An Overview of the Illinois Basin – Decatur Project Groundwater Compliance Monitoring Program

Abbas Iranmanesh, Randall A. Locke II, Bracken T. Wimmer

University of Illinois, Illinois State Geological Survey
615 East Peabody Drive, Champaign, Illinois 61820, USA

Introduction

The Midwest Geological Sequestration Consortium is conducting the Illinois Basin – Decatur Project (IBDP), a large-scale carbon capture and storage (CCS) project in Decatur, Illinois, USA. The objective of the project is to validate the capacity, injectivity and containment of the Mount Simon Sandstone which represents the primary carbon storage formation in the Illinois Basin and Midwest region. The IBDP study area (Figure 1) covers approximately 160 acres (0.65 km²/0.25 mi²). Injection began in November 2011 and was completed in November 2014 after 999,216 tonnes of CO_2 were injected.

As a part of an extensive monitoring and verification program, groundwater monitoring has been conducted to establish pre-injection conditions and demonstrate that project activities are protective of human health and the environment [1].

Groundwater monitoring and methods:

Four shallow groundwater monitoring wells were installed (G101 - G104 in Figure 1) as part of the project's regulatory monitoring program. The project also monitors a multilevel monitoring well called VW1 drilled to a depth of 7,272 feet (2,216.5 meters). Data from the shallow compliance wells are the focus of this poster. The wells are about 140 feet (43 m) deep with 10-foot (3 m) screened intervals installed in a thin sandstone of Pennsylvanian-age bedrock (Table 1). Groundwater sampling began in October 2010 as part of the project's Class I - UIC permit. Effective February 15, 2015, post-injection monitoring is being conducted under the USEPA UIC Class VI permit and the ILEPA Class I permit was subsequently terminated. This study contains historical quarterly shallow groundwater compliance data collected between October 2010 and January 2017. In total, twenty-five quarterly sampling events have been conducted; five pre-injection, eleven during injection, and nine post-injection.

Well Name	Measuring Point Elevation (ft above MSL)	Screened Interval (ft below ground surface)	Distance to Injection Well (ft)
G101	675.59	131 to 141	50
G102	676.13	132 to 142	43
G103	675.28	131 to 141	237
G104	684.52	129 to 139	1,858

Table 1. Construction information for IBDP shallow regulatory compliance wells.

Water samples were collected using low-flow sampling techniques. Laboratory analyses included alkalinity, TDS, dissolved CO_2, major anions, major cations, and trace metals. During sampling, field parameters [i.e., pH, dissolved oxygen (DO), specific conductance (SC), oxidation-reduction potential (ORP) and temperature] were measured. Table 2 provides a list of compliance parameters, analytical methods and representative method detection limits as described in the Class VI permit.

	Analyte	Analytical Method	Detection Limit (mg/L)		Analyte	Analytical Method	Detection Limit (mg/L)
Major Cations	Al	SW 6020	0.01	**Trace Metals**	As	SW 6020	0.001
	Ba	SW 6020	0.001		Cd	SW 6020	0.001
	Ca	SW 6010	0.05		Cr	SW 6020	0.004
	Fe	SW 6020	0.01		Cu	SW 6020	0.003
	K	SW 6010	0.5		Pb	SW 6020	0.001
	Mg	SW 6010	0.05		Sb	SW 6020	0.003
	Mn	SW 6020	0.001		Se	SW 6020	0.001
	Na	SW 6010	0.5		Tl	SW 6020	0.001
	Si	SW 6010	0.01	**Field parameters**	pH	EPA 150.1	2 to 12 pH units
Anions	Br^-	US EPA 300.0	1		SC	APHA 2510	0 to 200 mS/cm
	Cl^-	US EPA 300.0	1		T (ºC)	Thermocouple	5 to 50°C
	F^-	US EPA 300.0	0.25	**Others**	Alkalinity	SM 2320B	2
	NO_3	US EPA 300.0	0.02		TIC	ASTM D513-11	25 mg/L
	SO_4	US EPA 300.0	1		TDS	SM 2540C	17

Acknowledgements

This research was funded by the U.S. Department of Energy through the National Energy Technology Laboratory (NETL) Regional Carbon Sequestration Partnership Program (contract number DE-FC26-05NT42588) and by a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute. We greatly appreciate the staff of the Illinois State Geological Survey contributed to field sampling efforts and data management. PDC laboratories and the Illinois State Water Survey, Public Service Laboratory, performed chemical analyses.

Figure 1. IBDP Shallow groundwater network.

	Constituent	Unit	G101	G102	G103	G104
Most sensitive to CO_2 interaction	**Alkalinity**	mg/L	407–462	396–440	397–532	364–428
	CO_2	mg/L	373–423	340–395	352–493	326–395
	pH	units	6.8–7.7	6.7–8.2	7.0–7.9	6.9–7.8
	Ca	mg/L	27–38	30–43	37–47	34–130
Most sensitive to brine interaction	**Br**	mg/L	0.5–1.0	0.4–1.1	0.7–1.4	<0.08–0.66
	Cl	mg/L	273–471	246–500	286–621	103–272
	Na	mg/L	330–432	333–453	339–504	88–313
Others	**DO**	mg/L	0–0.65	0.0–18.5	0.0–4.3	0.0–3.59
	SC	µS/cm	1.5–2.7	1.5–2.7	1.5–3.2	1.2–2.4
	Fe	mg/L	0.06–0.7	0.03–0.9	0.04–1.9	0.05–4.2
	K	mg/L	3–5	3–5	3 - 5	2–3
	Mg	mg/L	13–19	15–19	17–23	15–58
	SO_4	mg/L	3–8	2–163	<0.21–21	2–209
	TDS	mg/L	937–1,256	1,050–1,250	1,060–1,378	774–898

Table 3. Measured concentration ranges of selected constituents in groundwater samples collected in 25 sampling events from October 2010 to January, 2017.

	Constituent	G101	G102	G103	G104
Most sensitive to CO_2 interaction	**Alkalinity**			✓	
	CO_2	✓		✓	
	pH				
	Ca				
Most sensitive to brine interaction	**Br**				
	Cl	✓			
	Na				
Others	**DO**				
	SC				
	Fe				
	K				
	Mg				
	SO_4				
	TDS	✓			
✓ Significant variation					

Table 4. Analyses of variance test results showing sporadic significant variation.
Note: *If leakage were to occur and impact these locations, **all** sensitive parameters would be expected to show significant variation.*

Results and Discussion

Groundwater data from the IBDP site have been essential to characterize site conditions and better understand subsurface dynamics. Table 3 shows a summary of concentrations for selected constituents. Statistical analysis was used to evaluate IBDP quarterly compliance data [2]. Leven's Equality of Variance test ($\alpha = 0.05$) was applied to injection (11 quarters) and post-injection (9 quarters) datasets to assess if CO_2 injection has affected shallow groundwater.

- In general, analyses of variance test indicates no variation at 5% significant level (Table 4).
- The variability observed in some shallow water quality data were related to variations in sampling equipment performance, natural groundwater heterogeneity, and initial effects of well installation.
- No trends or changes in shallow groundwater chemistry have been observed that are expected to be the result of CO_2 injection.

Sources of variability in IBDP shallow groundwater quality data

- **Well G102 - Sampling equipment performance**
  Since July 2013, elevated dissolved oxygen and sulfate concentrations in well G102 were observed. A pump tubing leak was suspected as the cause for the elevated oxygenation of the sampled water. In turn, sulfate concentrations increased because of the increased presence of oxygen [3] [4]. However, the mechanical issue did not significantly change the ability of the well (or an adjacent well) to detect CO_2 or brine leakage. The pump was repaired after the October 2016 sampling event and DO has returned to previous values (Figure 2). In the future, the sulfate concentration is expected to also decrease.

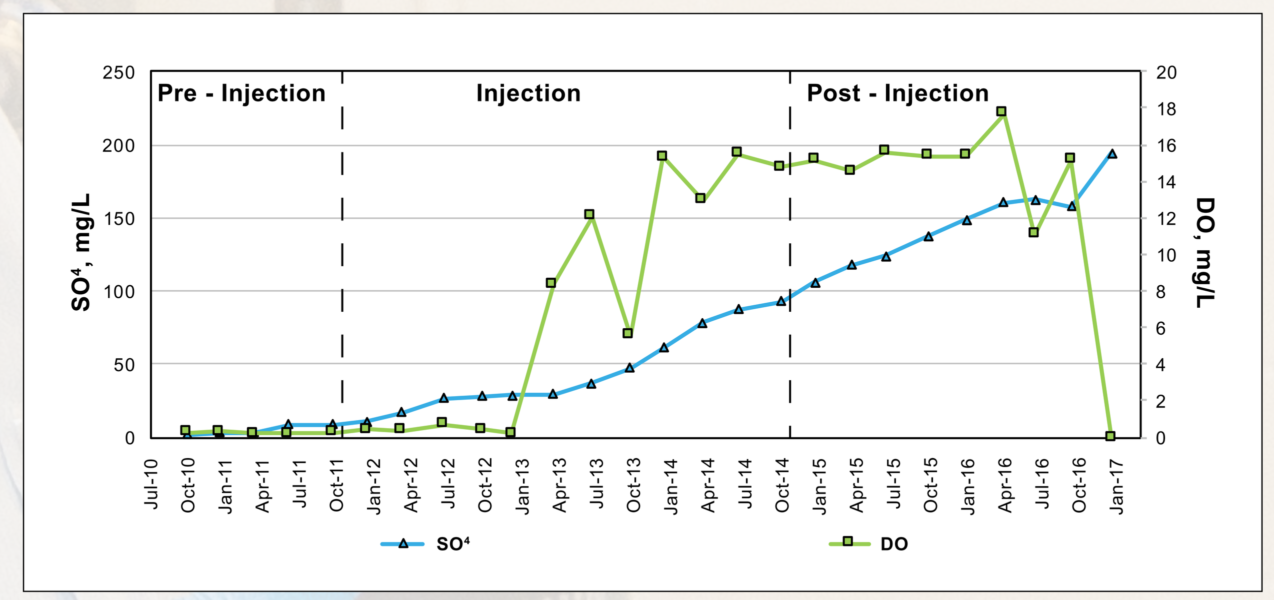

Figure 2. Monitoring data influenced by a leaky sampling pump in well G102.

- **Well G103 - Decomposition of organic matter**
  Since July 2015, groundwater concentrations of iron, as well as alkalinity and dissolved CO_2, in well G103 increased gradually (Figure 3). These trends are expected to be related to greater dissolved organic matter content at well G103 as compared to other wells. It is expected that decomposition of organic matter (C), has created a reducing environment with the associated redox reaction of Fe^{+3}[5]:

$$4Fe^{3+} + (C) + 2H_2O \rightarrow 4Fe^{2+} + CO_2 + 4H^+$$

As the reaction occurs, the produced CO_2 increases alkalinity and decreases the pH (Figure 3). Thus, while the trends observed could be also observed in a scenario of leakage that is not the case. Statistical evaluation of data from this well indicates no-significant trends for other elements sensitive either to CO_2 interaction (i.e., calcium) or brine interaction (i.e., Br and Cl).

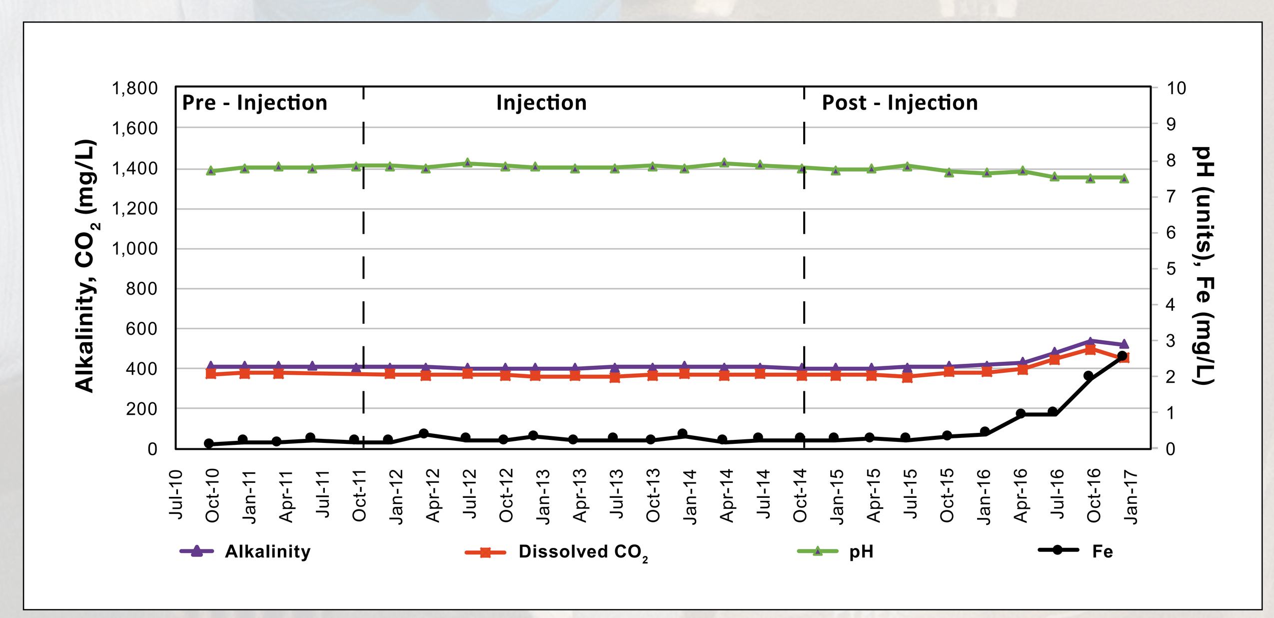

Figure 3. Influence of organic matter decomposition in G103.

- **Well G104 – Groundwater recharge/dilution**
  Increases of calcium and sulfate concentration and decreases of chloride and sodium concentrations (Figure 4) were measured in well G104. A comparison of groundwater level data and water chemistries of well G104 to well 04UG, a research well monitoring the Upper Glasford Formation, a unit directly above the well G104 monitoring zone, suggests that the two strata are in moderate hydraulic communication. Higher variations of elevation in 04UG (Figure 5) is expected to generate downward flow from Glasford aquifer (04UG) to Pennsylvanian aquifer (G104). An observed downward hydraulic gradient is likely the primary mechanism by which Upper Glasford groundwater (average calcium and chloride concentration, 171 and 74 mg/L respectively) moves downward into the Pennsylvanian strata (average calcium and chloride concentration, 46 and 250 mg/L respectively).

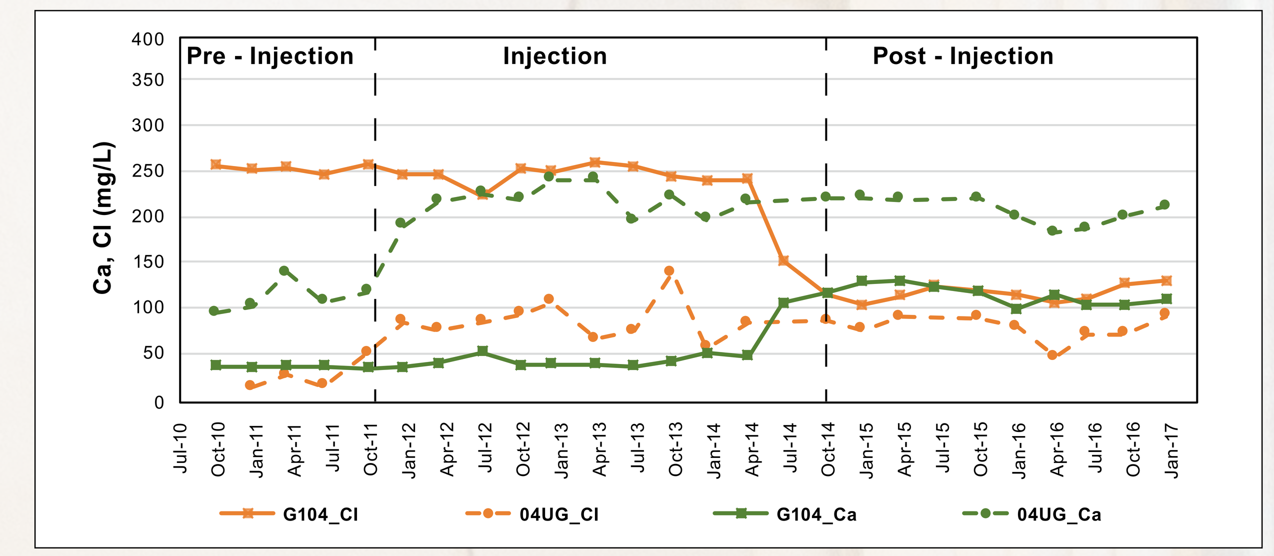

Figure 4. Calcium and chloride concentrations in wells G104 and 04UG.

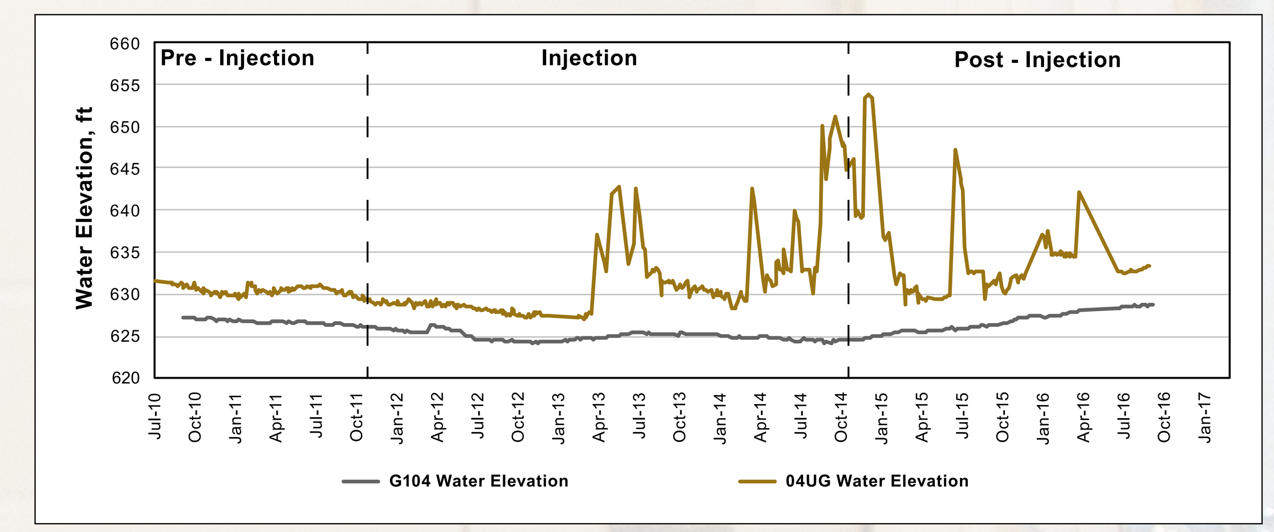

Figure 5. Groundwater elevation in G104 and 04UG. Higher differential elevation in 04UG potentially causes downward flow from Glasford (04UG) to Pennsylvanian (G104) aquifer.

Conclusion

The IBDP groundwater compliance monitoring program indicates:

- Groundwater compliance monitoring programs for CCS projects should anticipate significant natural variability (especially in shallow groundwater monitoring) and need to carefully corroborate observed variations with anticipated leakage signals.
- Trends and variations observed in groundwater quality data are not related to CO_2 injection or brine leakage.
- Leaky pump tubing influenced oxygen sensitive components (e.g., G102).
- Oxidation - reduction causes variations in groundwater quality data (e.g., G103).
- Groundwater dilution (e.g., recharge) due to hydraulic connections between aquifers causes water quality variations (e.g., G104).

References

[1] Randall Locke, David Larssen, Walter Salden, Christopher Patterson, Jim Kirksey, Abbas Iranmanesh, Bracken Wimmer, Ivan Krapac, 2013. Pre-injection reservoir fluid characterization at a CCS demonstration site: Illinois Basin – Decatur Project, USA, Energy Procedia 37: 6424–6433, 2013.

[2] Sanitas Technologies, 2012. Sanitas Statistical Analysis Procedure, Version 9.4.

[3] Minnesota pollution Control Agency, 1999. Sulfate in Minnesota's Groundwater.

[4] http: //oregon.gov/DHS/gwater, Sulfur in Groundwater.

[5] James I. Drever, 1997. The Geochemistry of Natural Waters, 3rd edition.

The Midwest Geological Sequestration Consortium (MGSC) is funded by the U.S. Department of Energy through the National Energy Technology Laboratory (NETL) via the Regional Carbon Sequestration Partnership Program (contract number DE-FC26-05NT42588) and by a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute.