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Impacts of Fugitive Gas on Shallow Groundwater Quality: Insights from a Controlled Release Field Experiment

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Increased levels of shale gas development have raised concerns on the potential environmental impacts associated with natural gas extraction. A primary concern is the potential for natural gas to migrate from compromised well casings into aquifers containing potable groundwater, forming dissolved gas plumes of natural gas constituents (i.e. methane, ethane and propane). While methane (CH4), as the primary component of natural gas, is non-toxic in drinking water, it may react with solutes present in groundwater and minerals contained in the aquifer matrix to create bi-products that can degrade water quality. Currently, geochemical processes induced by the ingress of CH4 at elevated concentrations and associated secondary water quality impacts are poorly understood. To address these knowledge gaps, a controlled natural gas release experiment was undertaken in a glacio-lacustrine sand aquifer at CFB Borden near Alliston, Ontario, Canada. Over 72 days 51 m3 of natural gas was injected at depths of 4.5 m and 9 m. Evolution of aqueous chemistry was monitored before and up to 700 days after gas injection. Samples were collected from multi-level monitoring wells and analyzed for dissolved gases, major and minor ions, alkalinity, and stable carbon isotopes (13C) in CH4 and carbon dioxide (CO_2). Observed hydrogeochemical changes occurred in two distinct temporal phases. During gas injection, an extensive and dispersed plume of free and dissolved natural gas constituents formed in the aquifer. Both vertical and lateral migration of free gas, due to buoyancy effects and small-scale heterogeneities, respectively, contributed substantially to the growth and spreading of the dissolved gas plume. In the short term (up to 250 days since start of injection) subtle changes in aqueous chemistry were attributed to the gas release inducing mixing of deep lower quality water and shallower higher quality water. Mixing resulted in; a) increased saturation and precipitation of hydroxide minerals, b) a decline in pH and c) increases in some trace metals (Al, As, Ni, Si). In the longer term (i.e. 250 - 700 days), CH4 oxidation became apparent in conjunction with additional subtle aqueous chemistry changes. Through this research, we demonstrate that leaking energy wells at depth may induce vertical mixing of waters of different composition, potentially deteriorating shallow groundwater quality. Additionally, our data reveal a time lag of approximately one year for the onset of microbially mediated CH4 oxidation, which leads to additional water quality changes. Results from this research suggest that over a multi-year scale, both vertical mixing and CH4 oxidation may contribute to degradation of shallow groundwater quality due to a leaking energy well.