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Research paper

Understanding shallow and deep flow for assessing the risk of hydrocarbon development to groundwater quality

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ABSTRACT

In recent years, concerns have been raised about the potential environmental impacts of oil and gas (O&G) exploitation, especially regarding groundwater resources. However, there have been few studies carried out to assess the actual risk of O&G exploitation based on specific local conditions. This paper reports on a study aiming to assess the potential risk to groundwater quality related to the development of a tight sandstone petroleum reservoir underlying a shallow fractured rock aquifer system in the Haldimand sector of Gaspé, Québec, Canada. In this generally rural setting, the drilling of a provincially permitted horizontal O&G exploration well was halted by new municipal regulations. Draft provincial environmental regulations were subsequently issued to define environmental requirements for hydrocarbon exploration wells. Our study thus also aimed to provide an example of how to comply with the new hydrogeological characterization requirements. This paper reports on the process followed to qualitatively assess the risk of O&G operations and natural oil seeps to groundwater quality. The assessment focused on indicators of potential preferential fluid migration paths between the reservoir level and shallow aquifers. Field work and data analysis were used to define geological, hydrogeological and geochemical contexts on which a numerical model was developed to represent groundwater flow, mass transport and groundwater residence time. The risk for groundwater quality was qualitatively assessed from the implications of the study area context relative to 1) the new provincial regulatory requirements; 2) potential contaminant release mechanisms related to O&G exploration drilling operations; and 3) the expected effects that contaminant releases could have on groundwater.

1. Introduction

Development of unconventional hydrocarbon resources has been rapidly increasing in North America over the past 15 years. This development is now spreading over geographic areas that have never before experienced upstream oil and gas (O&G) operations. Especially in these new areas, environmental concerns are being raised, notably when hydraulic fracturing (or fracking) is involved. Regulatory frameworks have been enhanced to deal with the new types of operations involved with unconventional resources but also conventional O&G operations, with some jurisdictions recently imposing groundwater monitoring near O&G wells (MDDELCC, 2014; Esser et al., 2015). However, the adaptation of regulations is hampered by the paucity of scientific data and the poor understanding of the environmental risks involved (CCA, 2014). Despite the need for field-based hydrogeological research to better assess the environmental risks to groundwater (Jackson et al., 2013), it has proven difficult to characterize and monitor aquifers in the subsurface near unconventional O&G wells in general, and shale gas wells in particular (Soeder, 2015).

This paper focuses on the risk to groundwater quality related to O&G development, which is one aspect of environmental risks, themselves a part of overall risks which also include operational,

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human health and socioeconomic risks (Small et al., 2014). This paper specifically focuses on the links between operational risks and their potential environmental impacts on groundwater. Although formulated for shale gas development, similar risk factors of conventional O&G operations can be classified according to their relations with a) community issues, b) atmospheric issues, c) land issues and d) water issues (Zoback and Arent, 2014). Water issues can be grouped into regional water, surface water and groundwater components and are related to shale gas operations involving a large number of wells, wastewater disposal and potential effects on water quality and quantity (Zoback and Arent, 2014). Issues specifically related to groundwater have recently been reviewed by Vengosh et al. (2014) and by Lefebvre (2016).

A number of mechanisms potentially leading to the degradation of groundwater quality in relation to O&G operations have been identified, including surface spills associated with the handling and storage of fluids (e.g. fracking fluids, flowback fluids and produced hydrocarbons), fluid leaks through casings and cement and along boreholes, and fluid migration from exploited O&G reservoirs to shallow aquifers through permeable migration paths that can be natural (faults, fractured zones) or related to O&G operations (active or decommissioned O&G wells) (Jackson et al., 2013; Kissinger et al., 2013; CCA, 2014; US EPA, 2015). Although known instances of fluid migration through O&G wells exist (Watson, 2013; AER, 2013), there is an on-going scientific debate about the potential for fracking of unconventional O&G reservoirs to induce fluid migration into shallow aquifers (Gassiat et al., 2013; Flewelling and Sharma, 2014, 2015; Lefebvre et al., 2015; Reagan et al., 2015; US EPA, 2015), which is further discussed by Birdsell et al. (2015) and Lefebvre (2016).

O&G production operations have not generally included targeted monitoring to detect their potential environmental impacts on groundwater quality. The Council of Canadian Academies (2014) states that shale gas exploitation would require appropriate environmental monitoring, including for groundwater. Jackson et al. (2013) advocate for field-based scientific research to understand potential contamination mechanisms related to O&G wells and adequate monitoring. Following a social debate on shale gas development in the Utica Shale (Rivard et al., 2014; Lavoie et al., 2014), the province of Quebec, Canada, was the first jurisdiction in North America to impose both hydrogeological characterization, including baseline groundwater quality of water wells within a 2 km radius of an O&G well site, and groundwater monitoring of all O&G drill sites (MDDELCC, 2014). California recently considered such monitoring of O&G well sites (Esser et al., 2015). In Alberta, Baseline Water Well Testing (BWWT) of coalbed methane wells was implemented in 2006 and its expansion to unconventional oil and gas is currently being considered (Wallace, 2015). Baseline water quality testing of water supply wells within 500 m of an O&G drilling rig is also required in New Brunswick, Canada (New Brunswick, 2013).

Since natural geochemical composition of groundwater can be quite variable (Cloutier et al., 2008), baseline characterization of groundwater quality prior to O&G operations has been advocated (e.g. Rao, 2012; AWWA, 2013; Vidic et al., 2013; CCA, 2014; Mauter et al., 2014). Examples of regional baseline studies for overall groundwater quality or studies focused on the presence of natural gas are provided by Moritz et al. (2015) and McPhillips et al. (2014). Local baselines can also be defined relative to a specific O&G drill pad (Soeder, 2015).

Since 2010, shale gas and unconventional hydrocarbon development has been the subject of a series of public inquiries in Québec (Canada) and has been the focus of an intense public debate (BAPE, 2011; 2014; CÉES, 2014). In this context, the objective of the present study was to assess the risk of O&G operations on groundwater quality in the hydrogeological context of the Haldimand sector of Gaspé, Québec, Canada. This study was sponsored by the Quebec Environment Ministry (*Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques*, MDDELCC). Frameworks for the assessment of environmental risks related to O&G operations have only quite recently started to be developed and applied (Lange et al., 2013; Kissinger et al., 2013; Rivard et al., 2014; Lavoie et al., 2014; Soeder et al., 2014; US EPA, 2015). However, it has proven difficult to monitor groundwater near unconventional O&G wells (Soeder, 2015).

In the Haldimand sector, the drilling of a horizontal exploration well (Haldimand No.4) in a tight sandstone reservoir was planned in the hope of achieving commercial oil production rates by intersecting natural fractures. The drilling was halted in December 2012 by a municipal regulation aimed at protecting the local water supply, even though provincial permits had been issued to allow drilling of the well. In response to this municipal initiative and to fill a gap in the regulatory framework, the Quebec Environment Ministry published a new draft regulation at the end of May 2013 for consultations (MDDELCC, 2014). This new regulation specifies minimum distances between O&G wells and water supply wells and it requires hydrogeological characterization and groundwater monitoring around all new O&G drill sites. The study in the Haldimand sector also served as an example of the type of study to be carried out to comply with the new regulation. Furthermore, even though the O&G operator (Pétrolia) was not required to comply with the regulation as the well had been permitted prior to its publication, the study also met the request by the local population and municipality for an independent scientific assessment of the environmental risk in that sector. This study built upon the initial hydrogeological characterization carried out in 2011 and 2012 for the O&G operator, which included the installation of monitoring wells (TechnoRem, 2013). The study reported here used available data and involved new field work carried out in the summer and fall of 2013. Based on this characterization, we assessed the risk to groundwater quality and to local groundwater users (residential and municipal) related both to existing decommissioned and operational O&G wells and the planned new Haldimand No.4 horizontal borehole.

This paper emphasizes the process used to assess the environmental risk of O&G operations for groundwater on the basis of specific local conditions, but considering both shallow and deep groundwater flow. This paper thus only presents a global overview of field work and data interpretation. Technical and scientific details could not all be presented in the paper but full information is accessible in a public report (Raynauld et al., 2014).

2. Field characterization and methods

Fig. 1 shows the Haldimand sector of Gaspé, where the study was carried out. Petroleum exploration wells have been drilled in the forested core of a hilly 50 km^2 peninsula by the sea, including two relatively recent wells (Pétrolia Haldimand No.1 and No.2) in a tight sandstone reservoir. The presence of natural oil seeps is known in the vicinity of Haldimand No.4. Residents on the periphery of the peninsula rely on shallow (20–40 m) wells for their water supply. A municipal surface water supply and a municipal well field not yet commissioned are located south of the study area.

The study involved the definition of 1) the geological and structural contexts of the bedrock, 2) the hydrogeological context based on various types of maps, and 3) the baseline groundwater geochemical conditions. On this basis, conceptual and numerical models of the study area were developed and the local risk to groundwater quality was assessed. The study used existing hydrogeological, geological and petroleum exploration data and