INVESTIGATION OF REGISTERED DOMESTIC WATER WELL COMPLAINTS RELATED TO OIL AND GAS DRILLING AND COMPLETION ACTIVITIES (2005-2010)

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EXECUTIVE SUMMARY

The objective of this study was to compile and review existing public information about impacts to domestic water well quality and quantity from oil and gas activities in Alberta to provide information and context for the risks to groundwater from these activities. Although conventional oil and gas activities have been occurring in Alberta since the early 1900's, more recent development of unconventional resources has led to shifts in the types of energy-related activity across the province. This study uses complaints reported to Alberta Environment and Sustainable Resource Development (AESRD) and stored in their Environmental Management System (EMS) database to quantify the number and nature of domestic water well complaints in Alberta between 2005 and 2010. This information will help provide accurate, independently derived information on the occurrences and types of oil and gas impacts to water wells to be used by industry, land owners and the general public to better understand the risks that energy activities pose to groundwater resources.

The information from the database records all domestic water well complaints reported to AESRD between 2005 and 2010 and identifies the nature of the complaint, and the steps taken by AESRD or consultants to characterise the cause of the complaint. However there are limitations to using the AESRD EMS database alone to evaluate oil and gas impacts on domestic water wells. The main limitation being that it does not include any complaints made directly by the water well owner to the energy company and only includes those registered with AESRD. This practice used to be quite common in the past, but in an effort to increase transparency and maintain good community relations, energy companies gradually began to require that all water well complaints be registered with AESRD. Some companies adopted this policy earlier than others, and it is possible that there may have been water well complaints not reported to AESRD or recorded in the EMS database. Another limitation with the AESRD EMS database is that it was derived as an internal information management system and is not designed specifically for compiling statistical information. We also note that the time period covered by this study (2005-2010) was prior to the recent developments in hydraulic fracturing for tight and shale gas resource development. Therefore, this study does not address the relationship between recent hydraulic fracturing activities and domestic water well complaints.

Phase 1 used AESRD's EMS database on domestic water well complaints to compile information about the number of complaints registered between 2005 and 2010, the nature of the complaint (e.g. change in water quality, water quantity), whether the well owner suspected energy activities as the cause, the steps taken to eliminate potential energy activities as the cause, whether an alternate cause was identified, and whether the complaint proceeded to a follow-up investigation. The complaints that proceeded to the investigation were the focus of Phase 2, which involved a review of the individual investigations and compilation of the different investigation techniques used to help identify the causes for changes in water quality or quantity.

Phase 1 identified that for 410 of 720 complaints (57%) the well owner suspected their problems to be related to oil and gas activities. Out of the 368 water well complaints that were investigated by AESRD there were two cases (0.5%) where it was confirmed that there were impacts related to energy activities. There were an additional 23 cases where the EMS database could not be used to conclusively eliminate potential energy related impacts (6%). If these cases are used as the upper limit, then the actual risk (0.5 to 6%) is much lower than the perceived risk (57%). The discrepancy between the number of complaints suspected to be related to oil and gas activities (410) and the number of confirmed or potentially related cases (2+23) indicates a high perceived risk held by

landowners about energy activities. Given the limitations of basing the statistics compiled in Phase 1 of this project on AESRD's EMS database, there is the potential that the numbers of impacted wells were underestimated (e.g. water well complaints not reported to AESRD). However, the orders of magnitude differences between the number of complaints thought to be related to energy-related activities, and the small number of confirmed cases suggests that the actual risks of energy related drilling activities are quite low.

For the two cases where impacts from drilling and completion activities were detected, water wells were located fairly close to the energy well (<600 m). In both cases, investigation of the energy wells revealed casing or completion problems that led to the impacts. In the first case study, the water well was impacted due to improper cementing of a new energy well, which led to the new energy well providing a hydraulic connection between two aquifers and resulted in a decrease in water levels in the shallower aquifer where the water well was located. The hydraulic connection between the two aquifers was confirmed with pumping tests and water flow and temperature logs on the energy well. In the second case study, a culvert well was impacted by gas leaking from a recently drilled well that was trapped by a confining clay unit, resulting in the build-up of gas in the underlying aquifer until it eventually entered the well. The isotopic composition of gases collected in the water well indicated the presence of deep thermogenic gases, generally associated with oil and gas development.

The water well complaint investigations typically included: a review of the history of the water well to identify potential maintenance and/or construction issues, a review of the history of energy wells in the area to see if there were any reasons to expect problems from any of the wells, and comparing pre- and post- water quality and yield data to see if there was a change. Even when the investigations involved re-testing of water wells for D35, many investigations included additional analyses or monitoring not required by the directive. Some of the approaches for investigating different types of water well problems included:

- Visually evaluate well construction, inspect for biofouling problems or identify zones where gases or sediment are entering the well screen, using down-well cameras.
- Identify whether sediment appearing in the domestic water well is composed of natural non-crystalline iron or manganese oxides or oxyhydroxides, that can cause aesthetic, water quality of well yield problems.
- Compare the mineralogy of sediment appearing in the domestic water well with solids present in drilling fluids to see if migration of drilling fluids from the energy well is a potential source of sediment or changes in water quality at the domestic water well.
- Use non-routine geochemical or isotopic analyses to help identify potential sources of solutes contributing to the changes in water quality.
- Provide the water well owner with a continuous record of fluctuations during energy activities using continuous, in situ measurement of water levels, turbidity, and electrical conductivity.
- Determine the geological origin of gases present in the water well by comparing the isotopic composition of gases in the well with gases from nearby energy wells.

This review of water well complaints and the processes in place to address them highlights a gap between the mandates of the various groups investigating domestic water well complaints (AESRD, industry) and the needs of the landowner. When landowners report their water well problems to AESRD it is often with the expectation that the source of the problem will be identified and some solution to their problem will be provided. AESRD's mandate is to identify whether any of the legislations for conventional or unconventional oil and gas activities in the province have been violated. Once AESRD has determined that there is no threat to human health and that there is no evidence to indicate contravention of regulations they close their investigation file even if the water well problem persists. They will direct the well owner to educational material or resources about maintaining their water well, or make specific recommendations for further steps to try to identify and solve the problem. Industry-led follow-up investigations aim to identify whether their specific energy wells are the cause of the complaint. These investigations often eliminate oil and gas activities without necessarily identifying the cause of the problem. This lack of resolution often leaves the well owner dissatisfied and may contribute to the high perceived risk of oil and gas activities to domestic water wells. Our results indicate that a large portion of the water well complaints thought to be related to energy-related activities are due to biofouling and inadequate water well maintenance, suggesting that improved educational resources for domestic water well owners are needed.

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List of Acronyms

AER- Alberta Energy Regulator (formerly ERCB, Energy Resources Conservation Board)
AESRD- Alberta Environment and Sustainable Resource Development (formerly Alberta Environment)
BGWP- the Base of Groundwater Protection
BWWT- Baseline Water Well Testing
CBM-Coal Bed Methane
D35- Directive 35
EDS- Energy-dispersive X-ray spectroscopy
EUB- Energy Utilities Board, reorganized in 2008 to ERCB
EMS- Environmental Management System (the AESRD database of water well complaints)
EPO- Environmental Protection Officer
FAO -Farmers Advocacy Office
FOIP- Freedom of Information and Protection of Privacy
SEM- Scanning Electron Microscope
SRD- Sustainable Resource Development (now AESRD)

1. INTRODUCTION

Alberta has a long history of oil and gas activities, starting in the early 1900s with conventional oil and gas and expanding more recently into unconventional resources like coalbed methane (CBM). As oil and gas development increased, regulatory requirements to ensure the safe operation and sound development of these resources have also evolved. Because the majority of rural residents in Alberta rely on shallow groundwater for domestic and livestock purposes (Alberta Agriculture, 1996), concerns surrounding potential impacts to water resources have increased and continue to be an area of public concern.

Some uncertainty exists surrounding the risk that energy activities pose to groundwater resources. Concerns about potential impacts of energy development on Alberta's water resources are frequently reported by the media (e.g. "Water rises to top of list for environmentalists", The Edmonton Journal, February 7, 2008), while some independently conducted studies have concluded energy activities pose a very small risk to groundwater resources, (CAPP, 2009; Worley Parsons, 2009).

Alberta Innovates - Technology Futures (AITF) was awarded a grant by Petroleum Technology Alliance Canada (PTAC) to provide a desktop study to review and compile information about impacts of oil and gas drilling to groundwater wells and completion activities. The aim is to provide the general public, well owners and industry with a clearer picture of the actual risk these activities pose to potable domestic groundwater resources.

1.1 Objectives

The objective of this study was to compile and review existing public information about impacts to water well quality and quantity from oil and gas activities in Alberta from 2005-2010 to provide some information and context for evaluating the risks to groundwater from energy activities. There are a few different organizations that can become involved with a domestic water well complaint starting with Alberta Environment and Sustainable Resource Development (AESRD) where complaints should be registered, but also energy companies, Farmers Advocacy Office, Alberta Energy Regulator (previously the Energy and Utilities Board and the Energy Resources Conservation Board), environmental consulting companies and Surface Rights Groups. However, the records kept by AESRD were the only recorded data for water well complaints that we could find. All of the calls received by AESRD Water Well Complaint hotline are documented in their Environmental Management System (EMS) database, and while there are some limitations in using this as our main source of data, it was the only inventory of water well complaints available. This study compiles information about domestic water well complaints contained in the AESRD EMS database to try to compare the number of complaints initially thought to be related to oil and gas activities with the number of confirmed cases of impacts from oil and gas activities. Information regarding the types of water well complaints reported by Alberta's water well owners, their attributed causes and the procedures used to identify these causes are also reviewed. The information can be used to help convey accurate, independently derived information about the numbers and types of oil and gas related water well impacts to industry, well owners and the general public.

Because this compilation and review is based solely on the AESRD EMS database, the study only includes complaints that were registered with AESRD or AER, and does not include complaints that may have been made by well owners directly to the energy companies. Any water well complaints made directly to AER (formerly EUB/ ERCB), would have been directed to AESRD so these complaints should be captured in the EMS database. The time period covered by this study (2005-

2010) precedes the development and application of extensive hydraulic fracturing to develop shale and tight gas resources. It also precedes the establishment of the Alberta Energy Regulator as the single regulator of the oil and gas production sector in Alberta. This study therefore does not attempt to assess the potential impacts to groundwater resources from fracing associated with shale gas. Note that fracing for CBM development is included in this assessment, as this was common practice during the review period.

The study consists of two phases:

Phase 1:
Compilation of statistics from AESRD's EMS database on domestic water well complaints received between 2005 and 2010.

Phase 2:
Compilation and evaluation of activities performed to follow-up on complaints that proceeded to the investigation phase.

2. BACKGROUND

2.1 Complaints to Industry

In the past it was common for domestic water well owners to make their complaints directly to the energy company without any involvement of government regulators. Energy companies had varying approaches for handling complaints, but many companies chose to provide compensation (usually in the form of paying for drilling of a new water well) rather than investigating the validity of the complaint. One of the reasons for using this approach was that it was viewed as being more economical to drill a new water well than to investigate the complaint. In addition, many companies considered this practice as a way of maintaining good relationships with local landowners.

Some in industry believe the practice of replacing wells rather than investigating the complaint has helped contribute towards a high perceived risk that many landowners and the general public currently associate with oil and gas activities. By providing compensation for water well problems that were not necessarily related to oil and gas activities, the oil and gas industry gave the impression that they were assuming responsibility for the water well problem. The past practice of investigating water well complaints internally and without regulatory oversight, has also been identified by industry as a way that they have contributed to the idea that water well impacts were being covered up.

As part of ongoing efforts to increase transparency, many companies now require that all water well complaints be registered first with AESRD to ensure that a formal complaint investigation is initiated and recorded. Industry is required to report any water well complaints to AESRD if they are related to coalbed methane (CBM) activities above the Base of Groundwater Protection (BGWP) under Directive 35 (D35) but there are no specific requirements for reporting on other energy-related water well complaints. Nonetheless, many energy companies now require that all water well complaints be registered with AESRD as part of their standard operating procedure.

2.2 Complaints Made to AESRD During 2005-2010

AESRD has a toll-free Central Complaint Line (1-800-222-6514) established for the reporting of all water well complaints. During the 2005-2010 study period domestic water well complaints received via the complaint line were dealt with by an AESRD Environmental Protection Officer (EPO). Typically, the complainant was asked to describe their concerns after which the EPO may recommend solutions by phone, provide an information package, or take further action. During the initial phone conversation the EPO recorded information about the well owner, and location of the water well. The EPO also documented the nature of the complaint (e.g. problems with water quality, quantity) and ask questions to try to identify potential causes. AESRD started keeping track of this information in their Environmental Management System (EMS) database in 2005. The current process for addressing water well complaints received by the hotline has changed slightly in that the initial calls are first triaged so that they are directed to either ESRD or AER for follow-up. However, the follow-up process is very similar to what was in place during the 2005-2010 period.

During the initial interview, the EPO will conduct a preliminary screening to properly direct the complaint (Figure 1). If the details surrounding the complaint suggest that there may be a fecal bacteria-related water quality problem the water well owner will be directed towards the Public Health Authority. If the complaint details suggest issues with well installation, such as well construction or the well drawing water from multiple aquifers, the EPO may recommend that the water well owner get advice from a driller to eliminate any well construction problems. When there isn't an obvious issue with public health or well construction, the first step is usually to eliminate well maintenance as the cause of the complaint. Questions such as whether there is staining in the toilet tank, differences in water quality for hot water vs. cold water, and the timing of when the water well problem was first noticed will be asked in an effort to troubleshoot the problem. If the well owner is not aware of the history of well maintenance (i.e. a new owner), or if they are sure that well maintenance procedures have not been followed, then the EPO will recommend that basic well maintenance such as shock chlorination be performed prior to continuing with the investigation. If improper or inadequate well maintenance does not appear to be a problem then follow-up activities by AESRD might include a site visit to inspect household water fixtures and collection of a water sample. If results of the initial phone interview suggest that oil and gas activities may be involved, Alberta Energy Regulator (AER) will be contacted to review oil and gas operations in the area. Should local drilling and completion activities be identified, AER will conduct a desktop study to review the operator's drilling and completion reports, the results of which would be sent via memo to AESRD to be included with the complaint file. AESRD will also contact the energy company in question who in turn may commission a third party hydrogeological consultant to investigate the landowner complaint and determine if there is any relationship to drilling and completion activities in the area.

Water well complaints related to seismic activities were dealt with separately from all other water well complaints, and during the 2005-2010 period all of these types of complaints would have been directed to Sustainable Resource Development (SRD).

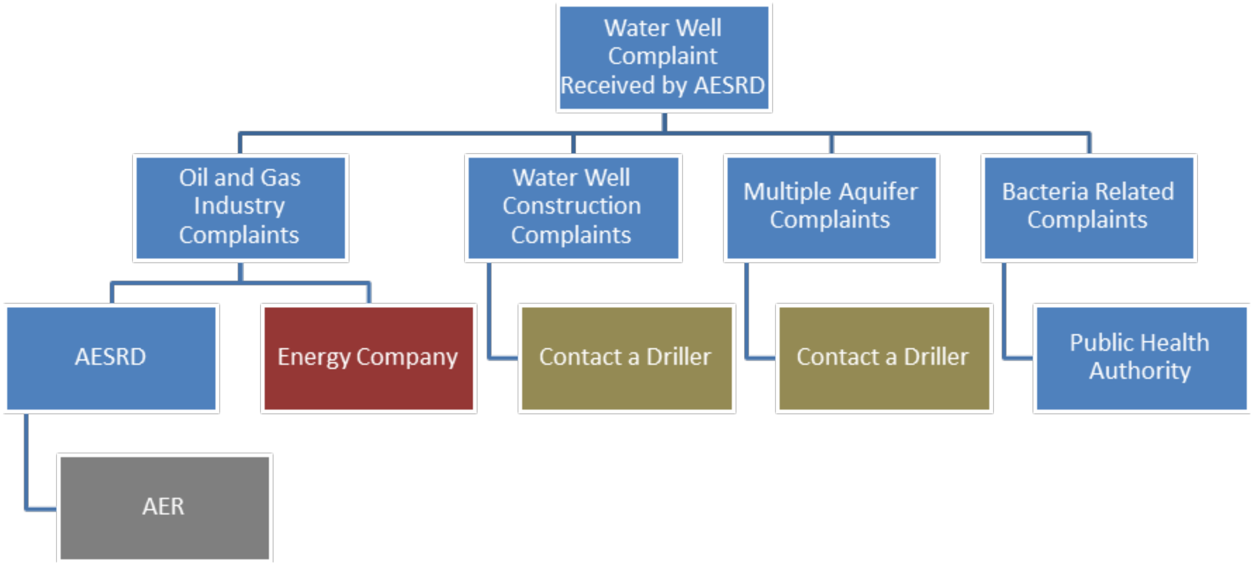


Figure 1 Schematic showing conceptualized process of dealing with a domestic water well complaint for the 2005-2010 study period.

AESRD's role in dealing with water well complaints is not to determine the root cause of the water quality or quantity issue, but to identify if it is related to an infraction of Alberta's environmental regulations. Proper maintenance and use of the water well is the responsibility of the well owner. Once AESRD has determined that there is no threat to human health and that there is no direct evidence to indicate contravention of regulations they close the investigation file even if the water well problem persists. They will direct the well owner to educational material or resources about maintaining their water well, or make specific recommendations for further steps to try to identify and solve the problem.

2.3 Farmer Advocacy Office

Once the complaint process to AESRD is complete, and results and conclusions have been delivered, the landowner has the option of submitting an application to the Water Well Restoration or Replacement Program administered by the Farmers Advocacy Office (FAO). The majority of the complaints that are received through the FAO are related to seismic activities but roughly 10% of the applications processed are related to oil and gas activities (pers. comm. Jim Kiss, 2011). When a well owner's application for reimbursement through the FAO is accepted, a request is made to AESRD for investigation details. A hearing will be held with an FAO representative, a EPO from AESRD, and members from the Agricultural Development Committee.

The program allows water well owners to apply for financial support to restore or replace a water well (from 0-100% of costs) where they feel that energy activities may have impacted their well, even in cases where the AESRD investigation is unable to find any direct indication of impact from energy activities. The approach of the FAO committee is to error on the side of the farmer if it feels there was any potential for energy activities to have been involved. Receiving compensation through this program does not necessarily mean that oil and gas activities (including seismic) have been linked to the water well problem, and water wells are often restored or replaced for cases where the AESRD investigation was inconclusive, or suggested no impacts from energy activities.

2.4 Regulatory Requirements of Energy Companies

There are a wide range of both conventional and unconventional oil and gas activities occurring in Alberta. These activities have varying potential impacts on groundwater resources and have different regulatory requirements. There are a large number of regulations covering the safe installation and operation of oil and gas facilities and a number of directives exist to ensure protection of non-saline groundwater resources. For this study we will focus on regulatory requirements related to identifying impacts on domestic water wells.

Depending on the type of energy-related activity and the potential vulnerability of water supplies, certain regulatory measures are in place to ensure cautionary testing is undertaken. Energy companies have generally been encouraged to adopt best practices to protect shallow groundwater and maintain healthy landowner relations. The level of involvement and extent of complaint investigations has generally been voluntary.

There is no obligation for energy companies to participate in the complaint process, except for complaints related to CBM development above the BGWP.

There are a few provincial regulations that are applicable to potential effects to water quality and quantity by energy activities. Section 109 of the Alberta Environment Protection and Enhancement Act (AEPEA) states that "no person shall release or permit the release into the environment of a substance in an amount, concentration or level or at a rate of release that causes or may cause a significant adverse effect" to human health or the environment. This would include the release of any liquids or gases associated with energy activities, and there are strict requirements for reporting if this type of release occurs (Section 110).

2.4.1 Coalbed Methane

The development of CBM resources in Alberta peaked around 2005-2006 at which point the number of CBM wells installed each year began to approach the number of new domestic water wells installed each year (Griffiths, 2007). Public concern about CBM production and related activities continued to grow, and prompted the development of the AESRD Standard for Baseline Water-Well Testing (BWWT) for Coalbed Methane/Natural Gas in Coal Operations (2006) and AER D35: Baseline Water Well Testing Requirement for Coalbed Methane Wells Completed Above the Base of Groundwater Protection (2006).

The BWWT Standard is implemented and enforced by the AER, which has an audit process designed to check well-drilling operations. AER determines if landowners were properly informed about testing and development (Griffiths, 2007). In addition, a CBM drilling license will not be granted if pre-testing requirements laid out in the BWWT Standard have not been met. The Standard requires companies to test water wells within 600 m of any proposed CBM well that will be producing above the BGWP. If there are no water wells within 600 m, companies are required to test water wells within 800 m of the proposed CBM well. Testing includes a two-hour yield test, sampling for routine potability water quality parameters, nuisance and indicator bacteria, and the presence and composition of gases in the well. The two main benefits of this program are that they contribute to the Alberta groundwater database and provide a baseline against which any suspected change can be compared.

If the well owner suspects a change in water quality and/or quantity, D35 requires that the complaint be registered with AESRD. The energy company is required by D35 to re-test the well if the well owner has any concerns after the CBM development has proceeded. The baseline testing will then provide a benchmark against which the re-testing data can be compared. The energy company will contract a hydrogeological consulting company to perform the re-testing and report on potential linkages to the suspected changes. The re-testing program is designed to address the landowner's concerns so developers are not required to replicate the entire pre-test but can focus the re-testing to address the well owner's complaints (e.g. if water quality is the well owners concern, a post-development pumping test may not be repeated). The AER may become involved to review and report on company activities. AESRD has developed a template for the data required for BWWT that is used in the pre- and post-testing of water wells under D35 (available at http://waterforlife.gov.ab.ca/coal/docs/sampling_template_final.xls). Some companies indicated that even when they are developing resources below the BGWP they often voluntarily follow the general template of testing described in D35 to provide baseline data for future comparison.

Although D35 and the general approach to BWWT has positive support from AESRD and AER, there has been some criticism from industry surrounding the extensive requirements of the program. Some of the aspects of the directive that have come under criticism from industry include the extensive list of parameters, many of which are not directly related to CBM activities, the lack of rationale for selecting the 600 m well testing radius, and the requirement that repeat testing of baseline data be conducted if pre-tests are more than two years old.

2.4.2 Conventional Oil and Gas

Despite recent concerns about unconventional gas activities, the number of conventional oil and gas wells drilled in the province far exceeds the number of wells drilled for CBM production. For example, in 2007, there were >13,000 conventional oil and gas wells drilled and only 1,273 CBM wells (AER 2008). Since the 2005-2010 period covered by this study, the CBM activity has decreased further, with >5,600 conventional oil and gas wells drilled in 2013 and only 50 CBM wells during the same period (AER 2013). While there are no regulations requiring baseline groundwater sampling prior to drilling for conventional oil and gas activities, the AER recommends first establishing baseline data prior to development. Many companies voluntarily complete local baseline sampling as part of their own best practices.

The AER requires companies adhere to directives during the drilling and production phases to minimize the risk of impact to the non-saline groundwater resources (Table 1).

Table 1: Summary of requirements outlined by AER directives.

Phase	Directive	Description	Requirements
Casing Installation	008	Surface Casing Depth Requirements	o Depends on well type, depth and geographical location, but provides details the minimum surface casing depth requirements to assist with well control and groundwater protection.
Casing Installation	009	Casing Cementing Minimum Requirements	o Outlines casing cementing requirements including methods for determining the required cement top, requirements for casing and outlines requirements for special cements such as foam and thermal cements.

Casing Installation	010	Minimum Casing Design Requirements	o Outlines requirements for the design of casing for different categories of wells, including design factors and material specifications.
Abandonment	020	Well Abandonment	o Outlines the minimum requirements for abandonments, casing removal, zonal abandonments and plug backs. o Remedial cementing mostly applies to wells without cement covering the surface to BGWP interval (D20)
Fracturing	027 (superseded by Dir. 083)	Hydraulic Fracturing – Subsurface Integrity (Formerly Shallow Fracturing Operations – Restricted Operations)	o Outlines the requirements for managing subsurface integrity associated with hydraulic fracturing subsurface operations. o D27: prohibits fracturing operations in any energy well that is within 200m of a water well if interval is <50m deeper than total depth of the water well (“conservatively safe margin)

2.5 Types of Water Well Complaints

The complaints recorded in AESRD’s EMS database cover a wide range of well problems including: aesthetic issues, sediment in the well, changes in water levels, changes in well yield and gas in the well. One of the challenges in investigating water well complaints and identifying impacts from oil and gas activities, is that in addition to being potential indicators of impacts from oil and gas activities, many of these types of problems can also appear when the water well is in need of maintenance.

2.5.1 Aesthetic Complaints

A common type of domestic water well complaint is about aesthetic aspects such as the smell and appearance of water coming out of their taps. Most domestic water well trouble shooting guides (e.g. Water Wells That Last for Generations, 1996) suggest that the presence of iron bacteria or sulfate-reducing bacteria can be the cause of these odour problems and that proper water well maintenance to limit these bacteria is necessary to prevent this problem.

2.5.2 Sediment in the Water Well

The U.S. National Ground Water Association fact sheet on water wells near oil and gas activities (NGWA, 2011) lists changes in turbidity as a potential impact of oil and gas activities due to disruption or change in the flow field. Increased turbidity in a well may occur if nearby oil and gas activities alter the groundwater flow, causing the well to receive flow from a finer grained, less consolidated unit, more prone to contributing sediment to the well, or from a previously unused unit that has not had the fine sediment removed during development. Drilling and fracing fluids can also contain solid material, and if these fluids were to reach a water well they may be a source of increased sediment.

However, there are also natural causes for the presence of sediment in a domestic water well including:

- precipitates from dissolved minerals in water, and

- entry of fine clay or sand particles from the adjacent sediments into poorly designed well screens.

Dissolved iron and manganese are present naturally in many Alberta aquifers. When this water enters a well or is pumped to the surface, changes in pH and redox conditions can result in a shift in the chemical equilibrium resulting in the precipitation of minerals that appear in the water as sediment (Bourg and Bertain 1993; Haveman et al., 2005; Hiscock and Grischek, 2002; Tufenkji et al., 2002; van Beek, 1989). As bacteria utilize the metals in solution they change iron and manganese from a soluble form into a less soluble form, causing precipitation and accumulation of red (iron) or black (manganese) gelatinous material ("slime") (NGWA, 2010). Bacterial reactions with iron or manganese do not cause any additional precipitation compared to normal exposure to oxygen, however, the bacteria does cause precipitation to occur faster and concentrates the staining, making it more noticeable.

Precipitation of iron and manganese minerals can also be caused when a well is screened over multiple aquifers, with different redox conditions and concentrations of dissolved metals. Calcium and magnesium can also precipitate out of solution but these typically result in carbonate scaling (white) noticeable in sinks, bathtubs or toilets. The precipitation of these mineral phases can result in a decrease of the hydraulic conductivity of the aquifer or the well screen, resulting in a plugging of the flow path, the extent of which may vary seasonally and in response to pumping fluctuations (Kwon et al., 2008; Tufenkji et al., 2002). The oxides produced by microbiological activity are typically poorly crystalline Fe(III)-oxides (Macalady et al., 1990) that eventually can lead to biofouling problems in water wells (Carlson and Schwertmann, 1987, Tuhela et al., 1992) and can clog the well screen and pump decreasing the water yield (Tuhela et al., 1993).

Proper well construction and development should prevent clay and sand from entering the well from adjacent aquifer units, but corrosion of the well casing, screen or liner over time, or failure of the annulus or casing seal can result in the sudden appearance of sediment in a well (Water Wells that Last for Generations, Alberta Agriculture, 1996).

2.5.3 Change in Water Levels

Depending on the depth of the aquifer that the water well is utilizing there may be seasonal or inter-annual variations in water levels related to changes in recharge. Superimposed on top of these climatic variations there can also be variations in the water levels due to changes in usage, by the water well owner themselves, or by other users of the aquifer. Identifying whether a change in water level is related to a specific oil and gas activity would be quite difficult unless there are reliable water level records for the water well. The main approach to identifying whether oil and gas activities have resulted in a change in water level or water yield is to compare water level measurements with data available from before the energy activities occurred.

2.5.4 Change in Well Yield

The well yield is determined during a pumping test and can be thought of as the maximum pumping rate that can be supplied by a well without lowering the water level. The well yield can change if there are changes in the hydraulic properties and pressure field around the water well. The inclusion of pumping tests in the CBM baseline groundwater testing was to address concerns that fracturing and depressuring the formation containing the methane might alter the hydraulic properties and pressure fields resulting in less water available in overlying shallow aquifers. However, the yield of a given water well can also vary over time due to changes in hydraulic properties of the screen.

Biofouling and the accumulation of gelatinous bacterially mediated mineral precipitates ("slime") around the intake screen and adjacent aquifer material can result in decreased water yield and would need to be eliminated as a potential cause for this change.

Large deposits of iron encrustations have been detected in sediment around water supply wells, extending 1-2 m (Medihala, 2012) or up to 4 m (Houben and Weihe, 2010) away from the well. These deposits can decrease the permeability of the screen and adjacent sediment reducing well yield (Houben and Weihe, 2010; van Beek 1989). Proper well maintenance will ideally prevent or remove accumulations of precipitates to keep the well at its optimum yield. Water wells that are not regularly maintained can show significant declines in well yield (e.g. Figure 2 from Houben and Weihe, 2010). In this example the rehabilitation events temporarily result in increased well yield.

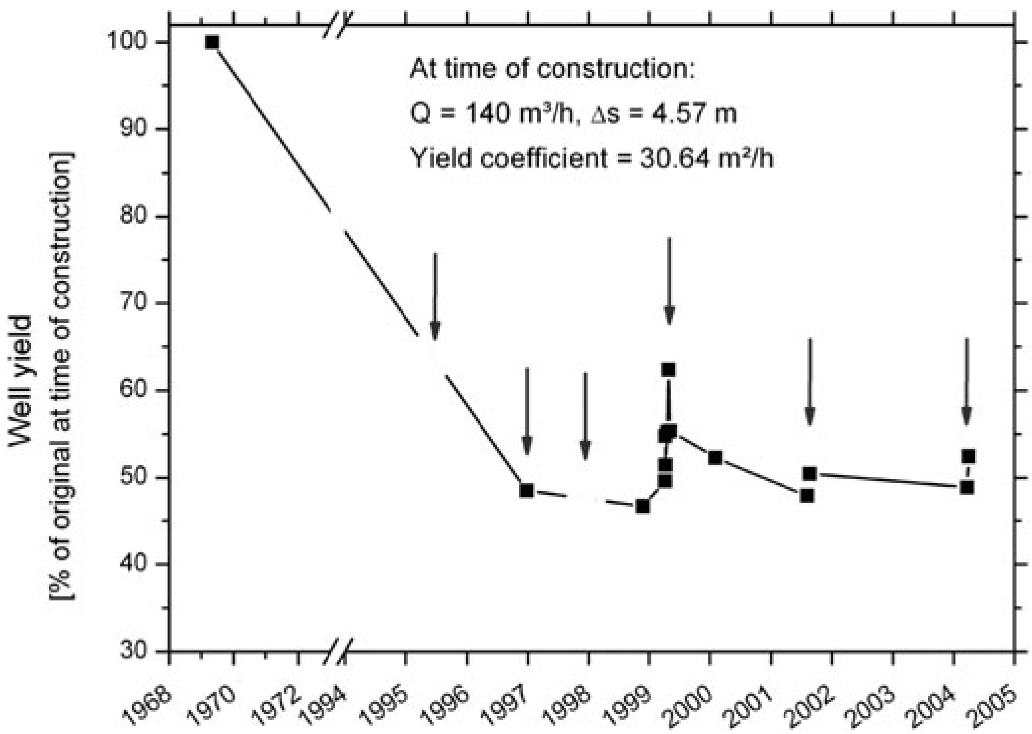


Figure 2: Example of changes in well yield at a water supply well with iron oxide precipitation in Germany (reproduced from Houben and Wiehe, 2010). The arrows indicate rehabilitation events, and show the potential for secondary precipitates and well maintenance to affect well yield.

2.5.5 Gas in the Water Well

Methane is a common, naturally-occurring dissolved gas in groundwater. Groundwater samples from water wells that are installed in coal zones often contain methane, but it can also be present in groundwater due to methane producing bacteria. Methane is often present in coal zones and when water wells are installed in coal zones, methane gas can be present naturally in groundwater from those zones. Methane is typically present as a dissolved gas at depth in groundwater, but as the water is pumped to the surface, the lower pressures encountered at shallower depths can cause the gas to bubble out of solution. The amount of gas present in groundwater can change due to variations in pumping rate or improper well maintenance. If routine water well maintenance (e.g. shock chlorination of the water well) is not performed, methane producing bacteria can thrive and result in increased methane production in a well. Methane is non-toxic and non-poisonous, but it is flammable and accumulation of methane gas in an enclosed space is an explosion risk. In areas where methane is naturally present at high concentrations in groundwater, installing properly vented water wells and water distribution systems is important to prevent the accumulation of flammable gases.

The sources of methane gas in a water well can be anthropogenic (e.g. leakage from an improperly sealed gas well, leakage from a geological formation due to pathways created by energy activities) or natural (e.g. bacterial activity or migration of gas from an accumulation at depth along a fault or pathway).

The D35 baseline testing requires analysis of the elemental and carbon isotopic composition of any hydrocarbon free-gases present in wells, so that baseline pre-development reference values can be developed. The general approach to identifying the source of gases present in a water well usually includes sampling free and/or dissolved gases present in the water well and comparing the compositional and isotopic data with expected ranges for biogenic and thermogenic gases, existing data for Alberta, nearby wells or pretesting data if it exists (Figure 3). In some areas detailed profiles of the isotopic composition of the different hydrocarbon gases present in different formations ("mud gases") are available allowing for better identification of potential source depths. Matching the isotopic composition of carbon ($\delta^{13}C$) of multiple components of the gases sampled in the near surface aquifer (e.g. $\delta^{13}C$ of methane, ethane, propane and butane) with those profiles at depth can be used to identify specific formations (Rowe and Muehlenbachs, 1999). This type of comparison was used to determine that many of the gases present in surface casing vent flows from oil wells were generated within the Colorado Group shales (shallow) and not the Mannville Group sands (deeper) (Rowe and Muehlenbachs, 1999).

Isotopic composition of multiple hydrocarbon gases present in the well has the potential to provide greater constraints on identifying the depth of origin for gases sampled at the near surface, however even when there is an exact match for the isotopic composition of the gases, often there is still no information about the pathway or mechanism for how the gases migrated to the near surface. For example, finding gases with isotopic signatures consistent with a deep formation used for oil and gas development in a domestic water well does not differentiate whether it migrated to the shallow aquifer via a natural fracture in the bedrock, or via a poorly sealed energy well or some combination of the two.

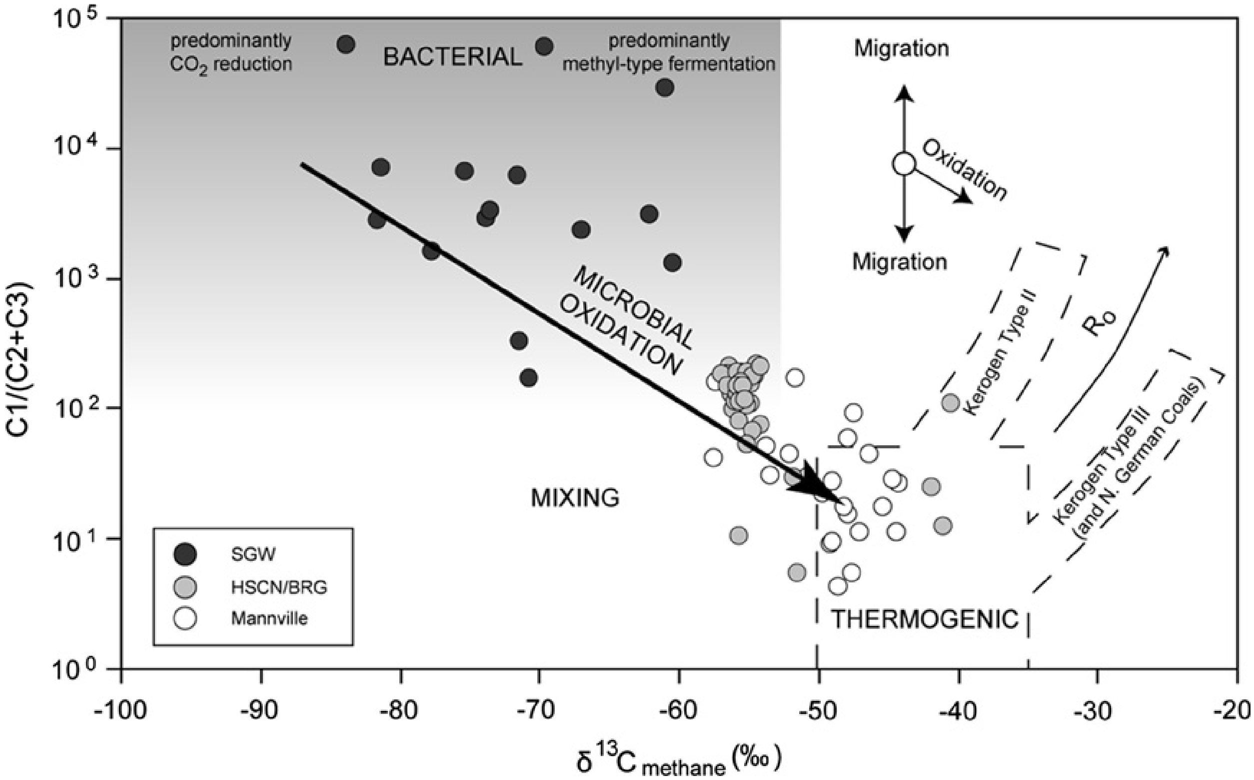


Figure 3: Barnard plot of hydrocarbon gas composition versus $\delta^{13}C_{methane}$ for shallow groundwater (SGW), Horseshoe Canyon/ Belly River Group (HSCN/BRG) and Mannville gases for Alberta (Cheung et al., 2010).

In Pennsylvania, higher concentrations and the more thermogenic isotopic composition of methane present in shallow groundwater wells near active shale gas activities were used as a line of evidence to demonstrate that shale gas activities in the Marcellus Formation resulted in an impact to shallow aquifers (Osborn et al., 2011). An area of active gas extraction (1 or more gas wells/km) was found to have higher methane concentrations and had a more thermogenic signature than methane sampled from groundwater wells where gas extraction had not occurred (no gas well within 1 km) within similar geological formations. In this case the $\delta^{13}C_{methane}$ in the active area ($\delta^{13}C_{methane}$ = -37‰, ±7 ‰) was significantly more positive than at the non-active sites ($\delta^{13}C$ = -54‰, ±11 ‰). The concentration and isotopic composition of gases detected in water wells can provide a method to identify thermogenic gases originating from deeper formations, but it is still difficult to determine whether the gases are present due to oil and gas activities or natural processes. Without any data on water quality prior to fracking, the methane concentrations and $\delta^{13}C_{methane}$ values measured in the Marcellus development are difficult to attribute specifically to fracking, and have also been attributed to natural processes (Davies, 2011; Molofsky et al., 2011).

3. METHODS

3.1 Sources of Data

AITF contacted AESRD, AER, FAO, and industry and Landowners groups to identify sources of data on domestic water well complaints that could be used in this study. Even though all of these organizations dealt with various aspects of domestic water well complaints, none of them keep records specifically tracking the types of water well complaints and their causes. The most relevant data that we could identify was in AESRD's Water Well Complaint EMS database. This database was established as a log that documents all of the water well complaints received by AESRD and includes fields filled in by the EPO as the initial complaint is received and notes all activities related to the water well complaint until the file is closed. However, this database was not established specifically for the purpose of tracking complaints and there are some limitations to our methodology. Because the Water Well Complaint hotline is entered into AESRD's EMS database this source also had the benefit of being accessible digitally. AITF made a request to AESRD through the Freedom of Information and Protection of Privacy Act (FOIP) to gain access to the EMS database for the period of 2005-2010. The EMS database was provided from AESRD to AITF with all personal information that could identify the complainant (e.g. names, legal locations, addresses etc.) removed. The EMS database included a call ID, date, incident ID, incident resolution, a description of the initial complaint and all subsequent correspondence conversations, what follow-up activities were undertaken by AESRD (e.g. site visit, water testing, investigation), whether an investigation was undertaken, whether an enforcement action was taken, and when the file was closed.

3.2 Phase 1

In Phase 1 the information contained in the EMS database was reviewed and compiled to obtain information on the number of domestic water well complaints that were reported in Alberta between 2005 and 2010, and to identify how many complaints were initially thought to be related to oil and gas activities, and how many were eventually linked to oil and gas activities. Information about whether follow-up investigations were conducted and the investigation techniques used to either rule out or establish the link between the problem identified and the energy activities was also compiled. The EMS database contained information about 720 separate complaints registered through the AESRD Water Well Complaint hotline between 2005 and 2010. AITF reviewed all of the information contained in the EMS data for each of these incidents to gather the following information:

- nature of the problem (e.g. decreased water yield, water level decrease, presence of gas in the well, change in odour/taste, changes in quality, sediment present in the well).
- were oil and gas activities suspected?
- were any specific oil and gas activities mentioned? (e.g. drilling, fracing, well maintenance)
- what actions did AESRD take? (e.g. site visit, water sample, initiate investigation)
- if an investigation was initiated what activities did it include? (e.g. comparison of pre- and post- data, water sampling, gas analyses, sediment analyses).

The EMS database was first reviewed to identify duplicate records, which were flagged and removed. The conversation details noted in the EMS were reviewed and information about each of the above bullets were tabulated. Well owners were not contacted during this project and the EMS database did not include any information indicating who the complainant was or where they were located. Cases that proceeded to the investigation phase were flagged to be included in Phase 2 of this project, which involved reviewing individual investigations to compile information about the methods used. AITF also informally interviewed energy company representatives from both the conventional and unconventional fields and reached out to landowner groups. One of the initial objectives was to see if these companies received and investigated any domestic water well complaints that were not included in the AESRD database, to evaluate the validity of using this database. The interviews were also used to identify the steps that industry typically uses to investigate domestic water well complaints, and maintain good relationships with local landowners.

The EMS database includes all correspondence between the EPO and the water well owner until the file is closed. There are a number of reasons for AESRD to close a file including:

- no adverse effect to human health or environment,
- no likelihood of an adverse effect being caused by an external source (e.g. dates, or groundwater flow directions indicate that it was not feasible for the water well complaint to be caused by the suspected energy activity),
- water well owner took steps to resolve their problem and it is no longer an issue (e.g. repaired electrical wiring on pump, shock chlorinated the water well, etc.),
- assessment/report results show that there was no change in water quality/quantity and that the problem is likely related to biofouling or natural causes or well deterioration.

There were some water well complaint files that were not actually about an existing water well problem. Some of the water well owners called the complaint hotline to register a complaint even though they did not have a current water well problem. These were typically cases where the water well owner had noticed nearby oil and gas activity and wanted to register their concern that their water well may be impacted in the future. The complaints in EMS that were not for an existing problem were separated into a different category.

There were also some water well complaints in the EMS database where AESRD was unable to conduct follow-up activities because they were unable to reach the landowner or because the landowner did not want to participate.

For the remaining cases, where the water well complaint was for an existing problem and where AESRD was able to conduct follow-up activities investigating the problem, AITF used the information present in the EMS description of each case to categorize the cause of the problem as being one of:

- not oil and gas impacted,
- inconclusive (i.e. unable to eliminate oil and gas impacts based on data available in the EMS),
- oil and gas impacted.

In some cases the notes would simply describe the cause of the complaint as not being related to oil and gas activities, whereas in others they would give a potential cause (e.g. age or maintenance or bacteria). There were differences in the terminology used to describe why cases were closed, because the EMS database includes reporting from multiple EPO officers.

3.3 Phase 2

Phase 2 involved reviewing water well complaint investigation reports identified in Phase 1, to obtain information about the type of water well problem initially reported and to determine the types of investigative techniques and follow-up activities that were conducted to explore the complaint.

The results of Phase 1 were used to identify the domestic water well complaints that proceeded to the investigation phase. Information compiled from these reports included follow-up investigations outlining the different investigation techniques for different types of complaints. Gaining access to these reports could have either been done through individual FOIP requests to AESRD for each of the reports, or by requesting access to the reports directly from the relevant energy company. Since some of the larger companies accounted for significant proportion (55%) of the complaints, we elected to request the investigation reports directly from industry. In some cases, the EMS database did not contain sufficient information to identify complaint details (e.g. energy company involved, legal locations and well owners names had been removed) and the report could not be located. Of the 49 investigation reports requested, AITF was able to access to 33.

3.4 Limitations

Prior to discussing the results, it is important to note some of the inherent limitations in the study due to limitations in the available data sources. The AESRD EMS database was the only source of data identified, and as a result our study only includes complaints that were registered through AESRD's water well complaint hotline, and does not include complaints made directly to energy companies. Attempts were made to locate sources of information about water well complaints filed independently from AESRD or the energy industry, but we were unable to identify an independent organization with anything other than anecdotal information about domestic water well complaints in the province. The opinion expressed by the industry representatives that we spoke with and by AESRD was that this practice is not as common as it once was, and for the 2005-2010 period would not include many cases. Some companies refuse to consider a water well complaint unless it has first been registered with AESRD. However, the only surface rights group that we were able to interview thought that many domestic well complaints were still settled directly between oil and gas companies, and expressed their concern that we would greatly underestimate the number of impacted wells because of cases of impacted water wells where the owners had signed non-disclosure agreements with the energy company. They were unable to provide any estimates of how many complaints they thought were settled through non-disclosure agreements, or estimates of how many water well owners in their jurisdiction were unsatisfied with the results of their water well complaint investigation conducted by AESRD. While acknowledging that there are some limitations in using the AESRD EMS database to compile these kinds of statistics, we were unable to find any other source for this information either from government, industry, or landowner groups.

Another limitation of the EMS as our main source of data for this study is that it was designed and used as an internal information management system not specifically for compiling information and statistics. An incident file is started for every water well complaint received, and all communications with the well owner and subsequent actions are recorded. The EPOs recording this information are based in different regional offices and there may be differences in how complaints are described and the level of detail included for each of the complaints recorded.

The EMS database also does not include any record after AESRD has completed their investigation and closed the file, so it is difficult to gauge how many of these well complaint investigations identified in the database are being contested by the water well owners. However, the dissatisfaction of some water well owners with the findings of the investigations conducted about their complaints has been featured in the media (e.g. Calgary Herald, 2007. Troubled Waters; Calgary Herald, 2011. Gas drilling critic launches multimillion-dollar suit; Edmonton Journal, 2007. Gov't ignoring tainted groundwater problems: rancher), so there are clearly at least a few contested cases.

4. RESULTS AND DISCUSSION

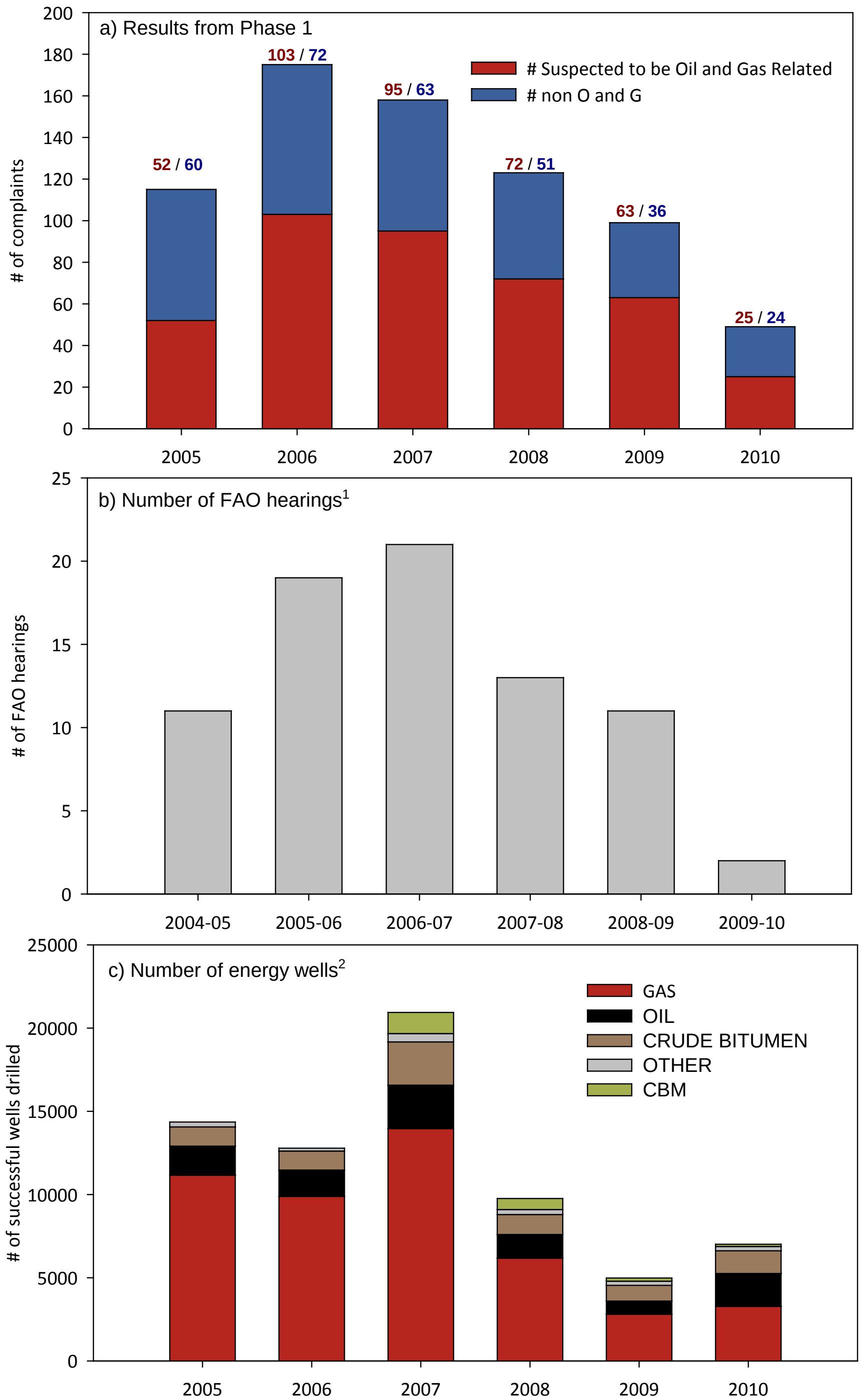
4.1 Phase 1

A total of 720 separate domestic water well complaints were included in the EMS database for the period of 2005 to 2010 and all were reviewed for this study (Table 2). The well owners identified energy activities as the potential cause for their water well problem in 410 of the 720 complaints (57%).

Table 2: Summary of water well complaints received by AESRD for the period of 2005-2010.

2005-2010 Summary of Well Complaints Received by AESRD	#
Number of Complaints Received	720
Number of Complaints Where the Water Well Owner Suspected Well Problem Related to Oil and Gas Activities	410
Number of Follow-Up Investigation Reports	60
Number of Water Wells with Confirmed Impacts from Oil and Gas Activities	2
Number of Contested Cases	>2

The number of complaints received each year varied (Figure 4a) with the largest number of total complaints, and complaints identified by the well owner as being energy-related, occurring in 2006, which corresponds with the peak of CBM activities in Alberta. This trend is also evident in the number of hearings the FAO conducted for the Water Well Restoration and Replacement Program over the same time period (Figure 4b). As was previously noted for water well complaints related to CBM activities (CAPP, 2009) the number of water well complaints roughly tracks the trend in the numbers of energy wells drilled (Figure 4c). The correlation between energy activity and complaints may be due to actual risk caused by the higher densities of CBM wells and production in zones shallower than most oil and gas plays in Alberta, or simply due to the tendency for people to attribute problems with their water well to energy activities, when they notice energy activities in their area. This tendency may be particularly true for CBM development as it is a new type of activity with wells generally located closer to populated areas.



[1] *Annual Report of the Office of the Farmers' Advocate of Alberta (FAO), 2008-09, 2010*
[2] *EUB Alberta Drilling Activity Monthly Statistics, 2005 to 2010, CBM wells were not included as a separate category until 2007*

Figure 4 a) Numbers of complaints received by AESRD during the 2005-2010 period compared with b) numbers of FAO hearings, and c) total numbers of successfully completed energy wells installed during the same period.

Similar types of complaints were made for the water well complaints suspected to be related to oil and gas activities, as well as the well complaints not specifically linked to energy activities (Figure 5). The most common complaints associated with oil and gas activities were regarding aesthetic qualities of the water (odour and taste) (Figure 5). Some water well owners noted multiple problems during their initial complaint so individual complaints might have included multiple quantity and quality issues, which is why the sum of the totals presented in Figure 5 is greater than the number of complaints.

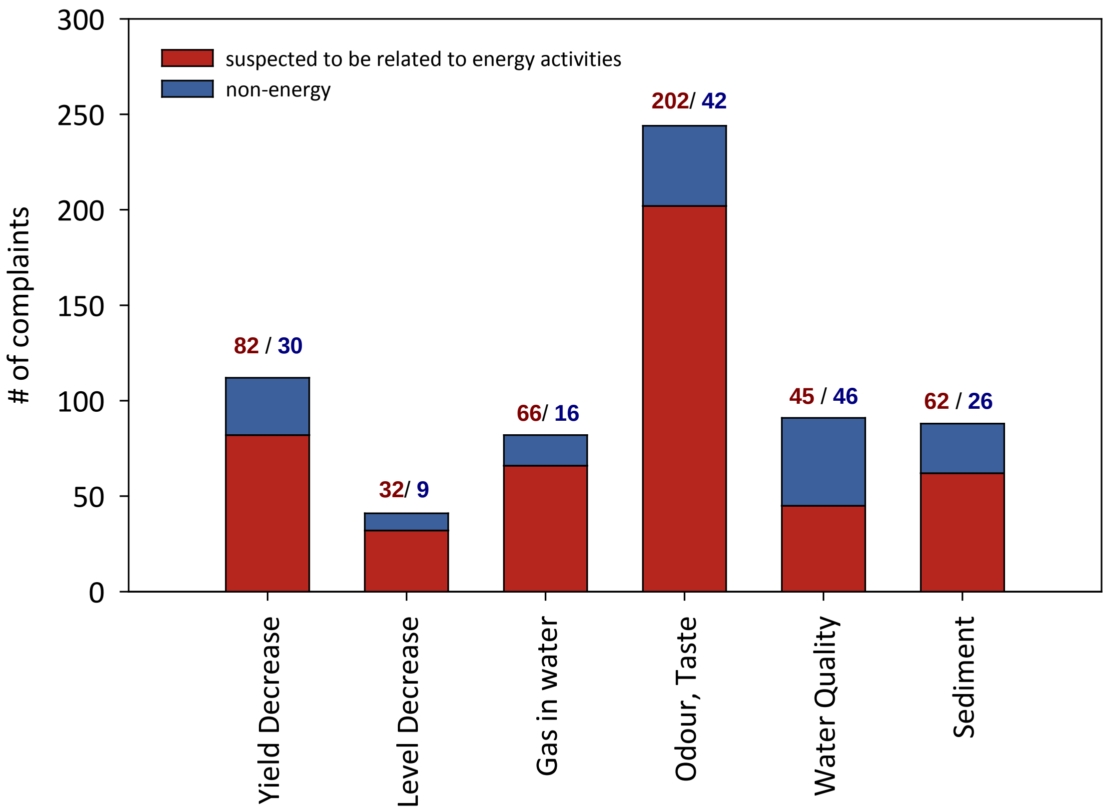


Figure 5 Summary of all of the causes mentioned in the 710 water well complaints logged in the EMS database for the period of 2005-2010 (number of cases reported in each category are given above the bar).

A summary of the 720 water well complaints is presented in Figure 4. Of the 410 water well complaints where the well owner suspected oil and gas activities being the cause, 20 were not actually related to a current problem at the water well. In 15 of these cases a water well owner called in to express concern about potential future impacts at their water well based on current oil and gas activity in the area. For these 15 complaints the water well owner hadn't actually observed any changes in the water quality or quantity in their well, but they wanted their concerns about potential future oil and gas impacts on record with AESRD. The other 5 cases were questions or complaints about the pre-testing procedure. In these cases energy companies had come to take pre-development testing at their water well (e.g. mandatory D35 CBM testing, or voluntary pre-testing for other wells) and the water well owner called the AESRD hotline to request an explanation for some of the results, or request additional analyses. Removing these 20 cases, in which no issues were observed at the well, resulted in 390 complaints where well problems were reported and suspected to be related to oil and gas activities.

Of the remaining 390 complaints there were 22 cases where AESRD was unable to conduct any of the follow-up activities used to evaluate the well complaint (e.g. phone interview, site visit, water sample) (Figure 6). In these cases the water well owner either could not be reached (n=18) or did not want to participate in an AESRD investigation (n=4). Reasons given for choosing not to proceed to the investigation phase included not trusting an investigation led by AESRD and wanting an independent investigation (n=2), just wanting the complaint on record (n=1) and not wanting to release baseline results (n=1).

Removing the 22 cases where AESRD was unable to proceed with their investigation, leaves 368 cases where AESRD conducted investigations on a complaint where the well owner suspected impacts from oil and gas activities. In 343 of these cases the notes in the EMS database clearly specify that the results of the interview and investigation did not indicate impacts from oil and gas activities. For 30 of these cases the file was closed because the water well owner reported that the problem stopped during the AESRD complaint process. In some instances the problem had already stopped by the time the EPO made initial contact with the water well owner, while others stopped during the investigation. When the initial interview between the EPO and water well owner seemed to indicate an obvious water well maintenance problem (e.g. no history of the water well ever having been shock chlorinated) the EPO would recommend maintenance steps, and provide educational material about proper well maintenance and instruct the water well owner to get back to them if the problem persisted. There were 76 cases where the complaint file was closed after the water well owner was given instructions for maintenance and was told to call back if the problem persisted.

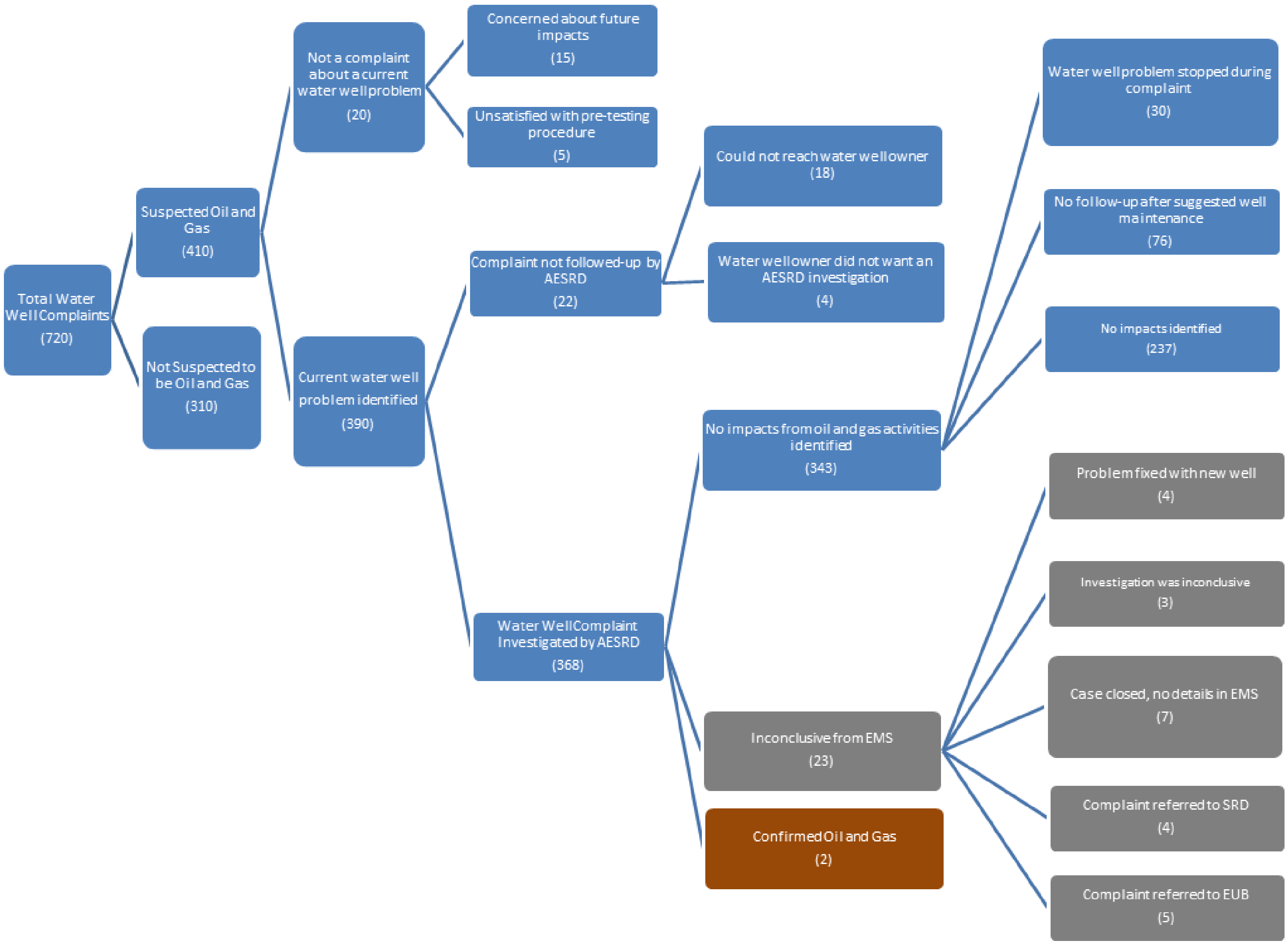


Figure 6: Breakdown of the 720 complaints registered in the AESRD EMS database. Of the 410 complaints for which the well owner identified oil and gas activities as the suspected cause, 2 were confirmed to be related to oil and gas activities.

The remaining 237 cases were closed after AESRD could not find any evidence of adverse impacts from oil and gas activities. These decisions were sometimes made based on the phone interview, or after a preliminary site visit, the results of water quality analyses, downhole camera inspection of the well, or results of a hydrogeological investigation (Table 3). In some cases the well owner had the well shock chlorinated or inspected by a water well driller to try to eliminate potential causes.

Table 3: Summary of actions taken to investigate the 237 cases that were closed after no impacts from oil and gas activities were found.

Complaint Follow-up Activities	**#**
Initial AESRD telephone interviews	237
AESRD site visits	62
Water samples for geochemical analyses	59
Water sample for bacterial analyses	40
Water well was shocked	9
Driller called	9
Energy company contacted by AESRD	58
External hydrogeological investigation conducted	60

The entries in the EMS database for the 237 cases that were categorized as not having any impacts from oil and gas activities, can be used to identify some of the potential causes for the water well complaints (Figure 7). In some cases the file was closed because no clear evidence of a change in water quality or quantity could be detected. This was sometimes made based on direct comparison of pre- and post-data where available (n= 38) or based on the results of the AESRD follow-up activities (n=35). For 15 of the water well complaints the location or timing of activities at the suspected energy well were inconsistent with the water well complaint. If the energy well suspected to be the cause of the water well problem was inactive, or not started until after the water well problem had already appeared; if the energy well was very far away, downgradient or in some way not a plausible cause for the problem identified at the water well then, unless there was some other line of evidence, the case was closed (n=15). For complaints where some change in water quality or quantity was identified (e.g. change in smell, appearance of gas or sediment in the well, decreased well-yield) the most typical causes cited in the EMS notes were evidence of biofouling or bacteria (n=84) or well maintenance problems (n=79). Evidence of biofouling, casing failure, clogged well screens or collapsed wells can result in the appearance of gas and sediment in the well as well as changes in aesthetics and decreased well yield. There were 6 water well complaints about the appearance of sediment in the well that were attributed to over pumping. The investigations for the 237 cases included 60 reports, and the results of these external investigations were often cited as the reason for closing the file. In 31 cases, the EMS notes say that no impact from oil and gas activities was identified, but an alternate cause is not provided. We should note that the objective of the AESRD investigations is to gather evidence of a possible contravention to Alberta Environment legislation. If there is no evidence of oil and gas impacts their mandate does not require them to find the actual cause. Even though the EMS notes often cite potential other causes for the water well problem, identifying these causes is not the objective for their investigation so it is not surprising that the notes do not always describe potential causes.

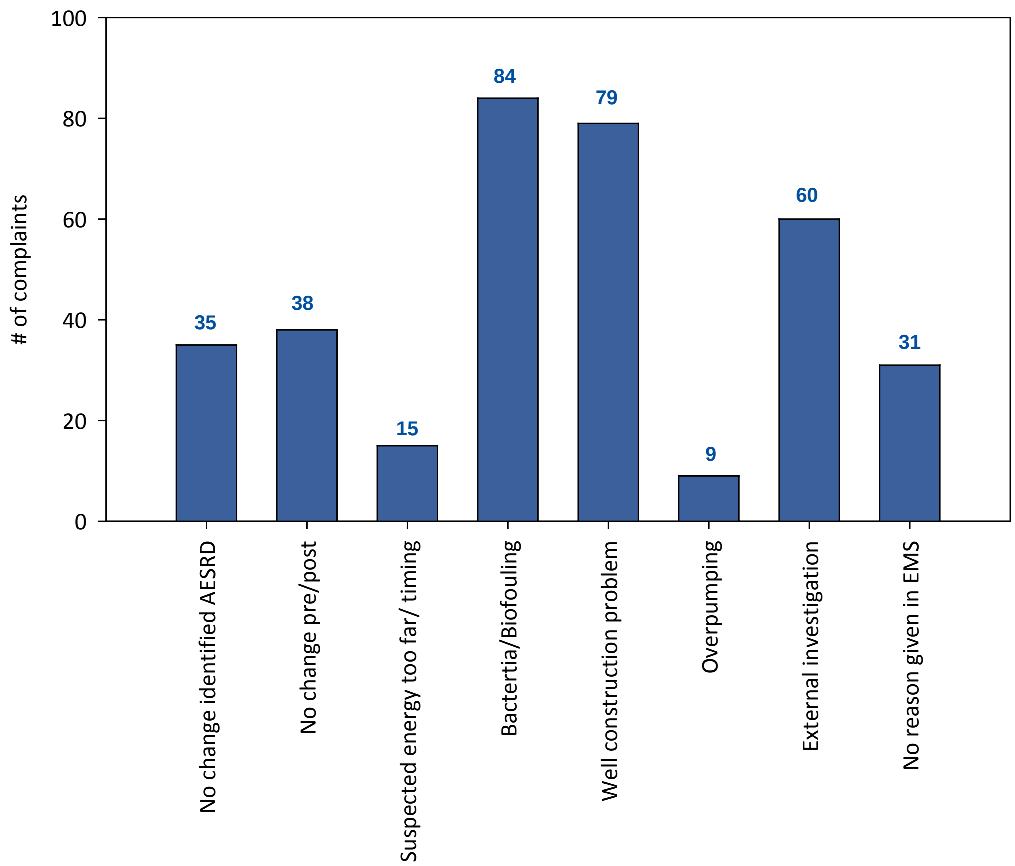


Figure 7: Explanations for closing case files in the EMS database for the 237 domestic water well complaints where AESRD found no impacts from oil and gas activities. Multiple causes were given in some cases.

In the 368 investigated cases there were 23 where the notes in the EMS database cannot be used to conclusively decide whether adverse impacts from oil and gas activities were eliminated (Figure 6). In all of these cases AESRD must have been satisfied that there was no risk to human or the environment to close the file, but it is not clear from the notes what the final outcome was for these cases. Included in this category are 4 cases where the EMS notes indicate that the problem was resolved after a new water well was drilled. This does not necessarily indicate impact from oil and gas activities, but because a new well was drilled the original problem was not investigated. One of these new wells was provided by the energy company, but this was because they had lost a piece of equipment down the water well during routine testing. There were 7 cases where the file was closed, but with no information about the reason for closing the file. There were 3 cases where the investigation gave inconclusive results, but the files were closed because the problem stopped. There were 4 water well complaints that were referred to SRD because they were related to seismic activities. Similarly there were 5 cases that were referred to AER predecessor organizations. For some of these cases the referral was not related to a problem that resulted in an impact to a water well (e.g. see Case Study 3 below).

In total, 2 cases in the EMS database were confirmed to be related to oil and gas activities. These are described in more detail in Phase 2.

In 410 of the 720 complaints (57%) of the water well complaints the well owner identified oil and gas activities as a potential cause of the problem. The results of the AESRD investigation confirmed oil and gas impacts in 2 (2 out of 368 cases investigated = 0.5%; 2 out of total 720 cases =0. 3%) of the cases. A cautious upper limit for the number of water well complaints can be estimated using the 23 inconclusive cases. There were 23 cases where we could not rule out impacts from oil and gas activities, and this upper limit can be used to estimate (23 out of 368 cases investigated 6 %; 23 out of 720 cases 3%). As noted in the limitations inherent in using the EMS database, these statistics are only based on the cases registered to AESRD. However the number of domestic water well impacts suspected to be related to oil and gas activities (57%) compared to the number of confirmed (0.5%) or potential (6%) indicate that the public perception of risk posed by oil and gas activities on domestic wells is an order of magnitude higher than the actual recorded risk. Even though a lot of the oil and gas activity occurred in areas without any nearby domestic water wells comparison of the number of energy wells drilled over the 2005-2010 period (Figure 4c, 5000/year to 20,000/year), to the total number of water well complaints (Table 1, n=720) registered in the province over the same time period does place the number of complaints in context of the high level of oil and gas activity in the province.

In Phase 1 of this study, AITF found only 2 confirmed energy impacted water wells. It should be emphasized that the dataset evaluated only included water well complaints reported to AESRD and not complaints that may have been reported to energy companies. Additionally, there is a gap in the mandates of those involved (AESRD, AER, energy companies, and well owners) in that none of the involved parties are responsible for determining the cause of the water well issue. For this reason, an additional 23 wells in the AESRD EMS database may have been affected by energy activities however the cause of the well issue was not identified. Despite these limitations, the total number of confirmed (2) and potential (23) wells affected by energy activities between 2005 and 2010 is small. The results of Phase 1 of this study are similar to the results of the technical review of the D35 and baseline water well testing requirements undertaken by CAPP in 2009. The CAPP study indicated that the potential for impact to groundwater from shallow CBM developments in the Horseshoe Canyon was negligible and no impacts on water wells were found when repeat or post testing was conducted. The report found that of the 10,000 water well tests and 15,500 CBM wells drilled, there were only 100 complaints related to 86 wells. Of these, one impact was found and this was one of the two impacted wells identified in the AESRD EMS database. Phase 1 of this study differed from the CAPP (2009) study in that we used a completely different database that included a slightly expanded time period and included all types of energy related drilling and completion, with the exception of hydraulic fracing for shale and tight resources, which became prevalent after the time period of this study. Despite these differences, our review has only identified one additional impacted well than the CAPP (2009) study, and a maximum of 23 potentially impacted wells that were included in the statistics to give a worst-case scenario for risk.

4.2 Phase 2

As previously described, the typical approach to investigating water well complaints was first to eliminate well maintenance as the cause of the water well problems. If well maintenance could be ruled out, then the next type of action typically involved a site visit by an EPO to inspect household fixtures such as the toilet tank, hot water tank, or taps, and in some cases to take a water sample. Of the 410 complaints that were identified by the well owners as potentially being due to energy-related activities, the EMS database indicated that there were 60 reports describing follow-up investigation that were targeted for Phase 2 of this study

We were able to obtain 33 of the 60 reports in Table 1, and these were reviewed and summarized below. Part of the difficulty in getting some reports was that, in some cases, sufficient details of the investigation were not available to locate the report as the EMS database that we received via the FOIP process had all of the information about the well owner and the location of the property removed. The majority of the reports were provided in full to AITF to review, but in some cases AITF was only able to acquire a description of the investigation by phone. The reports reviewed included a wide cross-section of different types of complaints including changes in water quality, sediment in the water and changes in well yield. The water well complaint investigations ranged from simple comparisons of pre- and post-water quality data to very involved investigations that included installation of additional monitoring wells and comprehensive testing and sampling of existing water wells, monitoring wells and energy wells (Table 4). We have separated out the D35 reports because the basic steps required for post-testing included in D35 are very specific: routine parameters, Fe, Mn and free gas for composition and isotopic analyses if present, and a 2 hour pumping test.

Of the 33 reports reviewed, 18 reports described investigations of water well complaints related to CBM development with pre- and post-testing following the requirements in D35 (Table 4). The remaining 15 investigation reports were for:

- water well investigations related to CBM development conducted prior to the implementation of D35 (May 2006),
- water well investigations of wells below the base of groundwater protection, and;
- water well investigations related to conventional oil and gas development.

Most of these reports followed the same general approach that is prescribed by D35 consisting of a comparison of water quality and/or water yield data for the water well both before and after perceived impacts. Baseline data for water quality or water yield of these water wells were often non-existent or were obtained when the water well was initially installed.

Despite the different types of energy wells investigated, most of the investigations included the following preliminary steps:

- review of existing information about the water well including geological setting, drilling logs, installation and completion details, usage, description of existing well maintenance steps, and the nature of the complaint.
- review of operational information about energy well(s) mentioned in the complaint to identify if any of the wells reported loss of circulation during drilling or any unusual activities and comparison of the timing of major events with the reported water well problem.
- comparison of pre and post energy related activity baseline information about water quality or well yield if available.

Depending on the results of these preliminary steps, many of the investigations included geochemical analyses and installation of piezometers. Even for the water well investigations that were conducted using the template of D35, many of the investigations went far beyond the analyses and monitoring required by the Directive.

Table 4: Summary of the types of complaints and investigation components for the 33 investigation reports reviewed for Phase 2 of this study.

	Initial Complaint	Total # of reports	# reports that reviewed multiple energy wells	# of reports including analyses not required by D35	# of reports that described installation of monitoring wells	Types of analyses
Investigation reports (BGWP or conventional oil and gas) (15 reports)	Aesthetics	3	2	1		-Downhole camera
	Water quality	2	1	1		-Analyzed pharmaceuticals and $\delta^{15}N$ of nitrate
	Sediment	1				
	Water level/yield	3	3	2	1	-Water flow logs and temperature logs of suspect energy wells
	Gas	7	6	6	1	-Comparison of isotopic composition of gases sampled from water wells with energy well data -Calculation of potential mixing models based on isotopic compositions
D35 Pre-post comparison investigation reports (18 reports)	Aesthetics	3	2	1		-Mineralogical analyses of sediment
	Water quality	1		1		-Mineralogical analyses of sediment
	Sediment	8	5	5		-Mineralogical analyses of sediment -Downhole camera -Continuous measurements of water levels, electrical conductivity and turbidity during CBM drilling
	Water level/yield	2				-Pre- and post-pumping test comparison
	Gas	3				-Pre- and post- comparison of gas composition and isotopic composition

The location and operational history of the suspected energy well(s) was an important consideration in most of the investigations. All of the investigations included a review of the energy well cited in the initial complaint including whether there was any loss of circulation reported during drilling, whether there were cement returns to surface, and the chronology of all activities at that well to see if it corresponded to changes observed at the water well. Some of the investigations did this kind of assessment for all of the energy wells located near the water well, whereas other investigations just evaluated the well mentioned in the complaint. When the investigation was conducted on behalf of a specific company, the investigation usually focused on wells owned by that company, but many included information about all of the wells in the area.

In many of the original water well complaints, CBM activities were specifically mentioned in the complaint, but the activity that was actually occurring near the property was often not CBM related. Even when the initial complaint was about CBM activities near the water well, the investigations often had to include a number of conventional oil and gas wells in addition to the CBM producing well. One of the water well complaints alleged that CBM activities near their property were the cause of sediment appearing in their well, but the activity they had noticed was just the installation of water monitoring wells as part of an investigation for a future underground coal gasification plant, and so no CBM or energy related activities had actually occurred on the site.

There were often a number of items included in the complaint. In the following sections we describe various complaints including: aesthetic, sediment, changes in water quality, changes in water level, changes in water yield and presence of gas in the water well. We provide some background on each of these types of deleterious changes and a summary of the approaches used to investigate these types of complaints in the 33 investigation reports that were reviewed.

4.2.1 Aesthetic Complaints

Many water well complaints included mention of aesthetic aspects of their water. These types of complaints often included a general complaint about the water smelling bad or like rotten eggs or being slimy. When the main water well complaint was odour, analyses of bacteria in the well (iron and sulfate reducing bacteria) was often conducted to establish whether bacteria was a potential cause of the problem. If there was evidence of iron and sulfate reducing bacteria present in the well, and no indication of any new or problematic energy wells in the area, the investigations would usually conclude that well maintenance was likely the cause of the problem, and shock chlorination was recommended before expanding the investigation. Additional analyses in these types of well complaints included downhole inspection of the water well using a camera, to evaluate the well construction and see whether the interior of the well showed evidence of biofouling, and analyses of sediment in the well to evaluate whether it was the product of microbial activity (Table 4).

4.2.2 Sediment in the Water Well

Our review of the water well investigations conducted in Phase 2 of this study identified a few different approaches that were used to investigate the appearance of sediment in the water well (Table 4). The first step typically involved eliminating bacterially mediated precipitation of oxides and oxyhydroxides. If the initial complaint included mention of sediment in combination with odour or slime and the interview with the well owner established that maintenance was infrequent, biofouling was determined to be the potential source for the sediment. Microbial analysis of water from the well could be used to confirm the presence of iron or sulfate reducing bacteria. Visual inspection of the interior of the water well, pump, and plumbing fixtures was also used to identify whether bacterial slime was present as a way of identifying if sediment present in the well could be due to bacterially mediated precipitation.

In one of the water well complaint investigations, drilling fluid solids from a nearby energy well were sampled and subjected to the same mineralogical and composition analyses as the sediment in the water well to see if migration of these solids with the drilling fluids could be the source of sediment appearing in the water well. In this case the mineralogical analyses clearly showed that the sediment present in the water well did not resemble the drilling solids, but was consistent with adjacent aquifer material. If it was suspected that energy activities mobilized material already present in the aquifer and caused it to move at a greater rate towards the water well than it did prior to the activity, then mineralogical analyses would not be useful for eliminating oil and gas activities. If the mineralogical analyses of sediment in the water well is similar to what is typically found in the adjacent aquifers then it does not really eliminate potential sources. Mineralogical analyses can also be very useful for providing additional support for mineral precipitation that occurs naturally in water wells due to changes in pH or redox conditions. If the sediment sampled in the water well is typical of secondary precipitates (e.g. iron or manganese oxides, oxyhydroxides or carbonates), it is likely that the sediment is being formed within the well due to natural geochemical processes. In most cases this can be improved with more regular well maintenance.

Some of the water well complaints noted that sediment appeared in their water or in fixtures after energy related activities were started nearby. Mineralogical analyses by x-ray diffraction and elemental composition by energy-dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM) were used in some investigations to identify the mineralogy and composition of sediment. When non-crystalline FeO and MnO are the main component then the sediment is likely due to the formation of precipitates in the water well.

4.2.3 Change in Water Levels

In some of the investigative reports reviewed in Phase 2, the water well owners were specifically concerned about the effects of nearby activities on water levels in their well and in situ water level sensors were installed in the water well during the drilling and development of the CBM well. This kind of monitoring goes beyond the monitoring required by D35, but the continuous measurements of water levels, dissolved oxygen, conductivity, turbidity etc. are able to show the natural variability in the water well and note significant changes in these parameters during, and shortly after drilling and completion.

As outlined in Case Study 1, the best documented case of impacts from oil and gas activities was one in which the impact was a 3-6 cm decrease in the water level at the well. In most settings this small water level decrease would not be noticeable by the water well owner, but the configuration of the water well was such that this small change in water levels significantly affected water availability.

4.2.4 Change in Water Well Yield

Investigations into potential changes in water well yield related to energy activities were typically approached by comparing data from pumping tests conducted before and after the oil and gas activities. Pumping tests involve pumping the water well at a specific rate and then using the rate at which water levels decrease in the water well during pumping to calculate the well yield. Once the pump is turned off, the rate at which the water level in the water well recovers can similarly be used to determine hydraulic parameters of the aquifer. In the case of CBM development, pretesting of nearby water wells is required under D35, so good quality data are usually available. For other types of oil and gas development recent pumping test data may not be available. Pumping tests are often performed by the water well driller when the well is installed, but some of these data are very old, and the tests are often of very short duration.

The inclusion of pumping tests in the CBM baseline groundwater testing was to address concerns that fracturing and depressuring the formation containing the methane might alter the hydraulic properties and pressure fields resulting in less water available in overlying shallow aquifers. However, the yield of a given water well can also vary over time due to changes in hydraulic properties of the screen. Biofouling and the accumulation of gelatinous bacterially mediated mineral precipitates ("slime") around the intake screen and adjacent aquifer material can result in decreased water yield and would need to be eliminated as a potential cause for this change.

In order to identify changes in well yield due to energy activities, the possibility that decreases in well yield may be due to biofouling of the screen or adjacent material must first be eliminated. The approach used in the investigations reviewed in Phase 2 of this study typically relied on comparison of pumping test results from before and after energy developments (Table 2), after well maintenance issues had been eliminated as a possible cause.

4.2.5 Gas in the Water Well

The water well complaints reviewed in this study included a number of cases where the isotopic compositions of hydrocarbon gases sampled in the water well were used to try to identify or eliminate potential sources of these gases. Isotopic data was also used quantitatively to calculate potential mixing scenarios for different combinations of shallow (biogenic) and deep (thermogenic) gases (Table 2). The challenges in these types of investigations was often that there would be very high concentrations of methane with a biogenic isotopic composition present in the water well with very low concentrations of ethane with a thermogenic isotopic composition. This method is best used to eliminate potential sources. If an energy well or geological unit has a very different isotopic composition than the shallow water well it can be used as evidence that it is not a source of gas to that well. However, finding a similar isotopic composition between an energy well and a water well gases does not necessarily imply that they came from the same geological unit. If other lines of evidence are available the isotopic compositions could support that conclusions, but on their own similarities in the isotopic signatures only show similar sources. Most of the investigations that we reviewed in Phase 2 of this study that included isotopic analyses had a much smaller range, with $\delta^{13}C_{methane}$ compositions that were within the biogenic or mixed field, so clear separations between gases of shallow or deep origins were not possible.

In cases where detailed mud logs of isotopic compositions of multiple gases are present with depth (e.g. $\delta^{13}C$ of methane, ethane, butane and propane), matching the isotopic composition of multiple hydrocarbon gases in a shallow gas to a specific depth may provide more concrete evidence of a similar source, but in most domestic water well cases, only methane with very low concentrations of ethane are present. The methane in these cases is usually predominantly biogenic, so the match to a specific depth has to rely on the isotopic composition of very low concentrations of ethane and possibly butane. Another challenge in using the isotopic labelling of gases in water wells is the lack of background or pre-testing gas compositions for comparison. In the case of D35 testing there may be good isotopic data available for both pre- and post-testing, but even in those cases, gases are only analyzed for their isotopic composition if they are present as a free gas.

4.2.6 Case Studies

A review of the two cases where energy related drilling and completion activities were linked to water well complaints is useful in understanding the past activities and settings where impacts occurred to better identify where there may be risks to water wells. A third study is also outlined to demonstrate a situation in which the investigation identified that the energy well had a non-compliance issue, but where impacts to the water well were never confirmed.

Case Study 1: Water Level Impact to a Water Well

The initial complaint logged by AESRD was that water levels in a well and spring on the well owner's property decreased shortly after a CBM well was drilled 600 m from the water well. The energy company had a series of investigations conducted by third party hydrogeological consultants that included a review of nearby energy wells including the recently drilled well and found that the new well had a documented surface casing issue and circulation problem. Investigations of the suspect well included waterflow and temperature logs which indicated vertical water flow along the annulus (between the cement and the adjacent sediment).

This case study was previously described in the CAPP report (2009) and it was noted that it occurred in the early CBM days of developments in the Horseshoe Canyon. The results of the investigation found that the problem was related to wellbore cement integrity, not the actual production of CBM. The gaps in the cementing around the wellbore allowed water to leak from an upper aquifer to a deeper zone, resulting in a 2-3 cm drop in water levels in the owner's well. The investigation of this complaint included installation of monitoring wells in the same interval as the water well. Monitoring of water levels in these wells during pumping showed a clear connection between the aquifers units. The energy company completed remedial activities at the problem energy well and then repeated the water flow and noise-temperature logs and found that that flow between the upper and lower aquifers was stopped. Leaking casing at the energy well caused a 2 to 3 cm drop at the water well and a 6 cm drop at the monitoring wells. An enforcement action by the AER was taken for failure to report loss of circulation when the casing was being cemented, and for not cementing the casing to the surface.

Case Study 2: Gas Impact to a Water Well

The initial complaint in this case involved the appearance of gas bubbles in a culvert (~0.6 m diameter) farm water well near a conventional oil well. The composition and isotopic signature of the gas sampled in the shallow aquifer was similar to deep, Cretaceous bedrock. The energy well in question was directionally drilled and it is possible that a good annular cement seal was not obtained, allowing gas migration. The investigation did not conclusively identify a pathway, but the company provided the well owner with a new well based on the similarity in gas composition and isotopic labelling. The geological setting was also atypical in that a highly plastic clay unit was present and appeared to act as a confining layer preventing migration of gases to the surface, creating the charged gas aquifer. The leakage of small amounts of gas that might have gone unnoticed in a different geological setting were likely trapped beneath the clay unit. The problem at the energy well was fixed, gas in the aquifer was bled off and a new water well was drilled for the owner.

In our review of the 410 water well complaints in the EMS database we found 3 complaints that led to AER enforcement actions. The first was described above in Case Study 1 (failure to report loss of circulation). The second AER enforcement action was initiated when a water well complaint investigation identified that a well within 600 m of CBM developing was not included in the D35 pretesting. In this case the investigation of the actual well complaint did not find any evidence of impacts from oil and gas activities, but it did result in an AER enforcement action because the investigation identified a well that should have been included for D35 pretesting. The third AER enforcement action is described below in Case Study 3. We have included it here because it shows an example where there was an AER enforcement action, but no identified impacts to the water well.

Case Study 3: No Impacts Identified but AER Enforcement Issued
In this well complaint, the well owner called the AESRD water well complaint hotline to request that pressure and temperature measurements be made at the owner's water well during on-going CBM activities. The well owner reported that after CBM activities started in the area black specks appeared in their well water. The well was tested before development, but the water well owner did not want retesting of their well, just installation of equipment to provide continuous monitoring of pressure and temperature in their water well. The water well owner believed that these types of measurements would identify whether the CBM activities were causing any disturbance to their well. AESRD explained that pressure and temperature testing during drill fracing operations associated with CBM is outside of the regulatory requirements based on the BWWT for CBM Development. The well owner was told that they could request post-drilling testing of their well, that would then be compared with the initial baseline data collected before the CBM development to identify whether any impact had occurred. The water-well owner declined having the post-testing done on their well, and believed that continuous monitoring during the CBM development would provide a better assessment of whether there were any impacts.

Even though the investigation did not identify an impact at the water well, the AER issued an enforcement order because they found that the energy company was noncompliant with the AER requirement Directive 027 Shallow Fracturing Operations Interim Controls, Restricted Operations and Technical Review. This directive requires that companies use only non-toxic fluids above the base of groundwater protection. In this case they found that the BGWP depth was shallower than the energy company originally thought and that they had injected 3 m above the BGWP. The well owner requested more information about the CBM well including cement logs, hydraulic fracing program details, etc. and they were directed to the AER for this information. This case study was included as an example where a water well complaint investigation did not find any indication of impacts from oil and gas activities, but where the investigation identified that the energy company was noncompliant with one of AER's directives.

4.2.7 Community Engagement Approaches to Water Well Complaints
Separate from the technical approaches described above, our review of the EMS database, the investigation reports and interviews with industry representatives also identified a number of outreach activities that industry has developed for addressing water well complaints. The importance of maintaining transparency by ensuring that all of the domestic water well complaints received are first registered with AESRD was identified as an important community engagement activity by many of the industry representatives interviewed in this project. Since well maintenance issues can have a large impact on water quality and quantity and can mimic the expected impacts from oil and gas

activities, some operators have found that paying for a local and locally-trusted water well driller to evaluate the water well to first rule out any well maintenance issues was very useful in eliminating complaints. However, the usefulness of relying on local drillers to help provide a trusted evaluation of the water well problem is largely dependent on the availability of knowledgeable drillers in the area.

5. RECOMMENDATIONS TO MITIGATE HIGH PERCEIVED RISK

The results of Phase 1 of this study demonstrated that, while only a very small percentage of the complaints investigated were ever clearly (0.5%) or potentially (6%) linked to oil and gas activities, 57% of well owners that reported issues indicated that they believed oil and gas activities were responsible for the issues with their well. The much larger percentage of reported oil and gas related complaints to actual oil and gas related complaints demonstrates that the perceived risk of energy activities on water wells is higher than the actual risk. Several factors may be contributing to the high perceived risk of energy activities on groundwater resources and may provide insight into how to improve the situation.

5.1 Transparency

One of the recurring themes that emerged in our interviews with industry representatives was the opinion that the lack of transparency in dealing with domestic water well complaints has contributed to the high perceived risk by the general public and water well users for drilling and completion activities. Many industry representatives felt that the past practice of replacing wells without first establishing that an impact had occurred, led to the widespread perception that energy activities are a frequent and serious source of impacts to shallow groundwater quality and quantity. Replacing wells without first establishing whether there was any link to their activities used to be a more common industry practice motivated in some cases by the hope that it would help maintain good relationships with local land owners, or often because it was less expensive than conducting a full investigation. There is now recognition of the importance of maintaining transparency by involving AESRD in all of the water well complaints received. Many also felt that the practice of dealing with water wells internally, without involving AESRD, may also have contributed to the level of distrust many water well owners feel towards how industry treats their environmental concerns.

5.2 Resolution in Investigations

This review of water well complaints and the processes in place to address them highlights a gap between the mandates of the various groups investigating complaints (AESRD, industry, AER) that may contribute towards some of the dissatisfaction domestic water well owners have with the process and contribute to the elevated perceived risk given to oil and gas activities.

AESRD investigates well complaints thought to relate to energy activities to see if they can find any evidence that the water well complaint is related to a contravention of any of the legislation for conventional or unconventional oil and gas activities in the province. Their investigations are often conducted with the goal of identifying polluters, and while the results rule out causes, they may not provide an explanation for the cause of the original complaint. Determining the cause of a water well problem is beyond their mandate: their purpose is to identify whether the water complaint was caused by an infraction that needs to be addressed.

The investigations conducted by industry or third party investigators hired on their behalf also do not necessarily meet the goals of the domestic water well owner in that they focus on investigating whether their energy wells or activities can be directly linked to the water well complaint. As some of the industry representatives interviewed for this study indicated, while they like to make every effort to maintain good relations with landowners they cannot take on the responsibility of diagnosing water well problems for all of the well owners near their leases.

This often leaves the well owners unsatisfied in that they've been told that oil and gas activities are not the cause of their problem, but they have not been told what is the cause of their water well problem. Even though AESRD and the industry funded investigations have identified that the water well issue is not related to energy activities, as enforced by AESRD, they have not provided the well owner with an explanation or solution to their problem. This is not reflecting lack of diligence by AESRD, but rather shows that there is gap between AESRD's mandate, industries responsibilities and what many water well owners would like to receive.

5.3 Knowledge Gaps

One of the challenges in investigating water well complaints is that there are very few methods that can show a definite link between potentially impacted water wells and energy activities. A direct hydraulic connection between an energy well and a nearby water well that resulted in water level changes in the water well during activities would establish a direct connection, but most of the other investigation techniques rely on accumulating multiple pieces of evidence. Many of the potential symptoms of impact from energy activities (e.g. appearance of gas in the wells, change in well yield) are similar to well maintenance problems and it is often only through the appearance of multiple different pieces of evidence that a connection is suspected.

The difference between the isotopic signature of shallow biogenic hydrocarbon gases and deeper thermogenic hydrocarbon gases can be used to determine whether gases present in shallow aquifers originated from deeper zones used for oil and gas development, but these labelling techniques do not give any information about the pathways that brought the gases to the surface. For example, finding gases with isotopic signatures consistent with a deep formation used for oil and gas development in a domestic water well does not differentiate whether it migrated to the shallow aquifer via a natural fracture in the bedrock, or via a poorly sealed abandoned well or some combination of the two. This difficulty is compounded by the lack of background information about the concentrations of hydrocarbon gases in shallow aquifers across Alberta. The data being accumulated as part of D35 will help build this understanding.

The abundance of oil and gas resources in the province suggests that there may be areas where there are naturally high concentrations of hydrocarbon gases in shallow aquifers. With the history of oil and gas development in the province, there is also the possibility that we now have higher ambient concentrations of hydrocarbon gases in shallow aquifers due to legacy effects of historical development.

5.4 Education Resources and Outreach Efforts

Domestic water well owners are responsible for ensuring that their wells are constructed, operated and maintained properly. The problems described in the majority of water well complaints received by AESRD in the 2005-2010 period included classic symptoms of poorly maintained wells. The initial telephone conversation between the well owner and the EPO typically included screening questions to identify possible well maintenance or construction problems. If these did not appear to be an issue, or if the well owner has performed the recommended maintenance activities and the problem persists, then the complaint is followed up with a site visit, sampling and possibly an investigation. Between 2005 and 2010 a total of 710 water well complaints were received, but only 122 proceeded to the site visit phase. The steep drop-off in complaints once well maintenance and construction issues have been addressed highlights the importance of properly maintaining water wells and suggests there is still room for educating Albertans about the maintenance required to maintain domestic water wells.

Recently there have been significant efforts to improve the resources available for domestic water well owners. The publication produced by Alberta Agriculture "Water Wells that Last for Generations" is an excellent resource that is often provided to well owners when water well complaints are received. The Working Well program, a collaborative effort led by AESRD and supported by Alberta Agriculture & Rural Development, Alberta Health, Alberta Water Well Drilling Association and Alberta Health Services, provides well owners with information and tools to care for their wells in the form of workshops and educational materials. In addition, Synergy Alberta has also developed a "Water Well Information Series" and has hosted information sessions on water wells to provide information on well maintenance and care to domestic well owners.

6. SUMMARY

The results of the study are summarized below:

- 720 water well complaints were registered in AESRD's EMS between 2005 and 2010. In 410 of the complaints (57% of cases) the well owner stated that they believed oil and gas activities were responsible for the well issues. Of the 720 total cases, 2 (0.3%) were confirmed to be energy-development impacted and an additional 23 (3%) were potentially energy-development impacted. These results demonstrate a high perceived risk of oil and gas activities on domestic water wells compared to the actual risk. However, it should be emphasized that there are several limitations to the methodologies used in the study, the most important being that our analyses only includes water well complaints reported to AESRD. There is the potential that the numbers of cases with confirmed impacts from oil and gas activities could be underestimated if there were water well complaints not reported to AESRD.
- The two cases where impacts from drilling and completion activities were detected were water wells located fairly close to the energy well (<600 m). In both cases investigation of the energy wells revealed casing or completion problems that led to the impacts at the water well.
    - In the first impacted water well case study, improper cementing of an energy well led to the new energy well providing a hydraulic connection between two aquifers and led to a decrease in water levels in the shallower aquifer where the water well was located. The hydraulic connection between the two aquifers was confirmed with pumping tests and water flow and temperature logs on the energy well.
    - In the second impacted water well case study, gas leaked from a recently drilled well and was trapped by a confining clay unit resulting in the build-up of gas in the underlying aquifer eventually entering a culvert well. The isotopic composition of gases collected in the water well indicated the presence of deep thermogenic gases.
- The water well complaint investigations typically included: a review of the history of the water well to identify potential maintenance and/or construction issues, a review of the history of energy wells in the area to see if there were any reasons to expect problems from any of the wells, comparing pre- and post- water quality and yield data to see if there was a change. Even when the investigations were re-testing water wells for D35, many included

additional analyses or monitoring not required by the directive. Some of the approaches for investigating different types of water well problems included:

- o using down-well cameras to evaluate well construction and visually inspect for biofouling problems or identify zones where gases or sediment were entering the well screen.
- o mineralogical analyses of sediment in the water well to see if it is non-crystalline iron or manganese oxides or oxyhydroxides typical of bacterially mediated precipitates. Combined with measurements showing that bacteria are present can be used to identify whether biofouling might be the cause of aesthetic, water quality or well yield problems.
- o comparison of mineralogical analyses of sediment sampled in the water well with solids present in drilling fluids to see if migration of drilling fluids from the energy well is a potential source of sediment or changes in water quality.
- o inclusion of non-routine geochemical analyses to help resolve sources of solutes. There are a variety of isotopic or geochemical tracers that can be used to help understand the source of changes in water quality (e.g. comparison of $\delta^{15}N$ to identify sources of nitrate in a water well).
- o using continuous, in situ measurement of water levels, turbidity, and electrical conductivity during the energy-development activities to provide the water well owner with a continuous record of fluctuations during the activity.
- o using the isotopic composition of gases sampled in the water well with data from nearby energy wells (surface casing vent flows, or produced gases) to calculate hypothetical mixing proportions.

- This review of water well complaints and the processes in place to address them highlights a gap between the mandates of the various groups investigating domestic water well complaints (AESRD, industry, AER) that may contribute towards some of the dissatisfaction water well owners have with the process and contribute to an elevated perceived risk given to oil and gas activities.

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