Analysis of contamination, remediation, and geothermal potential of orphan wells in Alberta

Magsipoc, E[1]; Yang, Z[2]; Hui, G[3]; Lim, M[4]; Becerra, D[2]

[1] Department of Civil and Mineral Engineering, University of Toronto, Toronto, Ontario, Canada M5S 1A4; Tel.: +1 416-669-4632; e.magsipoc@mail.utoronto.ca

[2] Geoscience Department, University of Calgary, Calgary, Alberta, Canada T2N 1N4; Tel.: +1 403-700-5883; zhengru.yang@ucalgary.ca; daniela.becerrarondo@ucalgary.ca

[3] Schulich School of Engineering, University of Calgary, Calgary, Alberta, Canada T2N 1N4; Tel.: +1 403-700-5883; hui.gang@ucalgary.ca

[4] School of Public Policy, University of Calgary, Calgary, Alberta, Canada T2P 1H9; Tel.: +1 403-210-7000; milim@ucalgary.ca

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Abstract

Orphan wells are oil and gas wells that are not properly abandoned due to economic factors, politics, mismanagement, etc. They pose a potential environmental risk to their surroundings if left unchecked. In Alberta, orphan wells continue to proliferate as unfavourable economics hinder the Canadian oil and gas industry.

Although this problem is largely a regulation issue, solutions made on a regulatory level should have a technical basis. Public well data from the Alberta Energy Regulator (AER), Orphan Well Association (OWA) and well information database from GeoSCOUT® is presented in this study.

This work reviews the current orphan well distribution in Alberta and discusses current environmental impacts and controlling factors. Well abandonment procedures and practices by the AER are also discussed. Finally, the potential for converting oil and gas orphan wells for geothermal energy is discussed.

1.0 Introduction

The Orphan Well Association (OWA), operating under the legal authority delegated by the Alberta Energy Regulator (AER), is responsible for the abandonment and reclamation of oil and gas orphan wells in Alberta. According to the OWA, a well becomes orphaned when a legally responsible party with the financial capabilities to perform abandonment and reclamation duties no longer exists [1].

Orphan wells are classified into two main categories: "To be abandoned" and "To be suspended". As of April 2018, there are 2888 orphan wells, of which 1785 should be abandoned and 1103 should be suspended (all of which are Lexin Resources wells). Orphan wells in Alberta have continued to proliferate since 2008 (**Figure 1a**). This is primarily related to the insolvency of junior companies stemming from the decline of oil prices since 2014. In 2017, a dramatic 150% increase in orphan wells occurred primarily due to 1120 now-orphaned wells previously operated by Lexin Resources (**Figure 1a**). **Figure 1b** summarizes the top ten companies that previously operated 73% of the orphans in Alberta**.** Evidently, Lexin Resources owned 1120 (40%) of the orphans while Sydco Energy owned 163 (6%) of the orphans.

Geographically, the orphan wells are broadly distributed across Alberta. Orphan wells were geospatially subdivided using Alberta's census divisions for comparison of orphan well distribution to population density (**Figure 2**). While census division #5 holds the highest number of orphans (22%), it is relatively unpopulated (**Figures 1c, 2**). Conversely, census division #6 holds about 20% of the orphans while also containing the highest population density (**Figure 2**). Most of these wells, previously operated by Lexin Resources, were found to have elevated concentrations of H_2S [2].

Finally, **Figure 1d** presents a histogram of orphan well age. Over 60% of the orphans were drilled between 2000 and 2015. However, there are still 941 wells drilled prior to 2000 which, according to Bachu [3], might pose a risk in terms of gas migration and or surface casing vent flow.

This work discusses the technical challenges involved with orphan wells including environmental contamination, well abandonment procedures and practices, and the potential for conversion of oil and gas wells for geothermal purposes. Although these issues are prevalent within North America, we only focus on the orphan well situation within Alberta.

2.0 Orphan well-induced gas and groundwater contamination in Alberta

Gas contamination from both active and orphan wells, particularly due to hydrogen sulfide and methane, is increasingly attracting attention from the Alberta government and the public. According to Sutton [4], there are approximately 59,000 farmsteads in Alberta with most having at least one well. In addition to creating fugitive gas emissions, gas can also contaminate shallow aquifers. Davies [5] indicated that groundwater contamination can be caused by casing leaks (i.e. integrity failures), to which orphan wells are susceptible [6]. However, because orphan well-induced groundwater contamination is not reported annually, statistical data is non-existent. In comparison, gas emissions are easier for operators to monitor and track. Despite the lack of groundwater contamination data, AER gas emission data may potentially reflect areas of groundwater contamination.

Surface Casing Vent Flow (SCVF) and Gas Migration (GM) are two commonly recognized mechanisms for gas contamination [7]. SCVF is defined as the flow of gas and/or liquid along the surface casing/casing annulus [8, 7, 9]. GM is defined as a flow of gas that is detectable at the outer surface of the outermost casing string, usually occurring at very shallow reservoir layers [8, 7, 9]. In 2016, 617 billion m^3 of methane was released into the atmosphere through venting (GM and SCVF) and flaring in Alberta; this has been constantly decreasing since 2012 [10]. Among the total emitted gas, 81 million m^3 was released from 9,972 unrepaired wells through GM and SCVF. Historically, there are 18,829 repaired and unrepaired wells reported with SCVF, GM, or both; 7.0% of these are inactive (9,530 wells suspended and orphaned) [10]. Wells with reported gas migration issues are shown in **Figure 3**. It should be noted that most of the thermal wells are orphan oil/gas wells. Therefore, it can be observed that gas migration mostly occurs within the central-northeastern part of the province, focusing around the Edmonton, Cold Lake, and Lloydminster areas [3]. This observation agrees with total gas flaring and venting conditions reported by the AER [10].

2.1 Controlling factors of gas emissions

According to Hardie & Lewis [11] and Bachu [3], the primary factors to consider in evaluating gas emissions are: cementing, drilling orientation, geological conditions, well age, and reservoir depth.

Cementation. Primary cementing (i.e. during well completion) is regarded as one of the most important and efficient strategies for well safety. Hardie & Lewis [11] and Bachu [3] indicated that cementing to the surface casing shoe can dramatically decrease the occurrence of SCVF. During the repairing/plugging stage, squeeze cementing and plug cementing are the only two remedial (secondary) cementing strategies available for an orphan well. Cementing is a more commonly applied strategy with consistency among the Alberta oil and gas industry [12, 13, 14]. Techniques include the bradenhead squeeze, the retainer (packer) squeeze, the bullhead squeeze, the special tool squeeze [12], and the circulation cement squeeze performed between two sets of perforations [13]. Plugging details are further discussed in Section 3.

Drilling orientation. Although drilling direction is believed to be a major factor in fluid migration, this is not significant in Alberta [3, 11]. After comparing vertical, horizontal, deviated, and slant wells with full-length cementation, only slant wells present a dramatically higher leakage rate than the average value [11].

Geological conditions and reservoir depth. Bachu & Watson [7] indicated that shallow wellbore leakage is a dominant factor causing GM/SCVF. According to the provincial gas leakage map (**Figure 3**), most GM and SCVF occurrences are within the Cold Lake and Lloydminster areas where reservoir layers are quite shallow. Bachu [3] indicated that this might be caused by steam injection during production.

In addition, deep wells located within the Rocky Mountain area are also reported to have venting issues. This may be caused by both subsurface activities [3] and multi-stage hydraulic fracturing [15]. Consequently, strong subsurface seismic activities in Rocky Mountain Thrust and Fold belt might contribute to the high venting volume.

Well age. Generally, wells over 30 years old have a higher risk of GM and SCVF [11]. Bachu [3] suggested that wells with an age of 15-20 years should be closely observed.

3.0 Orphan well plugging, abandonment and expenditures

To address the environmental issues discussed in Section 2, well plugging programs for orphan wells have been developed. Procedures for plugging and abandoning wells outlined by Fields and Martin [16] include the identification of leakage parts [13], removal of equipment and tools, cleaning the wellbore, plugging, and testing [17].

3.1 Orphan well plugging

Cross flow between permeable formations is prevented by creating an impermeable barrier through well plugging. Well plugs are used for several different operations in the oil and gas industry, such as lost circulation control, formation testing, directional/sidetrack drilling, zonal isolation, and well abandonment [18]. This study is restricted to the two latter applications. Well plugs can be either cement or mechanical plugs. Specifications for well plugs and abandonment in Alberta are prescribed by AER [19]. It should be highlighted that the wellbore must be filled with non-saline water after plugging. Examples of plugging programs are provided in **Figure 4**.

3.2 Plugging effect evaluation

After the well is plugged, testing is required to ensure that the plug is a placed at the proper level for zonal isolation [17]. This can be verified by either tagging its top or performing tests including the pump pressure test and swab test. Tagging the top of cement can be done through the employment of a drill pipe, wire line, work string, or tubing. Alternatively, pressure tests can be executed using pump pressure. In this case, pressure is exerted uniformly on the plug with no corrections required. The "swabbing" technique, or swab testing, involves running a swabbing tool that reduces the pressure in the wellbore above the plug to levels below the pressure gradient from the isolated reservoir below the plug.

3.3 Abandonment practices

According to regional regulatory frameworks or international guidelines of OSPAR (or the London Convention), all respondents need report to perform well abandonment. Variations in regulations are reflected through the differences between plugging requirements. While some regulations demand records on the status or integrity of wells prior to abandonment, other agencies may not have such requirements. Most regulatory agencies stipulate plug emplacement using the balanced plug method, whereas the dump bailer method and a choice between the balanced plug and the two-plug methods are noted on a single occasion [17].

3.4 Abandonment expenditures

According to the OWA [20], well abandonment expenditures in 2016 and 2017 totalled $12,483k (a 23% decrease compared to $16,742k in the year prior). By focusing on efficiencies and large-scale planning, 232 well were abandoned compared to 185 in the previous year, representing a 25% increase in work and 23% reduction in cost.

The average expenditure per well decreased from $90.5k in the prior year to $53.8k. This decrease derives from three factors. First, a larger orphan well inventory provided an opportunity to plan abandonment operations using area projects as a cost-saving measure in 2016/17. Second, the lower commodity price obtained from competitive pricing of services reduced well abandonment costs. Finally, the OWA changed its usual practice to directly pay some services instead on selected projects and then reduce its costs.

4.0 Potential for the geothermal conversion of orphan oil and gas wells

After oil wells become depleted, their depth and size make them good candidates for geothermal energy extraction. Geothermal conversion of depleted wells is attractive for several reasons including potential recovery of abandonment costs, reduced consumption of non-renewable energy [21], and elimination of geothermal drilling costs (a significant component in geothermal projects) [22]. Several studies propose the conversion of existing wells into double pipe heat exchangers by installation of an insulated pipe within the wells for fluid circulation [21, 23-26]. Although mostly numerical studies were performed to investigate this prospect, an experimental study on geothermal water extraction from oil wells was performed by Wei, Wang, & Ren (as cited by Bu et al. [23]) demonstrating a flow rate of 1932 t/d with an outlet temperature of 116°C.

The economics of this alternative requires further analysis since geothermal systems typically require significant capital costs, posing a significant risk for investors [27]. Logistical issues, such as proximity to potential customers, could also significantly affect the feasibility of geothermal conversion.

4.1 Geothermal temperature in Alberta

Across the province, a general northwestern trend of increasing geothermal gradient is commonly reported with geothermal gradients ranging between 10°C/km and 55°C/km [28-37]. The controlling factors for this broad geothermal range in Alberta are poorly understood. Two main reasons have been proposed up to date to explain the observed pattern: (1) Formation water flow causes a significant distortion of the geothermal field. Low geothermal gradient areas coincide with water recharge areas (major upland areas) and high geothermal gradient with discharge areas (major lowland areas) [30-35, 38-39]. (2) The differences in lithosphere thickness affects the geothermal gradient distribution in Alberta; essentially, conduction is the main mechanism of terrestrial heat transportation from the basement to the surface [29, 36, 37, 40-42].

The bottom hole temperatures (BHT) of wells within reasonable proximity to Albertan communities are, at best, sufficient for heating. The BHT in **Figure 5** show that communities in Western Alberta are more likely to benefit from geothermal conversion for direct heat. Previous projects in the United States have shown that temperatures around 80°C are feasible for direct heating of institutions and district heating [22]. Wang et al. [43] also reported the use of a low-temperature geothermal well in China for heating within its proximity. Consequently, this work only considers geothermal heating targeting outlet temperatures of 80°C. Nine of the orphan wells presented have a bottom of hole temperature greater than 80°C (**Figure 5**). For geothermal well selection, the geothermal gradient should be at least 30°C/km and with depths greater than 3000

m. These criteria are selected based on numerical modelling studies that investigated the conversion of oil wells to geothermal sources (**Table 1**).

Geothermal wells for direct use can range between depths of 100 m to 3000 m depending on its expected usage [44]. Since output fluid temperatures can be cooler compared to temperatures for electrical geothermal generation, wells need not be drilled very deep. There was a recent push by the US Department of Energy to investigate the feasibility of Deep Direct-Use (DDU) of low temperature geothermal resources [27]. Future studies originating from this program may assist in better understanding the costs and technologies needed to convert oil wells for geothermal energy and reduce the financial risk inherent in geothermal technology.

4.2 Additional considerations for geothermal conversion of oil wells

Oil and gas well conversion to geothermal wells would require distribution infrastructure in addition to the components interacting directly with the well. Distribution networks would need to be installed as a new utility with new connections to existing buildings, representing a significant cost for investment. A binary fluid system would likely be used, since fluids contaminated by the well would be undesired in serviced homes and buildings. Therefore, equipment at the well site, such as heat exchangers, would be required. This can allow the use of a secondary working fluid which may be better suited for low-temperature heat extraction [21, 45- 47].

5.0 Conclusions

Orphan wells pose a potential threat to the environment. Hydrogen sulfide and methane are two gases that, if released in important amounts, may become a hazard to well surroundings. This may vary in severity depending on cementation, drilling orientation, geological conditions, reservoir depth, and well age. The main gas contamination mechanisms are surface casing vent flow and gas migration. Vent flow and gas migration within Alberta appears to be of greater concern within the Edmonton, Cold Lake, and Lloydminster areas.

For contamination prevention, procedures for plugging and abandoning wells are generally summarized as: the identification of leakage parts, the removal of equipment and tools, cleaning the wellbore, plugging, and testing. Specifications for well plugs and abandonment are prescribed by the AER [19]. The plug can be verified by either tagging its top or performing tests including the pump pressure test and swab test. According to the latest updates from OWA [20], the well abandonment expenditures in 2016/17 decreased from $90.5k per well in the prior year to $53.8k per well. The integrated plan orphan abandonment operations, the lower commodity price and changes of practice payment synthetically contribute to the cost decline.

Geothermal conversion of oil wells can help recover abandonment costs. However, Alberta generally has a low geothermal potential with few potentially feasible orphan wells in proximity to existing communities for heating. Additional infrastructure would need to be constructed to distribute the heated fluid which may represent a significant cost against well conversion.

6.0 Tables and Figures

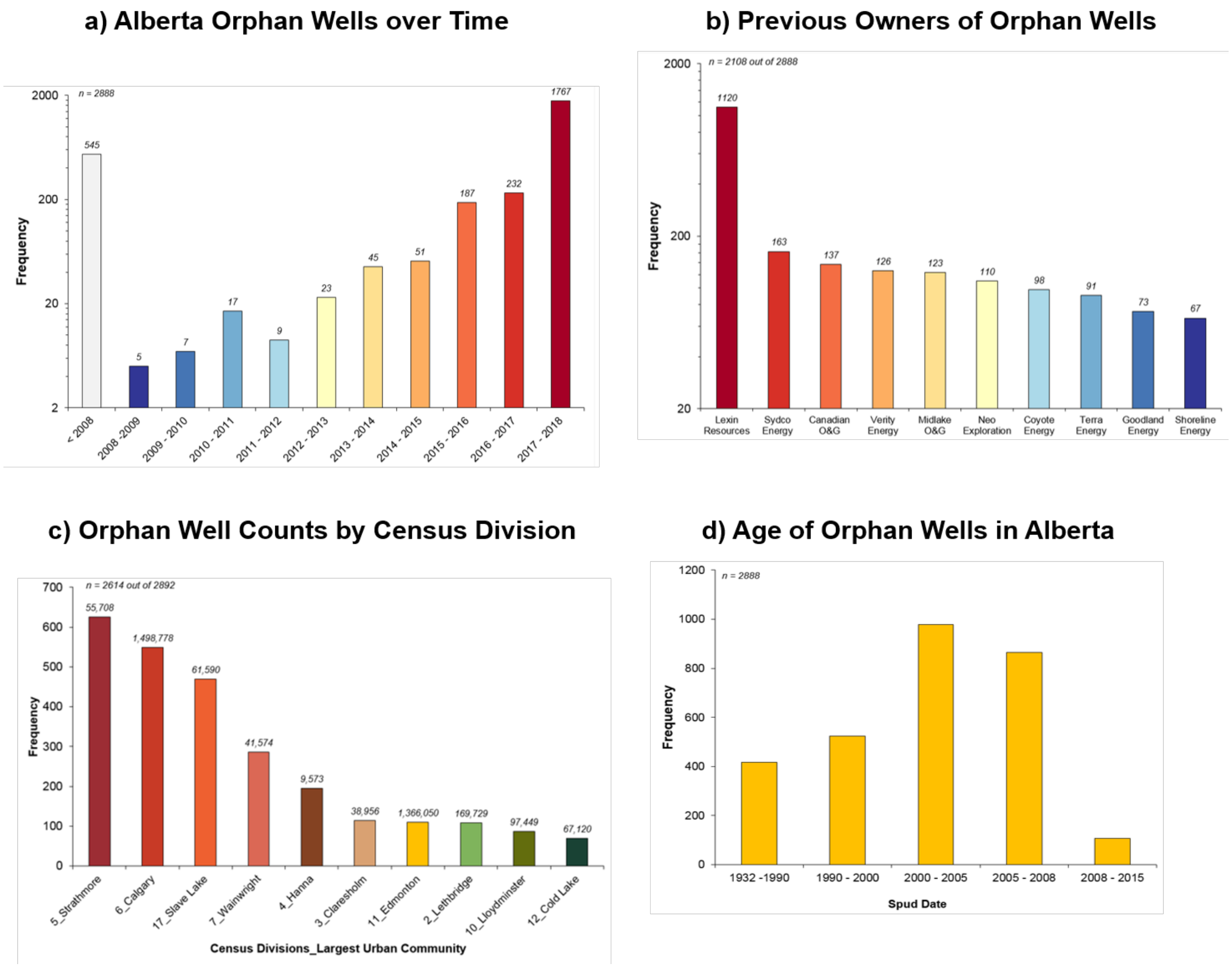

Figure 1. Histograms summarizing several aspects of orphan wells: a) Alberta orphan wells over time. b) Previous owners of orphan wells. c) Orphan well counts by census division. d) Age of orphan wells in Alberta.

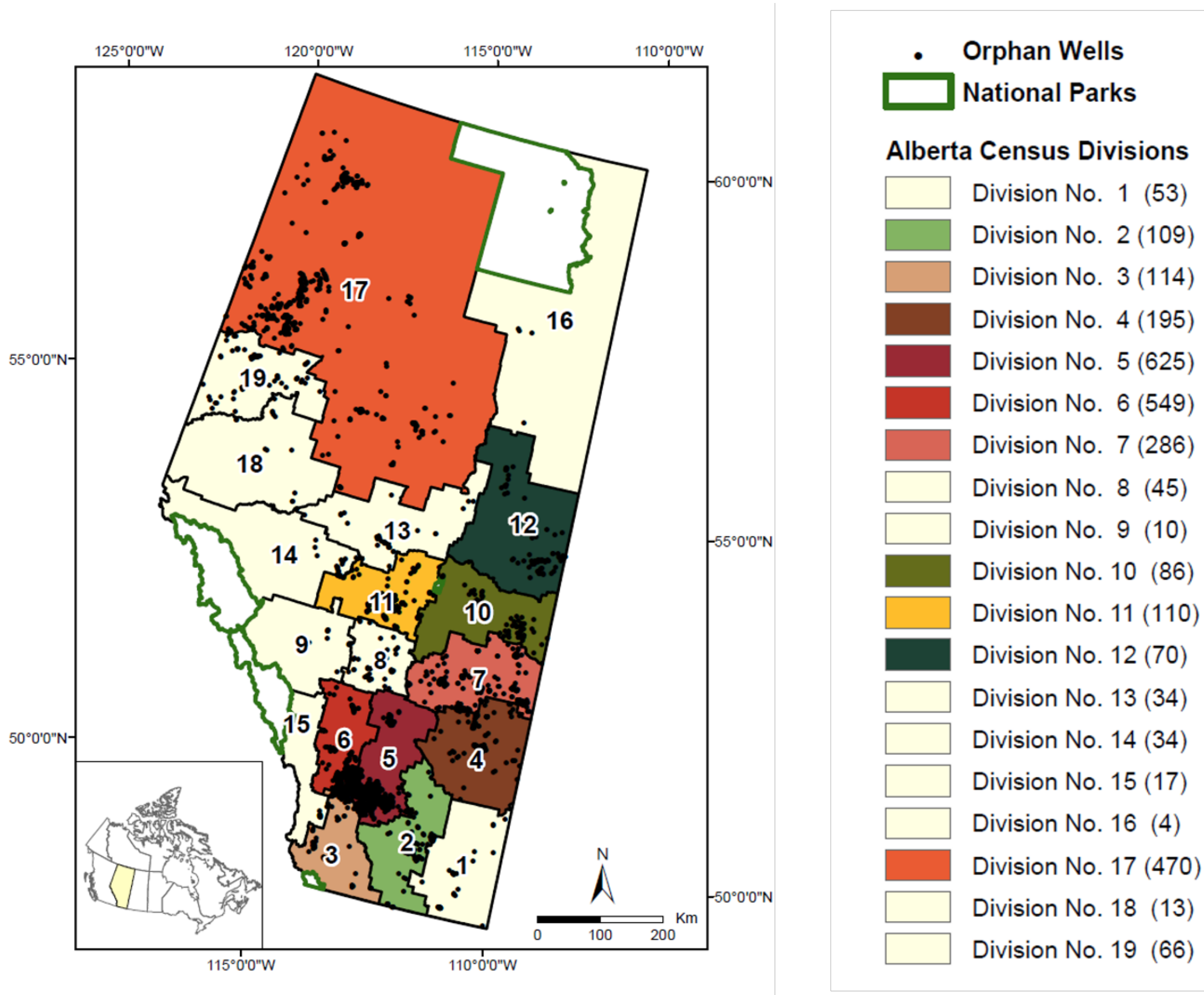

Figure 2. Orphan wells in Alberta are plotted in black in relation to the census divisions. The number of orphan wells within each census division is shown in parentheses. Shapefiles of Alberta were retrieved from Altalis webpage. The well list of orphans was gathered from OWA and specific location was based on GeoSCOUT® database.

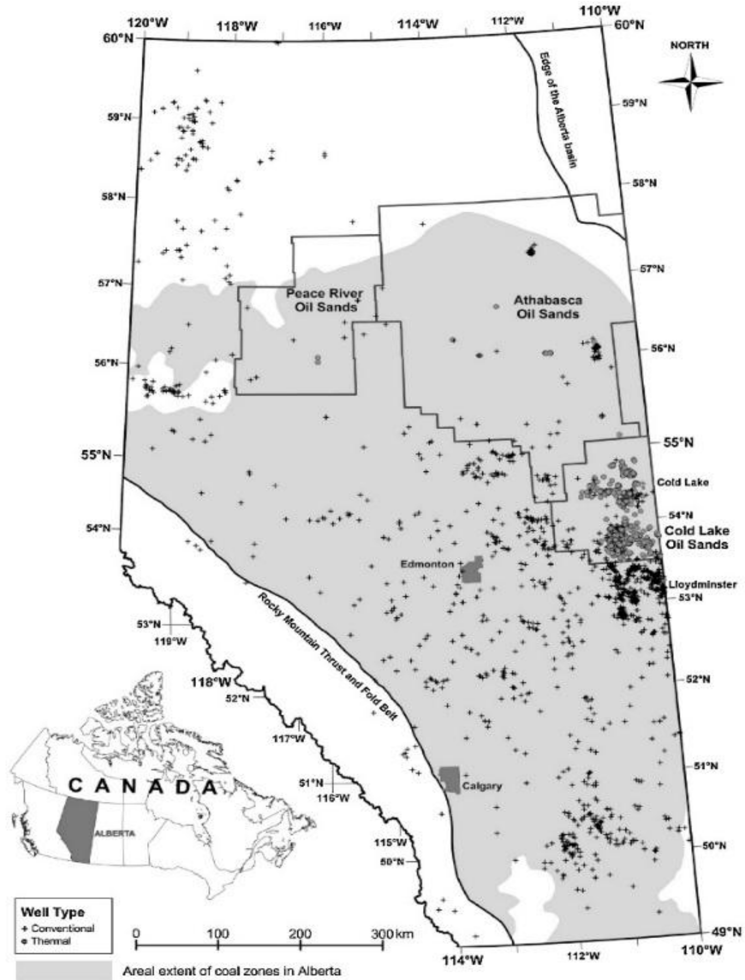

Figure 3. Alberta gas migration flow map (Bachu, 2017).

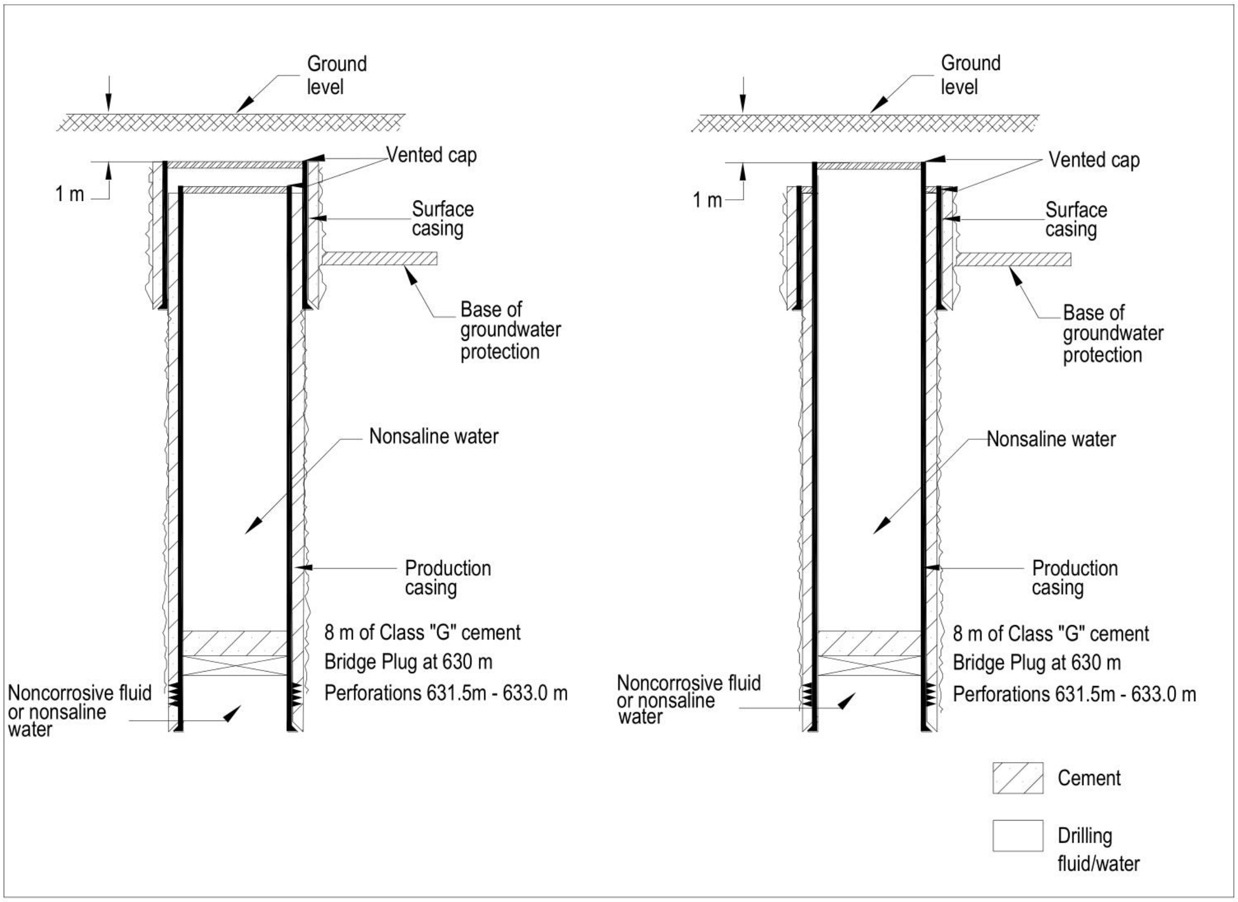

Figure 4. Plug placement examples for Central Plains (Alberta Energy Regulator, 2016).

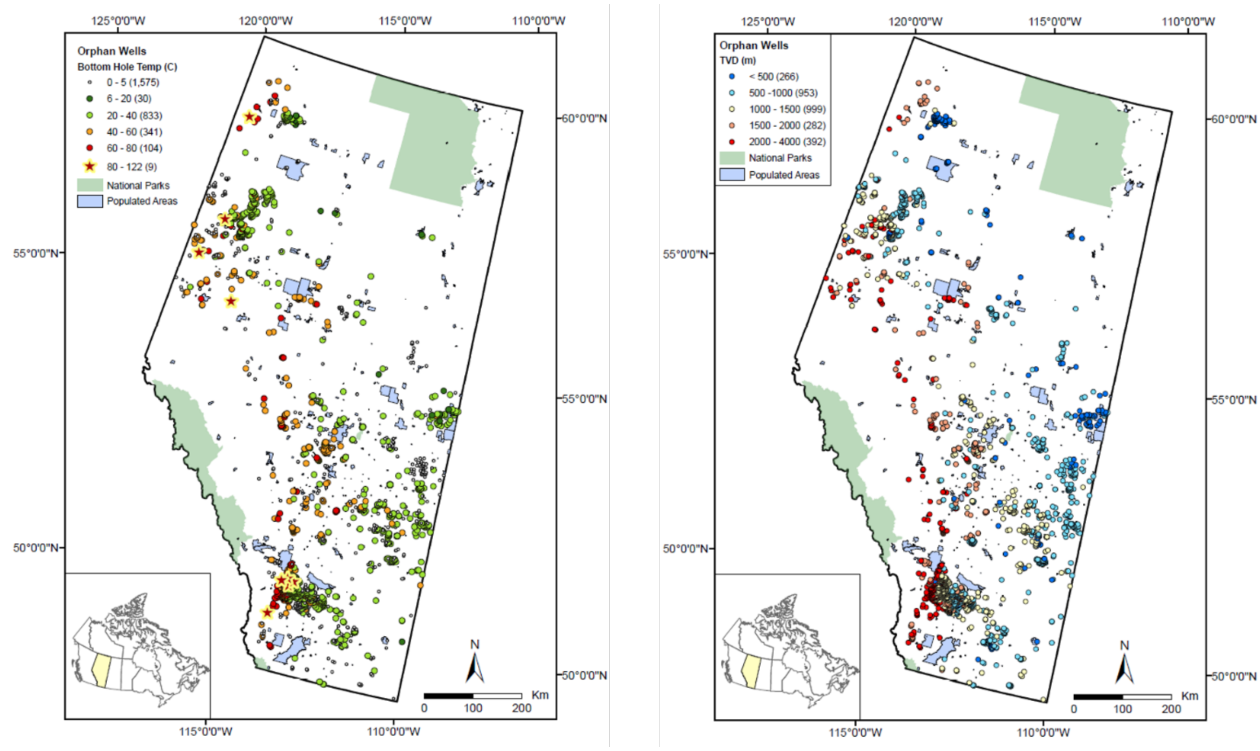

Figure 5. Bottom Hole Temperatures (BHT) and True Vertical Depth (TVD) of orphan wells in Alberta. BHT and TVD data was retrieved from GeoSCOUT® database.

Table 1. Numerical modelling results of geothermal conversion of oil well feasibility studies

Study	Example Location	Geothermal Gradient (°C/km)	Well depth considered (m)	Reported theoretical heat energy from well above T_{out}=80 °C (kW)
Davis & Michaelides (2009)	Southern Texas	40	3000	3400 (T=157 °C)
Bu et al, (2012)	Huabei Oil region - China	45	2500 – 4000	816
Wight & Bennett (2015)	Chena Alaska / Rocky Mountain Oil Field Testing Centre, Wyoming	31.1	4200 – 6800	109 – 652
Templeton et al, (2014)	Persian Gulf	30	2500 – 4000	502
Kujawa et al, (2006)	Jachowka, Poland	25	3950	140
Cheng et al, (2014a)	China	40/50	1000 – 6000	508 – 651 (at 4km)

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