AN INDEPENDENT REVIEW OF COALBED METHANE RELATED WATER WELL COMPLAINTS FILED WITH ALBERTA ENVIRONMENT

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1 INTRODUCTION

Alberta Research Council (ARC) was contracted by Alberta Environment (AENV) to conduct four reviews of complaints about coalbed methane (CBM) activities affecting private water wells. ARC undertook these reviews for AENV to independently assess the scientific evidence and provide conclusions identifying whether or not the water wells had been impacted by CBM or conventional oil/gas extraction activities. The complaints occurred in the Rosebud/Redland (3) and Wetaskiwin (1) areas. This report summarizes ARC's reviews and conclusions of these four water well complaints. The summary report discusses the regional geology and groundwater characteristics of the Central Plains region of Alberta where the complaints originated from, gives a brief overview of CBM activity in the area, and discusses the nature of water well complaints and potential impacts of CBM on water wells. Furthermore, the report discusses the specific lines of evidence used in the reviews of the well complaints and gives overall conclusions of the ARC water well complaint investigation.

2 CENTRAL PLAINS REGIONAL SETTING

2.1 Geological Formations

The Central Plains region of Alberta is found within the Western Canada Sedimentary Basin. Below the ground lies a series of geological formations created millions of years ago. All formations above the Base of Groundwater Protection (BGP) in Alberta are shown in Figure 1 from oldest (bottom) to youngest (top). Geological formations above the BGP contain aquifers with non-saline (fresh) water. Current laws and regulations with respect to oil and gas development serve to protect non-saline groundwater resources above the BGP.

2.2 Regional Stress Regime

In the ground, rocks are under stress from their own weight, compression from mountain building and fluid pressure. The stress regime of upper (<1000 m) coal-bearing strata in Alberta has a strong correlation to permeability and fracture directions in coal (face cleats). This has a strong effect on the direction fluids (both gas and groundwater) flow in these strata. Studies have shown that fractures line up in certain directions due to regional stress forces. In the areas of the well complaints, the most likely orientation of the predominant fractures (face cleats) in the coal would be about 55° E of N (approximately southwest to northeast).

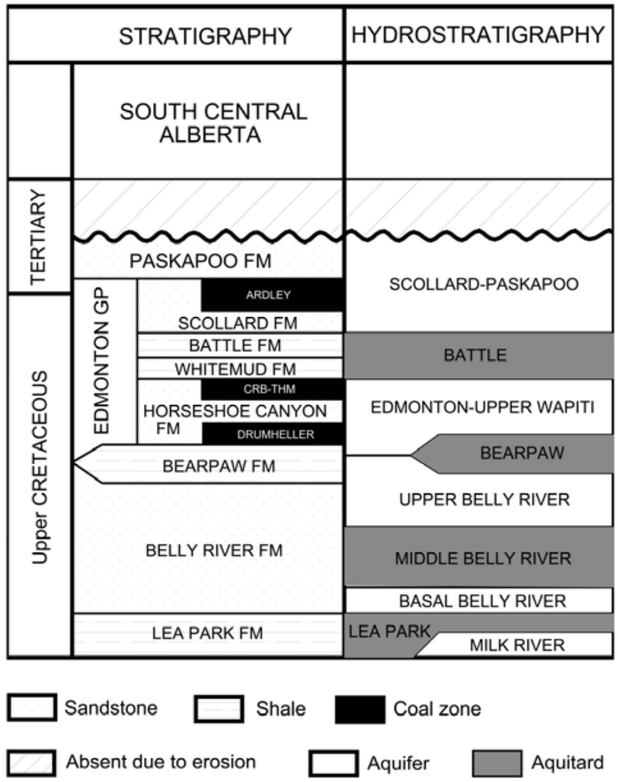

Figure 1 Rock formations and aquifers/aquitards above the base of groundwater protection in the central plains region of Alberta.

2.3 Groundwater Characteristics (Hydrogeology)

Regional groundwater flow systems across the Alberta basin are controlled, in part, by high areas along the Rocky Mountain front in western Alberta where precipitation water enters permeable rock (groundwater recharge areas). In general, regional groundwater flow within the basin is controlled by topography and is directed northeast towards the basin edge (Hitchon 1969a, b). However, groundwater flow in upper rocks in the south-western part of the basin is directed south-westward, due to erosional uplift. Regionally, the Scollard and Paskapoo formations act as an aquifer system (a rock unit that transmits usable amounts of water) above the regional Battle-Whitemud aquitard (a rock unit that does not transmit water). Below this, the Horseshoe Canyon Formation acts as an aquifer above the Bearpaw Formation aquitard. Below the Bearpaw, the upper Belly River Formation acts as an aquifer (Figure 1).

In the Wetaskiwin area, groundwater flow in the Paskapoo-Scollard aquifer, where most domestic wells are constructed, is directed to the northeast (Bachu and Michael 2002). The area is relatively flat-lying where the driving force of water (hydraulic gradient) is low. Rock permeability (hydraulic conductivity) is expected to be low to intermediate and yields from wells are expected to be five to 25 gallons per minute (Le Breton 1971). There is a groundwater divide (high point in groundwater level) in the deeper Horseshoe Canyon aquifer and water will flow both to the northeast and southwest away from the divide (Bachu and Michael 2002).

In the Rosebud/Redland area, shallow groundwater flow within the top 15 metres is directed towards the Rosebud River by gravity. Regional groundwater flow in the Horseshoe Canyon aquifer (including the Carbon Thompson and Weaver coals where most domestic wells are constructed) is directed to the northeast (Bachu and Michael 2002). The hydraulic conductivity of the rock is expected to be low to intermediate and yields from wells in this area are expected to be one to five gallons per minute (Borneuf 1972). In the deeper (below 200 metres) Horseshoe Canyon Formation, coal permeability is very low. Pressure measurements and water production data suggest that the coals (with the exception of the upper Carbon Thompson and Weaver members of the Horseshoe Canyon) are not water saturated.

Regional groundwater flow in the Belly River aquifer is directed to the southwest due to erosional uplift (Parks and Tóth 1995; Bachu 1999). Coal permeability is expected to be very low. Completion data from the energy wells in the area show that the coals are not water saturated. The implication of this is that hydrocarbon gases are not expected to be transported from the deep (gas saturated) coals to the shallow (water saturated) coals in a dissolved state.

Large downward vertical gradients between the Paskapoo or Upper Horseshoe Canyon aquifer (where most domestic water wells are completed) and the deeper Horseshoe Canyon coals (where most CBM wells are completed) are expected and were measured. Hence, if a water-bearing zone in the Paskapoo or upper Horseshoe Canyon aquifers becomes connected to the deeper CBM zones, water would flow downwards into the CBM zone rather than upwards into the overlying aquifers.

3 COALBED METHANE IN SOUTHERN ALBERTA

The southern half of Alberta has potential for natural gas in coal (NGC), also known as CBM (coalbed methane). This gas mostly contains methane and ethane (with small amounts of propane and butane), which are adsorbed to the surface of fractures and within the matrix of the coal. Gas is produced by depressurizing (or dewatering if water is present) the coal seam to allow the gas to desorb and flow to the well. A typical Horseshoe Canyon CBM well involves:

- Drilling and cementing a surface casing to a depth below non-saline water-bearing aquifers;
- Drilling to the CBM zone;
- Installing and cementing a production casing;
- Perforating the production casing at the zone of interest; and,
- Fracturing (stimulation) with 100% nitrogen to remove drilling damage in the well bore.

Alberta has three main zones for CBM (Figure 2). The oldest and deepest is the Mannville Group, which consists of thick coal seams and shale, siltstone and sandstone at a depth of about 1,050 metres below ground (Yurko 1975). This formation contains saline water (Hitchon and Friedman 1969) and has approximately 822 wells to date (as of December 31, 2006 – AEUB). The next zone is the Horseshoe Canyon and Belly River Formations, which contain coals deposited in ancient lake, delta and river systems. The shallowest coal (Carbon

Thompson member) occurs at a depth of about 100 to 500 metres in the central part of the province (Beaton et al. 2002). The Horseshoe Canyon and Belly River Formations are generally considered dry, but the uppermost members (Carbon Thompson and Weaver) sometimes contain non-saline water (Lemay and Konhauser 2006). The deeper, dry seams are the main target of CBM operations in Alberta with 9,762 wells as of December 31, 2006. The Ardley coal zone is the youngest CBM zone and occurs at a depth of 100 to 600 metres and often contains non-saline water. As of December 31, 2006,100 CBM wells have been completed in this zone, however very little non-saline water has been pumped from this zone to date.

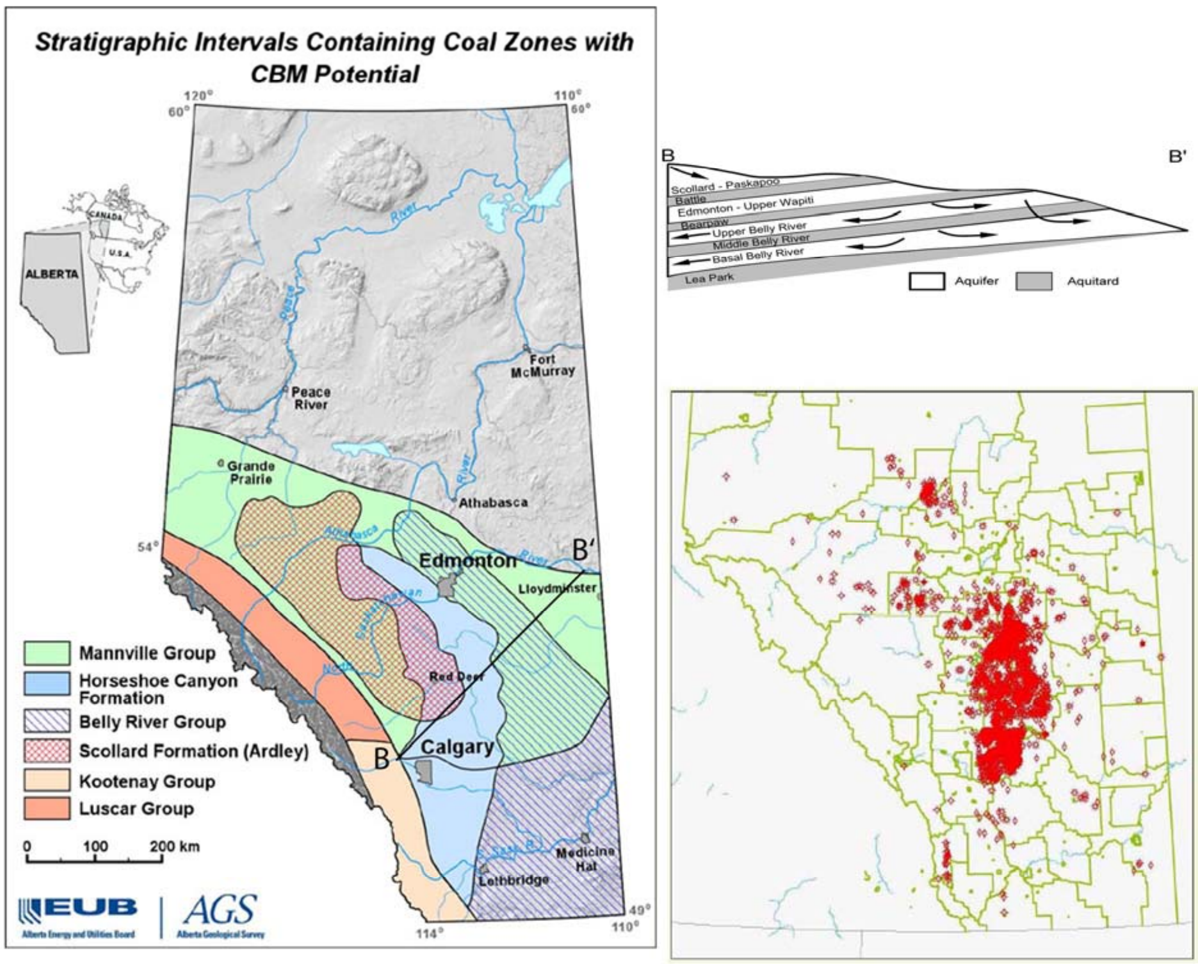

Figure 2 CBM Potential, cross-section and CBM Well Locations in Alberta (AGS).

4 WATER WELL COMPLAINTS

4.1 Initiation of Water Well Complaints

The four water well complaints reviewed by ARC were initiated in a number of ways. Some landowner complaints were presented directly to industry (to local personnel or in public meetings), or the landowner contacted AENV, EUB, the local health unit, or others (e.g. other government representatives, the media) directly. Often, more than one authority was contacted with the complaint. In one case, the complaint was initiated through the media, and AENV contacted the landowner to initiate an investigation.

4.2 Nature of Water Well Complaints

All the water well complaints reviewed by ARC were water quality related. Specific water quality complaints included:

- Livestock refusing water
- Methane gas in water
- Increased methane gas in water (pipes banging and taps “spurting” more)
- Mineral and bacteria deposits in well and plumbing system

4.3 Alberta Environment Complaint Process and Handling

A flowchart of AENV’s overall water well complaint response process is presented in Figure 3. Typically, water well complaints are received and dealt with through AENV‘s Compliance and Inspection staff. The department has a toll free Central Complaint Line (1-800-222-6514) to log the complaint and initiate a file. Phone calls are returned within 24 hours of the initial complaint. A file is also opened if the complaint is reported to AENV by an outside party that received the original complaint, such as a company or the EUB. AENV may be involved through communications with the company or complainant at various stages in the process.

When a complaint is received by the EUB, its procedure is to forward the complaint to the EUB Environment Group who contacts the landowner to discuss the complaint. The EUB then refers the owner to the AENV 1-800 number and provides follow-up and support or will act as a contact as needed/requested.

When AENV is involved, an inspector or investigator contacts the complainant with respect to the issue. If the investigator/inspector can identify the water well problem and recommend a solution by phone (based on the complaint and the investigator’s experience), this will happen. If there is insufficient information, the incident is logged and the investigative process begins. In some cases, the company may initiate its own investigation. AENV will direct the company and its consultants in the data gathering and evaluation phase until reasonable certainty to resolve the well complaint is obtained.

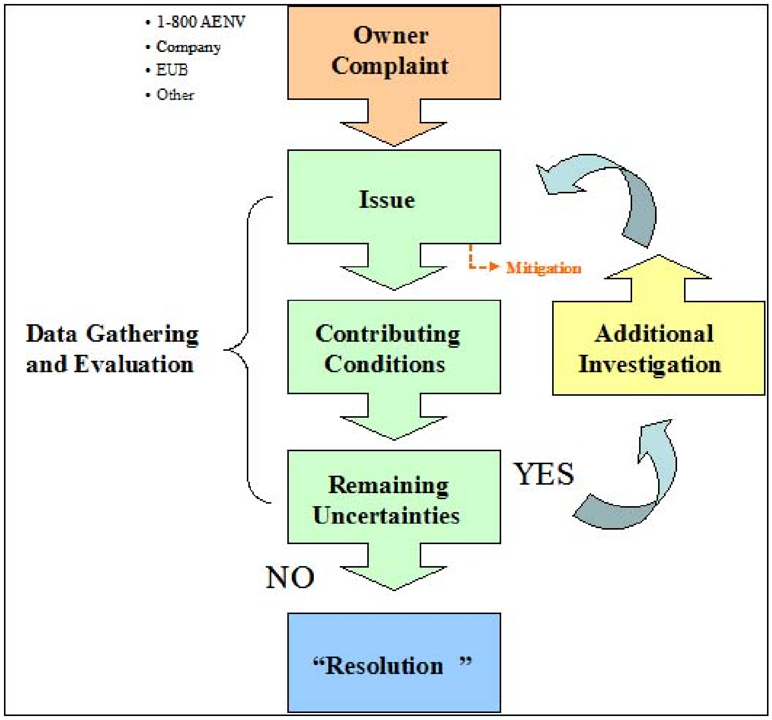

Figure 3 Flowchart of the overall water well complaint response process.

Although the described response process is applicable in a general sense, AENV does not have a specific and documented response process, with required tasks and decision points to direct the investigative process or the involved parties. Data gathering and evaluation decisions are made somewhat subjectively based on the experience of staff. Specific responsibilities of AENV towards the companies and water well owners are not clearly delineated and appear to vary between complaints. The process also may not advance when certainty of one party may be different than another and resolution cannot proceed.

If the resolution reached by the investigative staff does not satisfy the owner, the complaint may be remade to another person or body. The level of owner satisfaction with the proposed resolution may be related to outstanding non-scientific issues, such as trust or acceptance of scientific rationale, lack of understanding, the desires of the owner, etc. If the owner continues with the complaint, the path for resolution may not be clear.

5 SCIENTIFIC EVIDENCE USED TO EVALUATE WATER WELL COMPLAINTS

ARC used several lines of evidence to evaluate the water well complaints. Below is a brief discussion of their importance.

1) Geological and hydrogeological controls on groundwater flow

The geological controls on groundwater flow are important to understand at both the local and regional scale. Locally, geological units can direct water flow from surface or shallow groundwater into a water well resulting in impact to water quality. Regionally, the geology exerts control on the location and movement of CBM gas. It is necessary to understand the permeability of the aquifers and the driving force (gradient) between aquifers to determine the fate and transport of CBM gas. A review of the local and regional geology and hydrogeology (including rock permeability and gradients) was performed for each of the well complaints.

2) Surrounding Energy Well Information

Examination of energy wells in the vicinity of a well complaint was necessary to determine if any problems were encountered during drilling or completion of the well. Energy wells within a 1.5 km radius of the well complaints were examined using data available from the AEUB and a review of the tour reports by AEUB and ARC. Energy wells that lined up with the complainant water well and the predominant regional fracture direction were examined. Additional wells outside the 1.5 km radius were reviewed if they were specifically identified by a complainant or if they had any unusual drilling or completion aspects relevant to the complaints.

3) Water Well Construction and Maintenance

The construction methods used to install the complainants' water wells were evaluated where information existed. Well construction and sealing methods vary widely between drillers and certain methods are more appropriate in some geological and hydrogeological situations. The current condition of the wells and the maintenance regime followed by the complainant was examined and evaluated to see if they were relevant to the problems reported for the well.

4) Major Ion Chemistry

Historical water analyses of the major ion chemistry for the complainant wells was compared to analyses performed during the well investigations. Major ions include sodium, calcium, magnesium, iron, manganese, chloride, bicarbonate, sulphate and fluoride. Changes in the major ions chemistry can be indicative of changes to the well (such as casing failure) or widespread changes to the aquifer chemistry (such as mixing caused by energy extraction activities). Each water well complaint was also compared to between 105 and 145 nearby "D35" water wells from the AENV water well database collected under the AEUB Directive 35. (Standard for Baseline Water Well Testing for Coalbed Methane/Natural Gas in Coal Operations).

5) Dissolved Organic Chemistry

Dissolved organic chemical analyses included volatile and extractable organic substances (USEPA priority pollutants, BTEX and PHC F1-F4). These analyses were available for all the water wells investigated except the D35 water wells. These analyses can be used to identify the type and source of organic contamination in a water sample such as oil, gasoline, diesel, glues, degreasers, solvents or other hydrocarbons

6) Free Gas Composition and Carbon Isotope Geochemistry

The presence of free methane gas in water was the primary concern with the complainants. The composition and carbon isotope signature of free gas from the water wells was the primary data used to evaluate the well complaints. The gas composition and carbon isotope signature of the wells were evaluated using a series of plots and statistically compared to 105 to 145 nearby D35 water wells from the AENV water well database collected under the AEUB Directive 35.

Certain chemical elements (such as carbon) have two or more forms of atoms with differing atomic mass. Each of these different forms is called an isotope; hence a particular element (such as carbon) can have two or more isotopes. Differences in the mass of isotopes of an element can cause differences in the chemical properties of that element. The way an isotope of an element behaves during chemical reactions can cause a fractionation (preferential sorting) of isotopes. This fractionation is the basis for isotopic “fingerprinting” of ground water to help in the identification of the processes and sources of water found in a specific environment. The carbon isotopic signature of methane and ethane can sometimes be used to differentiate between biogenic gas (shallow production of gas through bacterial reduction of CO_2 or fermentation) and thermogenic gas (heat and pressure acting on kerogen).

6 CONCLUSIONS OF WATER WELL INVESTIGATIONS

The Alberta Research Council’s review of the four AENV complaint files, AEUB data, and our independent review of additional data and aspects of the complaints provide the following conclusions organized into the evidence categories listed above:

1) Geological and hydrogeological controls on groundwater flow

- The Rosebud/Redland complainant water wells are completed in the Upper Horseshoe Canyon Formation. In the Rosebud/Redland area, local water wells appear to be predominantly producing water from the Carbon Thompson and Weaver coals of the Horseshoe Canyon Formation. In the Wetaskiwin area, local water wells appear to be predominately producing water from the Paskapoo/Scollard Formations.
- Where water wells are completed in coal, gas is often present. Drilling records (AENV Groundwater Information Centre database) prior to CBM activities in Alberta show the Rosebud/Redland and Wetaskiwin areas have gas in water wells.
- The AENV deep observation well and CBM drilling and completions records indicate that, in the Rosebud/Redland and Wetaskiwin areas, the coals are not water saturated below the Weaver coal (i.e. coals are “dry”). Under natural conditions, groundwater flow within and between these coal zones is limited.
- A local geological study indicates the most likely orientation of fractures (face cleats) in the coals would be about 055° E of N (approximately southwest to northeast). In at least 2 of the complaints, no nearby CBM wells line up in the same direction as the water well of concern along these fractures.
- An estimate of downward vertical gradient, between the water wells and the Horseshoe Canyon CBM zones, is approximately 1.0. This represents a large downward vertical gradient. If these two zones become connected, water would flow downwards into the CBM well rather than up into the water wells.
- A theoretical evaluation of the potential migration of methane bubbles from the CBM well to the complainant wells (through an induced fracture caused by fracture stimulation) suggests that the downward flow of groundwater in the fracture would stop the upward migration of methane bubbles.
- Fluctuations in static water levels were observed in all the complainant wells. The cause of this fluctuation could be from groundwater resource extraction by the

complainant well, nearby users or drought. The drop in water level, and corresponding drop in pressure on the coal zone, can be shown to contribute to the increase in methane exolving from the groundwater. This effect would be even greater during pumping of the wells where the water level drops much more significantly.

2) Surrounding Energy Well Information

- Energy wells in the vicinity (within 1.5 km) of the complainant water wells have no apparent drilling and construction issues that would contribute to methane or degradation of water quality.
- One CBM well in the Rosebud/Redland area had perforations and fracturing in the same aquifer that many of the local residential wells are completed in. The connection between these wells has since been removed (well abandoned), and it is unlikely these short-lived perforations had any measurable effects on the complainant wells at a distance of 1.7 to 3.1 km away.

3) Water Well Construction and Maintenance

- Records indicate that all complainant wells were drilled using mud rotary rigs. In all cases, bentonite and/or cuttings were poured down the hole (annulus) beside the casing. This sealing method is not preferred because there is no way to ensure a proper seal the entire length of the annulus. In the Rosebud area, fine sand or gravel in all the boreholes (between five and 11 metres) could have lead to bentonite bridging (sticking caused by water swelling the bentonite). It is not clear if the existing seals provide adequate protection against contamination from surface water entering the well. Several water analyses (discussed below) did indicate coliform bacteria were present and this could indicate a poor seal in the upper part of the wells.
- Records in the AENV well complaint files indicate the complainant wells were not regularly shock chlorinated. The well casing of one well was shown to be in poor condition according to a camera inspection.
- Analyses show the presence of total coliform bacteria in exceedence of the maximum acceptable concentration in three of the four complainants' water wells. Those three wells had coliform bacteria numbers too numerous to count on at least one occasion.
- One well had E. Coli bacteria present, as well as amoebae, flagellates, ciliates and possible water fleas.
- The bacterial/microbial problems are likely due to surface water entering the well. The source of contamination is likely quite close, rather than from other sources, such as surface water used for drilling energy wells (these organisms do not typically survive long in a groundwater environment).
- Three of the four complainants had iron and sulphate related bacteria in their water wells. These bacteria naturally exist underground in aquifers and can sometimes cause taste, odour, staining and water production issues when wells are not properly maintained (e.g. shock chlorinated)

4) Major Ion Chemistry

- The major ion chemistry of the complainant water wells has not changed from prior to the complaint.
- The major ion chemistry for the complainant water wells are sodium-bicarbonate (Na-HCO_3) or sodium-bicarbonate-chloride (Na-HCO_3-Cl) type water. The complainant water well chemistries are not unique. They, along with more than 80 other wells in the areas, have this type of water and have methane.
- For all the D35 wells in the areas, sodium-bicarbonate (Na-HCO_3) and sodium-bicarbonate-chloride (Na-HCO_3-Cl) type waters are strongly associated with the presence of methane in the water.
- The analyses show the complainant well water consistently exceeds the aesthetic objectives under the Guidelines for Canadian Drinking Water Quality for total dissolved solids (TDS) and sodium. The maximum acceptable concentrations for fluoride have sometimes been exceeded. This water chemistry is typical of water wells in these areas. All complainant wells have maximum concentrations within health related limits under the Guidelines for Canadian Drinking Water Quality (Health Canada 2007) with the exception of fluoride and coliform bacteria as noted above.

5) Dissolved Organic Chemistry

- An analysis for USEPA volatile and extractable priority pollutants are available for three of the four complainant wells. All volatile and extractable organic compounds were below the analytical detection limit with the exception of two compounds not expected to be related to CBM activities. These compounds, 2-Methyl-2-Propanol (an alcohol) and phthalates (plasticizers) were detected at very low concentrations and may have come from the cleaning of AENV sampling equipment prior to sampling the well and from new sample tubing respectively. BTEX and F1-F4 analyses were low or below detection limit. No Canadian Drinking Water Guideline limits were exceeded for USEPA priority pollutants or CCME hydrocarbons.

- Dissolved methane analyses for the complainant wells with showed concentrations ranging from 11 to 110 mg/l. These concentrations are at or above saturation and methane would be expected to exsolve (bubble out) from the water when exposed to the atmosphere (such as pumping groundwater to the surface into a home's water distribution system). There is a risk that exsolved methane can form an explosive mixture with air within confined spaces (e.g. well shack). A small amount of dissolved ethane (2.2 to 3.1 µg/l) was detected in three of the for complainant wells.

6) Free Gas Composition and Carbon Isotope Geochemistry

- Free gas analyses were available for all the complainant wells. All analyses detected the presence of atmospheric gas (nitrogen, oxygen and carbon dioxide), methane (98,000 to 979,000 ppm) and ethane (13 to 300 ppm).

- One analysis from one well contained higher order hydrocarbons that are not normally associated with CBM activity. Re-sampling of this well for both free and dissolved hydrocarbons found only methane and ethane.
- The methane carbon isotope ($\delta^{13}C$) values for the complaint wells fall within the normal range of methane values for all D35 wells in the area (Figure 4). In other words, the complainants' wells had isotope fingerprints similar to other wells in the area.
- The complainant water well data all have $\delta^{13}C$ methane values that are clearly biogenic ($\delta^{13}C$ values more negative that -60 ‰ PDB). This means the methane likely formed from bacteria at a shallow depth.
- The CBM and conventional gas wells have $\delta^{13}C$ methane values that are less depleted (less negative) than the typical range for biogenic methane. These values represent a mixed thermogenic and biogenic origin (Figure 4).

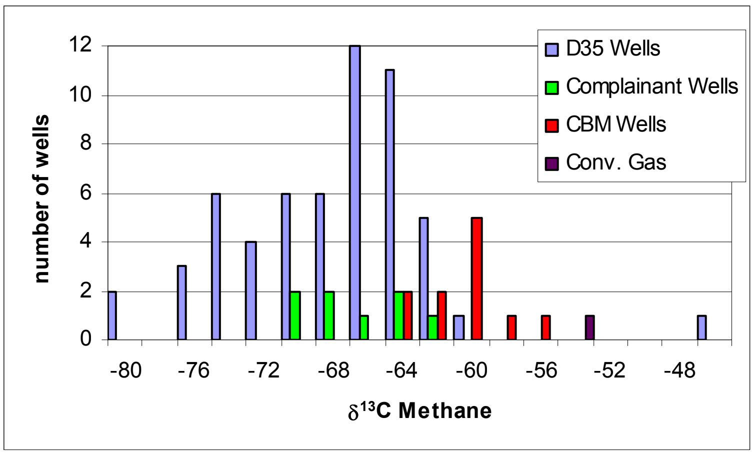

Figure 4 Histogram of carbon isotope values of methane.

- The ethane carbon isotope values for the CBM wells fall within the normal range of ethane values for all D35 wells in the area (Figure 5).
- The $\delta^{13}C$ ethane values of all the water wells are similar to the values of the CBM wells, but concentrations are lower (indicating a different origin or potential mixing, see next conclusion point).

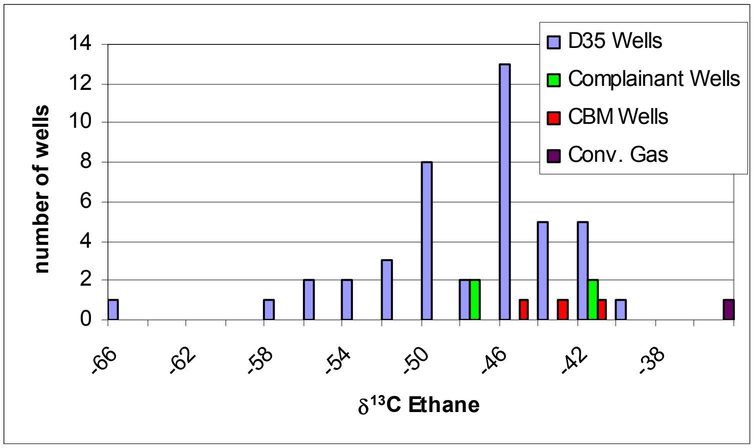

Figure 5 Histogram of carbon isotope values of ethane.

- It is possible for gases with different origins to mix with each other. For example, mixing curves 1 and 2 (Figure 6) mix a naturally occurring biogenic gas with typical CBM gas. These curves show that up to 4% of the total gas in the complainant wells could theoretically be of CBM origin. However while gas mixing is possible, the gas composition and δ^{13}C methane value of the complainant wells is not statistically different from the average D35 water well values in the areas. Therefore it cannot be concluded that mixing of biogenic and CBM gas has occurred.

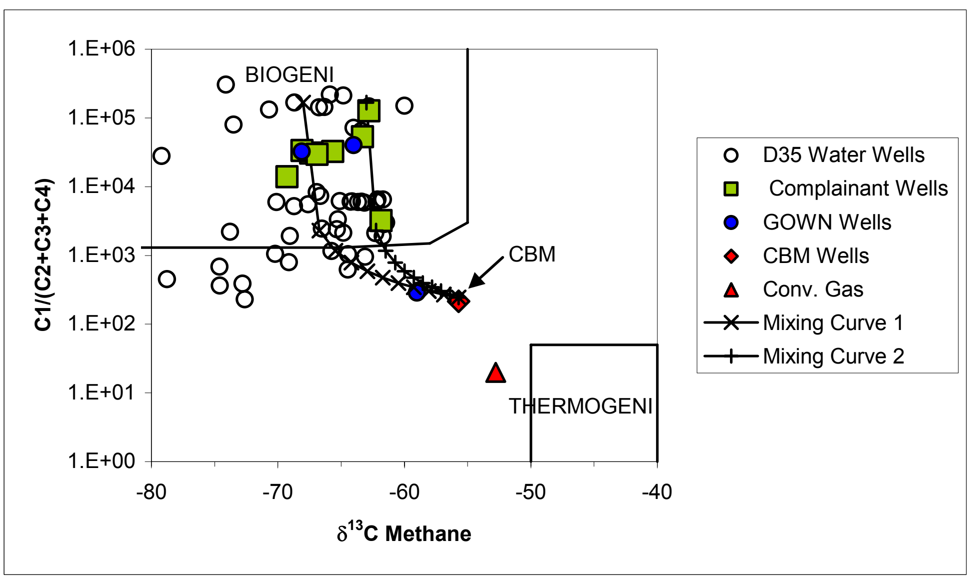

Figure 6 Mixing plot of δ^{13}C methane versus the methane/C2+ ratio.

- A statistical analysis of the methane and ethane carbon isotope value of the complainant wells, surrounding D35 water wells and energy wells in the area show:
    1) The carbon isotope value of the methane in the complainant water wells is the same as the methane isotope signature of the surrounding D35 water wells.

2) The carbon isotope values of the methane in the CBM wells is different than the methane isotope signature of the complainant and surrounding D35 water wells.
3) The carbon isotope value of the ethane in the CBM wells is the same as the ethane isotope value of the complainant and surrounding D35 water wells. The similarity between ethane isotope values is not unexpected as both the CBM wells and the water wells are completed in the same formation (but different coal members).

Overall Conclusion

- The Alberta Research Council's overall conclusion of the evidence from the reviews of the AENV and AEUB files, along with a new review and evaluation of additional data and aspects, is that energy development projects in the areas most likely have not adversely affected the complainant water wells.

7 CLOSURE

This report is a summary of four water well complaint reviews carried out by ARC. The reviews evaluated data from the AENV well complaint files, as well as additional evidence, regarding coalbed methane and conventional gas activities undertaken by energy companies and the subsequent perceived decrease in water quality of the complainant water wells.

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

Respectfully submitted,
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Permit to Practice P03619

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