Coal seam water quality and the impact upon management strategies

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ABSTRACT

The rapidly developing coal seam gas industry produces significant volumes of associated brackish water which needs to be appropriately managed. The aim of this study was to determine the variability of water composition within and between multiple gas fields in a defined geographic area and to discover relationships between species present. Water quality from 150 coal seam gas production wells from the Surat Basin, Queensland has been analysed. Chemical analysis revealed the associated water to predominantly contain bicarbonate (< 2030 mg/L), chloride (< 5910 mg/L) and sodium (< 3700 mg/L) species. In several instances, water parameters such as fluoride, were above recommended limits for direct beneficial reuse. Principal component analysis revealed three groups of water quality parameters which described the data. Iron, manganese and aluminium were in one group; bromide, magnesium, strontium, potassium, hardness, calcium, chloride, electrical conductivity, total dissolved solids and sodium appeared as a second group and a third group comprised of fluoride, bicarbonate alkalinity as $CaCO_3$, sodium adsorption ratio, pH, boron, silica, total organic carbon, and sulfate. The variability in water compositions may impact on water management technologies such as reverse osmosis as there may be a propensity for membrane fouling by alkaline earth ions or silica. This study suggested that the mineral quantities in coal such as clay, sulfide ores, oxide ores, quartz and phosphates may correlate with the water quality patterns. Through the use of multivariate analysis it was shown that depth of the CSG production well and the location of the CSG production well did not correlate with differing water quality patterns. The physical and chemical parameters that were analysed in this study will aid in the efficient management of associated water and provide information which allows better understanding of environmental impacts and the prospect for beneficial reuse.

1. Introduction

Coal seam gas (CSG) is an emerging industry worldwide, including Australia and in particular Queensland where it is an important part of the economy in terms of a domestic energy resource and also as a significant export commodity (Van Voast, 2003; Baker and Slater, 2008; Kinnon et al., 2010). The CSG industry has been operating in Australia since the early 1990's with commercial production commencing in 1996 (Kinnon et al., 2010). The industry has shown significant recent growth, for example from 1997 to 98 only 2 petajoules (PJ) of gas was produced in Australia compared with approximately 234PJ in 2010-11 (Kinnon et al., 2010, 2013a). Mining of CSG in the Surat Basin involves drilling of vertical wells from the surface to within the coal seam, wherein the trapped gas is released by dewatering (Jackson and Reddy, 2007a). The deeper the coal seam the higher the pressures acting on the seam (Taulis and Milke, 2007). As a consequence, a

substantial volume of water (termed either coal seam (CS) produced or associated water) is collected in retention basins with the water quality being typically saline in character (Millar et al., 2016a; Hamawand et al., 2013; Nghiem et al., 2011). The potential for vast quantities of CSG in Queensland is due to a combination of the shallow depth and quantity of gas present, with the Surat Basin containing more PJ of CSG than any other on the east coast (Papendick et al., 2011; Rice and Claypool, 1981, 2013b).

The use of water in Australia is of importance as it is a country which is prone to drought conditions with over 70% of the landscape being considered arid or semi-arid (Wolfe, 2009). Therefore, the sustainability of water resources is of immense concern. Estimated water production, which has been predicted through reserves of CSG in eastern Australia, is greater than 50,000 ML per year (Baker and Slater, 2008; Baker and Slater, 2011). If associated water is to be of value for a variety of industrial and agricultural industries, knowledge of the

physical and chemical composition of such water is a requirement. The Surat Basin is part of the Great Artesian Basin (GAB), which encompasses approximately one-fifth of Australia (Bekesi et al., 2012). There are a number of groundwater systems located within the GAB and water resources in Queensland are used for industries such as irrigation, stock intensive industries, mining and power generation (Millar et al., 2016a). CS water presents an opportunity to reduce reliance on the GAB water and enhance sustainability of water systems in the long term.

The chemical composition of associated water although not well reported in Australia has been described in other countries such as the USA and New Zealand. The associated waters from CSG extraction in New Zealand and the USA generally have high bicarbonate 402–435 mg/L (HCO_3^-), high sodium 184–334 mg/L (Na^+), low calcium 6–20 mg/L (Ca^{2+}), low magnesium 0.9–6.5 mg/L (Mg^{2+}) and low sulfate 0.7–27.6 mg/L (SO_4^{2-}) with high chloride 49.3–146 mg/L (Cl^-) concentrations (Van Voast, 2003; Taulis and Milke, 2007, 2012; Taulis et al., 2005). Other parameters that are characteristic of associated water are high sodium adsorption ratio (SAR), high total dissolved solids (TDS) and high alkalinity (Van Voast, 2003; Taulis and Milke, 2012; Wang et al., 2012). Factors that have been reported as possibly having an effect on the chemical composition of associated water include location of the gas field and depth of the coal seam (Hamawand et al., 2013). The chemical composition of untreated associated water normally renders it unsuitable for beneficial use therefore it is necessary for a treatment method to be implemented.

The most common treatment method currently used in the CSG industry in Australia is reverse osmosis (RO) (Averina et al., 2008), accompanied by various pre-treatment methods which include chemical pre-treatment and ion exchange (Millar et al., 2016b). There has also been work undertaken on alternative methods for pre-treatment of CSG associated water such as electrocoagulation (Millar et al., 2014). There are a number of chemical species in associated water that may cause scaling and fouling of process equipment and membranes and reduce RO efficiency. Chemical species of concern for scaling and fouling include silica (SiO_2), Ca^{2+}, Mg^{2+}, barium (Ba), fluoride (F^-), SO_4^-, bicarbonate alkalinity as $CaCO_3$, and boron (B), and thus removal of these species is required to maintain performance (Fritzmann et al., 2007). Additionally, there is potential for the associated water to adversely impact the environment if it is released onto land or surface waters untreated (Wang et al., 2012; Johnston et al., 2008; Patz et al., 2004).

Adequate evaluation of associated water quality data is therefore of importance. It has been shown that large data sets can be generated for water quality monitoring in areas which are highly regulated by legislation. However through the use of chemometrics (a multivariate analysis application) the data can be analysed more efficiently (Corona et al., 2013). Historically, water quality analysis has been assessed using a comparison method with the tested parameter being compared to a recommended value (Bhuiyan et al., 2011a; Najar and Khan, 2012). Environmental data has been successfully assessed using chemometric techniques in a number of situations including wastewater monitoring, water classification, selecting water sources for human consumption, and evaluation of pollution (Bhuiyan et al., 2011b). Chemometrics can provide useful information about the origin of particular water quality parameters, the anthropogenic activities, the water management options, interpretation of hydrochemical data, the spatial and temporal variability, seasonal effect and the most parameters to assess and manage water resources (Bhuiyan et al., 2011a, 2011b; Lu et al., 2011; Gazzaz et al., 2012; Giridharan et al., 2009).

The aim of this paper was to extensively analyse a large number of operating CSG wells in the Surat basin, determine compositional variability and to interrogate physical relationships for water within and between multiple gas fields. Specific objectives included the identification of trends in water chemistry, related to depth, or location of the CSG production well in order to provide information which could

aid management of the CS water. Multivariate analysis was employed to link parameters and to recognise patterns in the water data. From this information, systematic identification of the most appropriate and economical means to store and treat associated water may evolve based on location, depth and regional geology.

2. Materials and methods

2.1. Site selection and water sources

The study was conducted within a CSG production field in the Surat Basin, Queensland. The Surat Basin is 300,000 km^2 with one-third being located in northern New South Wales and the remaining portion in Queensland (approximately 200 km inland from the east coast at Dalby to 500 km NW at Mitchell). Associated water samples were collected from 150 production wells from 3 separate fields during July to September 2012. Water samples were obtained from a locally defined region of the Surat Basin and this was done in order to identify relationships between a large set of water quality parameters within small geographical proximity. Three field were investigated and are designated A, B and C due to commercial confidentiality reasons, located at the eastern end of the Surat Basin. Field A and C were relatively close to each other ($\approx$1 km) whereas field B ranged from approximately 9 km distance in some locations from field A and C up to 36 km in other locations. The samples were from both the Juandah and the Taroom Coal Measures and ranged in maximum depth of 573.69 m for field A, 640.08 m in field B and 497.71 m for field C.

2.2. Sampling and analysis

Water samples were taken directly from the CSG production wells and all water analysed was not treated prior to the analysis being undertaken. The precise location of each individual well cannot be divulged due to confidentiality reasons. The samples were all taken from three geographically close fields designated A, B & C in the Surat Basin. Wells were typically separated by 600 m or more from each other. Water samples were obtained from the production well by use of approximately 3 m length of plastic tubing, with water flow directed to a plastic flow meter and then to a plastic container. The flow meter was used to reduce bubbling due to the presence of CSG, with all samples being taken from the plastic container. The produced water was purged by approximately 5 times the volume of the length of the plastic tubing prior to samples being taken, to allow collection of representative samples conforming to standard groundwater practice. All samples were taken from current producing wells at the time of sampling, which was done to ensure that a representative sample from the aquifer was being investigated and that no residual stagnant water was contained in the well or pipework. Associated water samples were tested immediately for the following parameters using a water quality meter (Make: Yeo Kal / Model 611): temperature (°C), pH, and electrical conductivity (mS/cm). Water quality parameters were recorded 3 times at 1 min intervals to ensure that the parameters had stabilised. The water meter was calibrated for pH using a 2 point calibration with a pH 4 and 10 buffer at 25 °C, which was undertaken prior to each sampling round (minimum once daily). The water meter was also calibrated for electrical conductivity using 1413 µS/cm buffer at 25 °C prior to undertaking each sampling round (minimum once daily). In addition, decontamination using a cleaning agent (Decon90) and deionised water was undertaken of all field equipment that was in contact with associated water prior to each sample being taken. Associated water was stored in plastic sample containers, supplied by Australian Laboratory Services (ALS) and were kept in a chilled ice chest prior to and during delivery to Brisbane within 24 h of the sample being taken, which was undertaken in accordance with Australian Standards. Water samples were analysed by ALS for the following parameters shown in Table 1.