WATER RESOURCES RESEARCH, VOL. 49, 8310–8327, doi:10.1002/2013WR014287, 2013

Hydraulic fracturing in faulted sedimentary basins: Numerical simulation of potential contamination of shallow aquifers over long time scales

Claire Gassiat,[1] Tom Gleeson,[1] René Lefebvre,[2] and Jeffrey McKenzie[3]

Received 17 June 2013; revised 9 October 2013; accepted 23 October 2013; published 12 December 2013.

[1] Hydraulic fracturing, used to economically produce natural gas from shale formations, has raised environmental concerns. The objective of this study is to assess one of the largely unexamined issues, which is the potential for slow contamination of shallow groundwater due to hydraulic fracturing at depth via fluid migration along conductive faults. We compiled publically available data of shale gas basins and hydraulic fracturing operations to develop a two-dimensional, single-phase, multispecies, density-dependent, finite-element numerical groundwater flow and mass transport model. The model simulates hydraulic fracturing in the vicinity of a permeable fault zone in a generic, low-recharge, regional sedimentary basin in which shallow, active groundwater flow occurs above nearly stagnant brine. A sensitivity analysis of contaminant migration along the fault considered basin, fault and hydraulic fracturing parameters. Results show that specific conditions are needed for the slow contamination of a shallow aquifer: a high permeability fault, high overpressure in the shale unit, and hydrofracturing in the upper portion of the shale near the fault. Under such conditions, contaminants from the shale unit reach the shallow aquifer in less than 1000 years following hydraulic fracturing, at concentrations of solutes up to 90% of their initial concentration in the shale, indicating that the impact on groundwater quality could be significant. Important implications of this result are that hydraulic fracturing should not be carried out near potentially conductive faults, and that impacts should be monitored for long timespans. Further work is needed to assess the impact of multiphase flow on contaminant transport along natural preferential pathways.

Citation: Gassiat, C., T. Gleeson, R. Lefebvre, and J. McKenzie (2013), Hydraulic fracturing in faulted sedimentary basins: Numerical simulation of potential contamination of shallow aquifers over long time scales, *Water Resour. Res.*, *49*, 8310–8327, doi:10.1002/2013WR014287.

1. Introduction

[2] Over the past 15 years, shale gas has emerged as a viable and important energy resource. In order to produce economically viable quantities of natural gas from unconventional reservoirs such as shale, the technique of hydraulic fracturing (hydrofracturing or "fracking") is generally used [*BAPE*, 2011; *EPA*, 2012]. Hydraulic fracturing consists of injecting high volumes of "fracturing fluid" at pressures greater than lithostatic, causing the formation to fracture and thereby increase its local permeability [*EPA*, 2012]. After hydraulic fracturing the pressure is relieved by the "flowback," composed of fracture fluid and formation fluids, which returns to the surface [*Gregory et al.*, 2001]. The fracking fluid is commonly composed of ~99.5% water and proppants (generally sand), and ~0.5% chemical additives including acids, solvents, and biocides [*BAPE*, 2011; *Gregory et al.*, 2011]. Additionally, the flowback not only contains saline formation fluids and natural gas but also naturally occurring contaminants present in the host shale rocks such as radioactive compounds and heavy metals [*Gregory et al.*, 2001; *Groundwater Protection Council and All Consulting*, 2009].

[3] Concerns about the potential environmental impact of hydraulic fracturing have increased, especially risks relating to drinking water resources [*Kargbo et al.*, 2010; *EPA*, 2012]. Potential drinking water issues include: (1) water resource stress due to water withdrawal; (2) water pollution related to spills and leaks at above ground hydraulic fracturing operations; (3) unsuitable treatment of wastewater; (4) failures of wells in the shallow subsurface due to poor cementing or steel casing corrosion; and (5) geologic failures at depth as a result of the fracturing that could cause potential contamination of

This article was published with an incorrect title on 12 December 2013. This error was corrected on 18 December 2013.

[1]Department of Civil Engineering, McGill University, Montreal, Quebec, Canada.

[2]Institut National de la Recherche Scientifique, Centre Eau Terre Environnement (INRS-ETE), Quebec, Quebec, Canada.

[3]Department of Earth and Planetary Sciences, McGill University, Montreal, Quebec, Canada.

Corresponding author: T. Gleeson, Department of Civil Engineering, McGill University, 817 Sherbrooke St. W., Montreal, QC H3A 0C3, Canada. (tom.gleeson@mcgill.ca)

0043-1397/13/10.1002/2013WR014287