Degassing in the standing water column of a monitoring well completed in gas-charged groundwater.

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Summary

Total Dissolved Gas Pressure (P_{TDG}) measurements are critical to measuring accurate *in-situ* dissolved gas concentrations in groundwater wells, but difficult to obtain due to in-well degassing (Roy and Ryan, 2010). This study monitored vertical profiles of P_{TDG} and dissolved gas concentrations in a standing water column of a gas-charged groundwater monitoring well before and after pumping to gain insight into the process by which groundwater wells become degassed after pumping. During the pre-pumping period, P_{TDG} values remained relatively constant and below the bubbling pressure (P_{BUB}) at all monitoring depths. In contrast, significant increases in P_{TDG} values were observed after pumping was initiated at all monitoring depths, as fresh groundwater with in-situ P_{TDG} was pumped into the well screen and moved up in the well water column. P_{TDG} values subsequently decreased at all monitoring depths over the 15-day post-pumping period, indicating that in-well degassing occurred. Dissolved gas concentration measurements at multiple monitoring depths were used to evaluate the hypothesis that decreased P_{TDG} after pumping occurs due to mixing within the well water column. In each of the two monitoring periods, groundwater gases throughout the water column were mixed with the headspace above the well water column (atmospheric gases during the pre-pumping and SF_6 tracer gas during the post-pumping period), indicating that bubble-induced mixing is likely the main mechanism controlling the long-term in-well degassing observed.

Theory / Method / Workflow

The mechanism and rates of degassing were investigated by measuring P_{TDG} profiles in the standing water column of a gas-charged groundwater monitoring well before and after pumping. Sulphur hexafluoride (SF_6) gas tracer was injected into the headspace volume above the standing water column immediately after pumping to evaluate the mixing mechanism, and its concentration in the water column measured after 15 days. Vertical P_{TDG} and gas concentration profiles were measured to provide an understanding of the relative rates of degassing in the well water column over time and estimate *in-situ* (i.e., aquifer) gas concentrations. Passive dissolved gas samplers (McLeish et al., 2007) were collected prior to pumping 7 days after deployment (pre-pumping period) and 15 days after deployment after pumping (post-pumping period).

Results, Observations, Conclusions

PTDG and gas concentration monitoring indicated that the well water column was degassed and mixed with the atmosphere prior to pumping. During the pre-pumping period, P_{TDG} values were constant, and substantially lower than the corresponding P_{BUB}, at all monitoring depths. After an initial rise in P_{TDG} due to pumping, P_{TDG} values decreased at all monitoring depths throughout the 15-day post-pumping period, indicating the occurrence in-well degassing. The rate of degassing was highest after peak P_{TDG} values were measured, and decreased exponentially with time. In-well degassing reflected in P_{TDG} values below respective P_{BUB} at several monitoring points, including the deepest monitoring point where P_{BUB} exceeds the *in-situ* P_{TDG}.

During the post-pumping period, P_{TDG} values remained similar to the corresponding P_{BUB} at the shallowest monitoring depth, indicating that there was continuous potential for free-phase gas (i.e., bubbles) formation at this interval. The buoyant migration of bubbles formed in the water column could induce convection currents, with increasing effect as bubble size increases during buoyant ascent (Climent and Magnaudet, 1998; Almeras et al., 2015), resulting in the movement of deeper water (with higher P_{TDG}) upwards in water column with a commensurate decrease in P_{BUB}. Thus, findings from this study suggest that bubble-induced convection is a key mechanism controlling the long-term degassing (lowering of P_{TDG}) observed at all monitoring depths, including those where P_{TDG} is lower than P_{BUB}.

Additional evidence of mixing is provided by the gas concentration measurements with depth throughout the water column. In each of two monitoring periods, groundwater gas concentrations suggested interaction between the well water column and the headspace above the water column. Gas concentrations reflected a mixture of dissolved gases in 'fresh' groundwater and the well casing headspace. Headspace gases were atmospheric gases during the pre-pumping period, and SF_6 tracer gas during the post-pumping period. The similar gas composition at all monitoring depths associated with the low temperature gradient (< 0.01 °C/m) measured with depth during both monitoring periods is consistent with bubble-induced mixing.

Novel/Additive Information

The results from this study have provided insight into the possible degassing mechanisms and conditions within an over-pressured groundwater well after pumping. Monitoring of vertical P_{TDG} profiles and gas concentrations demonstrated that in-well lowering of P_{TDG} after pumping occurs due to a) formation of bubbles at the interval where $P_{TDG} > P_{BUB}$ b) in-well mixing process.

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References

Almeras, E, F. Risso, V. Roig, S. Cazin, C. Plais and F. Augier. 2015. Mixing by bubble-induced turbulence. *Journal of Fluid Mechanics* 776: 458-474.

Climent, E. and J. Magnaudet. 1999. Large-Scale Simulation of Bubble-Induced Convection in a Liquid Layer. *Physical Review Letters* 82, no. 24: 4827-4830.

McLeish, K., M. C. Ryan and A. Chu. 2007. Integrated Sampling and Analytical Approach for Common Groundwater Dissolved Gases. *Environmental Science and Technology* 41, no. 24: 8888-8393.

Roy, J. W. and M. C. Ryan. 2010. In-Well Degassing issues for Measurements of Dissolved Gases in Groundwater. *Groundwater* 48, no. 6: 869-877.

Figure/Visual Abstract