Journal of Hydrology: Regional Studies 4 (2015) 452–471

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Groundwater methane in a potential coal seam gas extraction region

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ARTICLE INFO

Article history:
Received 12 February 2015
Received in revised form 26 May 2015
Accepted 28 June 2015
Available online 24 August 2015

Keywords:
Stable isotopes
Aquifer
Baseline research
Geology
Catchment
Hydrochemistry
Coal bed methane
Unconventional gas

ABSTRACT

Study region: This study investigates dissolved methane distribution in groundwater from the Richmond River Catchment (New South Wales, Australia) before proposed coal seam gas (CSG, or coal bed methane) development.
Study focus: Unconventional gas exploration has rapidly expanded in recent years. However, the impact of these operations on groundwater systems is poorly understood. A total of 91 groundwater samples were analyzed from 6 geological units. Our observations act as regional baseline research prior to CSG extraction and may assist with long term impact assessment.
New hydrological insights for the region: Methane was found in all geological units ranging between 0.26 and 4427 $\mu g\,L^{-1}$ (median 10.68 $\mu g\,L^{-1}$). Median methane concentrations were highest in chloride-type groundwater (13.26 $\mu g\,L^{-1}$, $n = 58$) while bicarbonate-type groundwater had lower concentrations (3.71 $\mu g\,L^{-1}$). Groundwater from alluvial sediments had significantly higher median methane concentrations (91.46 $\mu g\,L^{-1}$) than groundwater from both the basalt aquifers (0.7 $\mu g\,L^{-1}$) and bedrock aquifers (4.63 $\mu g\,L^{-1}$); indicating geology was a major driver of methane distribution. Methane carbon stable isotope ratios ranged from −90.9‰ to −29.5‰, suggesting a biogenic origin with some methane oxidation. No significant correlations were observed between methane concentrations and redox indicators (nitrate, manganese, iron and sulphate) except between iron and methane in the Lismore Basalt ($r^2 = 0.66$, $p < 0.001$), implying redox conditions were not the main predictor of methane distribution.

1. Introduction

Exploitation of unconventional gas resources (coal seam gas, shale gas and tight sands gas) have significantly expanded in recent decades due to advanced extraction processes such as hydraulic fracturing, horizontal drilling and aquifer depressurization (Hamilton et al., 2014; Kargbo et al., 2010; Kerr, 2010; Kinnon et al., 2010; Ren et al., 2014). Coal seam gas (CSG), also known as coal bed methane (CBM), is composed primarily of methane (CH_4) which is trapped under pressure within coal seam pores and fractures. CSG represents a substantial natural gas resource and the Australian CSG industry has experienced

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http://dx.doi.org/10.1016/j.ejrh.2015.06.022

rapid growth within the last decade. However, there may be significant environmental issues associated with CSG extraction processes (Varade and Meshram, 2010).

Unconventional gas extraction methods require numerous wells over large areas. Faulty or inadequate well casings can lead to stray gas migration into overlying aquifers, and regional groundwater resources may become contaminated (Jackson et al., 2013a; Osborn et al., 2011). Aquifer depressurization of CSG target formations may lead to greater gas transfer into the overlying or underlying formations, and nearby surface water zones (Apte et al., 2014). Enhanced aquifer connectivity may possibly dewater aquifers surrounding the CSG target formation and/or deliver constituents within the coal seam water via groundwater transport into adjacent waterways.

Research to date on Australian unconventional gas development has mainly focused on CH_4 isotopic composition of CSG (Hamilton et al., 2014; Kinnon et al., 2010), groundwater quality within the coal seams (Kinnon et al., 2010; Owen et al., 2015; Papendick et al., 2011), CSG content in targeted geological formations (Faiz et al., 2007; Hamilton et al., 2012; Scott et al., 2007; Thomson et al., 2014) and changes in atmospheric chemistry associated with CSG development (Maher et al., 2014; Tait et al., 2013). As yet in Australia, the literature lacks baseline studies with a focus on groundwater chemistry within the overlying shallow aquifers that are often used as a regional water source. Lack of sufficient baseline groundwater information renders it difficult to adequately assess the impact of CSG extraction processes within Australia (Tait et al., 2013).

Methane has a global warming potential 72 times greater than carbon dioxide (CO_2) over a 20 year period, making it a potent greenhouse gas (Solomon et al., 2007). Methane is produced through organic matter decomposition and can be either biogenic (microbially derived) or thermogenic (thermally derived) in origin (Barker and Fritz, 1981). Biogenic CH_4 production processes usually occur at shallow depths and utilize predominantly two metabolic pathways: acetate fermentation and CO_2 reduction (Conrad, 1989; Oremland et al., 1988; Schoell, 1988; Whiticar, 1999). Thermogenic CH_4 results from diagenesis at greater depth, where increased temperature and pressure provide an optimal environment for subsurface thermal organic matter decomposition (Barker and Fritz, 1981). Thermogenic CH_4 generation is unlikely in groundwater systems less than 400 m deep but thermogenic CH_4 can be found in shallow aquifers due to upward CH_4 migration (Coleman et al., 1977).

Biogenic and thermogenic CH_4 result in different carbon isotopic signatures ($\delta^{13}C{-}CH_4$) which can be analyzed in combination with geochemical and hydrogeological information in order to assess CH_4 origin (Chung et al., 1988; Schoell, 1980, 1988). Biogenic CH_4 can have $\delta^{13}C$ values ranging from −110‰ to −40‰ while thermogenic CH_4 carbon stable isotope values range between −50‰ and −20‰ (Schoell, 1980; Whiticar, 1999). For biogenic CH_4, isotopically lighter carbon is utilized more readily by methanogens, resulting in ^{13}C depletion in the produced CH_4 relative to the substrate (Whiticar, 1999; Whiticar et al., 1986). $\delta^{13}C{-}CH_4$ can also be utilized to differentiate between biogenic pathways of CO_2 reduction (−110‰ to −55‰) and acetate fermentation (−70‰ and −40‰) (Rice, 1993; Whiticar, 1999; Whiticar et al., 1986). Transitional isotope compositions lie between the two biogenic CH_4 fields causing an overlap attributed to CH_4 migration, CH_4 oxidation and shifts in the isotopic composition of the original organic material (Boreham et al., 1998; Faiz and Hendry, 2006; Whiticar, 1999). Methane oxidation is an important microbial process where microbes oxidize CH_4 to CO_2, during which ^{12}C is preferentially oxidized which leaves residual CH_4 enriched in ^{13}C (Alperin et al., 1988; Coleman et al., 1981; Whiticar and Faber, 1986).

Groundwater may transport CH_4 through geological units into adjacent surface waters (Bugna et al., 1996). CH_4 concentrations and $\delta^{13}C{-}CH_4$ can vary due to factors such as geological and hydrochemical characteristics, organic matter concentration and redox parameters (Aravena et al., 1995; Darling and Gooddy, 2006; Hansen et al., 2001; Jakobsen, 2007). Assessing $\delta^{13}C{-}CH_4$ may provide information on groundwater and surface water CH_4 origins, and can be utilized to assess connectivity between deeper underlying coal seams and overlying shallow aquifers (DNRM, 2012). Investigating groundwater CH_4 dynamics and hydrochemistry are an important component for baseline research as a tool to monitor aquifers and detect potential long term changes brought about by CSG extraction. Cheung et al. (2010) found distinct differences between shallow groundwater and coal bed methane produced fluids in Alberta, Western Canada. Shallow groundwater contained lower total dissolved solids, higher sulphate concentrations and different hydrochemical characteristics in comparison to groundwater in coal bed methane aquifers. Sharma and Baggett (2011) utilized carbon stable isotopes of dissolved inorganic carbon ($\delta^{13}C$-DIC) to trace coal bed produced water infiltration from impoundments into shallow groundwater. In both cases, the investigation was performed after gas production commenced which complicates the interpretation of observations.

A recent study by McPhillips et al. (2014), established baseline dissolved CH_4 distribution patterns in New York State, USA, a potential future shale gas development region. Numerous studies have reiterated the importance of conducting baseline research before gas extraction commences (Jackson et al., 2013b; Sharma et al., 2014; Vidic et al., 2013). Concerns over the potential impacts of horizontal drilling and hydraulic fracturing extraction methods have instigated shallow groundwater and produced water analysis in shale gas and coalbed methane development zones (Chapman et al., 2012; Sharma and Baggett, 2011; Sharma and Frost, 2008; Vengosh et al., 2013; Warner et al., 2012; Warner et al., 2013). However, globally, the literature lacks baseline studies prior to unconventional gas extraction and many studies are conducted after the development of gas fields. For example, investigations in the Marcellus Shale region, Pennsylvania, concluded stray gas (predominantly CH_4) contamination of drinking water resulted from shale gas extraction, likely from leaky well casings (Osborn et al., 2011). However, a later study suggested the presence of CH_4 in that region is likely related to surface topography and hydrogeological characteristics rather than shale gas extraction technologies (Molofsky et al., 2013). A follow up study demonstrated that surface topography and hydrogeology were not responsible for stray gas contamination, rather distances <1 km between private drinking water wells and gas wells were significantly related (Jackson et al., 2013a). In Australia, a recent review into bubbling methane gas in the Condamine River, Queensland (a highly productive CSG region), concluded