JACK WATER WELL COMPLAINT REVIEW INTERIM REPORT

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Alberta Research Council Inc.
Permit to Practice P03619

Prepared for:

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EXECUTIVE SUMMARY

In the fall of 2005, Petrofund Energy Trust (now Penn West Energy Trust) initiated an investigation into a water well complaint by Mr. Bruce Jack regarding methane gas. In November, 2007, Alberta Research Council (ARC) was contracted by AENV to critically review the scientific and technical data contained in the AENV Jack water well complaint file.

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 in the Smoky Group and the oil/gas wells in the Charlie Lake Formation.
- An evaluation of mixing scenarios between shallow biogenic gas and conventional gas.

Alberta Research Council's overall conclusion of the evidence from the review of the AENV and ERCB files is that insufficient data exists to determine whether Mr. Jack's well has been impacted by conventional oil/gas wells in the area. Recommendations are made for additional sampling required.

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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 complaint placed by landowner Mr. Jack, located SW-12-078-08 W6M, near Spirit River, Alberta. The complaint was about conventional oil and gas activities undertaken by Penn West and his concerns about the presence of methane gas in his water well. 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 hydrocarbons 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 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 gas composition and isotope data from the Jack well, water well construction characteristics, oil and gas well drilling and completion information, and oil and gas well composition and isotope data. In addition, ARC endeavoured to compile, review and assess supplementary information not included within the complaint file. This supplementary information includes an evaluation of the regional geology and hydrogeology, and additional ERCB information on energy wells.

2 REGIONAL GEOLOGIC AND HYDROGEOLOGIC SETTING

2.1 Stratigraphy

The study area is found within the Alberta 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. A period of compression and uplift in the Tertiary led to the deposition of fluvial sandstone, siltstone and shale. Peat accumulation provided the source material for the coals in the Cretaceous/Tertiary Scollard Formation and the Tertiary Paskapoo Formation. Glaciation during the Quaternary eroded the bedrock and deposited unconsolidated sediments on the bedrock. A stratigraphic column for the Northwestern Plains and Deep Basin is presented in Figure 1. Descriptions of the geology from older to younger that are encountered in the area of investigation are as follows:

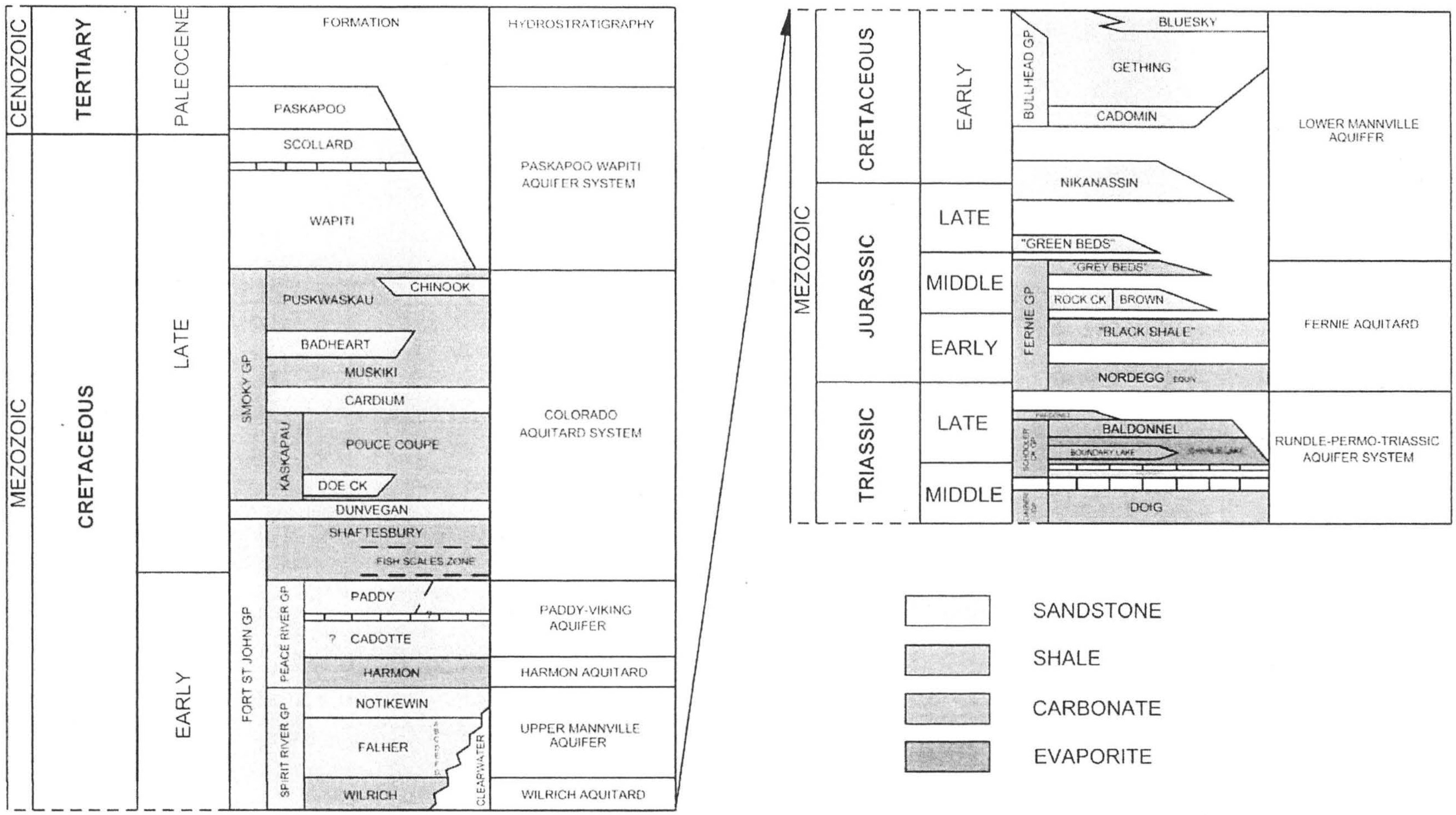

Figure 1 Stratigraphic column for the Northwestern Plains and Deep Basin.

Schooler Creek Group
The Schooler Creek Group, including the Charlie Lake and Baldonnel Formations are Late Triassic aged sediments that were continental shelf deposits on a passive margin. The Charlie lake Formation consists of sandstones, siltstones and anhydrite, deposited in near-shore marine, tidal flat, lagoon and aeolian environments. This formation is the target of all of the area energy wells and produces oil and some gas. The Baldonnel Formation consists of dolostones deposited on the continental slope.

Fernie Group
The Early Jurassic Fernie Group sediments (Nordegg Formation) are continental platform derived limestones and shales. The later formations (Black Shale, Rock Creek and Grey Beds are shales and sandstones are early sediments associated with the foredeep trough caused by the Columbian orogeny. The Nordegg Formation produces oil and gas, and the Rock Creek Formation produces gas.

Nikanassin Formation, Bullhead Group and the Fort St John Group
These Early Cretaceous rocks represent sediments derived from orogenic (mountain building) activity in south-western Alberta. The Nikanassin, Bullhead Group and Fort St John Group (equivalent to the Manville group in central Alberta) are predominantly fine sandstone and siltstone and interbedded sandstone with shale. These rocks contain oil and gas.

Dunvegan Formation
The Late Cretaceous Dunvegan Formation consists of argillaceous siltstone deposited in a fluviodeltaic setting. This formation contains oil and natural gas.

Smoky Group
The Late Cretaceous Smokey Group (equivalent to the Colorado group in central Alberta) is predominantly transgressive marine shale with several regressive events represented by sandstone. Several formations within this group contain oil and/or gas including the Doe Creek Cardium and Chinook Formations. The Jack well is completed in shale and sandstone of the Smoky Group at a depth of about 50 m.

In the area, the Smoky Group is covered by quaternary unconsolidated sediments and till.

2.2 Regional Stress Regime

The stress regime of upper Cretaceous – Tertiary coal-bearing strata in Alberta has a strong correlation to permeability and fracture directions in coal (face cleats). 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 coal would be about 055°E of N. Several energy wells (within 1.5 km) line up on the 055° azimuth to the Jack well. These wells, and others, will be examined in section 3 below.

2.3 Hydrostratigraphy and Groundwater Flow and Gradients

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).

In the Spirit River area shallow groundwater flow in the overburden is likely directed northeast towards Howard Creek and the Ksituan River.

Regional groundwater flow in the Smokey Group (where the Jack well is completed) is confined to relatively thin sandstone aquifers (Dunvegan, Cardium and Badheart) within a predominant aquitard system. Flow is directed to the northeast (Hitchon et al. 1990). Hydraulic conductivities of the rock are expected to be low to intermediate and yields from wells in this area are expected to be less than 1 imperial gallons per minute (Hackbarth 1977).

In the deeper (below 800 m) Paddy-Viking aquifer system groundwater flow is directed southeast towards a closed hydraulic head low. The permeability of this aquifer system is low, on the order of a few millidarcy (Hitchon et al. 1990). The Harmon aquitard separates the Paddy-Viking aquifer system from the Upper Mannville Aquifer.

Flow in the Upper Mannville Aquifer (Notikewin and Falher Formations) is directed to the northeast. Again, the permeability of this aquifer system is low, on the order of a few millidarcy (Hitchon et al. 1990). The Wilrich aquitard, the major aquitard in the Peace Rivers area, separates the Upper Mannville Aquifer from the Lower Mannville Aquifer.

Flow in the Lower Mannville Aquifer (Bluesky, Gething, Cadomin and Nikanassin) is directed to the northeast. The permeability of this aquifer system is low, on the order of a few millidarcy (Hitchon et al. 1990). The Fernie aquitard separates the Lower Mannville Aquifer from the Rundle-Permo-Triassic aquifer system. Flow in the Rundle-Permo-Triassic aquifer system is directed to the northeast.

3 ENERGY WELL INFORMATION

A map of the energy wells within an approximate 2 km radius of the Jack well was provided in the May 2007 Matrix Solutions Inc report and has been reproduced here (Figure 2). A summary of the cementing details for these energy wells is presented in Table 1. Several energy wells in the vicinity of the Jack well have surface casing vent flows (SCVF). SCVF are not necessarily an indication of shallow aquifers being impacted. However, there are potential concerns for energy wells with apparently good surface casing but have lower zones that may be leaking. The fresh water aquifers are not necessarily protected. The integrity of the surface casing cement needs to be considered. The cement log details just confirm the cement comes to the surface, but not whether there is a good bond to the formation and casing, or that there is no channelling. As well, there could be potential pathways outside of the borehole. There could be formation damage due to drilling, natural pathways (less likely) or induced pathways (potentially caused by temporarily closing the SCV) that could lead to gas migration to an overlying aquifer.

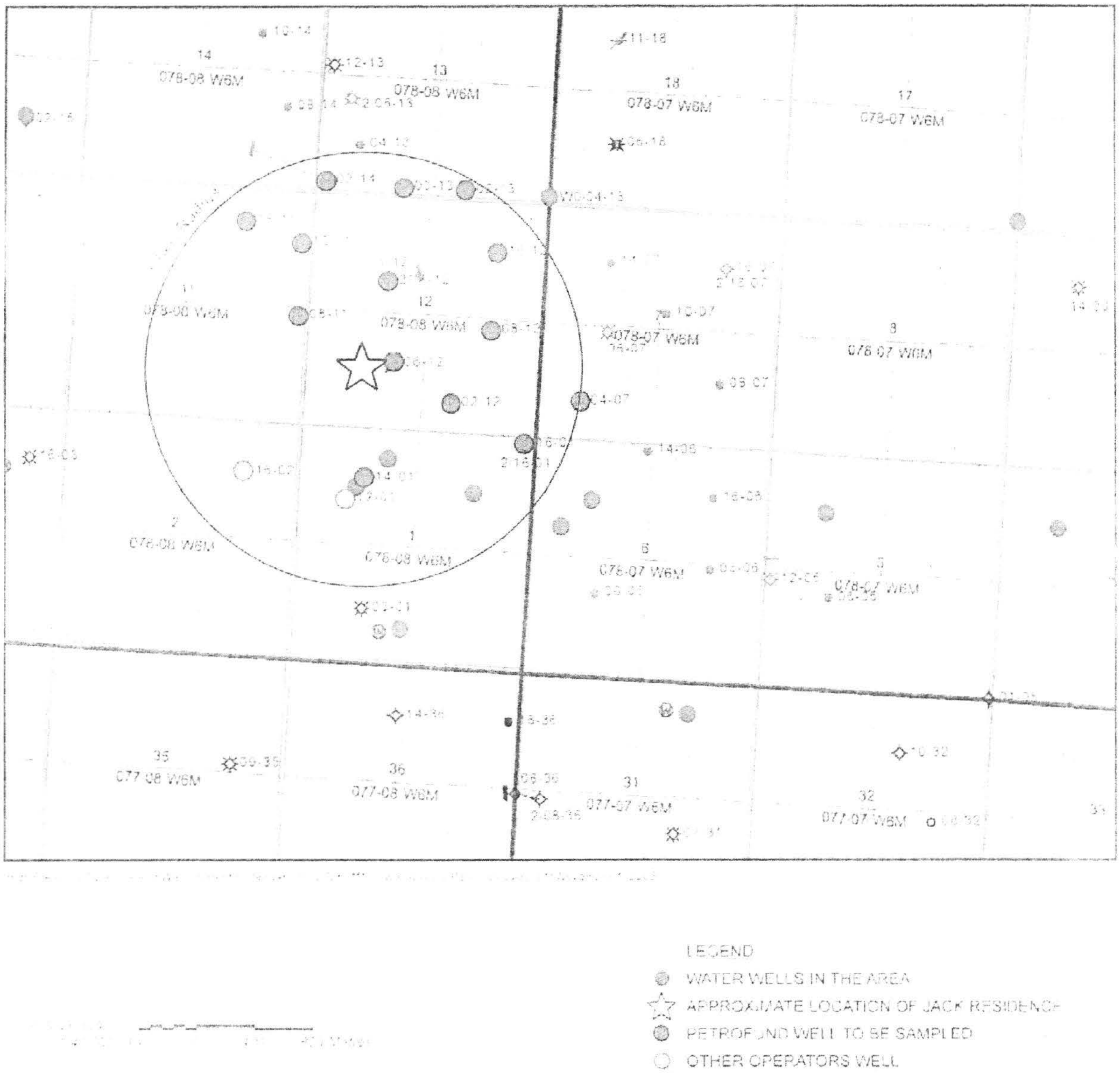

Figure 2 Map location of the Jack residence and surrounding energy wells (from Matrix Solutions 2007).

Several energy wells with SCVF that immediately surround the Jack well are discussed below. The energy well 100/6-12-078-8 W6M is the closest energy well to the Jack water well. The well was originally completed in 1982 as an oil well in the Charlie Lake Formation. In 2003 this well was converted to a water injection well. This well has a surface casing to 298 mKb and had cement returns to the surface. The production casing was cemented in two stages from 1610 to 1163 m Kb and from 1163 mKb to apparently above the bottom of the surface casing. In spite of an apparently acceptable cement job, this well has a surface casing vent flow of 32.1 m^3/day (Lionhead Engineering & Consulting 2006).

The energy well 100/11-12-078-8 W6M was completed in 1980 as a gas well in the Charlie Lake Formation. This well has a surface casing to 252 mKb and had cement returns to the surface. The production casing was cemented from 1628 to 745 m Kb. This well has an uncemented section between 252 and 745 mKb. This well has a surface casing vent flow of 9.8 m^3/day (Lionhead Engineering & Consulting 2006).

The energy well 102/11-12-078-8 W6M was completed in 2004 as an oil well in the Charlie Lake Formation. This well has a surface casing to 269 mKb and had cement returns to the surface. The production casing was cemented in two stages from 1620 to 810 m Kb and from 810 to the surface casing. In spite of an apparently acceptable cement job, this well has a surface casing vent flow of 1.4 m^3/day (Lionhead Engineering & Consulting 2006).

The energy well 100/16-12-078-8 W6M was completed in 1988 as an oil well in the Charlie Lake Formation. In 1998 this well was converted to a water injection well. This well has a surface casing to 224.6 mKb and had cement returns to the surface. The production casing was cemented from 840 to 1572 m Kb. This well has an uncemented section between 252 and 745 mKb. This well has a surface casing vent flow of 41.6 m^3/day (Lionhead Engineering & Consulting 2006).

The energy well 100/14-01-078-8 W6M was completed in 1982 as an oil well in the Charlie Lake Formation. This well has a surface casing to 290 mKb and had cement returns to the surface. The production casing was cemented in two stages from 1680 to 1102.5 m Kb and from 1102.5 to 543 mKb. This well has an uncemented section between 290 and 543 mKb. This well has a surface casing vent flow of 90.5 m^3/day (Lionhead Engineering & Consulting 2006).

The cement integrity of these energy wells may need to be further investigated after recommended new water and gas data from the Jack well has been collected and evaluated. The recommended new work is discussed in section 5 of this report.

Table 1 Summary of ERCB and Lionhead Engineering and Consulting Ltd review of cementing details from energy wells in the vicinity of the Jack well.

Designation	WELL ID	Pool or Zone	Status	Surface Casing Cement			Production Casing Cement (Stage 1)		Production Casing Cement (Stage 2)		Uncemtnted Zones		Cement Bond Log	SCVF
				Top (mKb)	Bottom (mKb)	Returns (m3)	Top (mKb)	Bottom (mKb)	Top (mKb)	Bottom (mKb)	Top (mKb)	Bottom (mKb)		
Jack Well	SW-12-078-08 W6M	Smoky Group	Water well	0	36.58	0	--	--	--	--	--	--	No	--
Energy Well	100/06-05-078-07 W6M	Charlie Lake Fm	Pumping oil	0.0	205.0	Yes	770.0	1638.0	--	--	205.0	770.0	--	**Yes**
Energy Well	100/12-05-078-07 W6M	Charlie Lake Fm	Flowing gas	0.0	226.8	Yes	Not logged	1633.0	0.0	655.0	?	?	--	**Yes**
Energy Well	100/06-06-078-07 W4M	Charlie Lake Fm	Pumping oil	0.0	188.0	Yes	<850.0	1746.0		--	205.0	<850.0	Yes	**Yes**
Energy Well	100/08-06-078-07 W6M	Charlie Lake Fm	Pumping oil	0.0	207.0	Yes	?	1624.0	--	--	?	?	--	**Yes**
Energy Well	100/14-06-078-07 W6M	Charlie Lake Fm	Pumping oil	0.0	206.0	Yes	?	1580.0	--	--	?	?	--	**Yes**
Energy Well	100/04-07-078-07 W6M	Charlie Lake Fm	Pumping oil	0.0	256.0	3.0	780.0	1576.0	Not logged	780.0	--	--	Yes	No
Energy Well	100/06-07-078-07 W6M	Charlie Lake Fm	Water Injection	0.0	208.5	Yes	<1047.0	1653.0	--	--	208.5	<1047.0	Yes	**Yes**
Energy Well	100/08-07-078-07 W6M	Charlie Lake Fm	Pumping oil	0.0	236.0	Yes	?	1555.0	--	--	?	?	--	**Yes**
Energy Well	100/14-07-078-07 W6M	Gething Fm	Flowing Gas	0.0	210.0	Yes	?	1565.0	--	--	?	?	--	**Yes**
Energy Well	100/14-01-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	290.0	5.0	1102.5	1680.0	534.0	1102.5	290.0	543.0	Yes	**Yes**
Energy Well	100/16-01-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	283.9	5.0	1183.0	1596.0	1183.0	400.0	283.9	400.0	Yes	No
Energy Well	102/16-01-078-08 W6M	Charlie Lake Fm	Flowing oil	0.0	256.0	4.0	816.0	1555.0	0.0	816.0	--	--	Yes	No
Energy Well	100/08-11-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	222.0	Yes	240.0	1638.0	--	--	222.0	240.0	Yes	No
Energy Well	100/15-11-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	255.0	3.5	800.0	1598.0	Not logged	800.0	--	--	Yes	No
Energy Well	100/16-11-078-08 W6M	Charlie Lake Fm	Water Injection	0.0	223.0	Yes	335.0	1638.0	--	--	223.0	335.0	Yes	**Yes**
Energy Well	100/02-12-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	255.4	--	808.0	1607.0	Not logged	808.0	--	--	Yes	No
Energy Well	100/06-12-078-08 W6M	Charlie Lake Fm	Water Injection	0.0	298.0	2.0	1163.0	1610.0	Not logged	1163.0	?	?	Yes	**Yes**
Energy Well	100/08-12-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	204.0	3.0	1097.0	1582.0	Not logged	1097.0	--	--	Yes	No
Energy Well	100/11-12-078-08 W6M	Charlie Lake Fm	Flowing Gas	0.0	252.0	4.0	745.0	1628.0	--	--	252.0	745.0	Yes	**Yes**
Energy Well	102/11-12-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	269.0	4.0	801.0	1620.0	Not logged	801.0	?	?	Yes	**Yes**
Energy Well	100/16-12-078-08 W6M	Charlie Lake Fm	Water Injection	0.0	224.6	6.0	1243.0	1571.2	840.0	1103.5	224.6	840.0	Yes	**Yes**
Energy Well	100/02-13-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	256.0	2.5	795.0	1570.0	125.0	795.0	--	--	Yes	**Yes**
Energy Well	100/03-13-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	352.0	5.0	1297.0	1576.0	120.0	1297.0	--	--	Yes	No
Energy Well	100/04-13-078-08 W6M	Charlie Lake Fm	Flowing oil	0.0	269.0	4.0	800.0	1582.0	0.0	800.0	--	--	Yes	No
Energy Well	100/02-14-078-08 W6M	Charlie Lake Fm	Pumping oil	0.0	290.0	8.0	390.0	1658.5	0.0	390.0	--	--	Yes	No
Energy Well	100/16-14-078-08 W4M	Charlie Lake Fm	Flowing oil	0.0	259.0	Yes	858.0	1575.0	0.0	858.0	--	--	--	**Yes**
Energy Well	100/08-23-078-08 W6M	Gething Fm	Flowing gas	0.0	256.0	Yes	860.0	1565.0	0.0	860.0	--	--	--	**Yes**

4 JACK WATER WELL INFORMATION

4.1 Initiation of Well Complaint

In the fall of 2005, Petrofund Energy Trust (now Penn West Energy Trust) initiated an investigation into a water well complaint by Mr. Bruce Jack regarding methane gas.

4.2 Well Design, Construction and Maintenance

A water well drilling report is available, through the AENV Groundwater Information Centre (GIC) (Well ID # 0299882), and is presented in Figure 3. The well was drilled and completed by Du-All Drilling from Valhalla Centre, AB on November 19, 2001. The borehole was drilled and a 141 mm diameter steel casing was inserted to 36.58 m and seated into the bedrock (Figure 4). After reaching competent bedrock and setting the casing, bentonite chips were poured into the annulus between the borehole and the casing. This method of sealing is not preferred, as there is no way to ensure a proper seal the entire length of the annulus. The hole was then drilled further to the total depth of the well which is approximately 60.96 m. A liner was installed from 30.5 to 60.96 m in the well to prevent loose material from the borehole wall entering the well. The liner was perforated by saw from 47.2 to 54.9 m. The casing extends above ground surface.

Alberta Environment

Water Well Drilling Report

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

Well I.D.	1820001
Map Verified	Not Verified
Date Report Received	2006/10/06
Measurements:	Imperial

1. Contractor & Well Owner Information

Company Name DU-ALL DRILLING		Drilling Company Approval No.: 124424
Mailing Address: BOX 10	City or Town: VALHALLA CENTRE AB CA	Postal Code: T0H 3M0
WellOwner's Name: JACK, BRUCE	Well Location Identifier:	
P.O. Box Number	Mailing Address:	Postal Code:
City SPIRIT RIVER	Province AB	Country CA

2. Well Location

1/4 or LSD	Sec	Twp	Rge	Westof M
SW	12	078	08	6

Location in Quarter
FT from N Boundary
FT from E Boundary

Lot Block Plan

Well Elev: FT
How Obtain: Not Obtain

3. Drilling Information

Type of Work: New Well
Reclaimed Well
Date Reclaimed
Materials Used: Unknown
Method of Drilling: Rotary
Flowing Well: No
Rate: Gallons
Gas Present: No
Oil Present: No

Proposed well use: Domestic & Stock
Anticipated Water Requirements/day: 5000 Gallons

4. Formation Log

Depth from ground level (feet)	Lithology Description
105	Gray Till
141	Gray Medium Grained Shale
150	Brown Sandy Shale
164	Light Gray Shale
181	Dark Gray Shale & Sandstone
200	Dark Gray Shale

5. Well Completion

Date Started(yyyy/mm/dd) 2001/11/19	Date Completed(yyyy/mm/dd) 2001/11/19
Well Depth: 200 FT	Borehole Diameter: 7.02 Inches
Casing Type: Steel	Liner Type: Plastic
Size OD: 5.562 Inches	Size OD: 4.5 Inches
Wall Thickness: 0.188 Inches	Wall Thickness: 0.144 Inches
Bottom at: 120 FT	Top: 100 FT Bottom: 200 FT
Perforations from: 155 FT to: 180 FT from: FT to: FT from: FT to: FT	Perforations Size: 0.125 Inches x 12 Inches Inches x Inches Inches x Inches
Perforated by: Saw	
Seal: Driven & Bentonite from: FT	to: 120 FT
Seal: Shale Trap from: FT	to: 150 FT
Seal: Other from: 115 FT	to: FT
Screen Type: Unknown from: FT to: FT	Screen ID: Inches Slot Size: Inches
Screen Type: Unknown from: FT to: FT	Screen ID: Inches Slot Size: Inches
Screen Installation Method: Unknown	
Fittings Top: Unknown	Bottom: Unknown
Pack: Unknown Grain Size:	Amount: Unknown
Geophysical Log Taken: Retained on Files:	
Additional Test and/or Pump Data Chemistries taken By Driller: No Held:	Documents Held:
Pitless Adapter Type Drop Pipe Type Length: FT	Diameter: Inches

Comments
4.181 DARK GRAY SH/SS LAYERS 20 GPM 4.200 DARK GRAY SH LAYERS SEAL TYPE. ALSO K-PACKER

6. Well Yield

Test Date(yyyy/mm/dd): 2001/11/19
Start Time: 5:05 PM
Test Method: Air
Non pumping static level: 53.4 FT
Rate of water removal: 20 Gallons/Min
Depth of pump intake: 200 FT
Water level at end of pumping: 200 FT
Distance from top of casing to ground level: 24 Inches

Depth To water level (feet)

Drawdown	Elapsed Time Minutes:Sec	Recovery
	1:00	146
	2:00	101
	3:00	86
	4:00	75
	5:00	70
	6:00	66
	7:00	63
	8:00	60.5
	9:00	58.1
	10:00	56.9
	12:00	56
	14:00	55.3
	16:00	55
	20:00	54.2
	25:00	53.6
	30:00	53.6
	35:00	53.5
	120:00	53.4

Total Drawdown: 146.6 FT
If water removal was less than 2 hr duration, reason why
Recommended pumping rate: 15 Gallons/Min
Recommended pump intake: 175 FT
Type Pump Installed
Pump Type:
Pump Model:
H.P.:
Any further pumptest information? No

7. Contractor Certification

Driller's Name: ALFRED STEINKE
Certification No: 40861A
This well was constructed in accordance with the Water Well regulation of the Alberta Environmental Protection & Enhancement Act. All information in this report is true.
Signature Yr Mo Day

Report 1 **Pump Test 1** page1

Figure 3 Water well drilling report for the Jack well.

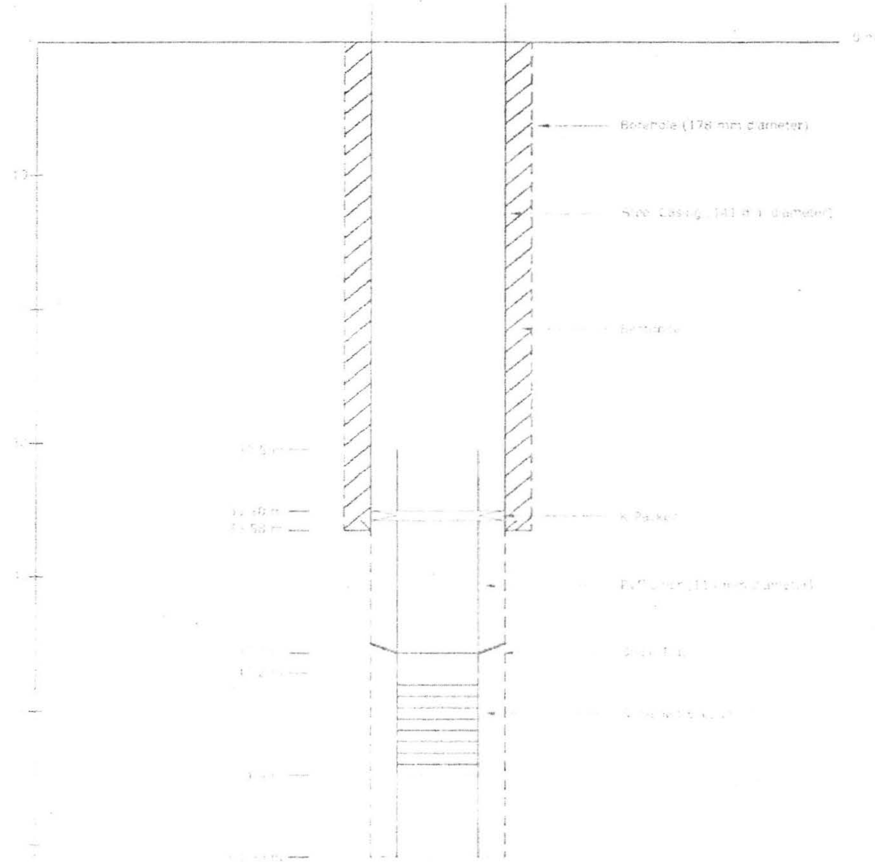

Figure 4 Completion details of the Jack water well.

4.3 Stratigraphy

There is a clear lithology log that indicates that this well is completed in shale and sandstone. The Jack well in the Smoky River Group (Figure 1), with the groundwater bearing zone at a depth of about 50 m (703 MASL).

4.4 Hydrogeology

4.4.1 General Groundwater flow directions

Local and very shallow groundwater flow is likely controlled by topography and flow directions are likely from the Jack well site to Howard Creek and the Ksituan River to the northeast. In the Jack well, the deeper confined groundwater flow within the Smoky Group bedrock is part of the regional groundwater flow system flow directed to the northeast (Hitchon et al 1990).

4.4.2 Vertical Hydraulic Gradient

An estimation was made of the vertical hydraulic gradient between the water bearing zone of the Jack well and that of nearest energy well with pressure data (100/08-12-078-08 W6M about 900 m to the northwest) using the following:

Depth of aquifer in Jack well = 703 MASL.

Depth of Charlie Lake zone well 100/08-12-078-08W6M = -758 MASL.

The head of water in the Jack well = 737 MASL.

A shut-in pressure of 11788 KPa was measured in the Charlie Lake Formation of well 100/08-12-078-08W6M (equivalent to 1204 m of water). Therefore the equivalent head of water in the energy well = 446 MASL assuming density of 1000 kg/m^3 (fresh water).

The vertical gradient is estimated from = $\Delta h/\Delta l$ = (737-446)/(703-(-758) = 0.2. This suggests a 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 be controlled by the fracture aperture.

4.4.3 Hydraulic Conductivity

One pumping recovery test was performed on the Jack Well when it was drilled on November 19, 2001. While only recovery data is available and the pumping interval length is not known, an attempt was made to estimate the hydraulic conductivity of the aquifer. The aquifer test data was analysed by ARC for this report using AQTESOLV, Version 3.50 Professional, Aquifer Test Design and Analysis Computer Software (1996-2003 HydroSOLVE Inc.). This software provides analytical solutions for evaluating parameters in confined, unconfined, leaky, or fractured aquifer systems, and allows evaluation of the aquifer test data by visual curve matching to select the most appropriate interpretation to represent aquifer conditions at the site. The raw data and graphical solutions are included in Appendix A.

The Theis (1935) confined aquifer solution was used to solve the recovery portion of the pumping test. An apparent transmissivity of 1.05×10^{-3} m^2/min to 9.79×10^{-3} m^2/min (1.5 to 14.1 m^2/day) was calculated, depending on which part of the recovery curve was analysed. Since no pumping information prior to the recovery test was available, the data was also analysed assuming a slug test was performed (a large slug of water was instantaneously removed from the well and the well was allowed to recover). The Bower and Rice (1976) confined aquifer slug test solution resulted in an apparent hydraulic conductivity of 3.3×10^{-4} m/min (equivalent to a transmissivity of 2.5 m^2/day). This value suggests that the aquifer has higher transmissivity than is normally found in sandstone.

A safe pumping rate can be estimated using a Q20 calculation (Farvolden 1959). This equation estimates the drawdown in a well after 20 years of pumping to determine the sustainable yield of the well. The calculated Q20 for the Jack well is about 6 IGPM. This driller recommended pumping rate (15 IGPM) is much higher than the rate calculated by the Q20 equation and could lead to aquifer depletion.

4.5 Water and Gas Chemistry

This section presents the results of ARC's compilation, review and assessment of chemistry data from the well complaint file including data from the Jack well and surrounding energy wells. An analysis of this new chemistry data is organized into major ion chemistry, gas chemistry and isotope geochemistry.

4.5.1 Major Ions, Metals and Bacterial Chemistry

No major ion chemistry (historical or new) is available for the Jack well. In addition, no chemistry from surrounding water wells from a similar depth is available from the AENV Groundwater Information System. This is a deficiency in the investigation of the well complaint as there is no data to comment on the water quality.

4.5.2 Dissolved Organic Chemistry

Analysis for EPA volatile priority pollutants and extractable priority pollutants are not available for the Jack well. A dissolved gas analysis was also not done on the Jack well to determine dissolved concentrations of C1 to C4 and atmospheric gases. These analyses can be very indicative of hydrocarbon contamination of a water well. This is a deficiency in the investigation of the well complaint as there is no data to comment on organic components of the water quality.

4.5.3 Atmospheric Elements and Hydrocarbon Gas Chemistry

Several free gas analysis are available for the Jack well (Table 2). The samples appear to be free from atmospheric contamination (based on low oxygen and nitrogen values). The gas samples contain 915,200 to 973,300 ppm methane and <100 to 1200 ppm ethane. The propane, butane and higher gases were below the detection limit. The laboratory method detection limit for hydrocarbon gases was poor (100 ppm) and better analyses would be preferred. One ethane value (1200 ppm) is anomalous and is therefore in question. In addition to the Jack well, 66 analyses from 27 nearby energy wells have gas chemistry. Methane concentrations are similar to those measured in the Jack well while ethane, propane, butane and higher order hydrocarbons are 1 to 2 orders of magnitude higher than the detection limit.

Table 2 Summary of Chemical Analyses for the Jack Water Well and surrounding energy wells.

[illegible]

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. Five carbon isotope analyses on hydrocarbon gas were available for the Jack well (Table 2). In addition to the Jack well, 27 nearby energy wells have carbon isotope analyses on the hydrocarbon gases. Analyses are from production casings and from surface casing vent flows (where present). The analytical techniques used for gas isotope results the Jack well sample and the energy wells are not known.

A histogram of the carbon isotope values of methane from the Jack water well and the surrounding conventional oil/gas wells is presented in Figure 5. Jack well has methane isotope signatures that fall within the range of -60 to -80, typical of biogenic methane (Schoell 1980; Whiticar et al. 1986; Rice 1993). The methane values for the conventional gas wells and the water injection wells have been coded for production casing samples and surface casing vent (SCV) samples. The conventional gas well isotope signatures are much less depleted than the Jack well signatures and are typical for conventional gas. The surface casing vent flow samples have methane isotope signatures that fall between those of the Jack well and production casing indicating a shallower source for the gas.

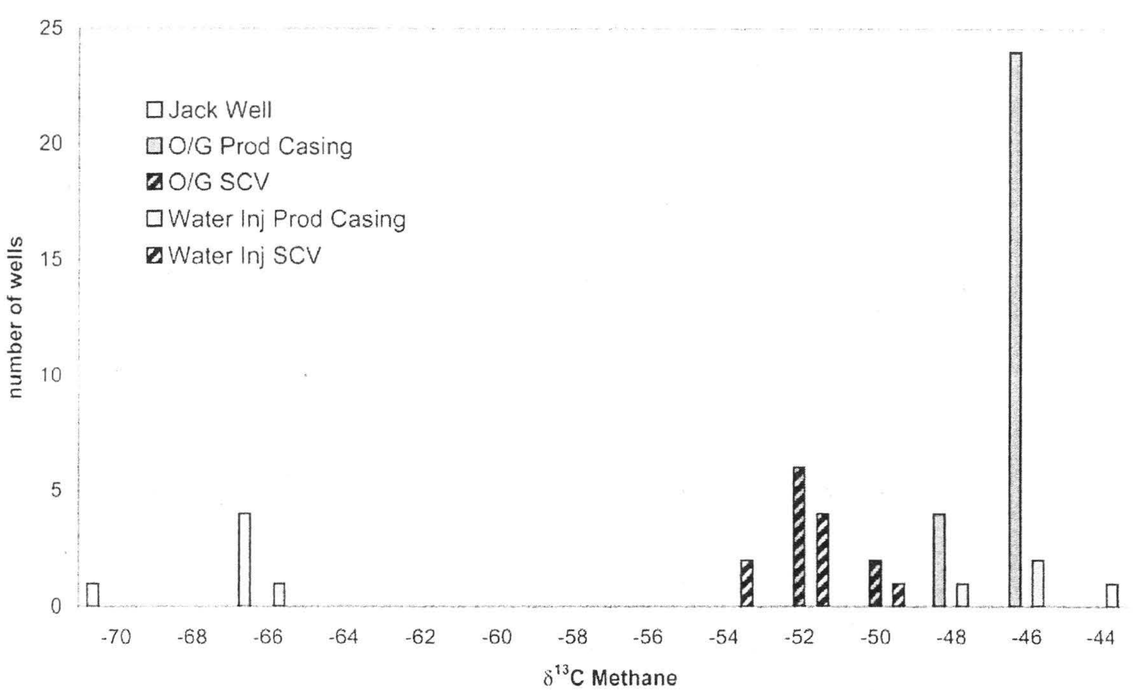

Figure 5 Histogram of the carbon isotope values of methane in the Jack energy wells.

A histogram of the carbon isotope values of ethane from the Jack well and conventional oil/gas is presented in Figure 6. The Jack well has an ethane isotope signature that is similar to the ethane signature of the surface casing vent flow samples. This could indicate a possible component of conventional gas is in the Jack well. The ethane isotope signatures of the SCVFs are heavier than the signature of the production casing samples. This is because the isotope signature of the ethane does not correlate directly to depth (i.e. heavier as you go deeper), but is also related to geologic seals (low permeability rocks) and different geological history of gas generation, migration and alteration (Muehlenbachs et al. 2000).

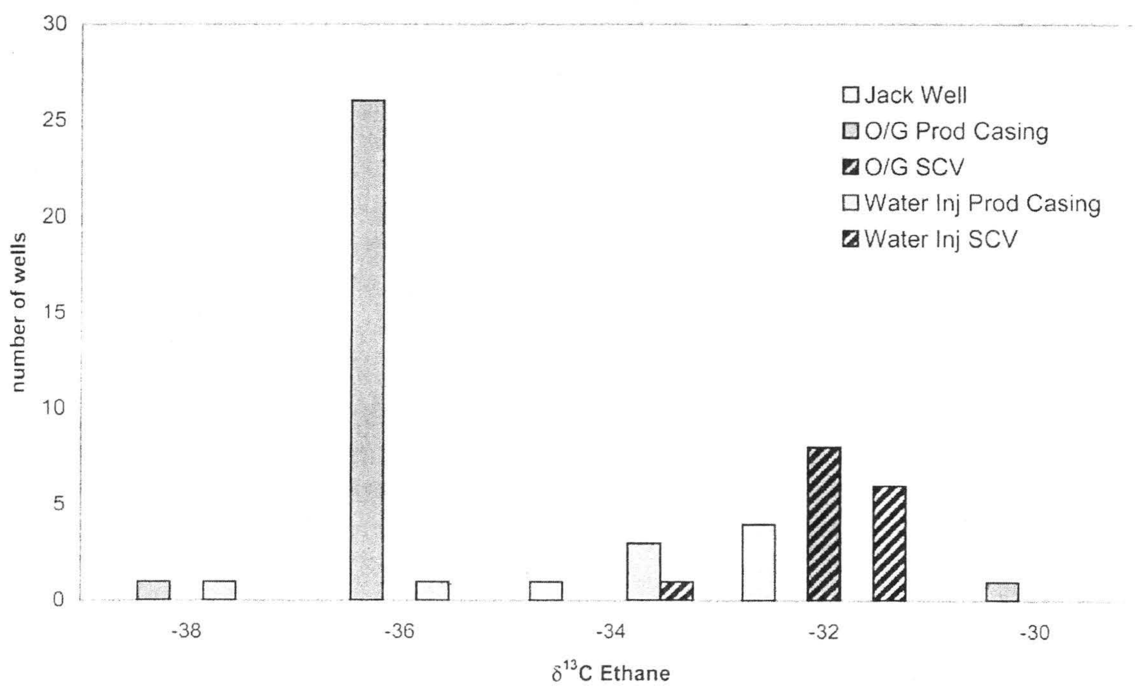

Figure 6 Histogram of the carbon isotope values of ethane in the Jack and energy wells.

A plot of the methane concentration versus the methane carbon isotope signature ($\delta^{13}C_{Methane}$) is presented on Figure 7. Below the line at -60 ‰ typically represents a biogenic (bacterial) origin for methane (Schoell 1980 and 1983; Whiticar et al 1986; Rice 1993). The conventional oil/gas wells have a $\delta^{13}C_{Methane}$ values that are less depleted (less negative) than the typical range of biogenic methane. These values represent a thermogenic origin. One of the water injection wells has a methane isotope value from the production casing that appears biogenic in origin. Most of the injection water is sourced from recycled produced water but at least one Cadotte source water well is in the area (personal communication with Brenda Austin, ERCB).

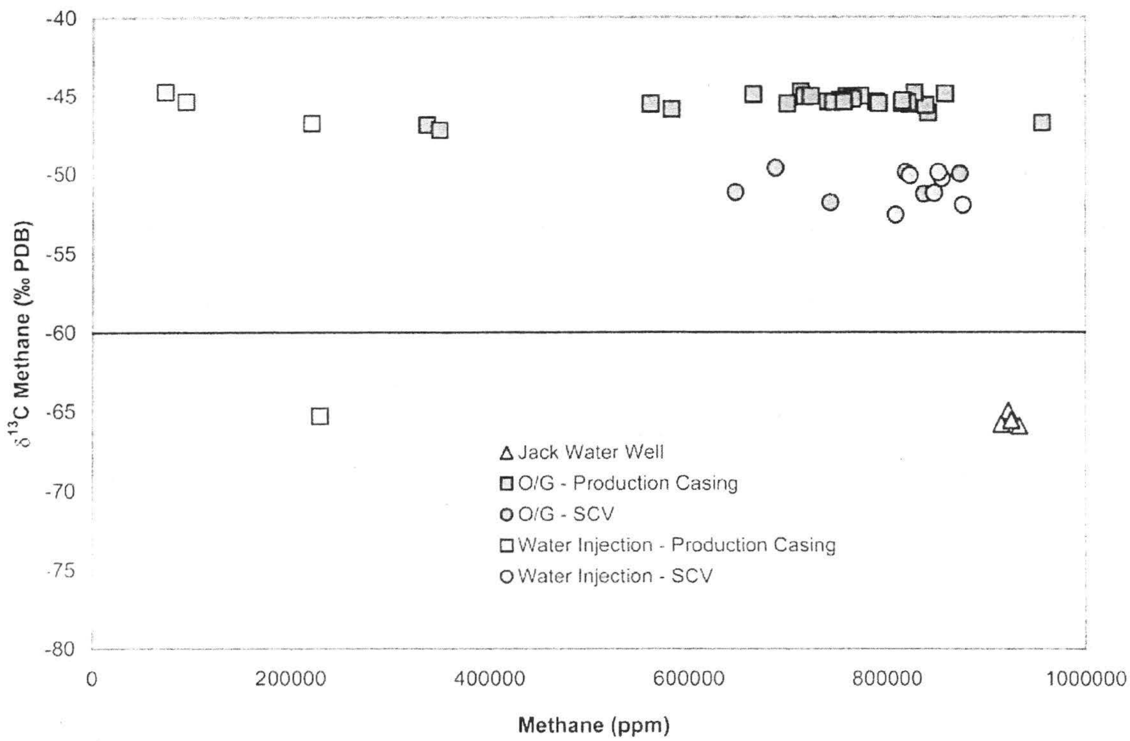

Figure 7 Methane concentration versus $\delta^{13}C$ of methane.

A plot of the ethane concentration versus the ethane carbon isotope signature ($\delta^{13}C_{Ethane}$) is presented on Figure 8. Most of the analyses from the Jack water well have ethane concentrations below the lab detection limit (which was high at 100 ppm). One anomalous sample had 1200 ppm. The samples with less than 100 ppm are below the method detection limit to run carbon isotopic analysis of ethane at the University of Calgary and the University of Waterloo (personal communication with Dr. Bernhard Mayer, University of Calgary and Robert Drimmie, University of Waterloo). The method, including the detection limit, used to determine ethane isotopes in the Jack well is not stated. Ethane isotope results on such low concentration may not be accurate. Ethane concentrations in the Jack well are at least 500 times less than that observed in the conventional oil/gas wells suggesting a different source for the ethane or only a small proportion of mixing (discussed later).

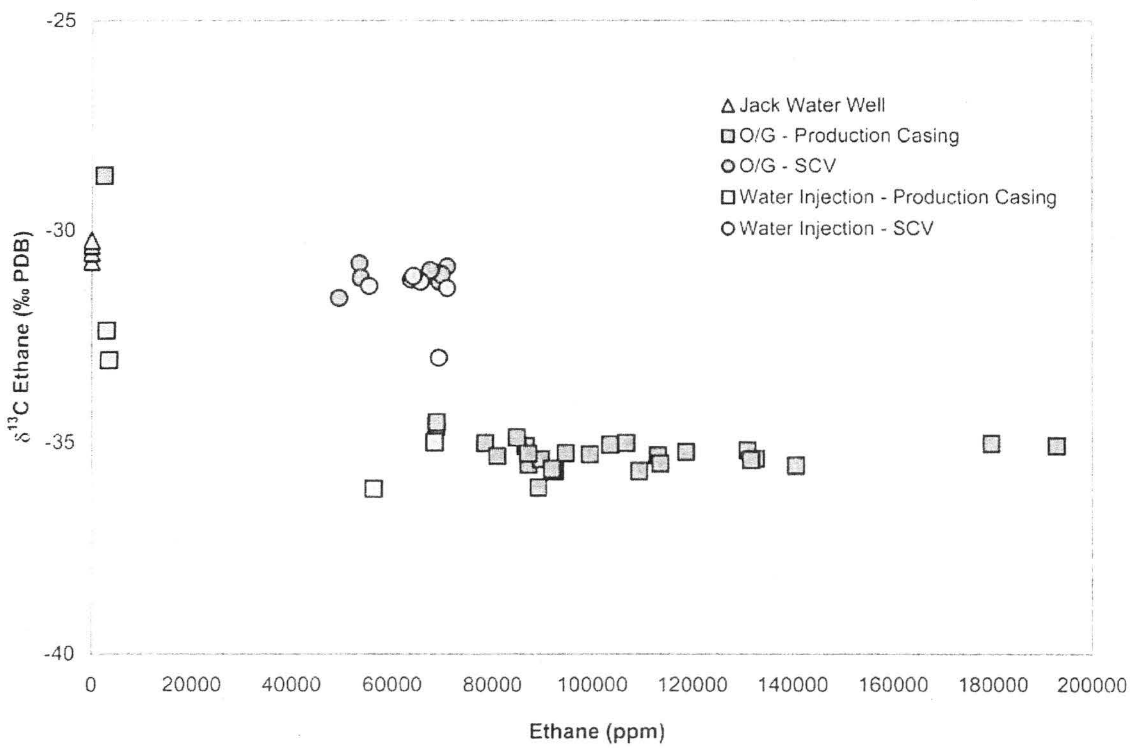

Figure 8 Ethane concentration versus $\delta^{13}C$ of ethane.

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 9. Three distinct groups of analysis occur on this graph; the production casing gas, the surface casing vent flow gas and the Jack water well gas. Each has a distinct methane and ethane isotope range indicating a different gas source. Again, the ethane isotope signature of the Jack well is similar to the ethane signature of the surface casing vent gases.

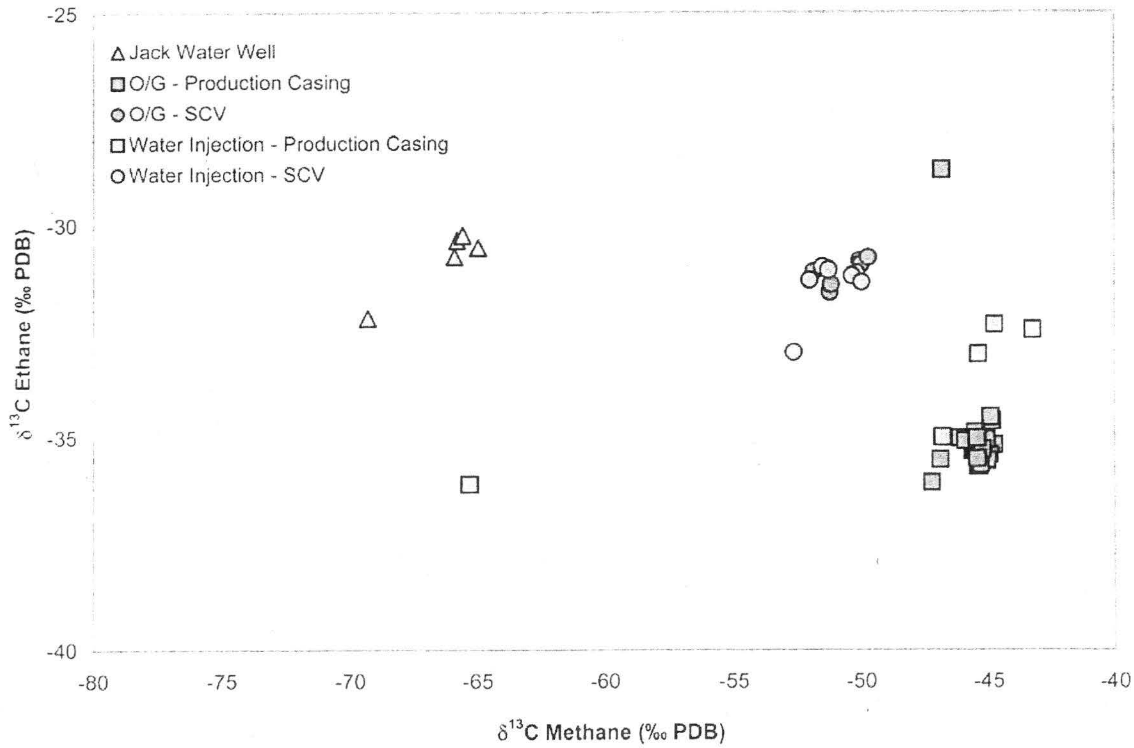

Figure 9 $\delta^{13}C$ Methane versus $\delta^{13}C$ Ethane.

Both the hydrocarbon gas composition and the isotopic signatures of gases can be modified by mixing between different sources of gases (such as biogenic methane with thermogenic methane). These hypothetical mixing curves can be calculated using the equations of Jenden et al. (1993) shown on Figure 10. The y-axis of this plot is the ratio of methane to all other hydrocarbon gases. For this mixing calculation two different end member gases were considered: a biogenic gas and a conventional gas, representative of the surface casing vent gas.

The mixing scenario (mixing curve) was a biogenic gas ([Methane=999,999 ppm], $\delta^{13}C_{methane}$=-65.5 ‰) mixed with a typical SCV gas from the area ([Methane=838,000 ppm], $\delta^{13}C_{methane}$=-50.7 ‰). The tick marks on the curves represent mixtures of conventional gas with the gas from water well, ranging from 0% to 100% in 5% intervals. The Jack well mixing curve shows a possible 0.01% mix of the conventional gas member with a biogenic end-member. This is a very small portion of thermogenic gas.

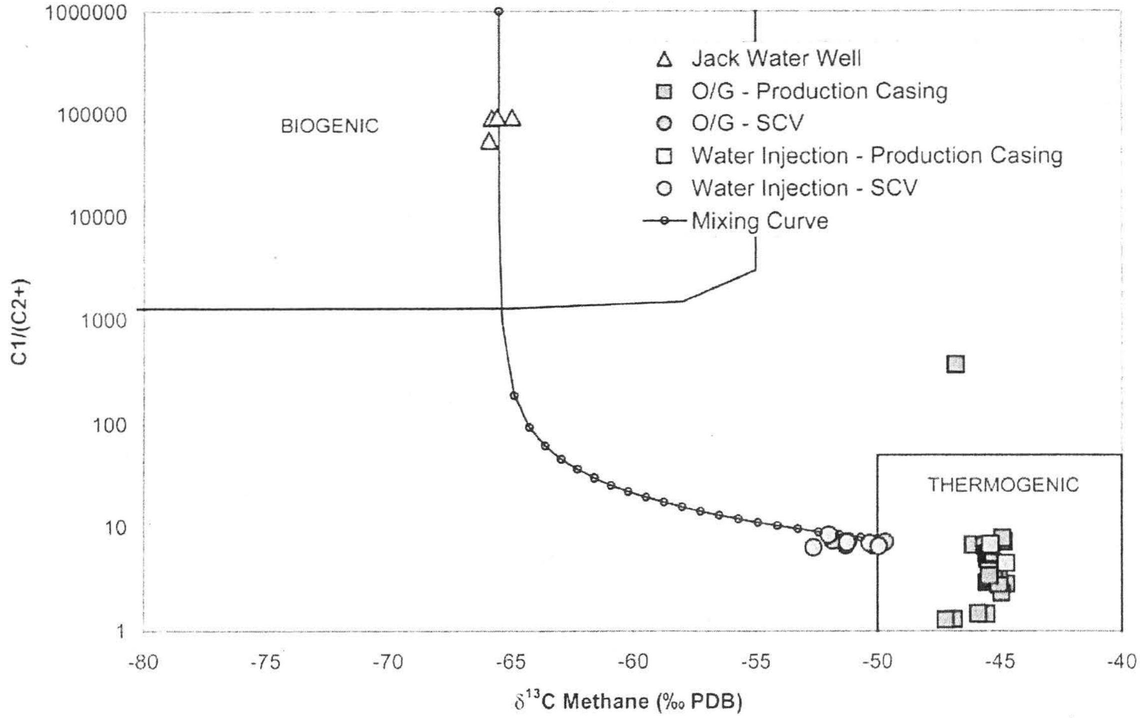

Figure 10 Mixing plot of $\delta^{13}C$ of methane versus the methane/C2+ ratio. Data for the bacterial and thermogenic fields are from Faber and Stahl 1984.

A similar plot can be constructed for ethane (Figure 11). The first mixing scenario (curve 1) was a biogenic gas with an ethane isotope signature chosen to fall through the Jack well ethane isotope signature ([Ethane=1 ppm], $\delta^{13}C_{methane}$=-30.8 ‰) mixed with a typical SCV gas from the area ([Ethane=105,300 ppm], $\delta^{13}C_{methane}$=-31.1 ‰). Again, the Jack well mixing curve shows a possible 0.01% mix of the conventional gas member with a biogenic end-member. This is a very small portion of thermogenic gas. A second mixing scenario (curve 2) was a biogenic gas with an ethane isotope signature more typical of water wells ([Ethane=1 ppm], $\delta^{13}C_{ethane}$=-45.0 ‰) mixed with a typical SCV gas from the area ([Ethane=105,300 ppm], $\delta^{13}C_{methane}$=-31.1 ‰). Again, the Jack well mixing curve shows a possible 0.01% mix of the conventional gas member with a biogenic end-member.

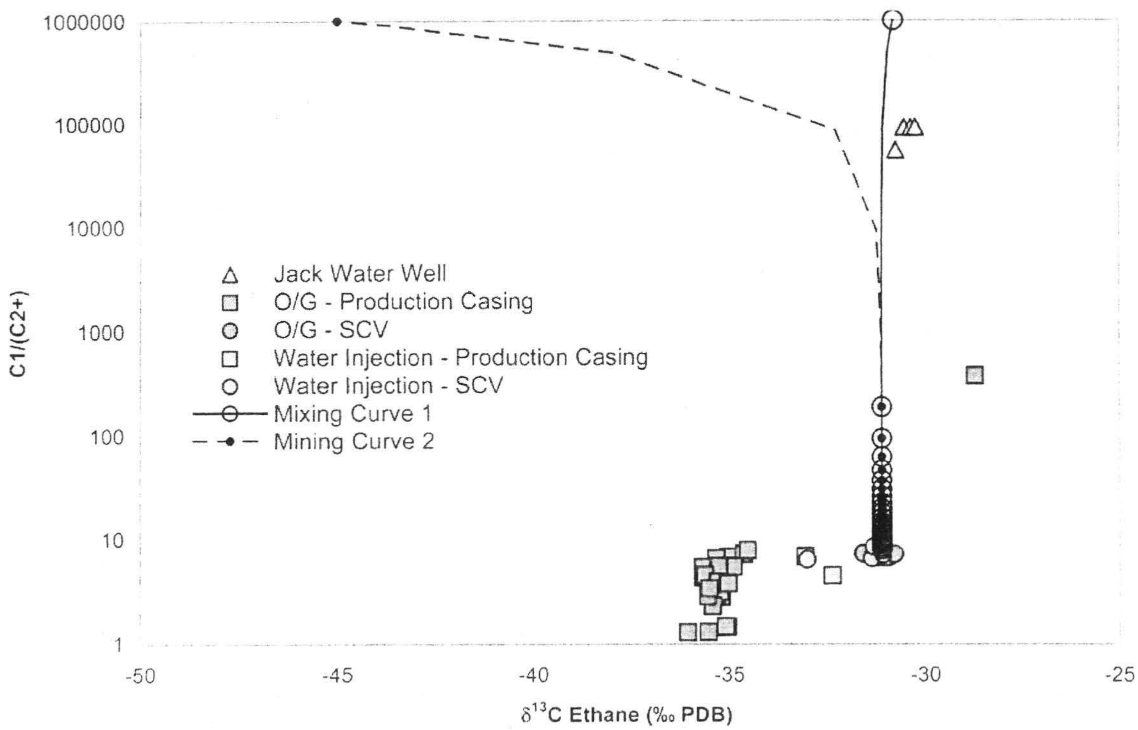

Figure 11 Mixing plot of $\delta^{13}C$ of ethane versus the methane/C2+ ratio.

5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

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

- The Jack water well is completed in shale and sandstone of the Smoky Group.
- A local stress analysis indicates the most likely azimuth (orientation) of fractures would be about 055° (Bachu and Michael 2002). Several energy wells (within 2 km) line up on the 055° azimuth to the Jack well.
- Several energy Wells in the vicinity (within 1.5 km) of the Jack well have surface casing vent flows. While SCVF are not necessarily an indication of shallow aquifers being impacted, there are potential concerns that energy wells with apparently good surface casing may have lower zones that may be leaking.
- An estimate of downward vertical gradient between the Jack well (Smoky Group) and the Charlie Lake formation is 0.2. This represents a downward vertical gradient. If these two zones become connected, water would flow downwards towards the deeper zone well rather than up into the Jack water well.

- The Jack well has a $\delta^{13}C$ methane value that is typical of shallow, biogenic methane. The production casing samples from energy wells have $\delta^{13}C$ methane values that are less depleted and are typical of thermogenic gas. The SCV gas has $\delta^{13}C$ methane values that are intermediate between the Jack well and the production casing gas, but is still thermogenic in origin. The SCV gases appear to be from a shallower formation than the well completion depth.
- The ethane carbon isotope values for the Jack well are similar to the ethane signatures of the surface casing vent flows. Ethane concentrations are very low (<100 ppm) and may be below the detection limit for isotopic techniques, especially when the associated methane concentrations are so high (>900,000 ppm).
- The hydrocarbon gas composition and isotopic values can be modified by mixing between different sources of gases. Mixing scenarios indicate a biogenic end-member gas mixed with 0.01% of a thermogenic gas with a composition the same as the SCF gas could produce results similar to the Jack well. This is a very small potential component of thermogenic gas.

There are several deficiencies in the data that has been collected for the Jack well investigation. ARC recommends the following work be carried out:

- A water sample should be taken from the Jack well to be analysed for major ion chemistry and bacterial parameters. If gas is present in surrounding water wells, it should be sampled for compositional and isotopic analysis.
- While it would be ideal to sample several adjacent water wells in the area, a review of available wells (>6 km radius) indicates the Jack well is the only well completed at this interval. Several deep wells have been drilled in the area, but were dry and were abandoned. All other wells were shallow (<10 m).
- A no headspace water sample should be taken from the Jack well to be analysed for USEPA volatile priority pollutants (vpp) and extractable priority pollutants (epp).
- A no headspace water sample should be taken from the Jack well to be analysed for dissolved hydrocarbons (C1 to C4) and atmospheric gases.
- A gas canister sample should be taken from the Jack well to be analysed for volatile organics and ozone precursors (EPA T014).
- A gas canister sample of the Jack well gas should have a high quality gas chromatograph analysis or C1 to C4.
- A gas canister sample (in duplicate) should be taken from the Jack for carbon isotope analysis in two independent labs (suggest University of Alberta and University of Victoria).

Overall Conclusion

- Alberta Research Council's overall conclusion of the evidence from the review of the AENV and ERCB files is that insufficient data exists to determine whether Mr. Jack's well has been impacted by conventional oil/gas wells in the area.

6 CLOSURE

This report details a thorough review of the AENV well complaint file for Mr. Jack regarding conventional gas activities undertaken in the area and the presence of methane gas in the Jack water well.

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

Respectfully submitted,
Alberta Research Council
Permit to Practice P03619

Alexander R. Blyth, Ph.D., P. Geol.
Research Hydrogeologist

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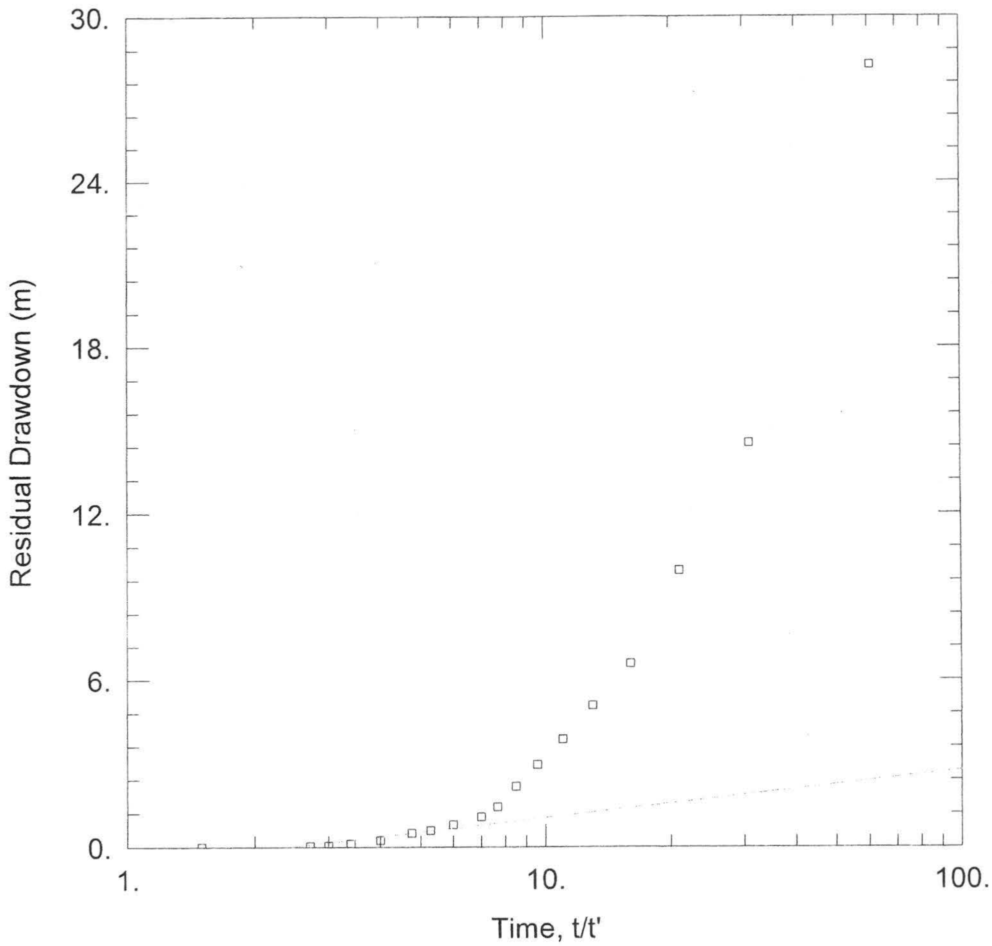
APPENDIX A
PUMPING TEST GRAPHICAL SOLUTION



WELL TEST ANALYSIS

Data Set:
Date: 02/08/08 Time: 12:10:49

PROJECT INFORMATION

Company: Alberta Research Council
Client: AENV
Project: 8789018
Test Well: Jack Well
Test Date: Nov 19, 2001

AQUIFER DATA

Saturated Thickness: 5.18 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Jack Well	0	0

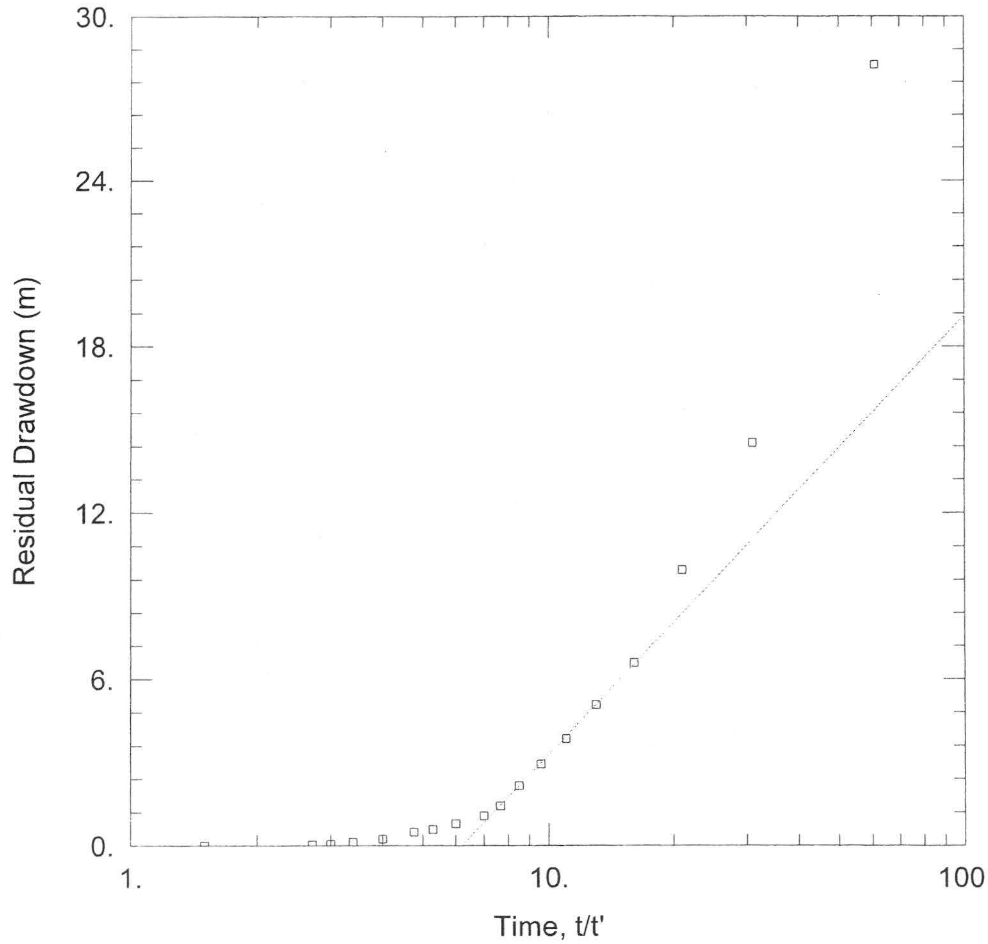
Observation Wells

Well Name	X (m)	Y (m)
□ Jack Well	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

T = 0.009791 m^2/min S/S' = 2.451



WELL TEST ANALYSIS

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Date: 02/12/08 Time: 15:15:40

PROJECT INFORMATION

Company: Alberta Research Council
Client: AENV
Project: 8789018
Test Well: Jack Well
Test Date: Nov 19, 2001

AQUIFER DATA

Saturated Thickness: 5.18 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
Jack Well	0	0

Observation Wells

Well Name	X (m)	Y (m)
□ Jack Well	0	0

SOLUTION

Aquifer Model: Confined Solution Method: Theis (Recovery)

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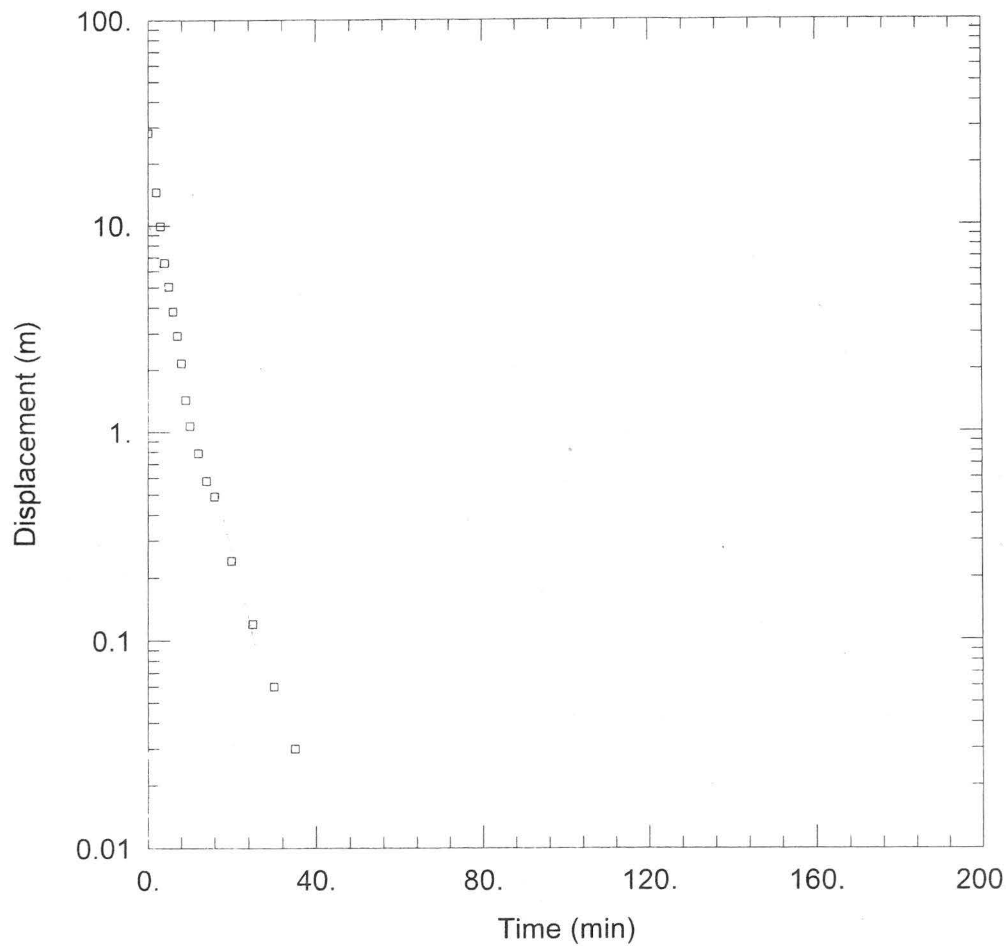

WELL TEST ANALYSIS

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Date: 02/14/08
Time: 09:46:46

PROJECT INFORMATION

Company: Alberta Research Council
Client: AENV
Project: 8789018
Test Well: Jack Well
Test Date: Nov 19, 2001

AQUIFER DATA

Saturated Thickness: 5.18 m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (New Well)

Initial Displacement: 28.22 m
Total Well Penetration Depth: 38.63 m
Casing Radius: 0.076 m
Static Water Column Height: 44.68 m
Screen Length: 7.7 m
Well Radius: 0.057 m

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.0003318 m/min
y0 = 10.67 m