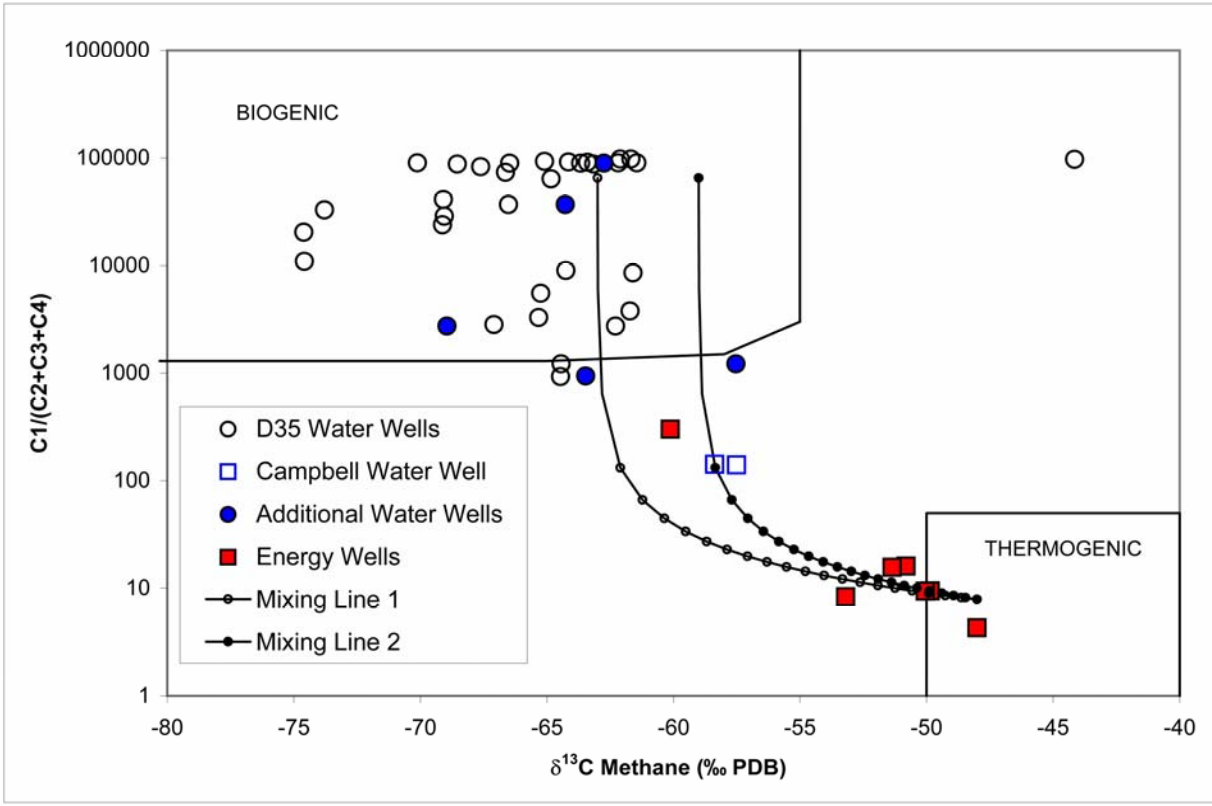

Figure 12 Mixing plot of $\delta^{13}C$ of methane versus the methane/C2+ ratio.
Data for the bacterial and thermogenic fields are from Faber and Stahl 1984.

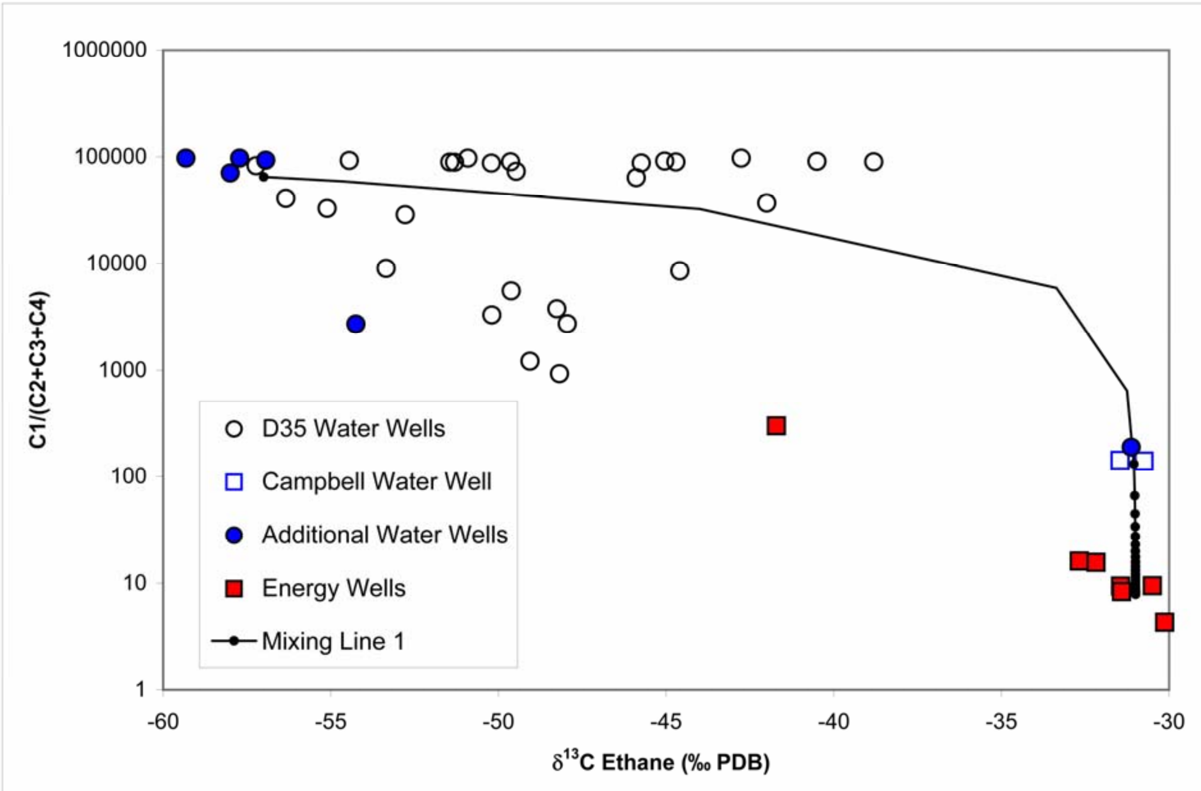

Figure 13 Mixing plot of δ^{13}C of ethane versus the methane/C2+ ratio.

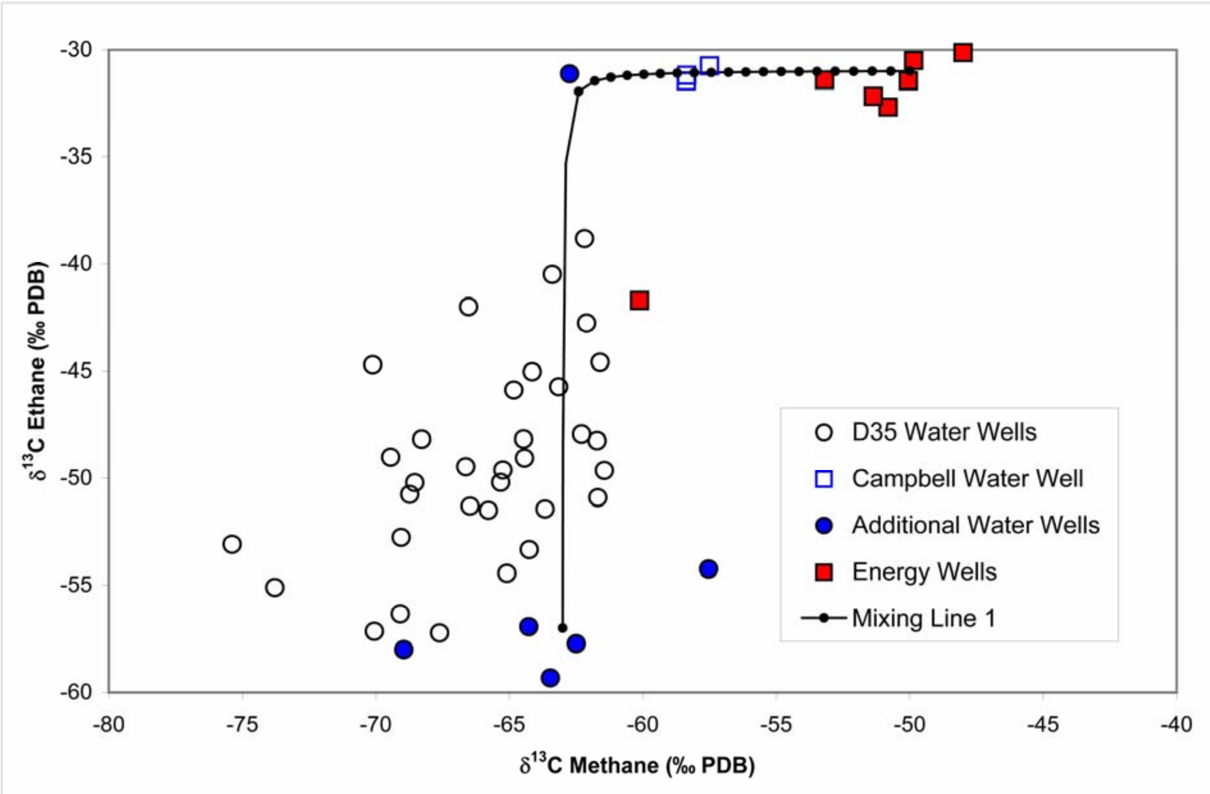

Figure 14 Mixing plot of $\delta^{13}C$ of methane versus the $\delta^{13}C$ of ethane.

APPENDIX A: CAMPBELL WATER WELL RECORD

Water Well Drilling Report

Alberta Environment

The data contained in this report is supplied by the Driller. The province disclaims responsibility for its accuracy.

Well I.D.:	0078001
Map Verified:	Map
Date Report Received:	1980/12/31
Measurements:	Imperial

1. Contractor & Well Owner Information

Company Name: FLINN DRILLING LTD.
Drilling Company Approval No.: ZZZZZZ
Mailing Address: GENERAL DELIVERY
City or Town: LACOMBE AB CA
Postal Code:
WellOwner's Name: CALCO RANCHES
Well Location Identifier:
P.O. Box Number:
Mailing Address: RR 4, PONOKA
Postal Code:
City:
Province:
Country:

2. Well Location

1/4 or LSD	Sec	Twp	Rge	Westof .M
SE	18	043	27	4

Location in Quarter
0 FT from Boundary
0 FT from Boundary
Lot Block Plan
Well Elev; 2825 FT
How Obtain: Estimated

3. Drilling Information

Type of Work: New Well
Reclaimed Well
Date Reclaimed:
Materials Used:
Method of Drilling: Rotary
Flowing Well: No
Rate: Gallons
Gas Present: No
Oil Present: No
Proposed well use: Stock
Anticipated Water Requirements/day 0 Gallons

6. Well Yield

Test Date (yyyy/mm/dd): 1980/11/28
Start Time: 11:00 AM
Test Method: Pump
Non pumping static level: 118 FT
Rate of water removal: 15 Gallons/Min
Depth of pump intake: 170 FT
Water level at end of pumping: FT
Distance from top of casing to ground level: Inches
Depth To water level (feet)
Elapsed Time
Drawdown Minutes:Sec Recovery
Total Drawdown: 52 FT
If water removal was less than 2 hr duration, reason why:
Recommended pumping rate: 0 Gallons/Min
Recommended pump intake: 180 FT
Type Pump Installed
Pump Type: SUB
Pump Model:
H.P.: 3/4
Any further pumptest information?

4. Formation Log

Depth from ground level (feet)	Lithology Description
21	Yellow Sand
69	Gray Clay
84	Gray Shale
121	Blue Shale
123	Gray Sandstone
194	Blue Shale
199	Gray Shale
220	Gray Sandstone

67.06m = 220.02 ft

5. Well Completion

Date Started(yyyy/mm/dd): 1980/11/27
Date Completed (yyyy/mm/dd): 1980/11/28
Well Depth: 220 FT
Borehole Diameter: 0 Inches
Casing Type: Steel
Size OD: 5.56 Inches
Wall Thickness: 0.188 Inches
Bottom at: 78 FT
Liner Type: Steel
Size OD: 4.5 Inches
Wall Thickness: 0.188 Inches
Top: 0 FT Bottom: 220 FT
Perforations
from: 180 FT to: 220 FT
from: 0 FT to: 0 FT
from: 0 FT to: 0 FT
Perforations Size:
0.125 Inches x 18 Inches
0 Inches x 0 Inches
0 Inches x 0 Inches
Perforated by: Torch
Seal: Driven
from: 0 FT to: 78 FT
Seal:
from: 0 FT to: 0 FT
Seal:
from: 0 FT to: 0 FT
Screen Type:
from: 0 FT to: 0 FT
Screen ID: 0 Inches
Slot Size: 0 Inches
Screen Type:
from: 0 FT to: 0 FT
Screen ID: 0 Inches
Slot Size: 0 Inches
Screen Installation Method:
Fittings
Top: Bottom:
Pack:
Grain Size: Amount:
Geophysical Log Taken:
Retained on Files:
Additional Test and/or Pump Data
Chemistries taken By Driller: No
Held: 0 Documents Held: 1
Pitless Adapter Type:
Drop Pipe Type:
Length: 168 FT Diameter: 1 Inches
Comments:

7. Contractor Certification

Driller's Name: UNKNOWN DRILLER
Certification No.:

* SUBJECT STOCK WELL

APPENDIX B: ASSESSMENT OF METHANE GAS MIGRATION POTENTIAL

Assessment of the forces controlling the methane gas bubble migration (personal communication with Dr. Jon Jones, PhD., University of Waterloo).

Buoyancy Force:

Buoyancy is the upward force exerted on an object produced by the surrounding fluid in which it is fully or partially immersed due to the pressure difference of the fluid between the top and the bottom of the object. Buoyancy is the force that gives the wings on airplanes the lift required for them to fly.

The net upward buoyancy force is equal to the magnitude of the weight of the fluid displaced by the object.

In simpler terms: Suppose you put a rubber ball in a beaker of water. One of three things will happen:

1) If the weight of the rubber ball equals the weight of the volume of water it displaces: the ball will remain stationary

2) If the weight of the ball is less than the weight of the volume of water it displaces: the ball will begin to float upwards until it breaks through the water surface and will continue to rise until the weight of the volume of water displaced equals the weight of the rubber ball. This is why ice bergs float. A cubic meter of iceberg weighs less than a cubic meter of ocean water.

3) If the weight of the ball is greater than the weight of the volume of water it displaces: the rubber ball will sink to the bottom of the beaker.

Weight Force (In Terms of Methane Gas and Water):

One cubic metre of methane gas under 1 atmosphere of pressure at 15° C has a mass of ~ 0.68 kg. One cubic metre of water under the same conditions has a mass of ~ 1000 kg. So if we placed a bubble of methane gas in our beaker, it would always float upwards because the mass of the methane is much less than the mass of the water it displaces.

Comparison of Forces:

Looking at the forces acting on the bubble of methane gas:

The net force pulling the methane gas bubble upwards is: Fb - Wm

Where Fb = Buoyant force [MLT-2]

Wm = Weight of the bubble [MLT-2]

We have established that the weight of the methane gas bubble is much less than the buoyant force (which is equal to the weight of the water that the bubble displaces). Therefore, the gas bubble will migrate upwards at some velocity.

If the velocity at which the methane gas bubble is rising were to be counteracted by water flowing downwards at the same velocity, then the bubble would remain stationary. If the water velocity were increased, the bubble would be pushed downward. Conversely, if the water velocity were decreased, the bubble would again begin to move upward, albeit at a slower rate.

The velocity at which a gas bubble migrates upward in a column of water is a function of the size of the bubble, i.e. the larger the bubble, the larger the upward velocity due to the increase in the net upward buoyant force. Also note that, as the gas bubble migrates upwards, it will be hindered by friction exerted on the bubble due to the viscosity of the fluid it is rising through.

Calculation Results:

Given the velocity that a gas bubble migrates upward in a column of water, it is simply a matter of determining if there is sufficient downward water velocity to counteract the upward migration of the bubble.

Radius of gas bubble (m)	Terminal upward velocity (m/s)
1.0×10^{-6}	2.18×10^{-6}
1.0×10^{-5}	2.18×10^{-4}
1.0×10^{-4}	2.18×10^{-2}
1.0×10^{-3}	2.18×10^{0}

Note: The upward velocities values listed represent theoretical maximum values. There are a number of factors that can affect these values.

The three most likely scenarios for the migration of the gas bubbles in natural systems would be through fractures, porous media and through cylindrical conduits like boreholes. The formulae for calculating the water velocities in these openings can be found in any standard hydrogeology textbook. Naturally, the site-specific conditions (and corresponding hydrological parameters) will dictate which particular formula (or formulae) is used.

Partial List of Mitigating Factors Affecting Upward Gas Migration

1. Tortuosity: Except for the case of upward migration through a borehole, the bubble will have to take a circuitous path in its upward migration as it manoeuvres through interconnected pore throats or fracture networks. As a result, the upward migration of the gas will be hindered.

2. Relative Size of the Gas Bubble to Pore Throat, Borehole or Fracture Aperture it is Flowing Through: If the diameter of the bubble is of the same order as the opening it is flowing through, there will be additional frictional forces slowing down the upward migration of the gas. The velocity values listed above assume that these forces are negligible.

3. Gas Entry Pressure: For the case of gas migration through fracture apertures or pore throats that are smaller than the diameter of the gas bubble, sufficient upward buoyant force is required

for the bubble to exceed the gas entry pressure. All other factors being constant, a single gas bubble whose initial buoyant force is insufficient to overcome the gas entry pressure will remain trapped. However, the usual case is a large number of gas bubbles migrating simultaneously. As the gas consolidates at entrapment sites, the buoyancy force will increase and eventually upward migration will resume.

4. Bubble Volume as a Function of Pressure: As the gas bubble migrates upward, the column of fluid exerting pressure on the bubble decreases. As a result, the bubble increases in size, thereby generating greater upward velocity due to an increase in the buoyant force. A quantitative expression relating the dynamics between bubble expansion and while moving upward and the accompanying increase in velocity are very difficult to obtain. For the velocities listed above, it was assumed that the size of the bubble remains constant. Whereas the first three mitigating factors in this list would tend to decrease the rate of upward gas migration, this factor would increase it.

5. Any geochemical processes that would make the bubble lose mass during migration (and thereby reduce its volume and decrease its upward velocity). However, it is very likely that this factor would be negligible in most instances.

APPENDIX C: CHEMICAL ANALYSES