

## Numerical interpretation of laboratory and field data showing CO<sub>2</sub>-induced groundwater changes

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The potential impact of leaking CO<sub>2</sub> on shallow groundwater quality is one of the issues related to the risk assessment of CO<sub>2</sub> geological sequestration. Here we discuss CO<sub>2</sub>-induced geochemical changes in a shallow sandy aquifer at ~ 50 m depth, focusing on the mobilization of trace elements and the underlying chemical mechanisms revealed by a controlled-release field experiment, laboratory tests and numerical modeling. The field test involved a dipole system in which the groundwater was pumped from one well, saturated with CO<sub>2</sub> at the pressure corresponding to the hydraulic pressure of the aquifer, and then re-injected into the same aquifer using a second well. Groundwater samples for chemical analyses were collected in four monitoring wells. A series of lab-scale sequential leaching experiments were also carried out with synthetic groundwater solutions at different pH and CO<sub>2</sub> concentrations. Upon introduction of CO<sub>2</sub>, a rapid increase in concentrations of some trace elements (e.g. Ba, Sr) was observed in both the field and lab tests; the lab experiments suggest that metal release was primarily driven by the decrease in groundwater pH from ~8 to ~5. Geochemical modeling was employed to interpret laboratory and field results and gain insights on the mechanisms potentially involved in the CO<sub>2</sub>-induced mobilization of trace elements. The increase in concentrations of alkali and alkaline earth metals can be explained by the dissolution of trace amounts of calcite and subsequent calcium-driven cation exchange reactions. Modeling also indicates that the magnitude and extent of metal mobilization depends not only on metal-mineral associations and sediment pH buffering characteristics, but also on the residence time of CO<sub>2</sub>-impacted groundwater relative to the rates of metal-release reactions, with the effect of slow reactions only noticeable under conditions of slow groundwater velocity.

## Navigating troubled waters

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In September 2000, the General Assembly adopted the United Nations Millennium Declaration. Under Article III development and poverty eradication, item 19 states “we resolve further to halve, by the year 2015, ...to halve the proportion of people who are unable to reach or to afford safe drinking water.” In 2012, the Joint Monitoring Program (JMP) of the World Health Organization and UNICEF reported that the drinking water target of the Millennium Development Goal has been achieved. In 2010, the proportion of the global population still using unimproved sources is estimated at only 11 per cent, which is less than half of the 24 per cent estimated for 1990. However, this is based on a proxy indicator for safe drinking water: an improved water source defined as those that, by the nature of their construction, are protected from outside contamination, particularly fecal matter. It is increasingly clear that this proxy indicator is inadequate because naturally occurring chemicals such as arsenic and fluoride that are harmful to humans can render the water unsafe. In addition, poor sanitation frequently leads to fecal contamination of shallow groundwater. Here, occurrences of arsenic in groundwaters in Bangladesh, China and United States are used as examples to illustrate research by hydrogeochemists that have been impactful on safe drinking water supply. A critical contribution made by hydrogeochemists over the last decade was the evaluation of the sustainability of the low arsenic groundwater sources as a safer drinking water source.

Bangladesh is the only country in the world when access to improved water source is reported by the JMP, a correction has been made for arsenic occurrence in groundwater. Based on a national drinking water quality survey conducted in 2009, access to improved water sources containing less than 50 µg/L As was estimated to be 81%. The vast majority of improved water sources in rural Bangladesh is a private, shallow tube well. The rapidly developing China saw the access to improved water increasing from 67% in 1990 to 91% in 2010, with 2/3 of the improved sources being water piped on premises. However, millions of rural Chinese are still exposed to As and F. Likewise, more than 10 million rural Americans relying on private well waters are at risk of exposure to > 10 µg/L As. Much work remain to identify alternative water sources to protect human health.