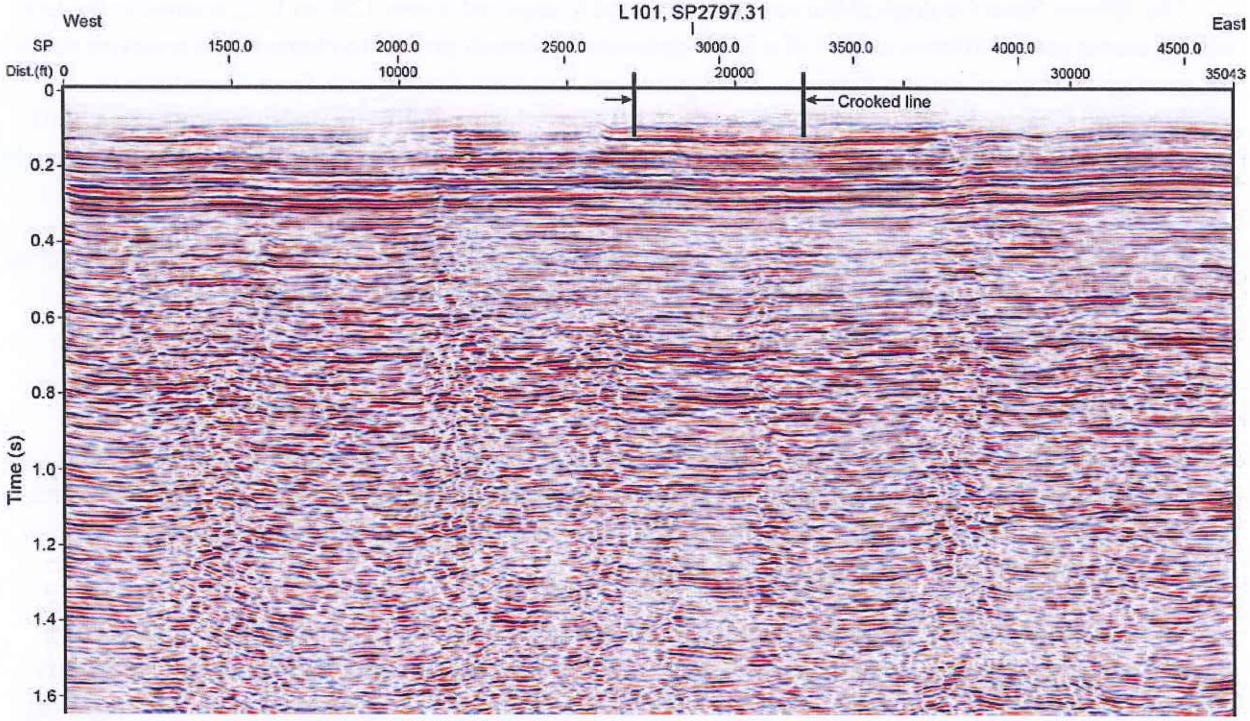

Figure 2.15. Reprocessed West-East 2D Seismic Line L201. Distance along horizontal axis is in feet and time (two-way travel time) along vertical axis is in seconds.

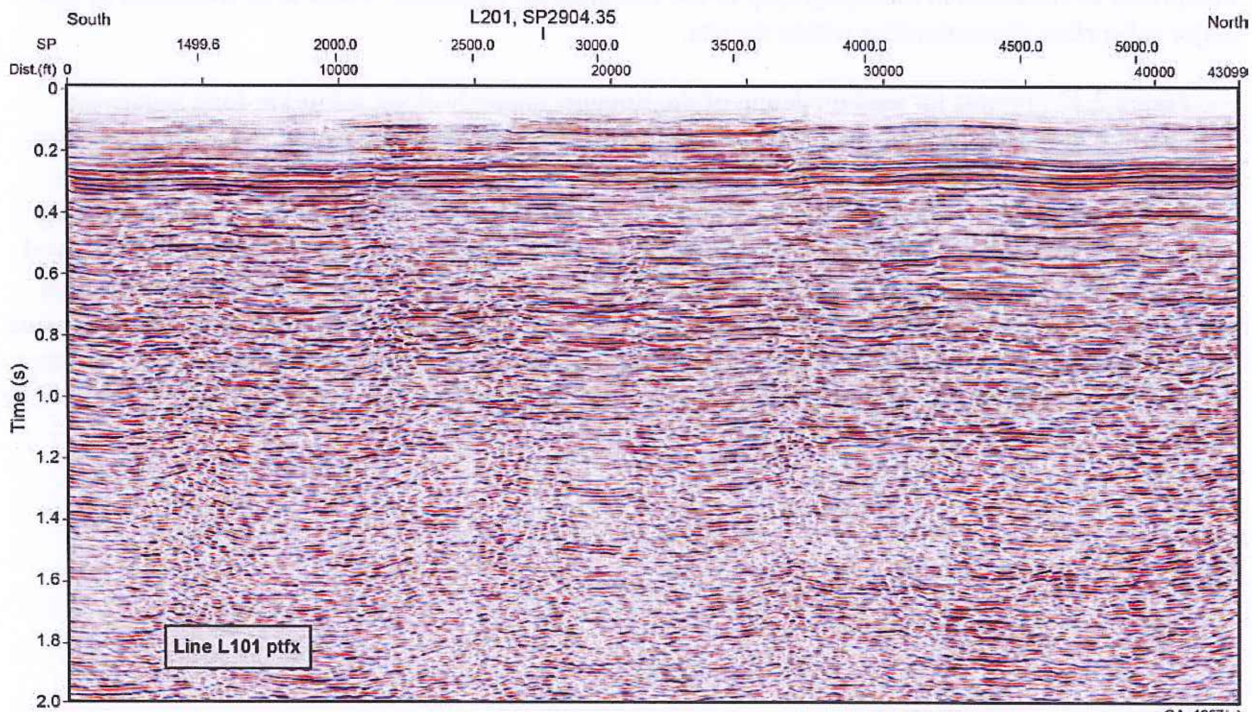

Figure 2.16. Reprocessed South-North 2D Seismic Line L101. Distance along horizontal axis is in feet and time (two-way travel time) along vertical axis is in seconds.

The Illinois State Geological Survey (ISGS) recently acquired a new 120-mi long seismic reflection survey across central Illinois as part of a DOE-sponsored research project to characterize reservoir rocks for geologic storage of carbon dioxide. The continuous east-west line extends from Meredosia to southwestern Champaign County (Figure 2.14). This line, which is currently under re-processing, will supply additional information about the structure of the sedimentary layers which will be correlated to the observations made on both profiles L101 and L201.

Future efforts at Morgan County will also include the acquisition of vertical seismic profiling data in the stratigraphic well to better evaluate the cause of the vertical disruptions in seismic reflections observed on the two existing seismic profiles.

2.3.1.2 Gravity Data

A site-specific surface gravity survey was conducted in November 2011, including 240 regularly spaced stations within a 2-mi by 2-mi area that covers the stratigraphic well site and the proposed storage site (Figure 2.17 and Figure 2.18). This survey will serve as a baseline for time-lapse gravity observations made after the beginning of the injection.

The survey results have a good correlation with the regional gravity maps of Daniels et al. (2008). Located at a minimum between two large-scale 15-mGal positive anomalies, the survey measurements complete the regional survey and allow a better definition of the short wavelength content of the gravity signal above the FutureGen storage site (Figure 2.18). At the scale of the survey, the Bouguer anomaly presents several small undulations (1,000–2,000 m in wavelength and 1–2 mGal in amplitude) that can be interpreted as variations in the topography of the Precambrian basement. There is no indication of any major subsurface discontinuities within the site.

Figure 2.19 presents forward modeling of the Bouguer anomaly along a 250-km-long southwest-northeast (W-SW to E-NE) profile passing through the deepest wells of the region. The observed short wavelength anomalies are well explained by variations in the basement topography (d = 2.70 g/cm^3) overlaid by a less dense Mount Simon Sandstone (d = 2.46); background density being 2.67. The long wavelength anomalies are linked to deep denser mafic intrusions (d = 2.80) in the basement as observed in other parts of the Illinois Basin and confirmed by the observed magnetic anomalies (not represented here). Other interpretations could also be valid but this one makes the most of sense especially when one looks at the importance of this phenomenon at the regional scale. Note the thickening of Mount Simon to the east of the stratigraphic well, which is compatible with the growth fault identified on the L100 seismic profile.

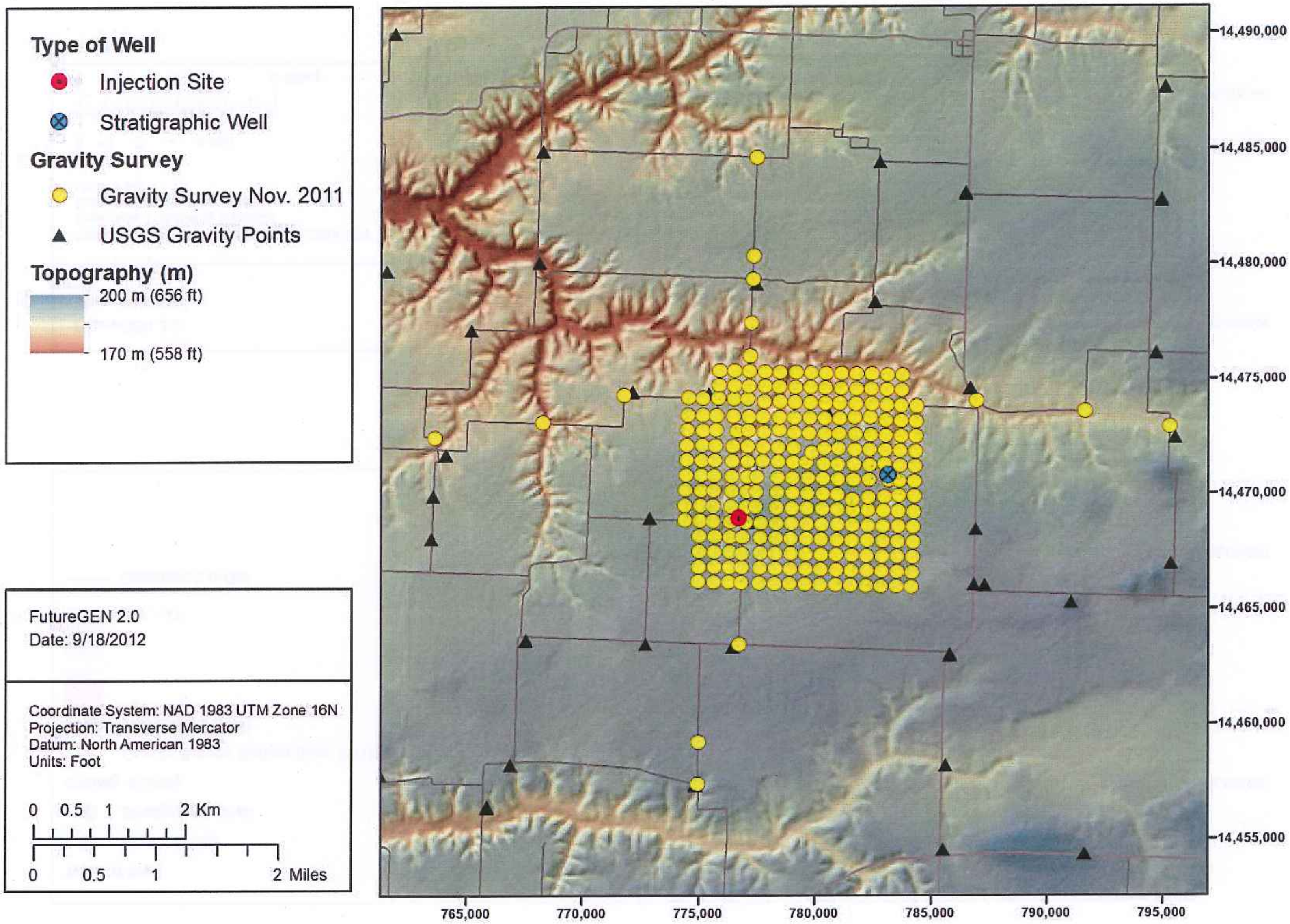

Figure 2.17. Gravity and GPS Stations for the 2011 Survey. Black triangles represent existing USGS gravity stations.

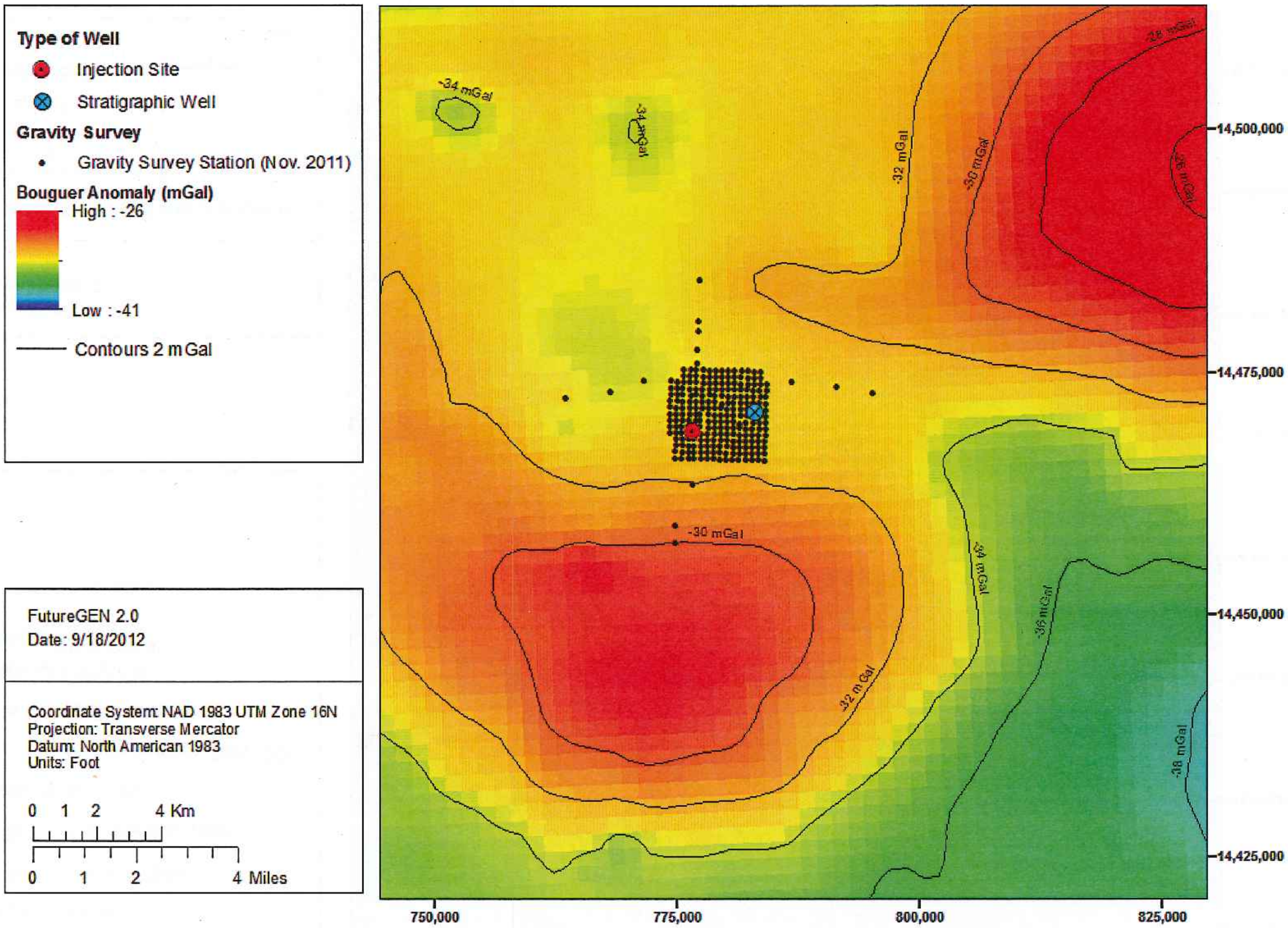

Figure 2.18. Overlay of Local Bouguer Gravity with USGS Regional Survey (regional survey data from Daniels et al. 2008).

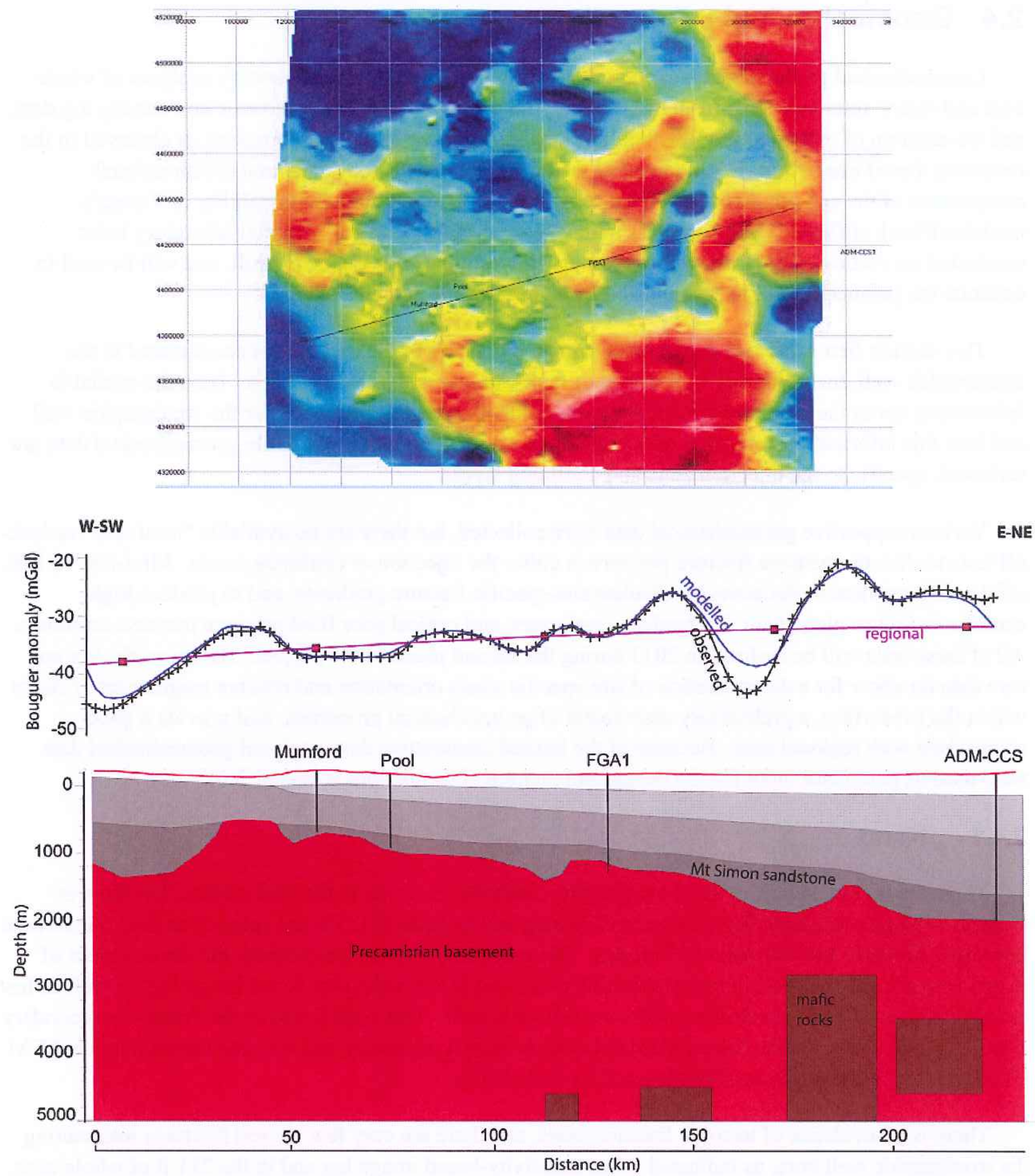

Figure 2.19. Regional WE Bouguer Anomaly Profile. Bottom: modeled depth cross section with Precambrian basement in red and Paleozoic rocks in grays. Middle: Bouguer anomaly in milliGals (black line = observed; blue line = modeled; pink = regional). Top: Bouguer anomaly map with location of the profile and of the deepest wells used to constrain the modeling.

2.4 Geomechanical Information

Geomechanical properties discussed in this section are derived from laboratory analyses of whole core and rotary side-wall cores from the stratigraphic well, as well as from acoustic and density log data, and the azimuth of open fractures, drilling-induced fractures, and well-bore breakout as observed in the resistivity-based image log. Geomechanical well logs, computed from shear and compressional components of the crossed dipole sonic log, provide information about the variability of Young's modulus ("rock stiffness") and Poisson's ratio ("rock compressibility"). Triaxial laboratory tests, conducted on vertical plugs from whole core, provide estimates for elastic moduli, and will be used to calibrate the geomechanical logs calculated from the wireline geophysical logs.

This section first addresses general mechanical properties of the rock layers encountered in the stratigraphic well, including any indications of faults, fractures, fissures, or karst. Next the available information about the stress tensors, or the nature of earth stress, is discussed for the stratigraphic well and how this information compares with regional stresses. Finally, the available geomechanical data are reviewed, specific to the injection zone and confining layers.

Various supportive geomechanical data were collected, but there are no available "mini-frac" or leak-off tests to directly measure fracture pressure in either the injection or confining zones. Mini-frac or leak-off data are required to definitively calculate site-specific fracture gradients, and to produce high-confidence failure plots, fault slip tendency estimates, and critical pore fluid pressure increase estimates. All of these tests will be realized in 2013 during the second phase of the project. However, the log and core data do allow for a determination of site-specific stress orientation and relative magnitudes of stress within the subsurface, a preliminary assessment of geomechanical properties, and provide a good comparison with regional data. Because of the limited quantitative data, regional geomechanical data were used as parameter input for the design and numerical simulations (Chapter 3.0).

2.4.1 Karst

There are no indications of karst topography, sinkholes, or voids in the near surface, but there is evidence of Knox-age karst features (sensu Freiburg and Leetaru 2012) in the subsurface Potosi Dolomite between 2,839 and 3,074 ft (865–937 m) bgs. The paleokarst expression includes the development of vuggy porosity, as observed in rotary side-wall cores and in the resistivity-based image log, as well as lost circulation zones during the drilling of the stratigraphic well. This zone is above the Franconia secondary confining layer. The buried Knox paleokarst zone is known regionally and was encountered in the ADM CCS wells at Decatur, Illinois (Freiburg and Leetaru 2012).

There is no evidence of tectonic fracture zones, and there are very few natural fractures intersecting the stratigraphic well bore, as indicated in the resistivity-based image log and in the 211 ft of whole core. The azimuth of the maximum horizontal stress in the stratigraphic well, as indicated by the azimuth of the dipole sonic fast shear wave, and by the azimuth of the sparse natural fractures detected by image logs, is N79.9°E, over the entire sedimentary interval, as logged from 4,416 (1,346 m) to 596 ft (182 m) bgs. Natural fractures that are parallel to the maximum horizontal stress are more likely to be transmissive (Streit and Hillis 2004).

2.4.2 Local Crustal Stress Conditions

Geomechanical analysis of sonic and density log data from the stratigraphic well, together with analysis of natural fractures, drilling-induced fractures, and well-bore breakout as observed in the resistivity-based image log (Schlumberger's Formation Microimager log) allow a partial determination of earth stress conditions within the well bore. A summary of the findings is as follows: the azimuth of the maximum horizontal stress (S_{hmax}) is N 79.9°E and has a much larger magnitude than the minimum horizontal stress (S_{hmin}). The lithostatic (vertical or Sv) stress is larger than S_{hmin} in both injection zones and confining layers indicating that the stress regime is not inverse. However in the absence of quantitative estimate of S_{hmax}, it is not possible to state whether Sv is greater than S_{hmax} (normal stress regime) or not (strike-slip stress regime). Uncalibrated geomechanical stress properties logs were calculated from the density log and the compressional and shear wave sonic log data. These geomechanical logs indicate there is strong stress anisotropy. These uncalibrated geomechanical logs will later have been calibrated over the cored interval with six triaxial core-plug tests. There are no indications of faults or tectonic fracture zones within the injection zone or in the primary or secondary confining zones, and the normal stress regime appears to be valid for the entire sedimentary logged interval from 4,416 (1,346 m) to 596 ft (182 m). Details of the basic determination of the stress regime follow.

2.4.2.1 Determination of Vertical Stress S_v from Density Measurements

The magnitude of the vertical stress (S_v) can be represented by the weight of the overburden (i.e., lithostatic pressure) and can be calculated by integration of wireline log-derived rock densities from the surface to the depth of interest (Zoback et al. 2003). Where density log data are not available (depth <596 ft [182 m]), Zoback et al. (2003) are followed in assigning a density of 2,300 kg/m^3 for siltstones, shales, and sandstones (typical lithologies of the shallow Pennsylvanian section at the site). The overburden gradient, calculated from these data is 1.1 psi/ft. Lithostatic pressures (S_v) at the top of the reservoir (base of primary confining zone), top of primary confining zone, and at the top and base of the secondary seals are shown in Table 2.8.

Table 2.8. Lithostatic Pressure at Important Interfaces

Unit	MPa	psi
Top of Franconia confining zone	3.36	3,388
Top of Ironton Saline Aquifer	25.34	3,675
Top of Proviso confining zone	26.15	3,792
Top of Elmhurst reservoir	29.9	4,249

2.4.2.2 Maximum and Minimum Horizontal Stress Azimuth from Resistivity-Based Image Logs

In vertical wells, the occurrence of breakout or tensile fractures usually implies that S_{hmin} is the minimum principal stress and that there are large differences between the two horizontal stresses S_{Hmax} and S_{hmin}. The azimuths of the maximum and minimum horizontal stresses are indicated by the azimuth of the induced tensile fractures and the borehole breakout, respectively (Zoback et al. 2003).

Both well-bore breakouts and tensile fractures are present in the borehole image logs. The calculated azimuth of borehole breakout minimum horizontal stress (S_{hmin}) is 169.9°N; the azimuth of maximum horizontal stress (S_{Hmax}) is 79.9°N. The azimuth of maximal horizontal stress (S_{Hmax}) in the stratigraphic well is consistent with regional stresses (Helmotz Centre Potsdam – GFZ 2012). However in the absence of quantitative determination of S_{Hmax}, it is impossible to state whether it is greater or not than Sv.

In summary, data from the stratigraphic well indicate that vertical lithostatic stress (S_v) is greater than the minimum horizontal stress (S_{hmin}). This indicates that the site is not in an inverse stress regime, and any undetected faults, if present, would be either normal or strike-slip faults (Table 2.9). The basic stress analysis data did not indicate any change in stress regime from the base of the Mount Simon to the top of the logged interval (4,416 [1,346 m] to 596 ft [182 m] bgs. Data are insufficient at this stage of analysis to be able to quantify the horizontal components of stress and thus distinguish between normal and strike-slip regimes.

Table 2.9. Relation of Principal Stresses to Fault Types (Zoback 2007)

	Stress		
Regime	S_1	S_2	S_3
Normal	S_v	S_{Hmax}	S_{hmin}
Strike-Slip	S_{Hmax}	S_v	S_{hmin}
Reverse	S_{Hmax}	S_{hmin}	S_v

2.4.3 Elastic Moduli and Fracture Gradient

The elastic moduli (or constants) include bulk modulus, Poisson's ratio, shear modulus, and Young's modulus, and characterize the properties of a rock that define how rock deforms when undergoing stress and how the rock recovers after the stress is released.

Fracture pressure is the pressure above which fluid injection will cause a formation to undergo brittle failure, i.e., to fracture hydraulically. Fracture-closing pressure is the pressure required to keep an existing fracture open, or to cause an existing fracture to widen. Fracture gradient is the pressure increase (change) per unit of depth that would initiate the onset of brittle rock failure.

Elastic moduli and fracture gradients were estimated from limited core analysis samples. Triaxial geomechanical tests were conducted on eight vertical core plugs from the cored intervals of the stratigraphic well. Table 2.10 lists the measured and calculated results of elastic moduli for the proposed injection zone and for the Precambrian basement. Table 2.11 shows the resulting calculated fracture gradients. For each table, samples 1 and 2 are from the Lombard member; samples 3 and 4 are from the Elmhurst; samples 5 and 6 are from the uppermost Mount Simon Sandstone; sample 7 is from the basal part of the Mount Simon, and sample 8 is from the Precambrian basement.

For comparison with regional data, Table 2.12 lists fracture gradients and elastic moduli determined for the Mount Simon at the ADM sequestration site at Decatur, Illinois, and at other Illinois Basin locations.

Table 2.10. Elastic Moduli Parameters from Triaxial Tests on Vertical Core Plugs in the Injection Interval and Precambrian Basement

Sample Number	Depth (ft)	Formation	Confining Pressure (psi)	Bulk Density (gm/cm^3)	Compressive Strength (psi)	Young's Modulus (10^6 psi)	Poisson's Ratio
1	3788.10	Lombard member	980	2.41	19,731	4.97	0.22
2	3802.80	Lombard member	1820	2.69	25,605	4.56	0.23
3	3867.90	Elmhurst member	890	2.25	9820	0.88	0.20
4	3887.30	Elmhurst member	750	2.28	7655	1.82	0.21
5	3929.10	Mt Simon SS.	770	2.42	18,076	2.89	0.23
6	3937.40	Mt Simon SS.	840	2.41	11,430	1.54	0.23
7	4401.90	Mt Simon SS.	1100	2.34	11,336	1.49	0.23
8	4434.50	Basement	1320	2.63	40,994	9.11	0.29

Table 2.11. Minimum Horizontal Stress and Fracture Gradient Calculated from Triaxial Tests (the red line represents the injection zone.)

Sample Number	Depth(ft)	Overburden Stress (psi)	Pore Pressure (psi)	Biot's Constant	Min. Horizontal Stress	Fracture Gradient (psi/ft)	Fracture Toughness (psi-in0.5)
1	3788.10	4167	1667	0.69	2533	0.669	1913
2	3802.80	4183	1673	0.70	2579	0.678	1836
3	3867.90	4255	1702	0.66	2502	0.647	802
4	3887.30	4276	1710	0.67	2560	0.659	1156
5	3929.10	4322	1729	0.71	2679	0.682	1464
6	3937.40	4331	1732	0.71	2682	0.681	1069
7	4401.90	4842	1937	0.70	2987	0.679	1050
8	4434.50	4878	1951	0.84	3301	0.744	2642

Table 2.12. Range of Geomechanical Properties (after EPA 2011, unless otherwise noted)

Hydrogeologic Unit	Fracture Gradient (psi/ft)	Young's Modulus (psi)	Poisson's Ratio	Bulk Modulus (psi)	Shear Modulus (psi)
Mount Simon Sandstone	0.57[(a)] to 0.715[(b)]	2.33-7.86E6[(c)]	0.17-0.36[(c)]	NA	NA

NA = Not available.
(a) EPA (1994).
(b) After EPA 2011 and 40 CFR 146.88.
(c) After Sminchak 2011.

2.4.3.1 Injection Zone Fracture Pressure

Geophysical logs from the stratigraphic well provide general estimates of geomechanical anisotropic elastic properties. Triaxial test data for log calibration are limited to six vertical plugs within the cored intervals, and validation of well-log and core data using mini-frac data or leak-off tests is still required to acquire accurate values for elastic parameters and fracture gradients. Fracture gradient (Table 2.11) ranges for the injection zone were calculated from 0.647 to 0.682 psi/ft. Although no step-rate injection tests or leak-off test data are currently available for the injection zone, these data will be obtained when the injection wells are drilled.

At the CCS#1 well at Decatur, about 65 mi east of the stratigraphic well, a fracture pressure gradient of 0.715 psi/ft was calculated for the base of the Mount Simon Sandstone formation using a step-rate injection test (EPA 2011). Additional comparison of regional fracture gradients is provided in the *Determination of Maximum Injection Pressure for Class I Wells in Region 5* (EPA 1994), which lists a default fracture gradient of 0.57 psi/ft for the Mount Simon Sandstone.

Based on these considerations, a pressure gradient of 0.65 psi/ft is suggested to model the injection-zone fracture gradient.

2.4.3.2 Confining Zone Fracture Pressure

Elastic moduli calculated from triaxial core tests on two vertical core samples from the lowermost Lombard member are presented in Table 2.13, and estimations of minimum horizontal stress and fracture gradient calculated from triaxial tests are presented in Table 2.14. Note that the lower Lombard has lithologies and rock properties that are transitional from the porous and permeable Elmhurst sandstones to lithologies and properties of the actual confining part of the upper Lombard. Thus, these moduli, stress estimates, and fracture gradients are not representative of the confining zone. Although no step-rate tests or leak-off tests are currently available for the primary confining zone in the stratigraphic well and no whole core is currently available from the Proviso member or from the upper part of the Lombard member, these data will be obtained when the injection wells are drilled.

Field analog data may be more representative of confining zone properties. The elastic moduli and fracture gradient for the Eau Claire confining zone at the CCS#1 well at Decatur, Illinois, are presented in Table 2.15.

Table 2.13. Elastic Moduli Parameters from Triaxial Tests of Core from the Lowermost Part of the Lombard Member

Depth (ft)	Member	Confining Pressure (psi)	Bulk Density (gm/cm^3)	Compressive Strength (psi)	Young's Modulus (10^6 psi)	Poisson's Ratio
3788.10	Lombard	980	2.41	19731	4.97	0.22
3802.80	Lombard	1820	2.69	25605	4.56	0.23

Table 2.14. Minimum Horizontal Stress and Fracture Gradient Calculated from Triaxial Tests

Sample Number	Depth(ft)	Overburden Stress (psi)	Pore Pressure (psi)	Biot's Constant	Minimum Horizontal Stress	Fracture Gradient (psi/ft)	Fracture Toughness (psi-in 0.5)
1	3788.10	4167	1667	0.69	2533	0.669	1913
2	3802.80	4183	1673	0.70	2579	0.678	1836

Table 2.15. Range of Eau Claire Geomechanical Properties in the CCS#1 Well, Decatur Illinois (after EPA 2011)

Hydrogeologic Unit	Fracture Gradient (psi/ft)	Young's Modulus (psi)	Poisson's Ratio	Bulk Modulus (psi)	Shear Modulus (psi)
Eau Claire Carbonate/Siltstone (Upper Unit-Proviso)	NA	NA	NA	NA	NA
Eau Claire Siltstone/Shale (Lower Unit 1)	0.93 to 0.98	5.5E6	0.27	3.92E6	2.17E6
NA = Not available.					

2.5 Seismic History of Region

In Illinois, most of the seismicity occurs in the southern and southeastern part of the state where two seismic zones (Wabash Valley and New Madrid) are found. Central Illinois is an area that has been historically low in earthquakes or seismicity (Figure 2.20). Statewide, the largest recorded earthquake (magnitude 5.4) occurred on April 18, 2008, in the southeastern part of the state; it caused minor structural damage. The closest known earthquake to the FutureGen 2.0 Project site (Intensity VII, magnitude 4.8 – non-instrumented record) occurred on July 19, 1909, approximately 28 mi (45 km) north of the site; it caused slight damage. Most of the events in Illinois occurred at depths greater than 3 km (1.9 mi) (Figure 2.20).

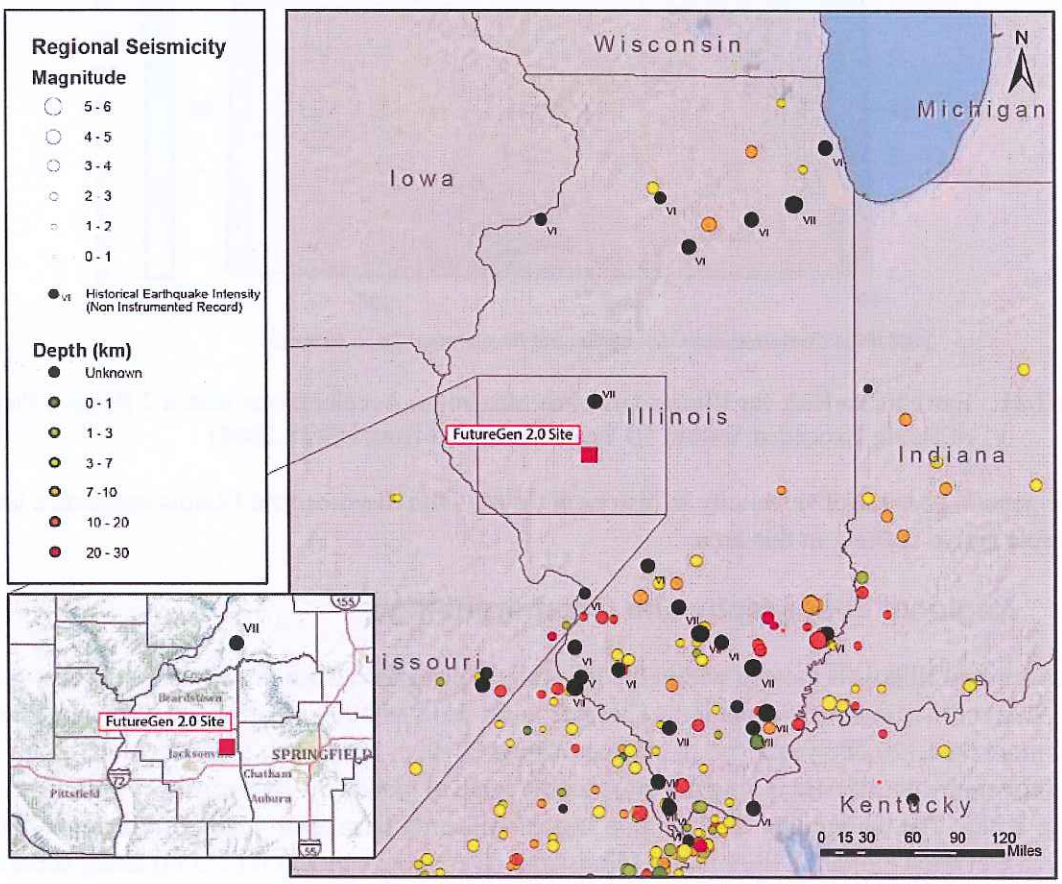

Figure 2.20. Regional Historic Earthquakes (data from USGS 2012a, b)

There is a 2 percent probability that the peak ground acceleration (G) due to seismic activity will exceed 9 percent G within 50 years (Figure 2.21; USGS 2008).

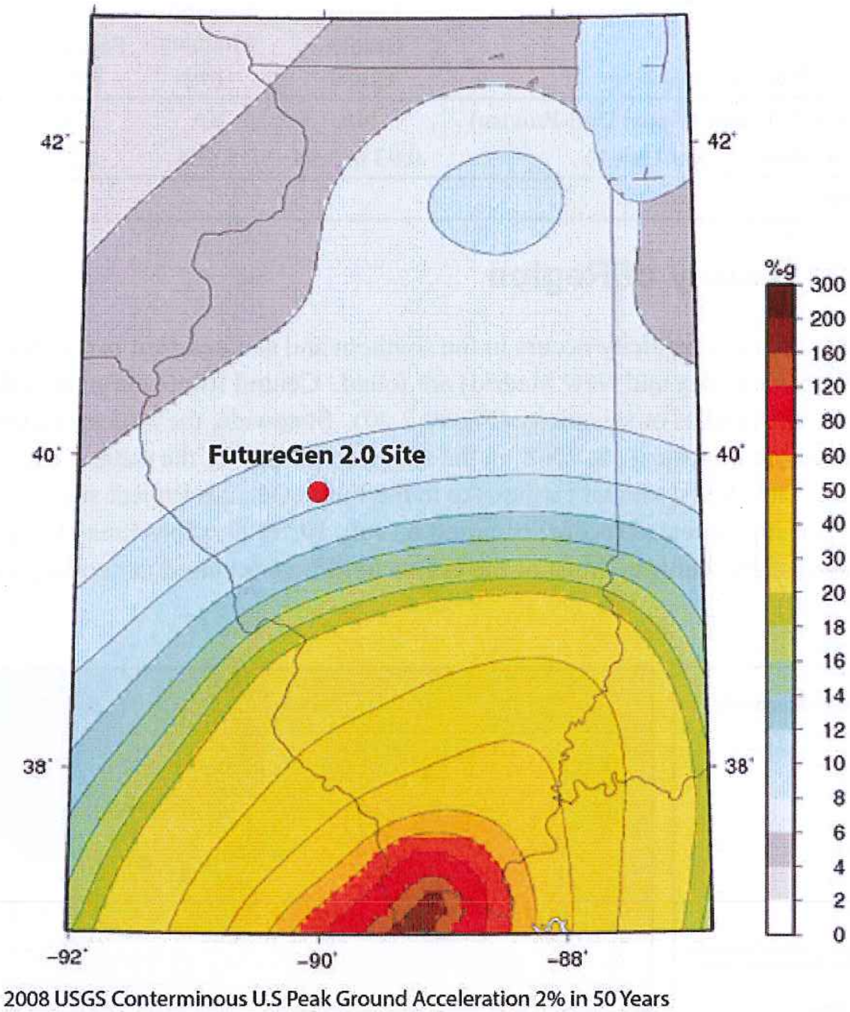

Figure 2.21. Earthquake Risk for Illinois Given as Maximum Accelerations with a 2 Percent Probability of Being Exceeded Within 50 Years (modified from USGS 2008)

The general absence of seismicity in historical times within west-central Illinois suggests a lack of appreciable active faulting in this area.

2.5.1 Regional Topography and Geomorphology

West-central Illinois is located within the low-relief Springfield Plain underlain by pre-last-glacial till (Figure 2.22) of the Glasford Formation. These deposits were laid down during the Illinoisan glacial episode more than 120,000 years ago (Kolata and Nimz 2010, p. 223). The Springfield Plain lies beyond the area covered with glaciers during the most recent cycle of glaciation (Wisconsin episode; green area in Figure 2.22). The topography of the region is predominantly farmlands ranging from about 400 ft (122 m) in elevation along the Illinois and Mississippi river valleys to 700 ft (213 m) along some drainage divides to the east.

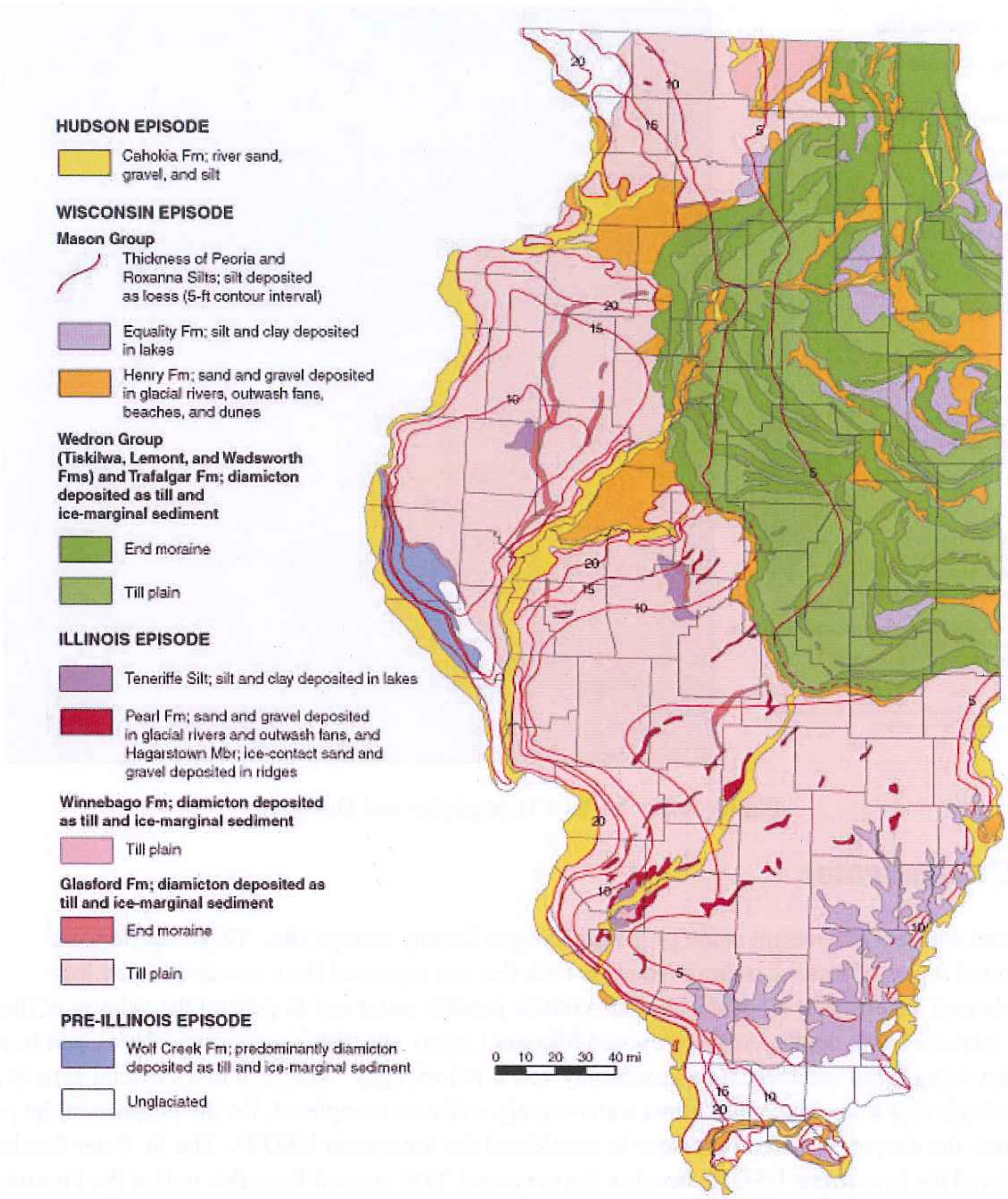

Figure 2.22. Surficial Quaternary Deposits of Illinois (modified from ISGS 2012d)

2.5.2 Site Surface Topography

The surface topography at the proposed Morgan County CO_2 storage site lies between 590 and 620 ft (180 and 189 m) above mean sea level (MSL). Surface drainage is to the north-northeast toward the Illinois River through Indian Creek, the nearest perennial stream (Figure 2.23). About 75 to 125 ft (23 to 38 m) of middle-to-early Pleistocene glacial drift and glaciolacustrine deposits (Glasford Formation) disconformably overlie the Pennsylvanian bedrock in the vicinity of the proposed CO_2 storage site (Figure 2.25 in Section 2.6.1). The uppermost bedrock consists of thinly bedded shale, siltstone, sandstone, limestone, and coal.

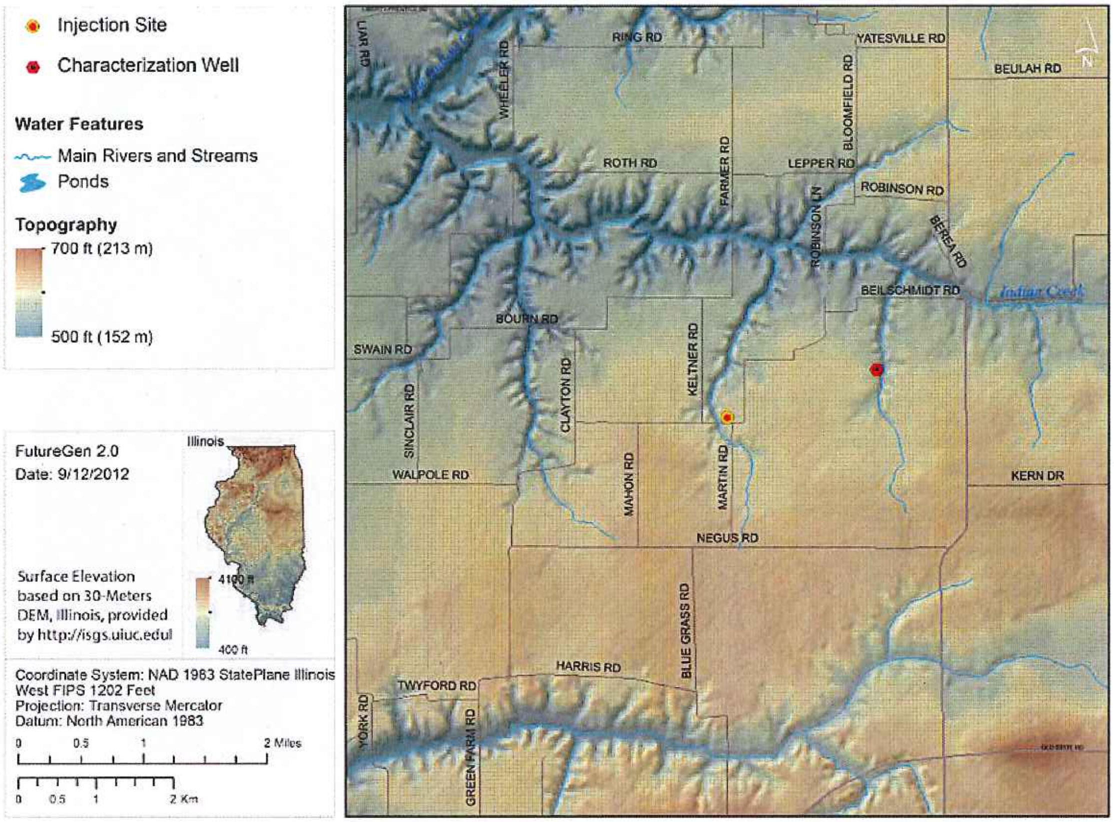

Figure 2.23. Surface Topography and Drainage

2.6 Groundwater

Several aquifers are present at the proposed Morgan County storage site. These aquifers are underground layers of water-bearing permeable rock that are separated from one another by less permeable rock layers. Not all of the aquifers contain potable water and in general the salinity of the aquifers increases with depth. At the proposed Morgan County site, drinking water is developed from the Quaternary-age glacial sediments (approximately 150 ft [46 m] bgs). Although this surficial zone is the hydrogeologic unit from which all known water-supply wells are completed, for the purpose of the permit application, the deeper St. Peter Sandstone is considered the lowermost USDW. The St. Peter Sandstone is considered the lowermost USDW, because the measured TDS content from this unit at the FutureGen stratigraphic well is 3,700 mg/L, which is below the regulatory upper limit of 10,000 mg/L for drinking water aquifers. A summary of both potable and nonpotable and brackish aquifers is presented below.

2.6.1 Surficial Aquifer System

Domestic, municipal, and agricultural water-supply wells in Morgan County typically do not exceed 100 ft (46 m) in depth, and only a few wells are deeper than 75 ft (23 m) bgs. All water-supply wells within a 20-mi^2 area are from the Quaternary glacially derived sediments that overlie Pennsylvanian bedrock (ISGS 2012b). While much of the Quaternary section consists of fine-grained, low-permeability clay and silt, lenses of glacial outwash sand and gravel are also locally present, particularly within paleo-stream valleys denoted by greater glacial drift thicknesses as shown in Figure 2.24. The variability of the different facies within the Quaternary sediments is illustrated in a cross section in Figure 2.25.

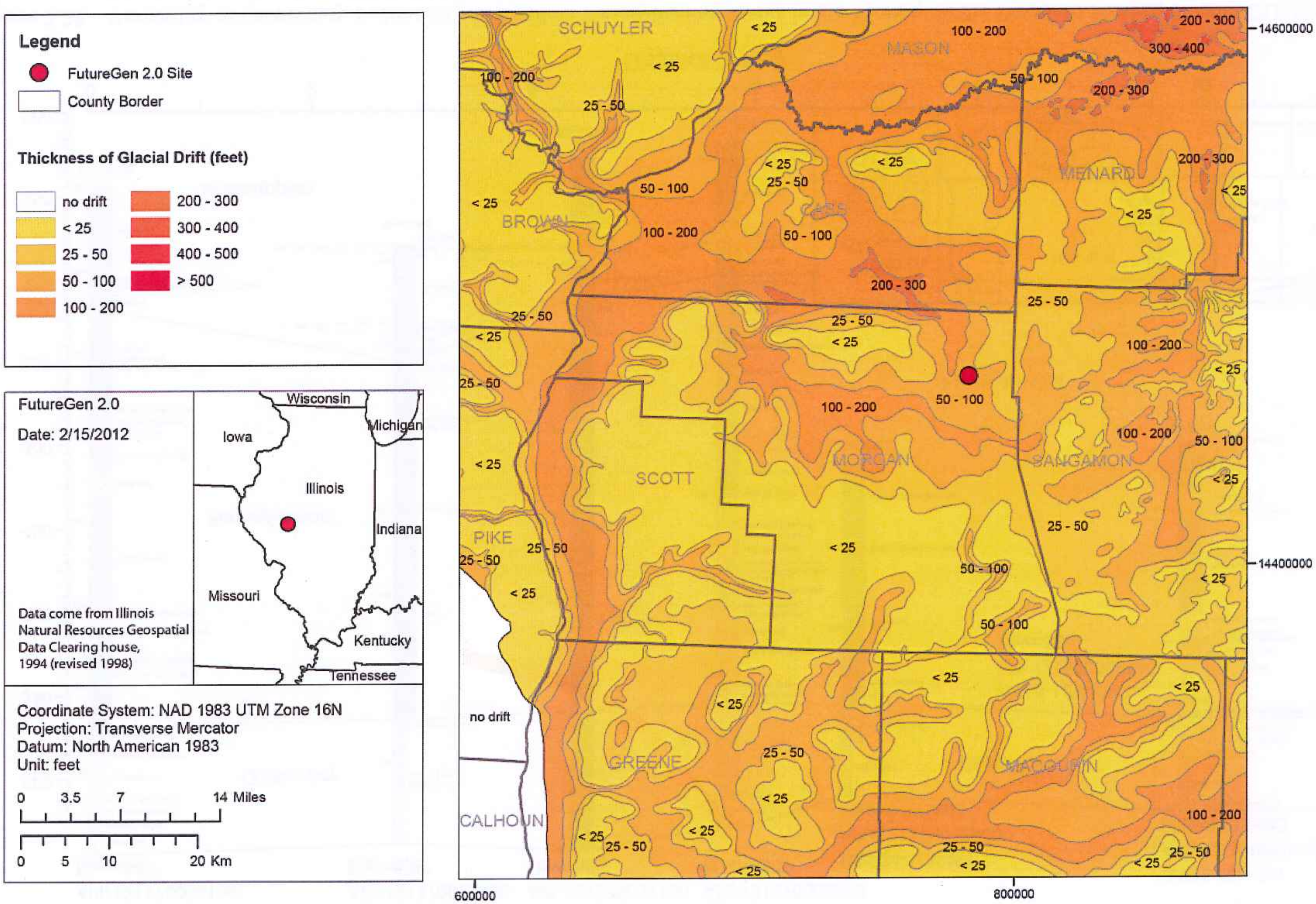

Figure 2.24. Thickness of Unconsolidated Pleistocene Glacial Drift in Morgan and Adjacent Counties (based on data from ISGS 2012b)

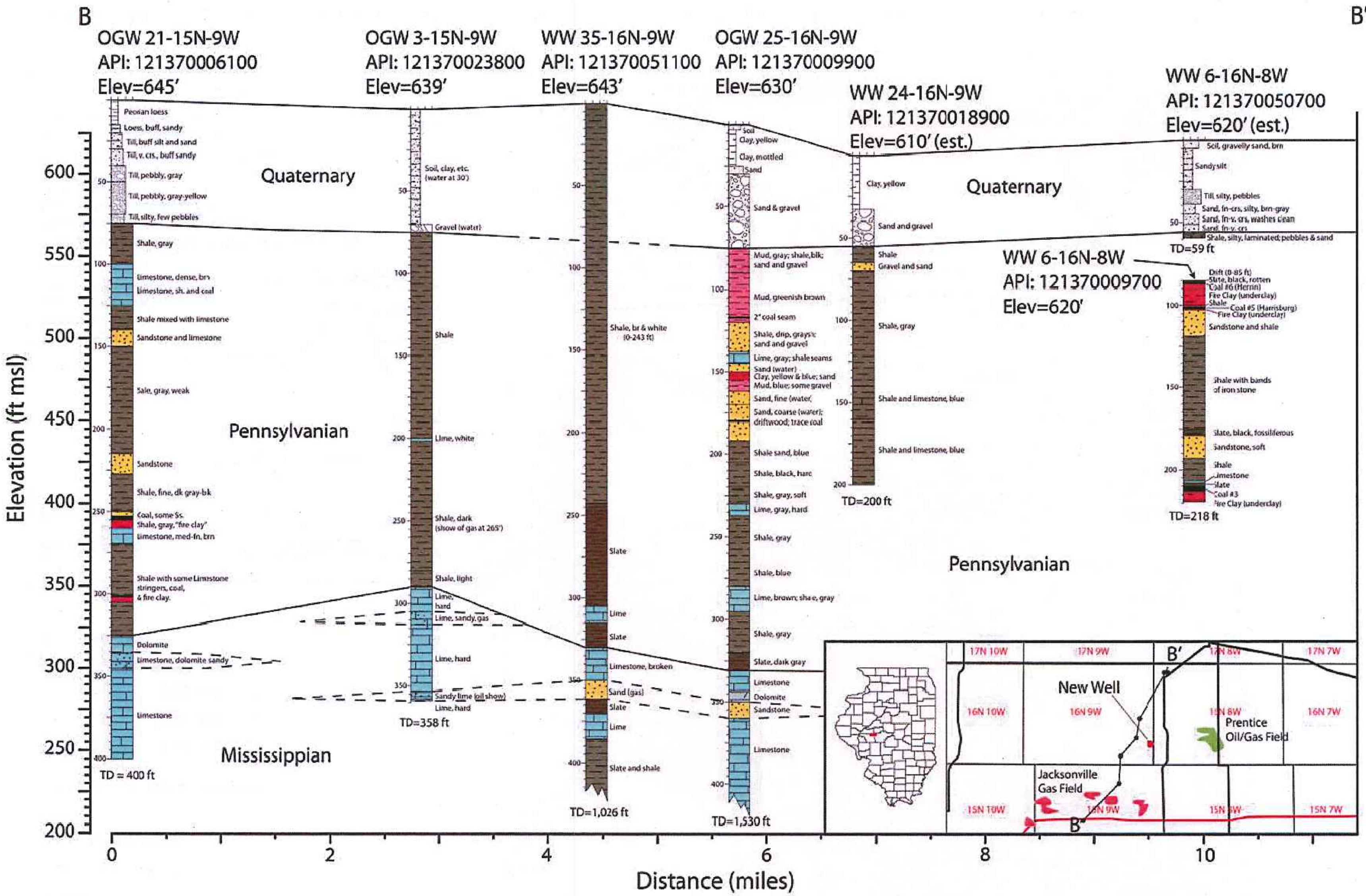

Figure 2.25. Variability of Quaternary Sediments and Shallow Pennsylvanian Rocks in the Vicinity of the Proposed Morgan County CO_2 Storage Site (based on data from ISGS 2011).

Detailed potentiometric surface maps and information about local groundwater flow direction are sparse for the shallow unconfined sand/gravel aquifer system at the Morgan County CO_2 storage site. However, groundwater flow within the shallow surficial aquifer is expected to conform to the local topography and discharge to local surficial drainages and surface bodies of water. Static water-level data available for water-supply wells in northwest Morgan County area indicate that water-table depth varies depending upon local topography and the seasonal variations in recharge and generally ranges between 5 to 30 ft (1.5 to 9 m) bgs (ISGS 2012c).

A shallow groundwater/well sampling investigation was performed in 2011 on 13 surrounding private/domestic water-supply wells within 1.5 mi (2.4 km) of the FutureGen stratigraphic well (FG1) location (Figure 2.26). All of the wells are shallow (14 to 47 ft [4 to 14 m] deep).

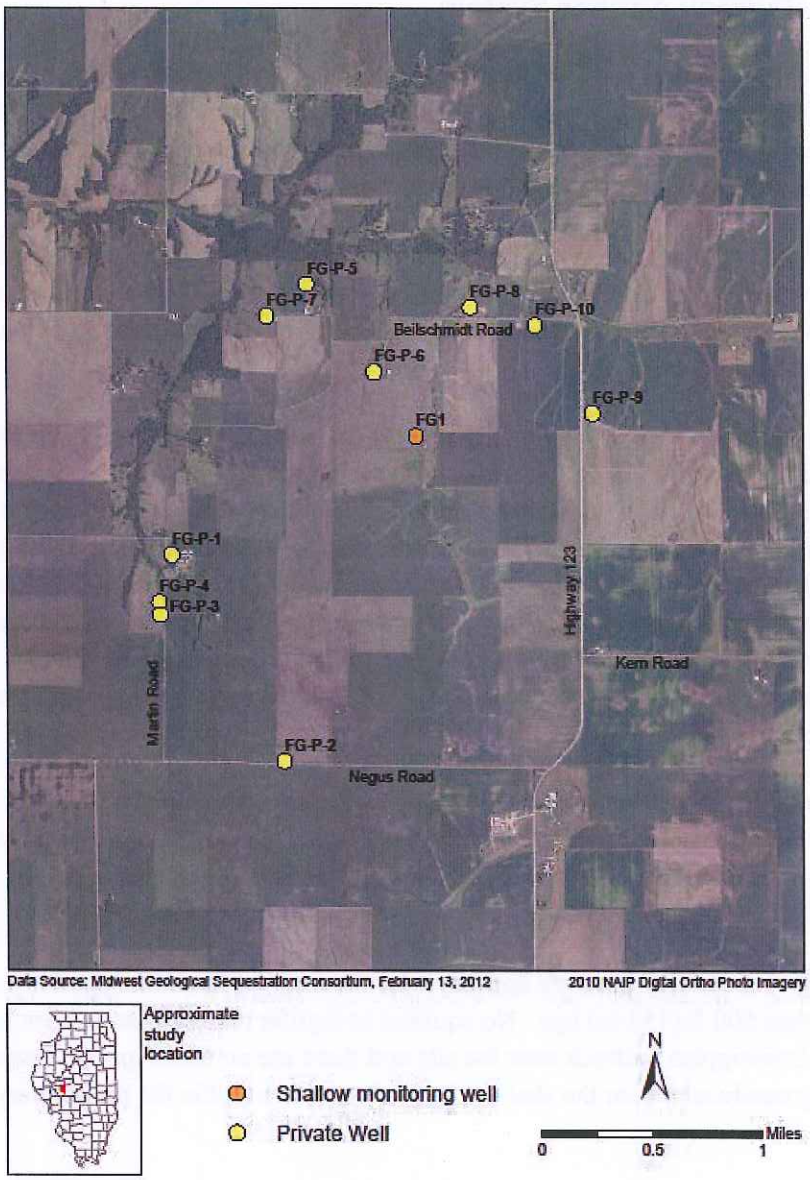

Figure 2.26. Locations of Private/Domestic Water Wells Within 1.5 Mi (2.4 Km) of the Stratigraphic Well (FG1; based on data from ISGS 2012c)

A total of 20 groundwater samples were collected between October 25 and November 10, 2011, including duplicate samples and blanks (Dey et al. in press). General water-quality parameters were measured along with organic and major inorganic constituents. Values of pH ranged from 7.08 to 7.66. Values for specific conductance ranged from 545 to 1,164 µS/cm, with an average of 773 µS/cm. Values of Eh ranged from 105 to 532 mV with an average of 411 mV. Values of dissolved oxygen (DO) ranged from below detection limit to 3.3 mg/L O_2.

Most dissolved inorganic constituent concentrations are within primary and secondary drinking water standards. However, the constituent concentration in water is elevated with respect to iron (Fe), manganese (Mn), nitrate (NO_3), and TDS. In some cases these constituents exceed the EPA secondary standards.

2.6.2 Upper-Bedrock Aquifer System

The shallow bedrock aquifers are discussed in descending stratigraphic order (i.e., youngest to oldest), and range from Pennsylvanian-aged bedrock units to the older Cambrian-aged Mount Simon Sandstone. The fluid salinity within these formations generally increases with depth and correspondingly their use as potential potable aquifers also diminishes.

Pennsylvanian-aged bedrock units (Kolata 2005) in Morgan County consist principally of shale with occasional sandstone lenses and do not offer potential as sources of groundwater except for the occurrence of discontinuous, thin beds of sandstone or fractured limestone that may yield small, domestic supplies (Woller and Sanderson 1979).

Mississippian-aged strata regionally dip to the east (Figure 2.27) at about 10 to 40 ft/mi in Morgan County (Woller and Sanderson 1979). The Salem and Burlington-Keokuk limestones are the principal, but relatively limited, Mississippian aquifers because their yield capacity depends on the abundance and interconnection of fractures and crevices within the rock that are intersected by the well (Woller and Sanderson 1979). The younger Salem Limestone occurs at a depth ranging from 175 to 650 ft (53 to 198 m) bgs in Morgan County and exhibits marginally adequate yields that become more saline with depth. Data from the Illinois State Water Survey (ISWS)[1] contain water-quality data for three bedrock wells in Morgan County. The TDS concentrations for the three Morgan County wells range from 3,894 to 10,420 mg/L.

A study conducted in 1978, found no water-supply wells were developed within the shallow bedrock aquifers in Morgan County (Woller and Sanderson 1979), although Pennsylvanian and Mississippian bedrock units were reported as water supplies for domestic use in Morgan and adjacent counties (Bergstrom and Zeizel 1957; Selkregg and Kempton 1958; Gibb and O'Hearn 1980).

Lack of primary or secondary porosity appears to be the limiting factor for aquifer development in bedrock shallower than 500 ft (152 m) bgs. No aquifers or aquifer materials have been identified in the Pennsylvanian or Mississippian bedrock near the site and there are no municipal or domestic water-supply wells that develop groundwater from the shallow bedrock aquifers within the preliminary AoR.

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[1] Obtained from the ISWS Online Database, http://www.isws.illinois.edu/data/gwdb, accessed in April 2011.

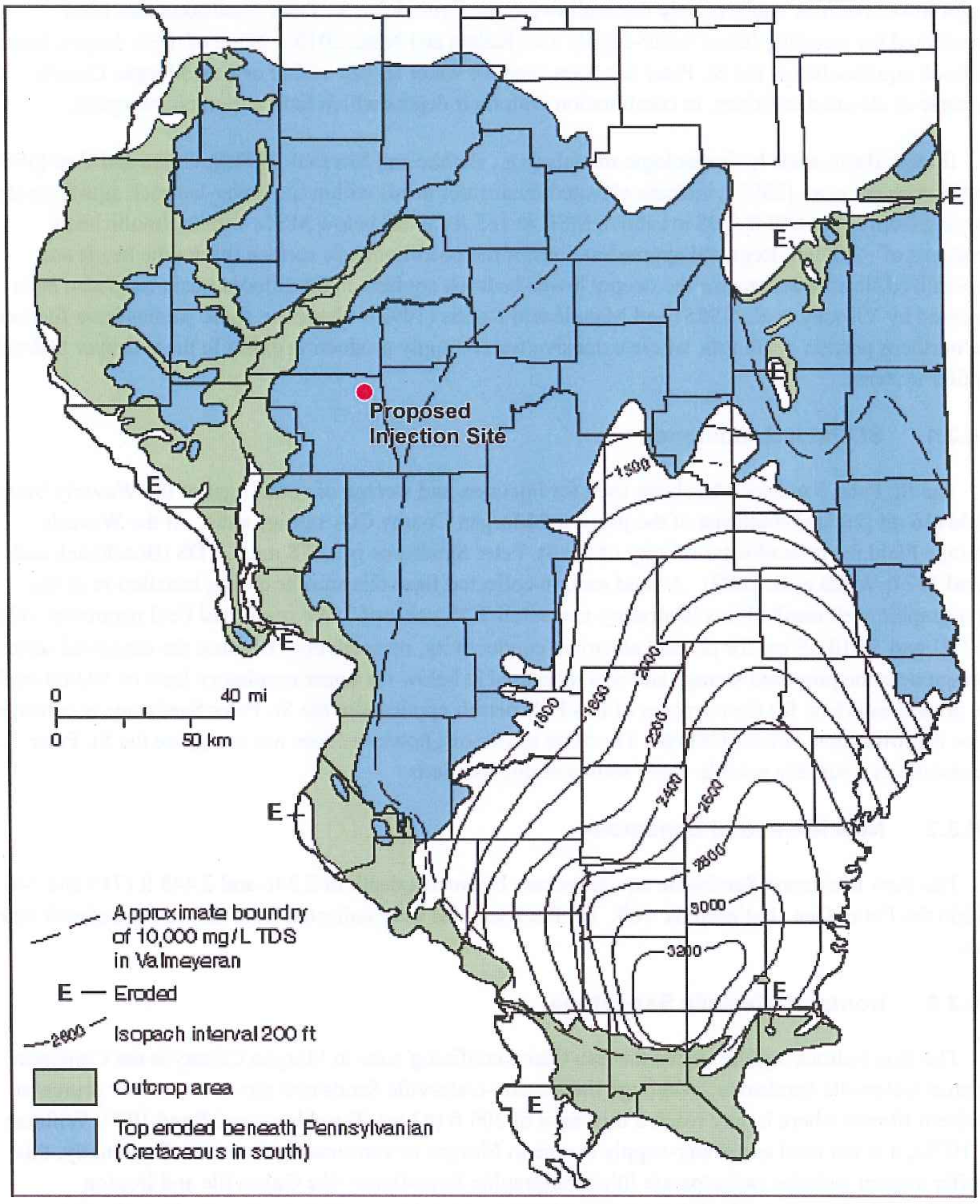

Figure 2.27. Thickness and Distribution of Mississippian Aquifers (after Willman et al. 1975) and the Boundary for 10,000 mg/L TDS in the Middle Mississippian Rocks

2.6.3 Lower-Bedrock Aquifer System

At least four, deep (>500 ft [>152 m]), aquifers are present beneath the proposed Morgan County CO_2 storage site. From youngest to oldest these are the Ordovician St. Peter, New Richmond, Cambrian Ironton-Galesville, and the Elmhurst/Mount Simon Sandstone intervals (see Figure 2.1). Of the four major lower-bedrock aquifers only the shallowest, the Ordovician St. Peter Sandstone, has been considered for possible, future water-supply use (Kolata and Nimz 2010). None of these deeper, lower-bedrock aquifers below the St. Peter has been used for water supply within or near Morgan County because of elevated salinities, in combination with their depths which limit economic pumping.

Illinois Basin-scale hydrogeologic models (e.g., Bethke and Marshak [1990], Gupta and Bair [1997], and Birkholzer et al. [2007]) indicate elevated freshwater heads within the lower-bedrock aquifer system varying from about 650 ft (198 m) above MSL to 165 ft (50 m) below MSL, with hydraulic head gradients of ~0.0003. Regional approximations of the potentiometric surface (hydraulic head) and generalized flow directions for the deeper lower-bedrock aquifers in the Illinois Basin have also been reported by Visocky et al. (1985) and Mandle and Kontis (1992). However, these studies have focused on the northern portion of Illinois, where extensive water-supply production exists in these deeper bedrock aquifer systems.

2.6.3.1 St. Peter Sandstone

The St. Peter Sandstone has been used for injection and storage of natural gas at the Waverly Storage Field (16 mi [26 km] southeast of the proposed Morgan County CO_2 storage site). At the Waverly Storage Field the groundwater salinity of the St. Peter Sandstone is 2,778 mg/L TDS (Buschbach and Bond 1974; Weiss et al. 2009). A fluid sample collected from this aquifer during installation of the stratigraphic well resulted in a laboratory-measured TDS value of 3,400 mg/L and field parameter values of 7.91 and 5,910 μS/cm for pH and electrical conductivity, respectively. Because the dissolved solids content near the proposed storage site was measured at below the upper regulatory limit of 10,000 mg/L for potable aquifers, for the purposes of this UIC permit application, the St. Peter Sandstone is considered to be the lowermost federal USDW. The State of Illinois, however, does not recognize the St. Peter Sandstone as a suitable potable water source at this location.

2.6.3.2 New Richmond Sandstone

The New Richmond Sandstone aquifer occurs between a depth of 2,346 and 2,448 ft (715 and 746 m) within the FutureGen stratigraphic well. No fluid samples were collected from this lower-bedrock aquifer unit.

2.6.3.3 Ironton-Galesville Sandstone

The first bedrock aquifer above the Eau Claire confining zone in Morgan County is the Cambrian Ironton-Galesville Sandstone. Although the Ironton-Galesville Sandstone serves as a water source in northern Illinois where it may reach a thickness of 200 ft (61 m) (Buschbach and Bond 1974; Willman et al. 1975), it is not used as a water-supply source in Morgan or surrounding counties. Regionally, this aquifer system includes two separate lithostratigraphic formations—the Galesville and Ironton formations; the former sandy dolomite is in places separated by a minor conformity from the latter overlying dolomitic sandstone (Willman et al. 1975). Within the FutureGen stratigraphic well, the top of the Ironton-Galesville Sandstone occurs at a depth of 3,300 ft (1,006 m) bkb and is 139 ft (42 m) thick. Little information is available about the potentiometric surface of the Ironton-Galesville Sandstone in Morgan County because of the lack of surrounding deep well characterization information.

Although no published data specifically address the salinity of the Ironton-Galesville Sandstone in wells in Morgan County, Lloyd and Lyke (1995) indicate (Figure 2.28) that groundwater within the Ironton-Galesville Sandstone at the proposed Morgan County CO_2 storage site is saline. No fluid samples were collected from this lower-bedrock aquifer unit. Calculated salinities, however, based on wireline resistivity survey results and observed temperature conditions, indicate an average salinity concentration of approximately 15,000 mg/L at the FutureGen stratigraphic well location. Similar calculations based on wireline log response results for the Mount Simon Sandstone indicate an average salinity concentration of a about 52,000 mg/L, which compares to a laboratory-measured TDS value of ~47,500 mg/L. This difference in calculated salinity concentration between the Ironton and Mount Simon sandstones supports regional information that the intervening Eau Claire acts as a hydrologic barrier above the combined Elmhurst/Mount Simon injection zone.

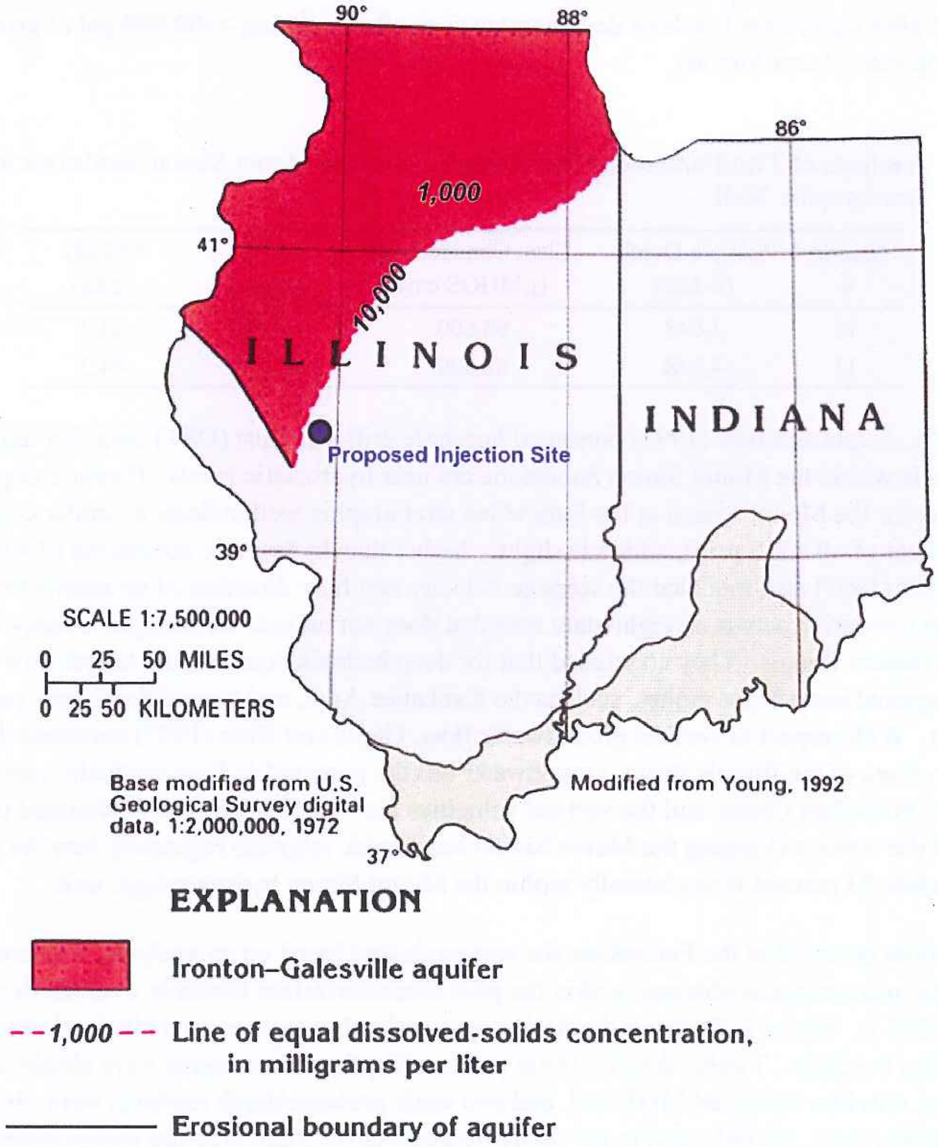

Figure 2.28. Regional Map Showing Limits of Freshwater in the Ironton-Galesville Sandstone Relative to the Proposed Morgan County CO_2 Storage Site (after Lloyd and Lyke 1995)

2.6.3.4 Elmhurst/Mount Simon Sandstone

Visocky et al. (1985) group the overlying Elmhurst member of the Eau Clair Formation with the underlying Mount Simon Sandstone as an individual hydrologic aquifer unit in northern Illinois. In the northern part of the state, the Elmhurst/Mount Simon Sandstone contains fresh groundwater that served as a water supply in northeastern Illinois until the 1970s (Visocky et al. 1985; Young 1992). However, in central Illinois the Mount Simon Sandstone is considered too deep (>3,000 ft [>914 m]) and the groundwater too highly mineralized to be a viable source of drinking water (Kolata and Nimz 2010). Analyses of Mount Simon water samples (Table 2.16) collected in the FutureGen stratigraphic well at a 4,048 ft (1,234 m) with a wireline-deployed formation fluid sampling tool indicated a TDS content of 47,000 mg/L, which is significantly well in excess of the 10,000-mg/L TDS limit recommended for drinking water (40 CFR 144.3). This discrete-depth sample result is consistent with laboratory results obtained from composite sampling of the open borehole Mount Simon section (3,942 to 4,430 ft), which was obtained after significant borehole development (i.e., after pumping >100,000 gal of groundwater from the composite Mount Simon).

Table 2.16. Analyses of Two Formation Fluid Samples from the Mount Simon Sandstone in the Stratigraphic Well

Sample #	Sample Depth (ft bkb)	Elec. Conductivity (μMHOS/cm)	TDS (mg/L)	Salinity (g/kg)
11	4,048	68,600	47,100	44.3
11	4,048	68,600	47,700	44.2

Regionally, Gupta and Bair (1997) presented borehole drill-stem test (DST) data that indicated hydraulic heads within the Mount Simon Sandstone are near hydrostatic levels. Pressure depth measurements for the Mount Simon at the FutureGen stratigraphic well indicate a similar condition with a pressure gradient of ~0.4375 psi/ft, which is slightly higher than hydrostatic conditions (0.4331 psi/ft). Gupta and Blair (1997) also modeled the seepage velocity and flow direction of groundwater in the Mount Simon Formation across an eight-state area that does not include the Morgan County area, but does include eastern Illinois. They concluded that for deep bedrock aquifers, the lateral flow patterns are away from regional basin highs arches, such as the Kankakee Arch, and toward the deeper parts of the Illinois Basin. With respect to vertical groundwater flow, Gupta and Blair (1997) surmised that within the deeper portions of the Illinois Basin, groundwater has the potential to flow vertically upward from the Mount Simon to the Eau Claire, and the vertical velocities are <0.01 in./yr. They estimated that 17 percent of the water recharging the Mount Simon basin-wide migrates regionally into the overlying Eau Claire, while 83 percent flows laterally within the Mount Simon hydrogeologic unit.

Vertical flow potential at the FutureGen site was evaluated based on an analysis of discrete pressure/depth measurements obtained within the pilot characterization borehole over the depth interval of 1,148 to 4,263 ft. Figure 2.29 shows the static pressure/depth measurements obtained within the pilot characterization borehole. Twelve discrete static pressure/depth measurements were obtained using the Schlumberger, wireline conveyed MDT tool, and two static pressure/depth readings were obtained from hydrologic packer tests. As indicated in the figure, representative static pressure measurements over this open pilot borehole interval were obtained for the Silurian Limestone Formation, St. Peter Sandstone, and the Mount Simon Sandstone. For comparison purposes, the normal freshwater hydrostatic pressure gradient (i.e., 0.4331 psi/ft; ρ_w = 1.000 g/cm^3 @STP) and brine hydrostatic pressure gradient (based on Mount Simon salinity conditions; 0.4478 psi/ft; ρ_w = 1.033 g/cm^3 @STP) are shown for comparison. As indicated in the figure, pressure/depth measurements for both the Silurian and St. Peter test intervals are slightly under-pressured in comparison to the projected, normal freshwater hydrostatic conditions, while pressure/depth measurements exhibit a similar under-pressured relationship in comparison to the projected brine hydrostatic profile.

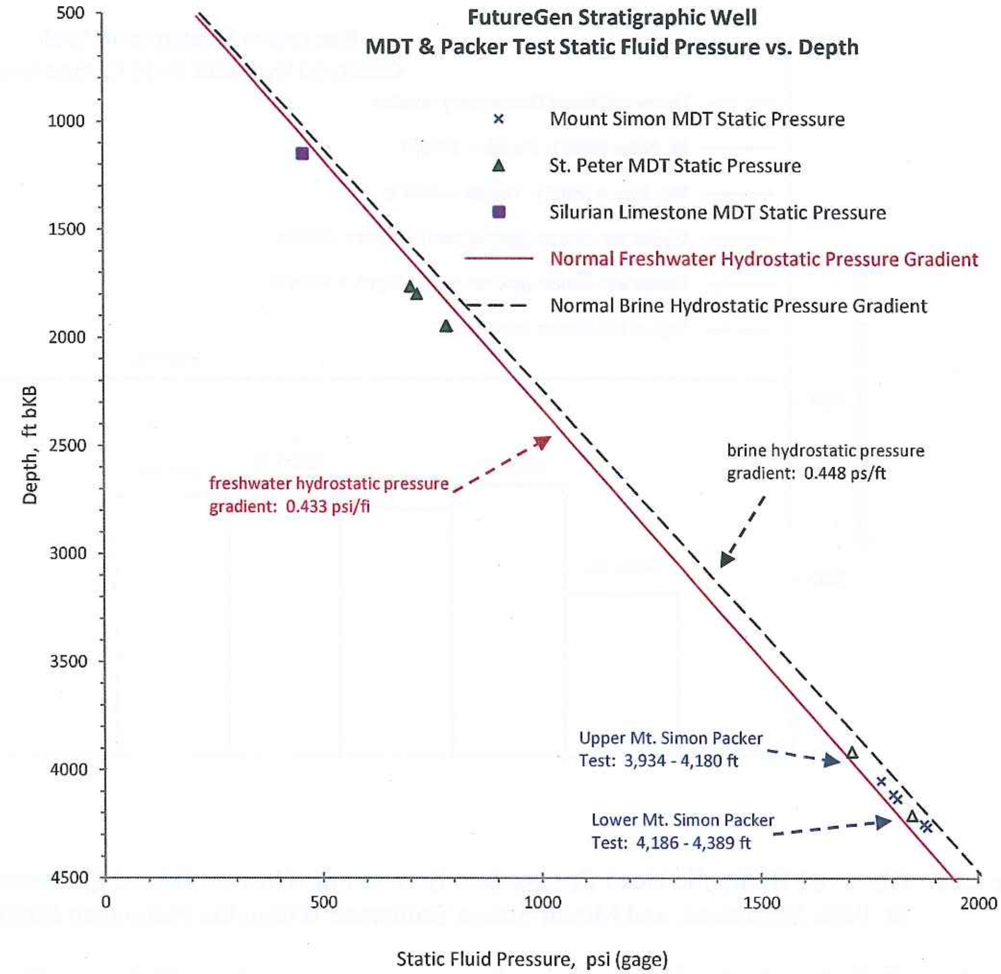

Figure 2.29. Pressure vs. Depth Profile Relationships Within the FutureGen Stratigraphic Well

To assess the vertical flow potential between the Mount Simon and the overlying St. Peter (the lowest USDW) formations, pressure measurements for those two hydrogeologic units were normalized taking into account variations in temperatures and fluid densities and then the calculated, or "observed", pressure heads were compared. The observed hydraulic head values were calculated using the HEADCO program (Spane and Mercer 1985) and represent the elevation of a water column for the static pressure/depth readings, and for the established formation fluid densities, and prevailing static fluid temperature/depth gradient at the stratigraphic well location (which varies between ~0.01 and 0.02°F/ft for respective depths). Figure 2.30 shows the calculated observed hydraulic head for the St. Peter and several selected Mount Simon pressure/depth measurements. The results indicate that there is a positive head difference in the Mount Simon that ranges from 47.8 to 61.6 ft above the calculated St. Peter observed static hydraulic head condition (i.e., 491.1 ft above MSL). This positive head difference suggests a natural vertical flow potential from the Mount Simon to the overlying St. Peter if hydraulic communication is afforded (e.g., an open communicative well). It should also be noted, however, that the higher head within the unconsolidated Quaternary aquifer (~611 ft above MSL), indicates a downward vertical flow potential from this surficial aquifer to both underlying St. Peter and Mount Simon bedrock aquifers (Figure 2.30).

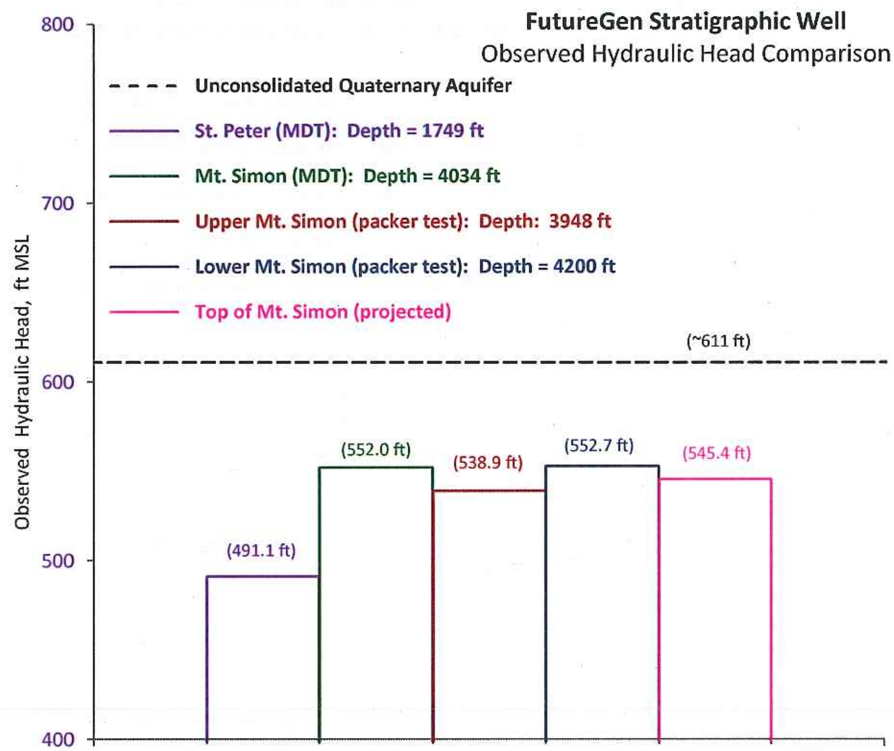

Figure 2.30. Observed Hydraulic Head Comparison Between the Unconsolidated Quaternary Aquifer, St. Peter Sandstone, and Mount Simon Sandstone Within the FutureGen Stratigraphic Well

The disparity in the calculated hydraulic head measurements (together with the significant differences in formation fluid salinity) also suggests that groundwater within the St. Peter and Mount Simon bedrock aquifers is physically isolated from one another. This is an indication that there are no significant conduits (open well bores or fracturing) between these two formations and that the Eau Claire forms an effective confining layer. Because the naturally occurring hydraulic head conditions are higher in the Mount Simon than the hydraulic heads in the St. Peter Formation, which is the lowest most USDW, the standard EPA methodology for determining the AoR pressure front is negated. However, it should also be noted that the upper unconsolidated Quaternary aquifer has a naturally higher hydraulic head than the Mount Simon. In addition, as indicated in Figure 2.30, all the bedrock aquifers, including the Mount Simon, have hydraulic heads lower than the upper unconsolidated Quaternary aquifer, which is the current source of drinking water for the area surrounding the FutureGen site. A discussion of the AoR determination is provided in Section 3.1.9 and a comprehensive monitoring plan that is protective of the USDW is presented in Chapter 5.0.

2.7 Site Evaluation of Mineral Resources

Other subsurface geochemical considerations include the potential for mineral or hydrocarbon resources beneath the proposed CO_2 storage site. While no significant mineral deposits are known to exist within Morgan County, natural gas has been recovered in the region, including at the Prentice and Jacksonville fields located within several miles of the stratigraphic well (Figure 2.31). ISGS oil and gas website data indicate that the Prentice Field contained more than 25 wells drilled during the 1950s; re-exploration occurred in the 1980s.[1] Both oil and gas have been produced from small stratigraphic traps in the shallow Pennsylvanian targets, at depths of 250 to 350 ft (75 to 105 m) bgs. It is important to note that gas produced from these wells may contain around 16 percent CO_2 (Meents 1981).

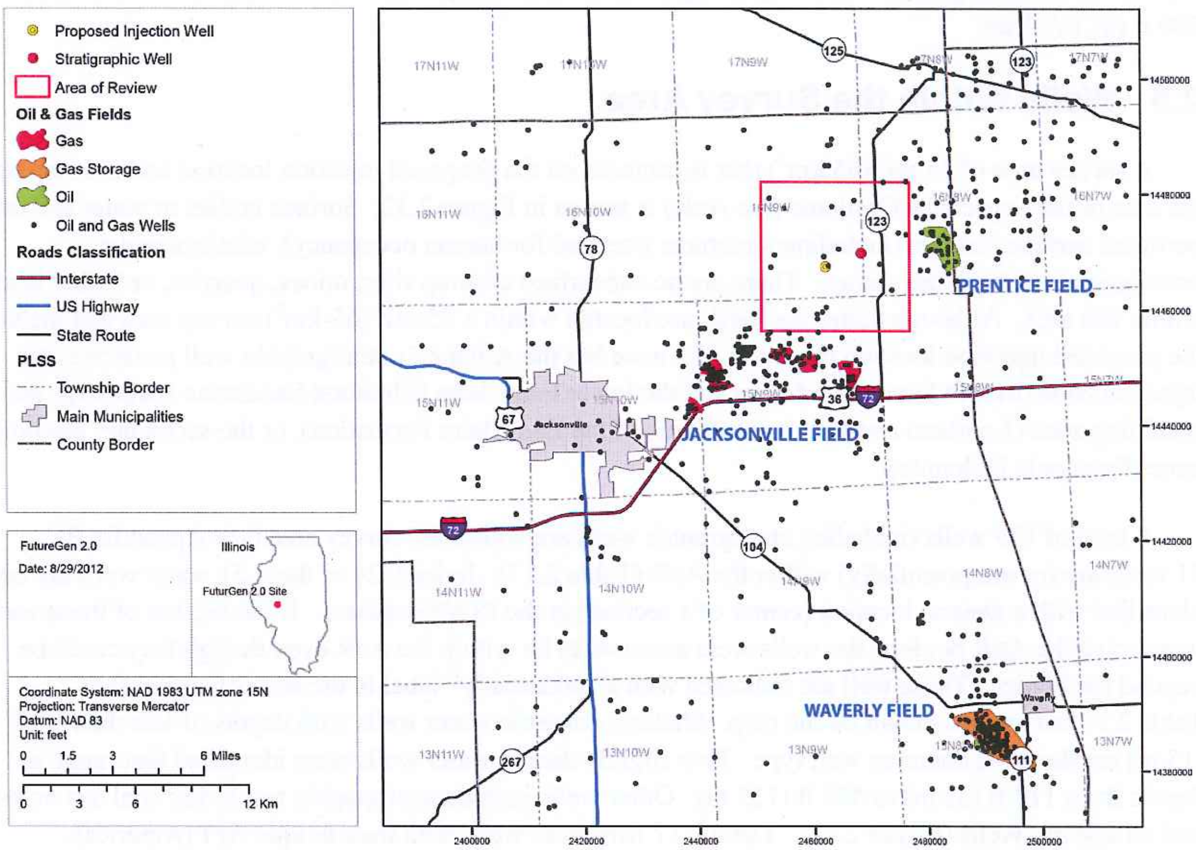

Figure 2.31. Map of Oil and Gas Wells Located Near the Proposed Morgan County CO_2 Storage Site (based on data from ISGS 2011a)

More than 75 wells have been drilled in the Jacksonville Field. Gas was discovered in the Jacksonville Field as early as 1890 (Bell 1927), but most oil and gas production from the Prentice and Jacksonville fields occurred between the late 1920s and late 1980s. The most productive formations in the Illinois Basin (lower Pennsylvanian and Mississippian siliciclastics and Silurian reefs) are not present in Morgan County. Only two boreholes in the vicinity of the Prentice Field and five boreholes near the Jacksonville Field penetrate through the New Albany Shale into Devonian and Silurian limestones.

[1] http://moulin.isgs.uiuc.edu/ILOIL/webapp/ILOIL.html, accessed on September 20, 2011.

Cumulative production from the Prentice and Jacksonville fields is not available, and both fields are largely abandoned. The Waverly Storage Field natural-gas storage site in the southeast corner of Morgan County originally produced oil from Silurian carbonates. This field no longer actively produces oil, but since 1954 it has been successfully used for natural-gas storage in the St. Peter and the Galesville/Ironton Sandstone formations (Buschbach and Bond 1974).

The nearest active coal mine is approximately 10 mi (16 km) away in Menard County and does not penetrate more than 200 ft (61 m) bgs (ISGS 2012a). A review of the known coal geology within a 5-mi (8-km) radius of the proposed drilling site indicates that the Pennsylvanian coals, the Herrin, Springfield, and Colchester coals, are very thin or are absent from the project area (ISGS 2010, 2011; Hatch and Affolter 2008). During continuous coring of a shallow groundwater monitoring well, immediately adjacent to the stratigraphic well, only a single thin (5-ft [1.5-m]) coal seam was encountered at about 200 ft (61 m) deep.

2.8 Wells Within the Survey Area

A survey area of 25 mi^2 (65 km^2) that is centered on the proposed injection location and encompasses the area of the expected CO_2 plume (the AoR) is shown in Figure 2.32. Surface bodies of water and other pertinent surface features (including structures intended for human occupancy), administrative boundaries, and roads are shown. There are no subsurface cleanup sites, mines, quarries, or Tribal lands within this area. Although numerous wells are located within a 25-mi^2 (65-km^2) survey area that includes the proposed injection location (Figure 2.32), none but the Alliance's stratigraphic well penetrates the injection zone (Mount Simon Sandstone and the lower Eau Claire [Elmhurst Sandstone Member]), the confining zone (Lombard and Proviso members of the Eau Claire Formation), or the secondary confining zone (Franconia Dolomite).

A total of 129 wells (including stratigraphic well) are within the survey area (see Appendix B); 51 wells are (or are potentially) within the AoR (Table 2.17). Indeed, 24 of these 51 water wells are only identified with a general location (center of a section) in the ISWS database. If the section of those wells intersected the AoR borders, the wells were assumed to be within the AoR even though they could be beyond the border. Those well are indicated with a "potentially" label in the last column of the Table 2.17 but are not shown on the map. Shallow domestic water wells with depths of less than 50 ft (15 m) are the most common well type. Five slightly deeper water wells were identified that range in depths from 110 ft (33 m) to 405 ft (123 m). Other wells include stratigraphic test holes, coal test holes, and oil and gas wells (Figure 2.32). Table 2.17 lists these wells with their unique API (American Petroleum Institute) identification number, ISWS well identification (ID), well location, depth, elevation, completion date, well owner, well type, and identified status.

The map in Figure 2.32 shows the locations of four proposed injection wells for which permits are being sought. It also shows the location of the Alliance's stratigraphic well and abandoned hydrocarbon test holes, coal test holes, oil and gas wells, other plugged and abandoned wells, known water wells, and other surface features within a 25-mi^2 (65-km^2) area centered on the location of the proposed injection wells. Figure 8.1 is a map of residences, water wells, and surface water features within the delineated AoR and survey area.

Table 2.17. List of Wells Located Within the AoR

Map ID	API Number	ISWS ID	Latitude NAD1983	Longitude NAD1983	Public Land Survey System	Total Depth ft	Elev ft	Completion Date	Owner	Well Num	Well Type	Status	Confining Zone Penetration Well	In AoR
0	121372213200		39.806064	-90.052919	T16n,R9w,Sec 25	4812	633	TBD	FutureGen Industrial Alliance, Inc.	1	Monitoring	Active	Yes	Yes
1	121372118200	116519	39.778074	-90.078443	T15N,R9W,Sec 2	25		19780712	A.A. Negus Estate	1	Water	Private Water Well	No	Yes
4	121370018700	115778	39.811025	-90.065241	T16N,R9W,Sec 25	115			Beilschmidt, William H.		Water		No	Yes
8	121370028500	115740	39.800661	-90.078386	T16N,R9W,Sec 26	127		1950	Martin, L. E.	1	Water		No	Yes
9		115741	39.800661	-90.078386	T16N,R9W,Sec 26	127			Martin, L. E.		Water		No	Yes
10	121372128600	115779	39.801129	-90.07342	T16N,R9W,Sec 26	25		19781213	Martin, Marvin & Jean	1	Water	Private Water Well	No	Yes
14		115763	39.792894	-90.078875	T16N,R9W,Sec 35	28			E Clemons		Water		No	Yes
15		115764	39.792894	-90.078875	T16N,R9W,Sec 35	25			B Sister		Water		No	Yes
16		115765	39.792837	-90.060294	T16N,R9W,Sec 36	35			J M Dunlap		Water		No	Yes
17	121370051100		39.792893	-90.078984	T16N,R9W,Sec 35	1056	643		O'Rear, Judge	1	Oil & Gas / Water		No	Yes
18	121370009900		39.808545	-90.06614	T16N,R9W,Sec 25	1530	630	19391001	Beilschmidt, Wm.	1	Oil & Gas	Dry and Abandoned, No Shows	No	Yes
19	121370023500		39.779153	-90.077325	T15N,R9W,Sec 2	338	644	19231101	Conklin	1	Oil & Gas	Dry and Abandoned, No Shows	No	Yes
20	121370023600		39.781298	-90.075082	T15N,R9W,Sec 2	348	646	19231101	Conklin	2	Oil & Gas	Dry and Abandoned, No Shows	No	Yes
21	121370023700		39.778057	-90.080754	T15N,R9W,Sec 3	342	645	19231001	Harris, A. J.	1	Oil & Gas	Gas Producer	No	Yes
22	121370023900		39.7779	-90.080756	T15N,R9W,Sec 3	334	644	19231107	Harris, A. J.	3	Oil & Gas	Gas Producer	No	Yes
25	121370036300		39.805251	-90.075597	T16N,R9W,Sec 26	1205		19670330	Martin	1	Oil & Gas	Dry and Abandoned, No Shows	No	Yes
26	121370036301		39.805251	-90.075597	T16N,R9W,Sec 26	1400		19731029	Martin	1	Oil & Gas	Junked and Abandoned, Plugged	No	Yes
27	121372088500		39.800861	-90.073017	T16N,R9W,Sec 26	302	630				Coal Test		No	Yes
		115735	39.807386	-90.060378	T16N,R9W,Sec 25	27			Beilschmidt, William H.		Water		No	Potentially
		115736	39.807386	-90.060378	T16N,R9W,Sec 25	30			W R Fowler		Water		No	Potentially
		115737	39.807386	-90.060378	T16N,R9W,Sec 25	28			Mason		Water		No	Potentially
		115739	39.807478	-90.079049	T16N,R9W,Sec 26	25			C H Matin		Water		No	Potentially
		115738	39.807478	-90.079049	T16N,R9W,Sec 26	22			T Gondall		Water		No	Potentially
		115650	39.807193	-90.041413	T16N,R8W,Sec 30	19		1930	R Allison		Water		No	Potentially
		115651	39.792765	-90.041512	T16N,R8W,Sec 31	28			W J Huston		Water		No	Potentially
		115652	39.792765	-90.041512	T16N,R8W,Sec 31	28			E Robinson		Water		No	Potentially
		116450	39.777005	-90.052023	T15N,R9W,Sec 1	25			A Harris		Water		No	Potentially
		116453	39.776968	-90.070521	T15N,R9W,Sec 2	32			A Harris		Water		No	Potentially
		116451	39.776968	-90.070521	T15N,R9W,Sec 2	22			W R Conklin		Water		No	Potentially
		116452	39.776968	-90.070521	T15N,R9W,Sec 2	30			B Negus		Water		No	Potentially
		116454	39.77688	-90.088996	T15N,R9W,Sec 3	28			C Negus		Water		No	Potentially
		116455	39.77688	-90.088996	T15N,R9W,Sec 3	30			L B Trotter		Water		No	Potentially
		115727	39.821881	-90.078925	T16N,R9W,Sec 23	30			D Flinn		Water		No	Potentially
		115728	39.821881	-90.078925	T16N,R9W,Sec 23	30			Hazel Dell School		Water		No	Potentially
		115729	39.821881	-90.078925	T16N,R9W,Sec 23	35			K. Haneline		Water		No	Potentially
		115733	39.821811	-90.060168	T16N,R9W,Sec 24	30			J L Icenagle		Water		No	Potentially
		115734	39.821811	-90.060168	T16N,R9W,Sec 24	30			G Lewis		Water		No	Potentially
		115775	39.821811	-90.060168	T16N,R9W,Sec 24	200		1944	E C Lewis		Water		No	Potentially
		115742	39.807531	-90.097566	T16N,R9W,Sec 27	23			J Stewart		Water		No	Potentially
		115743	39.807531	-90.097566	T16N,R9W,Sec 27	23			I J Stewart		Water		No	Potentially
		115761	39.792917	-90.097513	T16N,R9W,Sec 34	28			T Harrison		Water		No	Potentially
		115762	39.792917	-90.097513	T16N,R9W,Sec 34	30			J Mahon		Water		No	Potentially

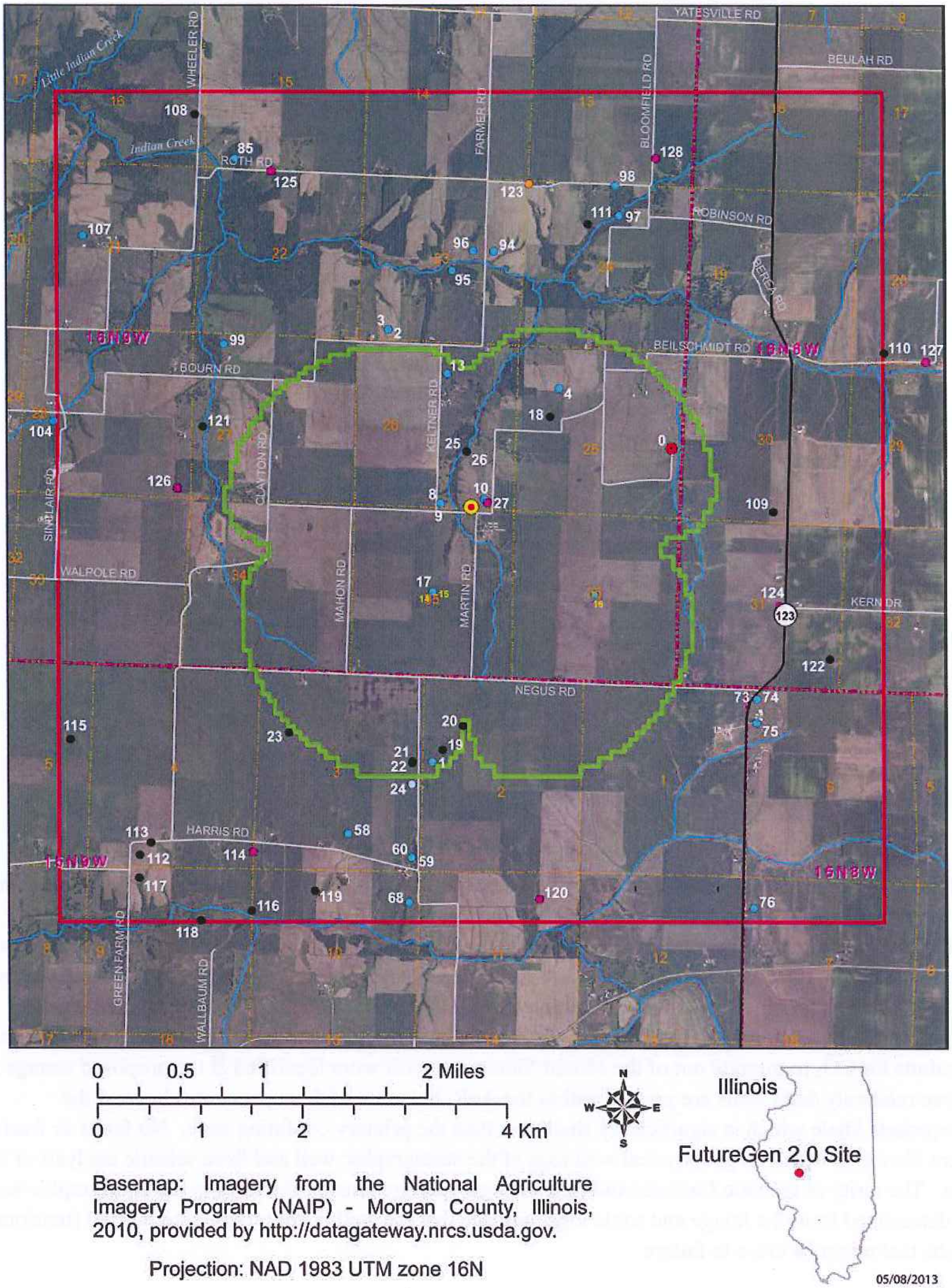

Figure 2.32. Wells Located Within the Survey Area. The map includes surface bodies of water, mines, quarries, faults, and other surface features. Tables of the data used to produce this map are provided in Table 2.17 and Appendix B.

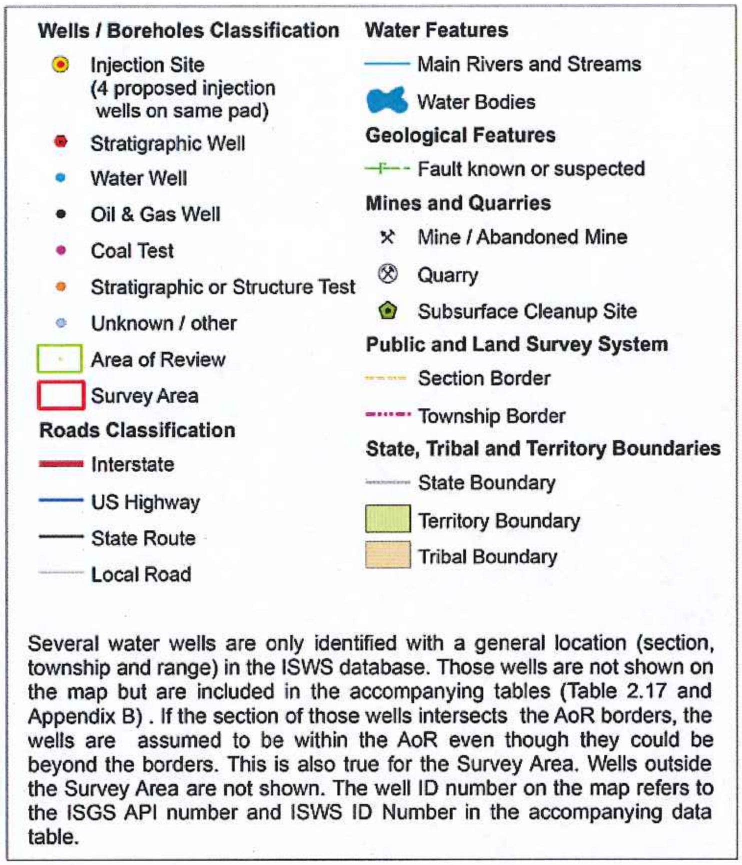

Figure 2.32. (contd)

2.9 Conclusion

The geologic setting of the proposed site indicates that the Mount Simon Sandstone at the site is sufficiently deep, and has sufficient thickness, lateral continuity, porosity, and permeability to store the proposed 22-MMT volume of CO_2. In addition, the Eau Claire Formation at the site is of sufficient thickness, lateral continuity, and has low enough permeabilities to serve as the primary confining zone. The site affords additional containment with several secondary confining zones, including the Franconian Formation. The basement rock was encountered at 4,430 ft and is a rhyolite, which will act as an impermeable lower boundary for the injection zones within the Mount Simon Sandstone. No potential conduits for CO_2 to migrate out of the Mount Simon reservoir were identified at the proposed storage site. Three relatively deep wells are present within the AoR, but none of them penetrates beyond the Maquoketa Shale which is significantly shallower than the primary confining zone. No faults or fractures were identified based on geophysical well logs of the stratigraphic well and from seismic analysis of the site. The rarity of tectonic fractures and lack of large-aperture tension fractures in the stratigraphic well, as determined from the image and sonic logs, indicate that the well is not proximal to normal (tensional) faults that might be close to failure.

Chapter 3.0 uses a conceptual model developed using the appropriate physical and chemical properties determined for the site to simulate the injection of 22 MMT of CO_2 over 20 years using a computational model. The physical and chemical input parameters for the computational model are described in more detail in Chapter 3.0.

2.10 References

40 CFR 144.3. Code of Federal Regulations, Title 40, Protection of the Environment, Part 144, "Underground Injection Control Program," Section 3, "Definitions."

40 CFR 146.82. Code of Federal Regulations, Title 40, *Protection of Environment*, Part 146, "Underground Injection Control Program: Criteria and Standards," Section 82, "Required Class VI permit information."

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40 CFR 146.88. Code of Federal Regulations, Title 40, Protection of Environment, Part 146"Underground Injection Control Program: Criteria and Standards," Section 88, "Injection well operating requirements."

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