Geophysical Research Abstracts
Vol. 16, EGU2014-62, 2014
EGU General Assembly 2014

Numerical assessment of potential impacts of hydraulically fractured Bowland Shale on overlying aquifers

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The success of unconventional gas extracted from shale formations (shale gas) over the last decade has changed the energy landscape in the United States. Shale gas rose from 2% of US gas production in 2000 to 30% in 2011, and is projected to rise to more than 50% by 2030. On the global scale, shale gas could increase total natural gas resources by approximately 32%, with an estimate of the total 7,299 trillion cubic feet (~200 trillion cubic meter) technically recoverable gas worldwide. In the UK, onshore shale gas reserve potential was first estimated to be 150 billion cubic meter by the British Geological Survey (BGS) in 2010. A recent study by BGS revised the previous estimates, with best estimate (50% probability) of total in-place gas resource of 37.6 trillion cubic meters in the Bowland Shale across central Britain. However, there are concerns of potential environmental impacts of hydraulic fracturing of the shale formations, particularly those related to water quality, such as gas migration, contaminant transport through induced and natural fractures.

To evaluate the potential impact of hydraulically fractured shale on overlying aquifers, we conduct numerical modelling simulations to assess flow and solute transport from a synthetic Bowland Shale over a period of 1000 years. The synthetic fractured shale was represented by a three-dimensional discrete fracture model that was developed by using the data from a Bowland Shale gas exploration in Lancashire, UK. The assessment was carried out to investigate chloride mass fluxes from the fractured Bowland Shale for a range of upward fracture height growths from 200 to 1850 meters, with three sets of hydraulic conductivities over three orders of magnitude for a multi-layered geological system. Of eighteen scenario analyses, the maximum upward mass flux towards the overlying Sherwood Sandstone aquifer is < 0.02 ton Cl^-/ yr when a constant chloride concentration of 100 g Cl^-/L is applied for the brine in the fractured shale. With this mass flux rate into the fracture area of $\sim$0.75 km^2, it is unlikely to create average chloride concentration over the UK maximum concentration level of 188 mg Cl^-/L in groundwater, although upward mass flux via fractures could create pollution 'hot spot' areas exceeding this concentration level. The model study also reveals that the upward mass flux is significantly intercepted by the horizontal mass flux within a high permeable layer between the Bowland Shale and its overlying aquifers, preventing further upward flux towards the overlying aquifers.