7.0 Post-Injection Site Care and Site Closure Plan

This chapter presents the post-injection site care and site closure plan for the FutureGen 2.0 Morgan County CO_2 storage site in compliance with 40 CFR 146.93. Section 7.1 provides an overview of the computational modeling of the post-injection period that was conducted to determine the pressure differential and areal extent of the CO_2 plume; a full description of the computational modeling used in the development of the Alliance's UIC permit applications is provided in Chapter 3.0, Area of Review and Corrective Action Plan. The post-injection monitoring plan and the site closure plan are described in Sections 7.2 and 7.3, respectively. The post-injection site care and site closure plan was based on *Federal Requirements Under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells* (EPA 2010) and *Draft Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance for Owners and Operators* (EPA 2011). Upon cessation of injection, the Alliance will either submit an amended post-injection site care and site closure plan or demonstrate to EPA that no amendment to the plan is necessary, pursuant to 40 CFR 146.93(a)(3).

7.1 Computational Modeling for the Post-Injection Period

The same computational model used for calculating the AoR was used for the post-injection site care and site closure analysis. The model is described in more detail in Chapter 3.0. Results in this section were generated from model output for the site care period. For the representative case, the aqueous fluid and $scCO_2$ pressure and migration of CO_2 were simulated for 100 years. The computational model will be calibrated to monitoring data during the operational period to provide more accurate representation of CO_2 sequestration processes.

7.1.1 Pressure Differential

Changes in pressure relative to initial conditions were calculated from simulation results. Pre-injection pressures were defined as the initial pressure measured before injection begins. Simulations were conducted for 20 years of CO_2 injection at a rate of 1.1 MMT/yr distributed into the injection wells, followed by 80 years of post-injection. Table 7.1 lists predicted aqueous pressure differentials over time at the top of the injection zone and for one depth interval immediately above the primary confining zone (MW3, the ACZ early-detection monitoring well). The planned locations for injection and monitoring wells are shown in Figure 5.1 and in Figure 7.4 below. The model suggests a maximum injection pressure differential of 446 psi at the injection well at the time injection is stopped. Simulation results show the magnitude and area of elevated pressure gradually decreasing over time after injection stops.

Figure 7.1 shows the pressure differential versus time for monitoring well locations in the AoR and at the geometric centroid of the four horizontal injection wells. Simulated pressures at the top of the injection zone at the injection "point" increase during the 20-year injection period from 1,693 psi to a maximum of 2,139 psi. The highest pressures are in the immediate vicinity of each injection well. As shown, pressures at the injection and monitoring well locations decline over time after injection is stopped.

7.1.2 Predictions of CO_2 Migration During the Post-Injection Site Care Period

CO_2 migration during the post-injection site care period was modeled to predict CO_2 plume redistribution after injection ceases. The model predicts that the areal extent of the CO_2 plume (defined as

99.0 percent of the separate-phase CO_2 mass) increases during injection and for 2 years post-injection and then begins to decrease as buoyancy forces dominate and plume migration is predominately upward. Figure 7.2 shows the cumulative area of the CO_2 mass plume with time. The maximum plume extent, 6.46 mi^2, occurs at 22 years after the start of injection (2 years after the cessation of injection).

Table 7.1. Pressure Differential to Baseline Conditions at Well Location at the Base of the Ironton Formation for Well 3 and at the Top of the Injection Zone for the Rest of the Wells During and After Injection

	Pressure Differential (psi)				
Year	MW 1	MW 2	MW 3	MW 4	Injection Well
Distance from Injection Well (ft)	7,749	3,149	1,221	6,574	0
0 (Start injection)	0	0	0	0	0
1	116	166	0	119	289
2	155	209	0	160	339
3	181	236	0	187	365
4	200	255	0	206	381
5	215	271	0	221	393
10	263	319	0	270	424
15	292	343	1	300	438
20 Stop injection at year end)	313	358	2	320	446
21	228	242	2	234	258
22 (Approximate maximum extent of CO_2 Plume)	183	191	2	188	200
23	155	161	2	160	168
24	136	141	3	140	145
25	121	125	3	125	129
30	81	84	4	84	85
35	62	64	4	64	64
40	50	51	5	51	51
45	41	42	5	43	42
50	35	36	5	36	36
60	27	27	5	28	27
70	21	22	5	22	21
80	18	18	5	18	17
90	15	15	5	15	14
100	13	13	4	13	12

Well Identifier on Figure 7.1

MW 1	Stratigraphic Well (converted to Single-Level Monitoring Well)
MW 2	Injection Zone Multi-Level Monitoring Well
MW 3	ACZ Early-Detection Monitoring Well
MW 4	Injection Zone Single-Level Monitoring Well
Injection Well	Geometric centroid of four horizontal laterals

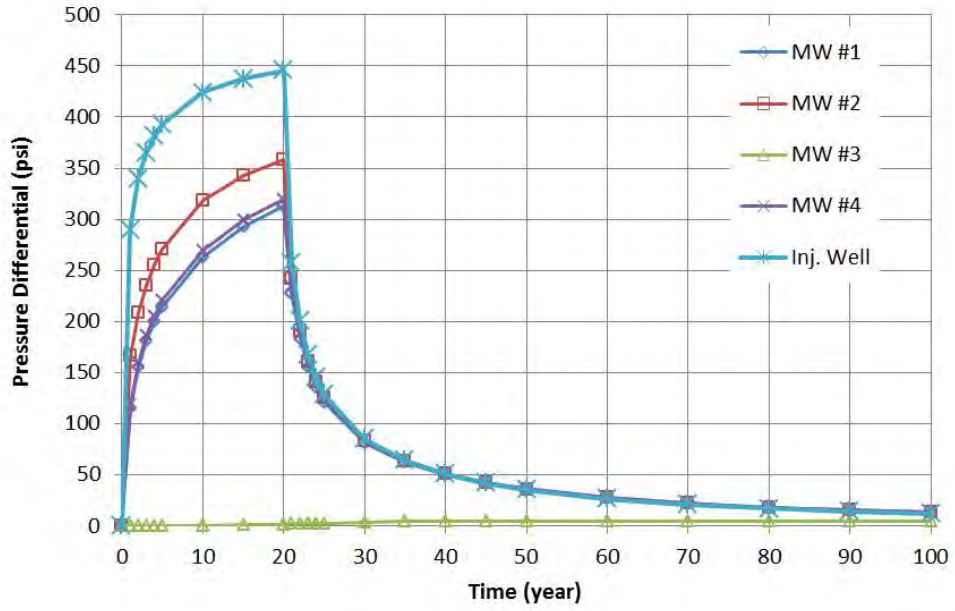

Figure 7.1. Simulated Pressure Differential Versus Time at Monitoring Well Locations

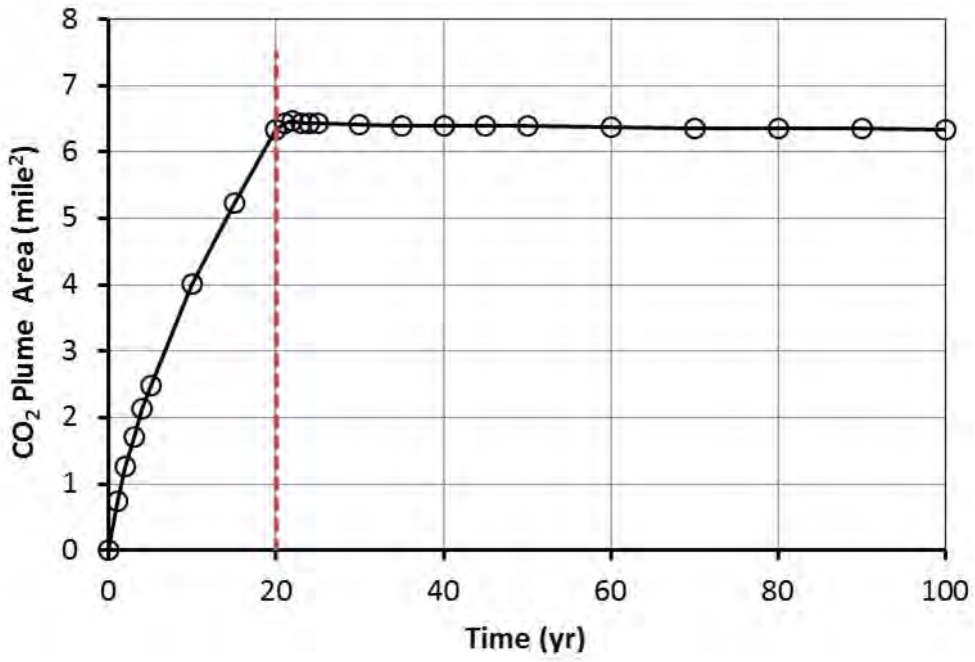

Figure 7.2. Simulated Plume Area over Time (the vertical dashed line denotes the time CO_2 injection ceases)

The physical trapping mechanisms that will facilitate the sequestration of the injected CO_2 are discussed in Section 3.1.2 in Chapter 3.0. No geochemical trapping mechanisms were modeled and such reactions are not expected to occur during the time frame of this project.

7.1.3 Predicted Extent of the CO_2 Plume at Site Closure

The predicted extent of the CO_2 plume at the time of site closure, 50 years after the cessation of CO_2 injection, was determined from the computational model results.

Figure 7.3 shows the predicted areal extent of the CO_2 plume (defined as 99.0 percent of the separate-phase CO_2 mass) at the time of site closure. The simulation predictions show that 99.0 percent of the separate-phase CO_2 mass would be contained within an area of 6.35 mi^2 at the time of site closure. This plume is only 1.7% smaller than the maximum plume area, which occurs at 22 years after the start of injection (Figure 7.2).

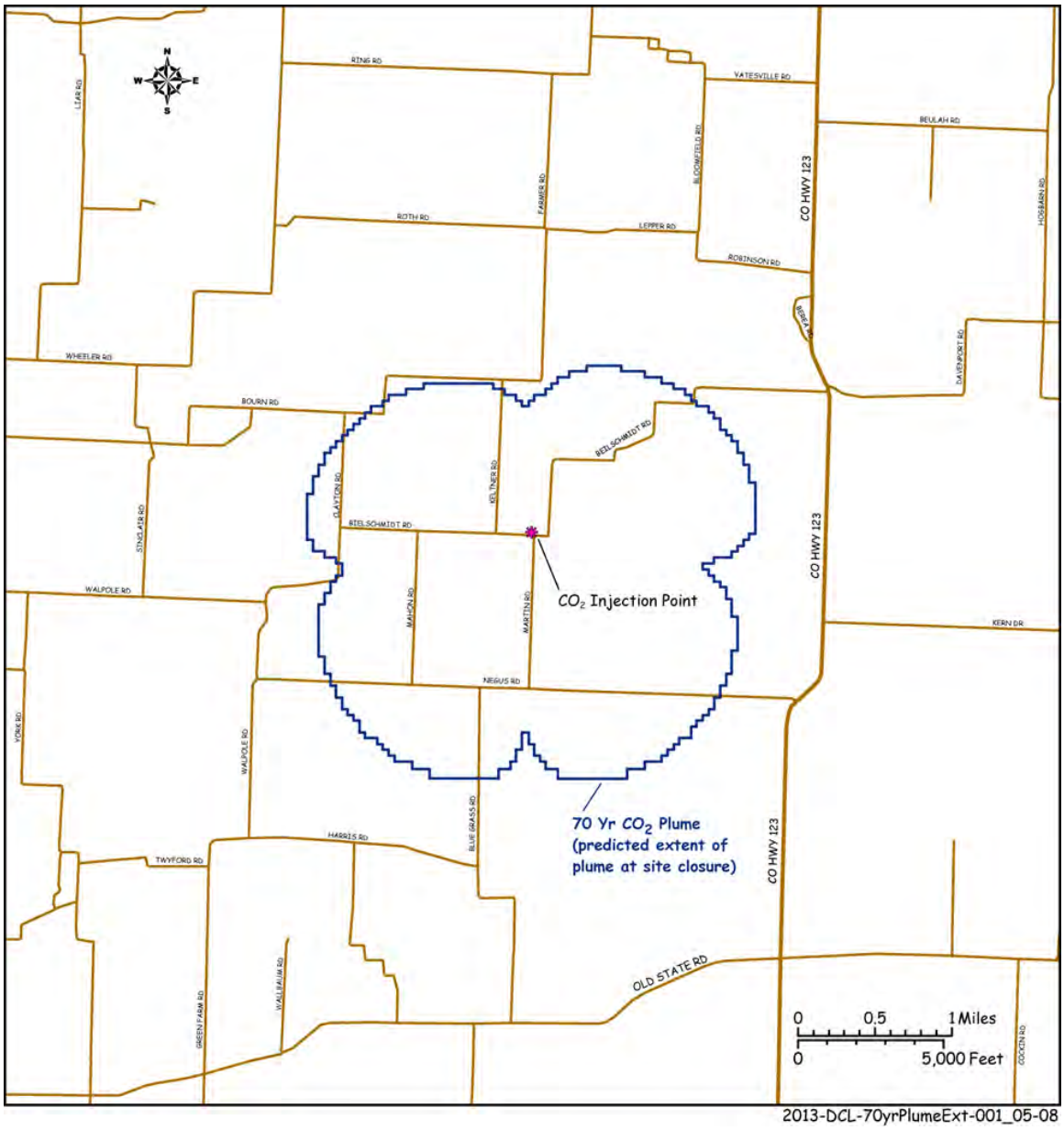

Figure 7.3. Simulated Areal Extent of the CO_2 Plume at the Time of Site Closure (70 years after CO_2 injection was initiated)

7.2 Post-Injection Monitoring Plan

Post-injection monitoring will include a combination of groundwater monitoring, storage zone pressure monitoring, and geophysical monitoring of the Morgan County CO_2 storage zone. The monitoring locations, methods, and schedule were designed to show the position of the CO_2 plume and pressure front and demonstrate that USDWs are not being endangered.

As shown in Section 7.1, lateral expansion of the CO_2 plume is projected to end at about year 22 (2 years after cessation of injection) and is relatively stable until the end of the simulation period (Figure 7.2). Pressure differentials (relative to pre-injection conditions) 25 years after cessation of injection (year 45) will decline by approximately 90 percent. The Alliance will continue to conduct monitoring as described in this plan for 50 years after cessation of CO_2 injection. Pursuant to 40 CFR 146.93((b)(2), however, the Alliance could propose a shorter post-injection site care monitoring period after injection ceases. Such a proposal would be made based on a demonstration to EPA that a shorter time period would be protective of USDWs.

7.2.1 Groundwater-Quality Monitoring

Groundwater monitoring will be conducted in a network of groundwater monitoring wells in the AoR during the post-injection site care period. Groundwater monitoring will include periodic sampling and analysis of water samples withdrawn from the wells. The groundwater samples will be analyzed for water quality and indicators of CO_2 movement into USDWs. The planned sampling frequency during the post-injection site care period will be every 5 years.

7.2.2 Carbon Dioxide Storage Zone and Pressure Monitoring

Carbon dioxide storage and pressure monitoring of the CO_2 storage zone will be conducted during the post-injection site care period with a combination of several injection zone monitoring wells and one ACZ early-detection monitoring well installed immediately above the primary confining zone. The objective of this monitoring is to detect CO_2 storage and pressure gradients, which may indicate potential for upward migration of brine with dissolved CO_2 into USDWs. As indicated in Figure 7.4 and described more fully in Chapter 5.0, Testing and Monitoring Plan, well installations will consist of four horizontal injection wells in the injection zone and an array of monitoring wells that includes injection zone, ACZ, and USDW monitoring:

- four injection wells, which will be plugged and abandoned after injection is stopped
- two single-level deep monitoring wells, which will be completed in the injection zone (one of these is the existing stratigraphic well)
- one multi-level completion located in close proximity to the injection wells, which will assess vertical anisotropy during subsequent site-characterization activities and monitor the vertical distribution of CO_2 within the injection zone
- one ACZ early-detection monitoring well, which will be installed within the first permeable interval above the confining zone. The ACZ monitoring well will be located near the injection well in the region of highest pressure buildup.
- one USDW monitoring well, which will be completed in the St. Peter Formation (the lowermost USDW) in proximity to the injection wells.

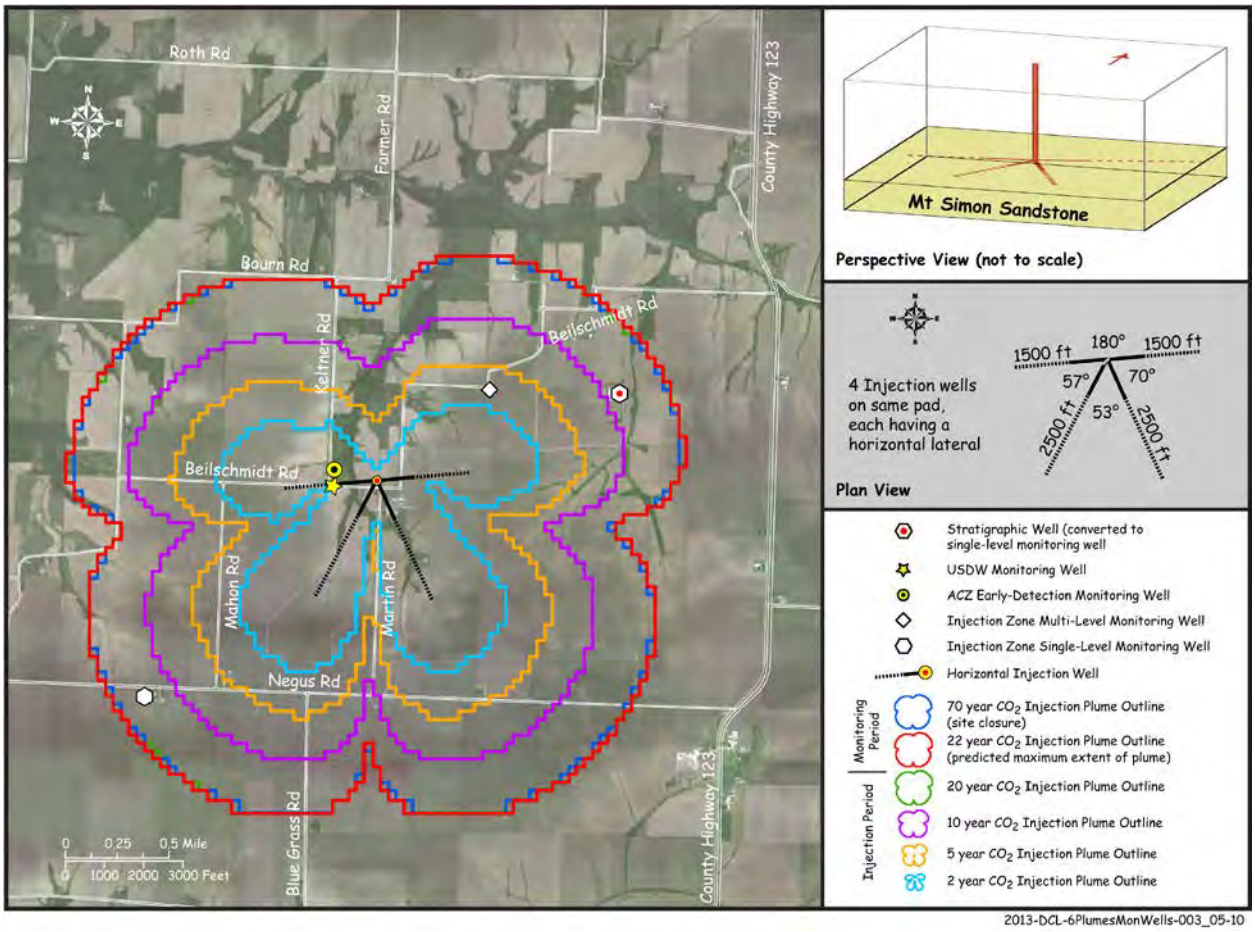

Figure 7.4. Layout of the Horizontal Injection Wells and the Monitoring Wells and the Predicted Plume Boundaries at Different Years.

Continuous monitoring of pressure and temperature will be performed with downhole pressure/temperature transducers installed in the monitoring wells that are completed in the injection zone and above the confining zone. Pressure and temperature monitoring will be recorded with the downhole memory gauges and downloaded on a periodic basis. The Mount Simon Formation multi-level monitoring well is designed to monitor multiple discrete depth zones within the Mount Simon Formation. This installation will use either a 1) dedicated multi-level monitoring system (e.g., a Westbay System) within a single casing string completed with multiple sampling intervals or 2) a multi-level piezometer installation. Similar to the injection wells, this well will be instrumented to provide continuous pressure data-logging capabilities. The pressure gauges will be removed from the monitoring wells only when necessary (e.g., for data downloads and/or maintenance).

7.2.3 Geophysical Monitoring for CO_2 Plume Tracking

As discussed in Chapter 5.0, the Alliance proposes to undertake several testing and monitoring activities. Planned monitoring activities, and additional monitoring activities under consideration, are summarized in Tables 5.1 and 5.2, respectively. At a minimum, at least one indirect geophysical monitoring technique will be carried forward through the operational phases of the project. Monitoring

approaches and methodologies will be evaluated and screened throughout the design and initial injection testing phase of the project to identify the most promising monitoring technologies under site-specific conditions. Using this screening process, the Alliance will conduct desktop studies to identify possible alternative testing and monitoring activities and will undertake field studies for those testing and monitoring alternatives that are found to be suitable.

7.2.4 Post-Injection Monitoring Locations, Methods, and Schedule

The post-injection monitoring locations, methods, and schedule are summarized in Table 7.2. Figure 7.4 shows the proposed well layout network. Final monitoring well locations will be determined during the site-characterization and construction phases. Overall, monitoring events will be scheduled every 5 to 10 years during the post-injection site care period. Groundwater quality will be monitored in the St. Peter Formation, which is designated as the lowermost USDW aquifer. As discussed previously, at least one indirect method will be used to monitor the CO_2 plume. Pressure monitoring will be performed in three deep monitoring wells and one ACZ well. Proposed monitoring methods are described in detail in Chapter 5.0

Table 7.2. Summary of Post-Injection Site Care Monitoring Schedule

Monitoring Method	Post-Injection Site Care Period
USDW Aquifer Monitoring	Every 5 years
Indirect Plume Monitoring	TBD
ACZ Pressure Differential Monitoring	Continuous
Injection Zone Pressure Differential Monitoring	Continuous

7.2.5 Reporting Schedule

During the post-injection site care period, monitoring reports will be prepared and submitted to the EPA Region 5 UIC office every 5 years. Post-injection site care monitoring reports will be submitted within 90 days of completion of field work associated with the monitoring event. The reports will summarize methods and results of the groundwater-quality monitoring, CO_2 storage zone pressure tracking, and indirect geophysical monitoring for CO_2 plume tracking. Monitoring reports will include appropriate sampling records, laboratory analysis, and field data.

7.2.6 Monitoring Plan Review and Maintenance

The post-injection site care monitoring plan will be reviewed prior to cessation of injection operations. Monitoring and operational results will be reviewed for adequacy in relation to objectives of the post-injection site care monitoring. The monitoring locations, methods, and schedule will be analyzed in relation to the size of the CO_2 storage zone, pressure front, and protection of USDWs. If the post-injection site care plan changes, a modified plan will be submitted to the EPA Region 5 UIC Branch for approval within 30 days of implementing the changes in the field.

The post-injection site care plan will be reviewed every 5 years during the post-injection site care period. Results of the plan review will be included in the post-injection site care monitoring reports. Monitoring and operational results will be reviewed for adequacy in relation to the objectives of post-injection site care monitoring. The monitoring locations, methods, and schedule will be analyzed in

relation to the size of the CO_2 storage zone, pressure front, and protection of USDWs. In case of change to the post-injection site care plan, a modified plan will be submitted to the EPA Region 5 UIC Branch for approval within 30 days of making of the changes.

7.3 Site Closure Plan

Site closure will occur at the end of the post-injection site care period. Site closure activities will include decommissioning surface equipment, plugging monitoring wells, restoring the site, and preparing and submitting site closure reports. The EPA Region 5 UIC Branch will be notified at least 120 days before site closure. A revised site closure plan will be submitted if any changes have been made to the original site closure plan. After site closure is authorized, site closure field activities will be completed.

7.3.1 Surface Equipment Decommissioning

Surface equipment decommissioning will occur in two phases: the first phase will occur after the active injection phase, and the second phase will occur at the end of post-injection site care phase. The surface facilities at the storage site will include the Site Control Building and the WAPMMS (Well Annular Pressure Maintenance and Monitoring System) Building.

At the end of the active injection period, plume monitoring will continue, but there will be no further need for the pumping and control equipment. The Site Control Building will be demolished. All features will be removed except the WAPMMS Building, a 12-ft-wide access road with five parking spaces, a concrete sidewalk from the parking lot to the building, underground electrical and telephone services, and a chain-link fence surrounding the building. The common wall between the WAPMMS Building and the Site Control Building will be converted to an exterior wall. The injection wells will be plugged and capped below grade (see Chapter 6.0). The gravel pad will be removed. The WAPMMS Building at the storage site will be repurposed to act as the collection node for data from the plume monitoring equipment. The building will contain equipment to receive real-time data from the monitoring wells and other monitoring stations and send the data via an internet connection to be analyzed offsite during the 50-year post-injection monitoring period.

All surface facilities will be removed at the end of the post-injection site care phase. These facilities will include the WAPMMS Building, the access road with parking spaces, all sidewalks, underground electrical and telephone services, and fencing at the injection well sites. The site will be reclaimed to and returned to pre-development condition.

7.3.2 Monitoring Well Plugging

Upon site closure, all monitoring wells will be plugged and capped below grade in a manner similar to that described in Chapter 6.0, Injection Well Plugging Plan, for the injection wells. All deep monitoring wells at the site will be plugged to prevent any upward migration of the CO_2 or formation fluids to USDWs. Each of the deep monitoring wells will be plugged and abandoned using best practices to prevent and communication of fluids between the injection zone and the USDWs. The deep monitoring wells in the injection interval have a direct connection between the injection formation and ground surface. The well-plugging program will be designed to prevent communication between the injection zone and the USDWs.

Before the wells are plugged, the internal and external integrity of the wells will be confirmed by conducting cement-bond, temperature, and noise logs on each of the wells. In addition, a pressure fall-off test will be performed above the perforated intervals (where present) to confirm well integrity. The results of the logging and testing will be reviewed and approved by appropriate regulatory agencies prior to plugging the wells.

The wells with perforations (the injection zone monitoring wells and the ACZ monitoring wells) will be plugged using a CO_2-resistant cement retainer method to cement the perforated intervals and a balanced plug method to cement the well above the perforated zones and the cement retainer. The seismic monitoring well will not have perforations; therefore, only the balanced plug method will be used to plug these wells. Once the interior of the casing has been properly plugged with cement, the casing will be cut off below ground and capped. Regulations at the time of the plugging and abandonment will dictate the specifications regarding the depth at which the casing is cut and the method used to cap the well.

7.3.3 Site Restoration/Remedial Activities

After the active injection phase, surface areas of the storage site will be reclaimed and returned to pre-development condition. All gravel pads, access roads, and surface facilities will be removed, and the land will be reclaimed for agricultural or other pre-development uses.

At the end of the post-injection site care phase, all remaining surface facilities will be removed, including all remaining buildings, access roads and parking areas, sidewalks, underground electric and telecommunication facilities, and fencing. The land will be reclaimed for agricultural or other pre-development uses.

7.3.4 Site Closure Reporting

A site closure report will be submitted to the EPA Region 5 UIC Branch within 90 days of site closure. The site closure report will include the following information:

- documentation of appropriate well plugging, including a survey plat of the injection well location
- documentation of the well-plugging report to Illinois and local agencies that have authority over drilling activities at the facility site
- records reflecting the nature, composition, and volume of the CO_2 injected in UIC wells.

In association with site closure, a record of notation on the facility property deed will be added to provide any potential purchaser of the property with the following information:

- notification that the subsurface is used for CO_2 storage
- the name of the Illinois and local agencies and the EPA Region 5 Office to which the survey plat was submitted
- the volume of fluid injected, the injection zone, and the period over which injection occurred.

Post-injection site care and site closure records will be retained for 10 years after site closure. At the conclusion of this 10-year period, these records will be delivered to the EPA Region 5 UIC Branch for further storage.

7.4 References

40 CFR 146.93. Code of Federal Regulations, Title 40, *Protection of Environment*, Part 146, "Underground Injection Control Program: Criteria and Standards." Section 93, "Post-injection site care and site closure."

EPA (U.S. Environmental Protection Agency). 2011. *Draft Underground Injection Control (UIC) Program Class VI Well Project Plan Development Guidance for Owners and Operators*. EPA 816-D-10-012, Office of Water (4606M), Washington, D.C.

EPA (U.S. Environmental Protection Agency). 2010. *Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells Final Rule* (40 CFR 146.93). Washington, D.C.