CLASS VI PERMIT APPLICATION NARRATIVE
40 CFR 146.82(a)

Wabash CCS Project

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INSTRUCTIONS

To reduce the potential for redundancy and to organize permit application components in a manner that facilitates efficient review by the permitting authority, the EPA recommends that Class VI permit applicants submit both:

1. A narrative with a characterization of the proposed site, overall strategies for site operations, and other general project information (compiled into a single file and submitted using the Project Information Tracking module of the GSDT).

2. Specific, detailed information required by certain Class VI Rule provisions (submitted using other GSDT modules, which are tailored to the applicable Class VI Rule requirements).

This template provides an outline for the narrative component of the permit application. If desired, appendices, attachments, or other supplemental information associated with the narrative that do not fit into one of the specific GSDT modules can be uploaded directly to the Project Information Tracking module using the module field designated for "any other information requested by the UIC Program Director."

In this template, examples or suggestions appear in **blue text**. These are provided as general recommendations to assist with site- and project-specific application development. The recommendations are not required elements of the Class VI Rule. This document does not substitute for those provisions or regulations, nor is it a regulation itself, and it does not impose legally binding requirements on the EPA, states, or the regulated community.

Please delete the **blue text**, complete the checklists, and replace the <mark>yellow highlighted text</mark> before submitting your document. Similarly, please adjust the example tables as necessary (e.g., by adding or removing rows or columns). Appropriate maps, figures, references, etc. should also be included to support the text. For more information, see the Class VI guidance documents at https://www.epa.gov/uic/class-vi-guidance-documents.

This narrative file does not need to repeat any information submitted with the GSDT, but it should clearly reference these other submissions to ensure that all Class VI requirements are met. The EPA recommends that you review the GSDT modules and/or user guides for each topic area below <u>before</u> developing your narrative, to avoid duplicating efforts or information.

After completing the narrative, upload it to the Project Information Tracking GSDT module, on the Initial Permit Application tab. The EPA recommends converting to PDF prior to uploading.

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Project Background and Contact Information

Despite global determined efforts to switch to clean sources of energy, fossil fuel will be part of our future. Fossil fuel energy is economical and abundant and remains the surest way to satisfy the world's enormous appetite for energy. But, since burning fossil fuel emits CO_2 and other

compounds into our atmosphere, experts have developed advanced technologies to capture the CO_2 and allow for its sequestration underground.

One way to make fossil fuel cleaner is Carbon Capture, Utilization and Storage (CCUS). In CCUS, which can be used at a variety of fossil fuel-based energy and industrial plants, CO_2 gas is captured before it can escape to the atmosphere. The gas is then converted to a supercritical liquid and injected deep into underground geological formations.

The goals of the Wabash Carbon Services (WCS) project are as follows:

1. WCS will develop a Carbon Sequestration Infrastructure that allows for the safe and environmentally sound injection of 1.67 million metric tons per year of CO_2 into a deep underground geologic formation.
2. The application of the CO_2 geologic sequestration allows the nearby Wabash Valley Resources (WVR) facility to become a net-zero carbon intensity hydrogen production and power generating facility.

The WVR project will redevelop the Wabash River Integrated Gasification Combined Cycle (IGCC) plant, located in West Terre Haute, IN into a Hydrogen Production and Power Generation facility. The redeveloped site will utilize approximately 2,000 tons per day of blended biomass, petroleum waste or coal. The project will capture CO_2 that is traditionally emitted from hydrogen purification processes and provide it to WCS for underground sequestration in the Potosi Dolomite of the Illinois Basin.

The application and supporting documentation are based on currently available data, including regional data and site-specific data derived from a stratigraphic test well (Wabash #1) drilled in 2019 near the site of the proposed injection wells.

The injection zone is part of the Knox supergroup, a primarily dolomite formation that extends from ~3,350 feet measured depth (MD) (2,750' True Vertical Depth subsea (TVDss)) to ~5,100 feet MD (4,550' TVDss). Within the Knox supergroup, multiple units with low enough permeabilities to serve as a primary confining layer exist. Core samples of the Maquoketa shale were collected and analyzed. Based upon the core analysis and the well understood regional extent of the Maquoketa Group, WCS has decided to consider the Maquoketa Group as the primary seal. The Maquoketa Group extends from 2,386 ft MD (1,836 TVDss) to 2,700 ft MD (2,150 TVDss). No faults or fractures were identified based on the geophysical well logs of the stratigraphic test well and seismic analysis of the site.

WCS will take the CO_2 generated at the nearby WVR facility and geologically sequester it in the Potosi Dolomite of the Knox supergroup located at a depth of approximately 4,600 feet MD formation top (~4,100' TVDss depth). The injection site will consist of two injection wells, Geologic Sequestration Well #1 (WVCCS1) and Geologic Sequestration Well #2 (WVCCS2). In addition to the injection wells, two in-formation monitoring wells, Formation Monitor #1 and #2 (FM1, FM2) will be used to monitor the pressure and temperature of the injection zone and acquire samples of formation fluid for investigation of any geochemical changes. This allows for tracking the CO_2 plume and detection of any abnormalities that may arise during the injection period and the Post-Injection Site Care (PISC) period.

Integrity of the primary seal, the Maquoketa Group, is critical to the protection of the Lowermost Underground Source of Drinking Water (LUSDW) and containment of the sequestered CO_2. To monitor the integrity of the Primary Seal, two (2) confinement monitoring wells will be installed. Confinement Monitor #1 and #2, (CM1, CM2) will provide continuous measurement of pressure and temperature in the Bainbridge or Salina group, commonly referred to as the Silurian, with top at ~ 2,000 feet MD (~1,400' TVDss). For this project, the Silurian is considered the LUSDW. The pressure and temperature data collected will inform WCS on the integrity of the primary seal. Any significant deviation in temperature or pressure could be evidence of potential issues with the primary seal. In addition to the continuous monitoring, CM1 & CM2 will allow for formation fluid samples to be collected from the Silurian and tested for water quality and geochemical properties to verify and/or confirm the integrity of the Maquoketa Group primary seal. This sample will allow for direct monitoring immediately above the confining layer allowing for early detection of any abnormalities.

To ensure the protection of residential and municipal sources of drinking water, ten (10) shallow water wells will be installed to verify the ongoing quality of the locally utilized drinking water sources. Ground Water Well #1,2, …10 (GW1, GW2, …GW10) will be used to track and verify that no adverse impacts to the local water supplies are encountered from CO_2 sequestration operations.

Since injection will not be taking place above any USDWs, no injection depth waiver or aquifer exemption expansion is being requested for this project. During testing of the Wabash #1 well a swab sample of formation fluid from the Potosi dolomite was collected and analyzed at 34,250 mg/l TDS (total dissolved solids), which greatly exceeds the 10,000 mg/l TDS definition of a USDW.

To implement CCUS, WCS has assembled a world-class research team led by the Illinois State Geological Survey (ISGS). This team has previously assisted with the commercialization of CCUS at the Archer Daniels Midland (ADM) facility in Decatur, IL.

The WCS project is expected to be ready for service and receiving CO_2 from WVR by the end of 2nd Quarter 2024. The injection period is expected to last for 12 years and result in the successful sequestration of 20 Million Metric Tons of CO_2.

Within the proposed Area of Review (AoR) there are no federally recognized Native American tribal lands or territories.

GSDT Submission - Project Background and Contact Information

GSDT Module: Project Information Tracking
Tab(s): General Information tab; Facility Information and Owner/Operator Information tab

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☒ Required project and facility details *[40 CFR 146.82(a)(1)]*

Site Characterization

Regional Geology, Hydrogeology, and Local Structural Geology [40 CFR 146.82(a)(3)(vi)]

INJECTION ZONE

Potosi Dolomite

The injection zone is within the Potosi Dolomite (Upper Cambrian) the basal unit of the Knox Supergroup in Indiana (*Figure 1*) or Knox Group as it is referred to in Illinois. In Indiana, the Knox Supergroup includes, from base to top, the Cambrian Potosi Dolomite followed by the Lower Ordovician Oneota and Shakopee Dolomites (*Figure 2* and *Figure 3*).

The Potosi Dolomite is an extensive formation that underlies most of Illinois and Indiana, except in parts of northern Illinois. Its thickness ranges from 100 ft in northern Illinois to more than 1,500 feet in southernmost Indiana. The Potosi is 689 ft thick at the Wabash #1 well site (*Figure 4*) and occurs at 4,473 ft MD (4,000 ft TVDss) in the Wabash #1 well.

The Potosi Dolomite is a relatively pure dolomite unit that conformably overlies and underlies, respectively, the relatively impure Franconia and Eminence Formations (in Illinois). Throughout Indiana, and observed at the Wabash #1 well, the dolomitic upper Franconia, Potosi, and Eminence stratigraphic units cannot easily be differentiated with confidence; thus, in Indiana the Potosi is recognized as a combined stratigraphic unit comprising these three units.

Generally, the Potosi is a fine to coarsely crystalline, commonly dense, dolomite, but contains characteristic drusy quartz and intercalations of vugular, brecciated, fractured and/or cavernous intervals. The pore spaces are generally lined with diagenetic quartz, calcite, or dolomite. Individual highly porous intervals are up to 10 feet thick; in density wireline logs (e.g. *Figure 2* and *Figure 3*) the intervals display abnormally high porosity and are widespread in the Illinois Basin (Leetaru et al., 2014; Lasemi and Askari, 2020).

Throughout the Illinois Basin, lost circulation intervals have been encountered when drilling the Potosi Dolomite. In Douglas County, Illinois, the Cabot Corporation Cabot-Tuscola #2, a chemical waste disposal well approximately 50 miles west-northwest of the proposed site, has injected over 50 million metric tons of CO_2 equivalent of liquid chemical wastes into the Potosi (Bell et al., 1964; Leetaru et al., 2014). In western Kentucky and southwest Indiana, millions of gallons of liquid industrial wastes have been injected annually into the Knox vuggy to cavernous reservoirs (Greb et al., 2012).

CONFINING ZONES

Shakopee Dolomite

Many wells in Illinois, Indiana, and Kentucky have injected millions of gallons of liquid waste in the vugular and fractured/cavernous intervals within the Knox carbonates which are confined by thick, dense dolomite intervals. Overlying the Potosi Dolomite, the Oneota and Shakopee Dolomites are generally dense and consist of fine to coarsely crystalline dolomite containing chert nodules (Lasemi and Askari, 2014; Greb et al., 2012); the dolomites are in part argillaceous

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and contain relatively thin shale intervals, and these units are over 1,100 ft thick in the Wabash #1 well (*Figure 2* and *Figure 3*).

The Shakopee Dolomite is present throughout Illinois and Indiana except to the north where it is absent due to extensive removal at the post-Knox unconformity. The Shakopee thickness is less than 50 to 150 ft in northern Illinois increasing in thickness to over 2500 ft near the southern extent of Illinois. The Shakopee increases in thickness from its eroded limit in northern Indiana to an estimated 2,000 ft in southwestern Indiana (Droste and Patton, 1986). In the Wabash #1 well the Shakopee Dolomite is 616 ft thick, from a depth of 3,354 ft MD (2,800 TVDss) to its base at 3,970 ft MD (3,400 TVDss *Figure 5*).

Dutchtown Formation

The argillaceous carbonate rocks of the Ancell Group (Dutchtown Formation and Joachim Dolomite) and Black River Group (Platteville Group of Illinois) are part of the confining zone. The Dutchtown Formation of Indiana (Dutchtown Limestone of Illinois) is a shaly interval and in the Wabash #1 well overlies the St. Peter Sandstone. It laterally and vertically grades to St. Peter Sandstone and is an argillaceous dolomite/limestone with intercalation of thin shale beds. The Dutchtown has a known thickness of about 150 ft in the Cape Girardeau area while drilling in Kentucky suggests it is as much as 200 ft thick in southeastern Illinois (DuBois, 1945; Templeton and Willman, 1963). In the Wabash #1 well, the Dutchtown is over 75 ft thick and, based on the mud log, 30% shale is present in well cuttings samples. Higher gamma ray and lower neutron signatures of this interval is likely due to clay content in the carbonate layers (SEE INJECTION AND CONFINING ZONE DETAILS SECTION).

Maquoketa Group

Upper Ordovician shale units of the Maquoketa Group represent a regional seal in the Illinois Basin (*Figure 6*). The Maquoketa Group disconformity overlies the Trenton Limestone and the Galena Group in Indiana and Illinois, respectively. This formation is found over the entire Illinois Basin and extends into parts of Michigan and Iowa. The Maquoketa Group has been eroded in northern Illinois. Across the basin the Maquoketa Group ranges from 100 ft in thickness near the Mississippi River to greater than 800 ft at the eastern edge of the basin. At the Wabash #1 well, the Maquoketa Group is 314 ft thick. The Maquoketa Group is overlain by Silurian strata (Gray, 1972; Kolata and Graese, 1983), which mark the base of the lowermost underground source of drinking water in the area (SEE ALSO HYDROGEOLOGY SECTION). In the Wabash #1 well, the Maquoketa Group is 314 ft thick, from 2,386 to 2,700 ft MD (1836-2150 TVDss) in depth, and is composed of interbedded shale, argillaceous limestone, and dolomite. For the WCS project the Maquoketa Group is considered the primary seal.

GEOLOGIC HISTORY

The intracratonic Illinois Basin was formed in Late Cambrian over the northeast extension of Reelfoot Rift system (Kolata and Nelson 1990) associated with the breakup of supercontinent Rodinia (e.g., Bond et al., 1984; Piper, 2004). The Illinois Basin (*Figure 7*) is bordered by a series of prominent structures (Kolata and Nelson, 1990).

By late Cambrian time lithospheric thinning had largely concluded, and the New Madrid Rift System gradually changed to a slowly subsiding cratonic trough or embayment plunging southwest towards the deeper ocean (Kolata and Nelson 2010). Rates of subsidence and sedimentation were greatest in the Rough Creek Graben, where the basin attains a maximum projected depth of 30,000 ft MD (29,500 TVDss), comprising the depocenter of the Illinois Basin (Nelson 2010). The Cambrian seas left widespread and thick deposits of mostly coastal and nearshore shallow marine sand.

The Knox carbonates are considered part of the Great American Carbonate Bank that was deposited during the Cambrian and Ordovician and is found throughout North America (Fritz et al., 2012). Within the Knox, the Potosi Dolomite is a fine to coarsely crystalline dolomite containing relics of bioclasts, ooids, peloids, and intraclasts recording deposition in a shallow marine ramp setting (Lasemi and Askari, 2020). In later times, marine and near-shore environments dominated, and the Cambrian through Permian sedimentary rocks in the Illinois Basin consist primarily of marine carbonates and, to a lesser extent, sandstone, shale, and siltstone (Leighton et al., 1990).

Major uplift of the La Salle anticlinal belt (see *Geologic Features*, below) began during the Late Mississippian and lasted throughout most of Pennsylvanian time, with the greatest magnitude of deformation occurring at the northern edge of the belt (Kolata et al., 1990). In post Early Permian time, uplift of the Pascola arch and later subsidence of the Mississippi embayment cut off the southernmost one-third of the Illinois Basin (Bethke, 1986).

The area near the proposed injection site is tectonically stable, and modern occurrence of earthquakes magnitude 3.0 and larger near the site are typically rare. The seismic frequency and intensity increase into southern Indiana and Illinois, towards multiple seismic zones over 90 miles away to the south-southwest (SEE SEISMIC HISTORY SECTION).

GEOLOGIC FEATURES

The injection site is in the east-central part of the Illinois Basin. There are no known structural features that would negatively impact the proposed injection site (SEE ALSO FAULTS AND FRACTURES SECTION). The closest large geologic structure to the site is the La Salle Anticlinorium, which extends into Edgar and Clark Counties, Illinois, approximately 20 miles away (*Figure 8*). Although some deep faults have been observed on seismic profiles farther south within the anticlinorium (Lawrence and Crawford Counties, Illinois), none are known within a 25-mile radius of the proposed site (Nelson, 1995). The closest major regional fault is the Mt. Carmel Fault in south-central Indiana, which extends as far north as the southern edge of Morgan County, Indiana, approximately 50 miles southeast of the proposed site (Gray and Steinmetz, 2012).
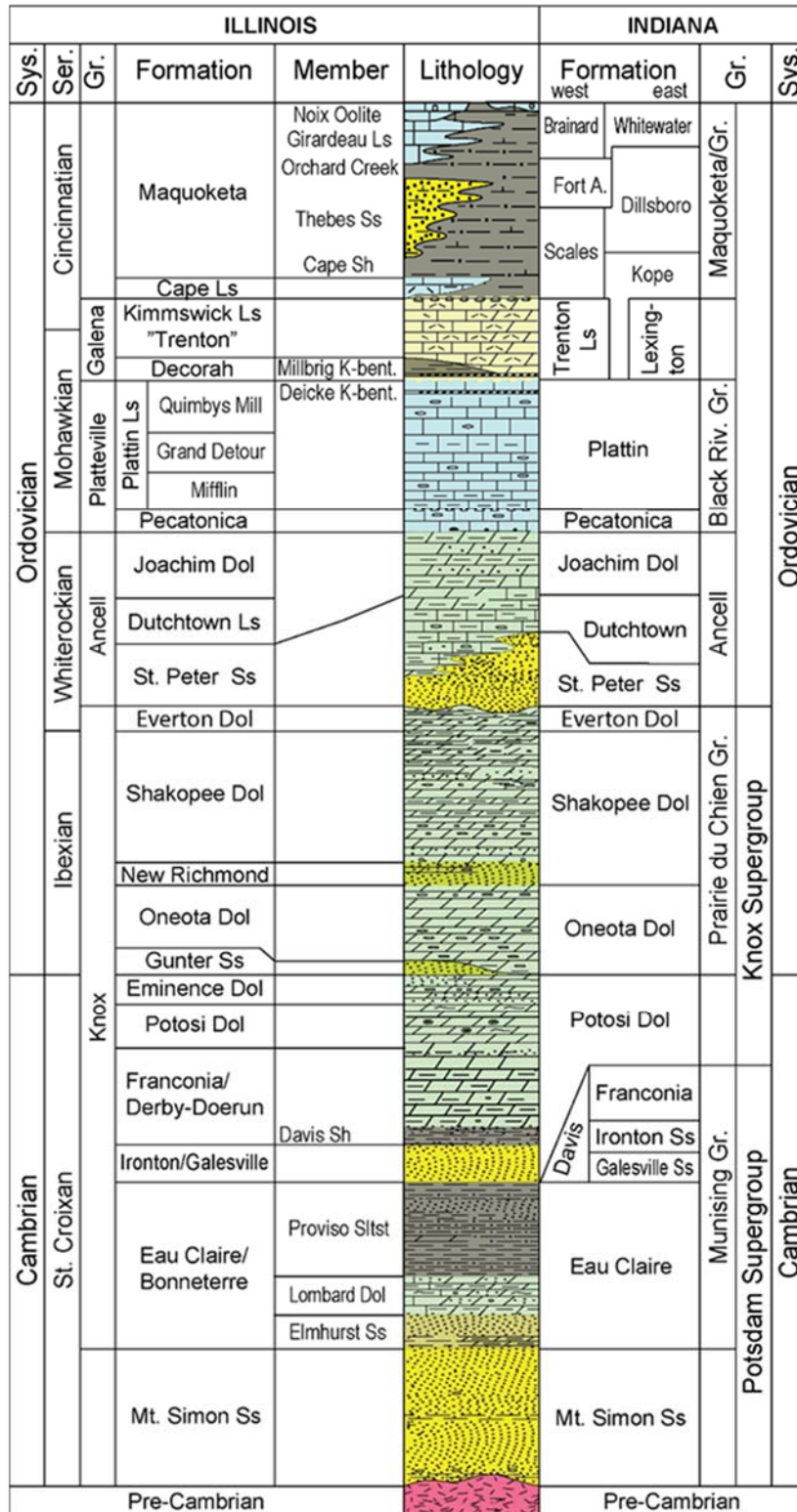
Figure — Stratigraphic column (ILLINOIS | INDIANA)

Sys.	Ser.	Gr.	Formation (Illinois)	Member	Lithology	Formation (Indiana) west — east	Gr.	Sys.
Ordovician	Cincinnatian		Maquoketa	Noix Oolite / Girardeau Ls / Orchard Creek / Thebes Ss / Cape Sh		Brainard / Whitewater; Fort A. / Dillsboro; Scales / Kope	Maquoketa/Gr.	Ordovician
			Cape Ls					
	Galena	Galena	Kimmswick Ls "Trenton"			Trenton Ls / Lexington		
			Decorah	Millbrig K-bent. / Deicke K-bent.				
	Mohawkian	Platteville	Plattin Ls: Quimbys Mill			Plattin	Black Riv. Gr.	
			Plattin Ls: Grand Detour					
			Plattin Ls: Mifflin					
			Pecatonica			Pecatonica		
	Whiterockian	Ancell	Joachim Dol			Joachim Dol	Ancell	
			Dutchtown Ls			Dutchtown		
			St. Peter Ss			St. Peter Ss		
			Everton Dol			Everton Dol		
	Ibexian	Knox	Shakopee Dol			Shakopee Dol	Prairie du Chien Gr. / Knox Supergroup	
			New Richmond					
			Oneota Dol			Oneota Dol		
			Gunter Ss					
Cambrian	St. Croixan	Knox	Eminence Dol					Cambrian
			Potosi Dol			Potosi Dol		
			Franconia/ Derby-Doerun	Davis Sh		Franconia	Munising Gr. / Potsdam Supergroup	
			Ironton/Galesville			Ironton Ss / Galesville Ss (Davis)		
			Eau Claire/ Bonneterre	Proviso Sltst / Lombard Dol / Elmhurst Ss		Eau Claire		
			Mt. Simon Ss			Mt. Simon Ss		
			Pre-Cambrian			Pre-Cambrian		

Figure 1. Stratigraphic column of the Cambro-Ordovician Succession in southern Illinois (from Kolata, 2005) and southwestern Indiana (from Thompson et. al., 2016).
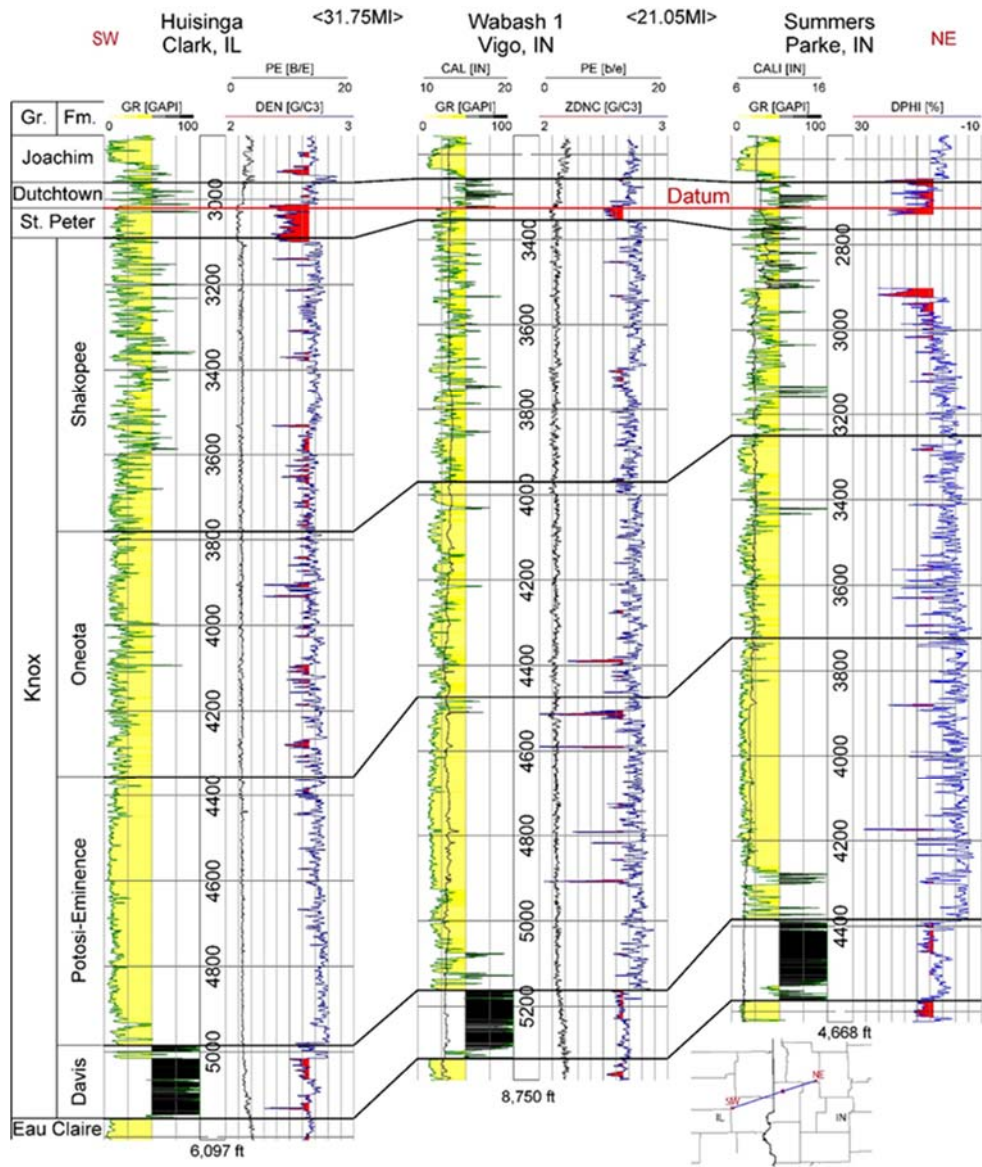
Figure 2. Southwest-northeast correlation of the units in the upper part of the Knox Group from east-central Illinois to west-central Indiana.
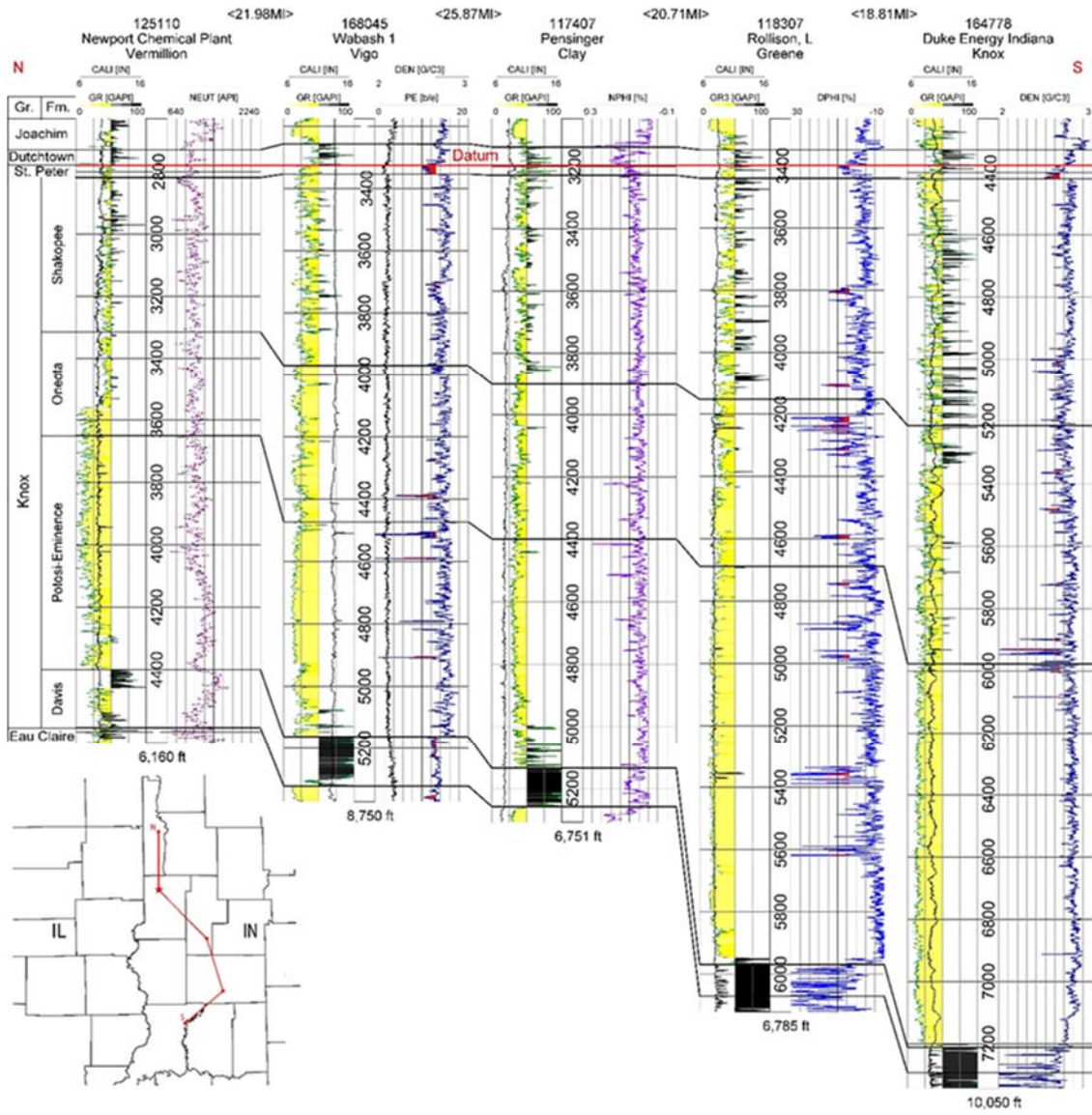
Figure 3. North-south correlation of the units in the upper part of the Knox Group in Indiana.
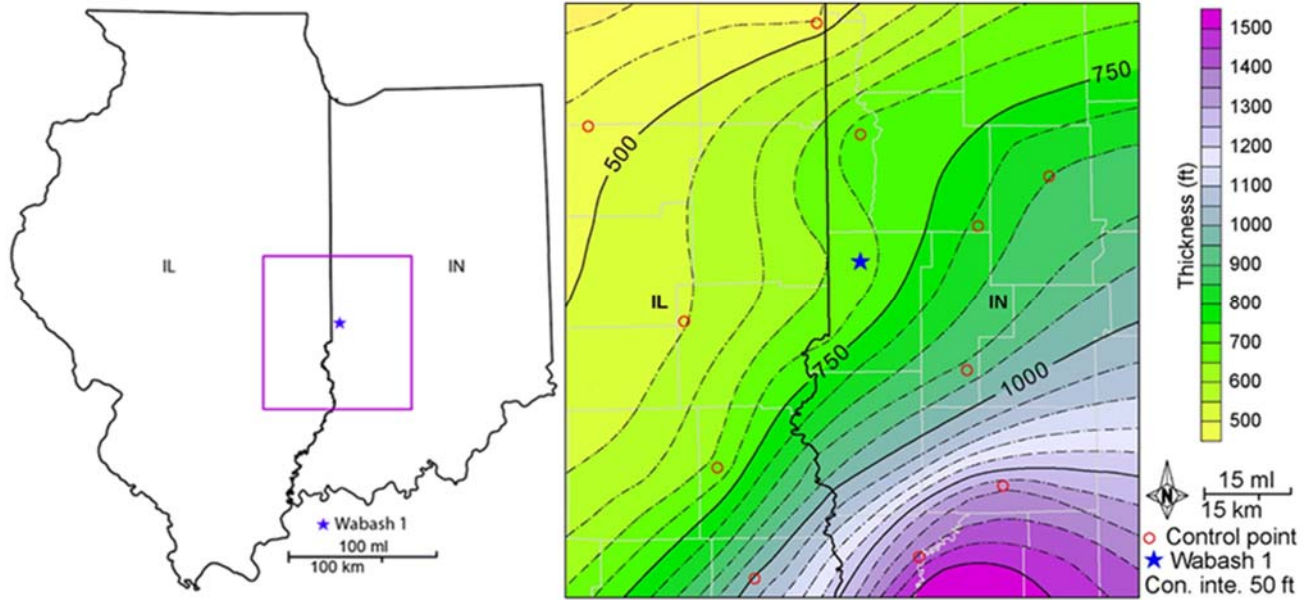
Figure 4. Thickness (in feet) of the Potosi Dolomite around the study area of the Wabash Well # 1 (denoted by the star). The Potosi generally thickens southeastward across the area.
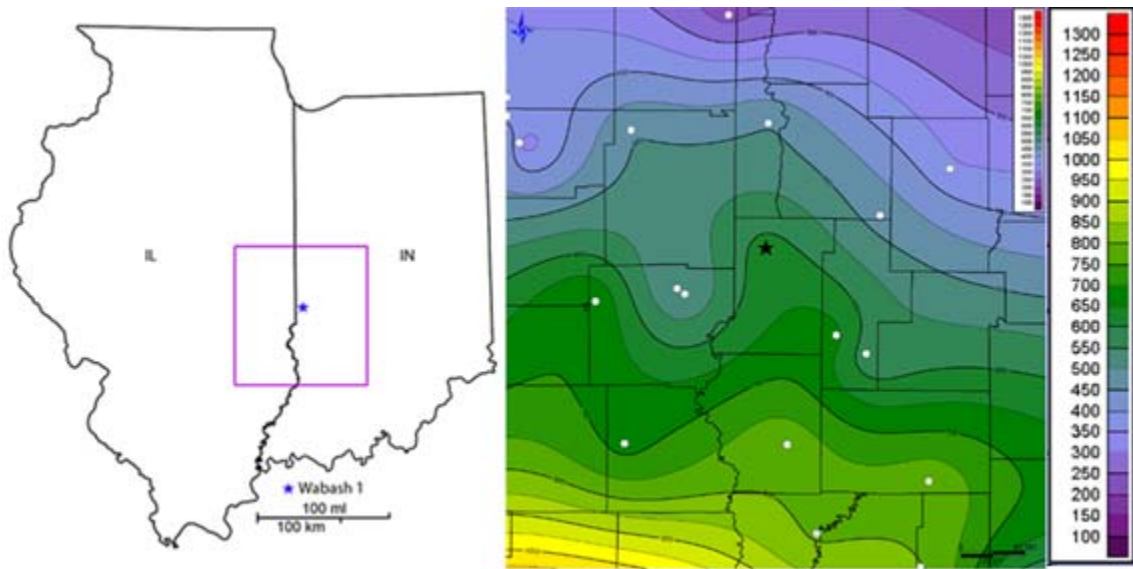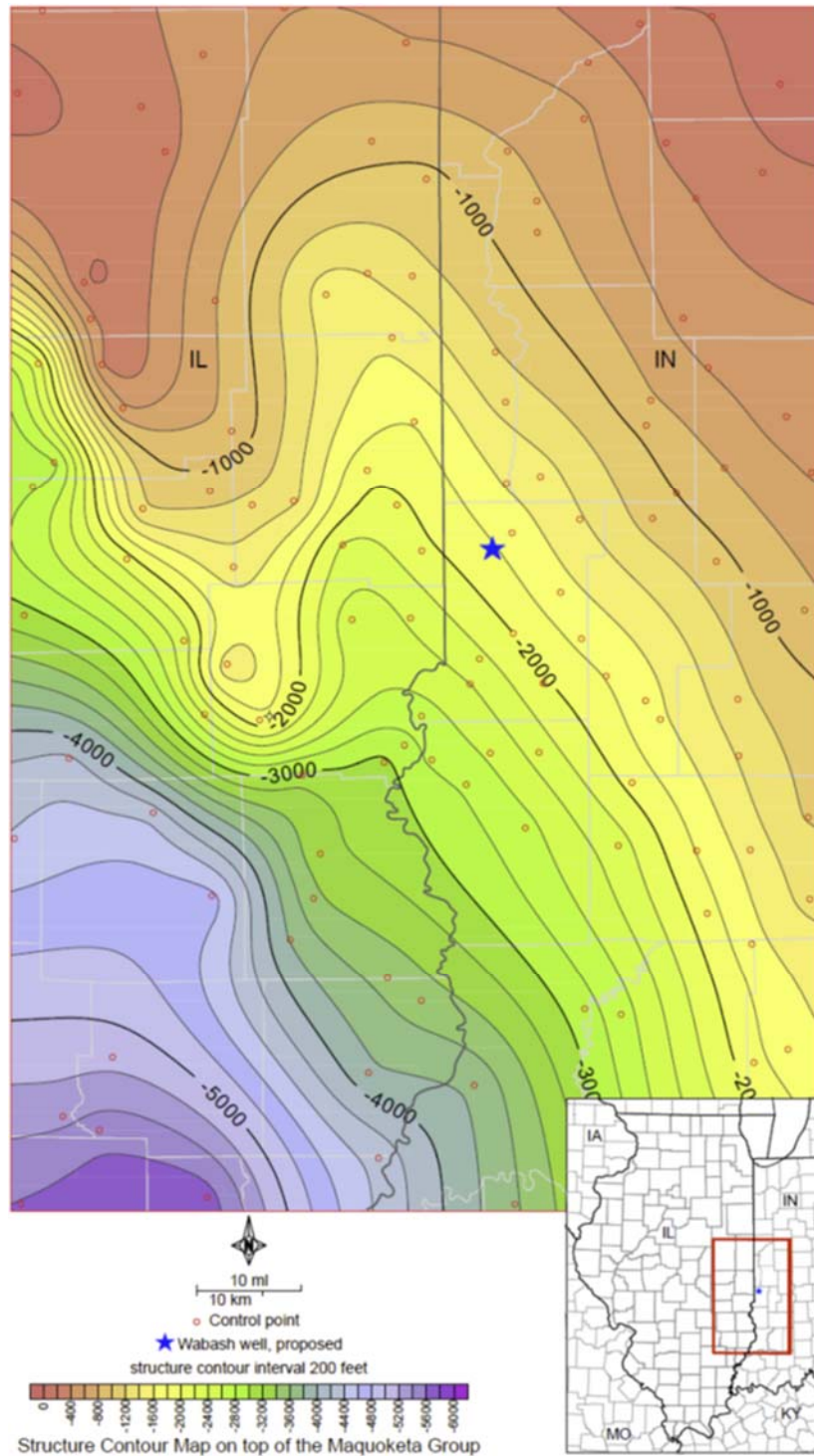

Figure 5. Thickness (in feet) of the Shakopee Dolomite around the study area of the Wabash Well # 1 (denoted by the star). The Shakopee generally thickens toward the south across the area.

Figure 6. Regional structure map of the top of the Maquoketa Group. The Wabash #1 well is denoted by the star.
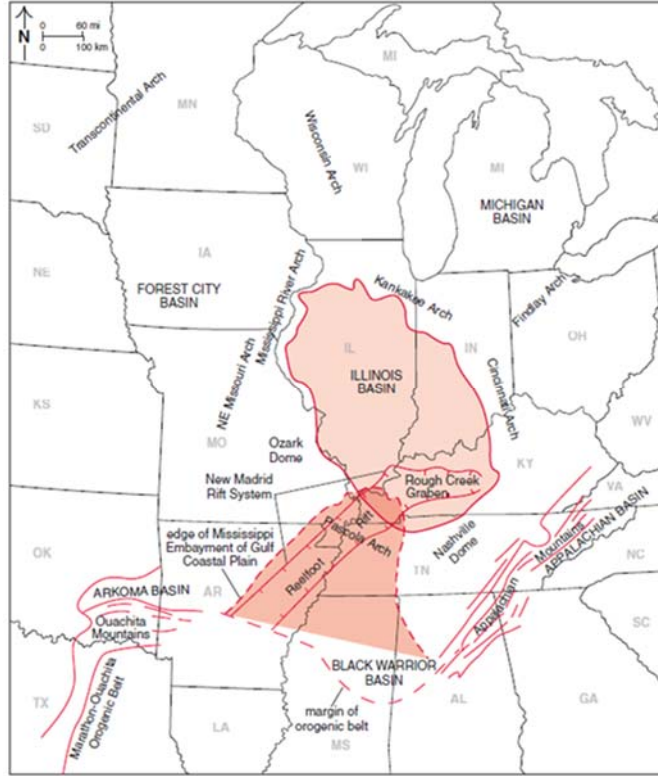
Figure 7. Regional map of the central United States showing the major tectonic features surrounding the Illinois Basin from various sources (Finley, 2005).
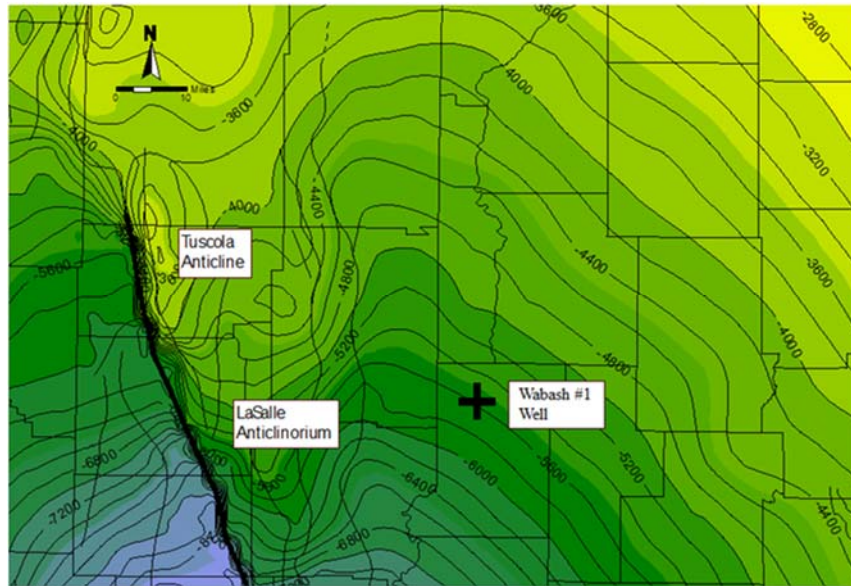
Figure 8. Structure on the Mt. Simon Sandstone in east-central Illinois and west-central Indiana. The Wabash #1 well in Vigo County, Indiana, is shown as a black cross. The nearest known structure is the LaSalle Anticlinorium approximately 20 miles west of the well location.

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Maps and Cross Sections of the AoR [40 CFR 146.82(a)(2), 146.82(a)(3)(i)]

The WCS project presents two distinct AoR's associated with each injection well. The AoR extent is dictated by the CO_2 plume generated by each individual injection site. The areal extent of the CO_2 plumes is represented in Figure 9 below. Displayed within this map are the locations of: both injection wells (WVCCS1 & WVCCS2); both confining layer monitoring wells (CM1 & CM2); and the location of the in-formation monitoring wells (FM1 & FM2). Within the 2 plumes all pre-existing wells have been identified (water/oil & gas). The total count of type of well and which plume it is locate in are summarized below:

Table 1 Total Count of Wells in AoR

	Water Wells	Oil & Gas Wells	Total
North Plume (WVCCS1)	6	6	12
South Plume (WVCCS2)	45	4	49
Total	51	10	61

Of the 61 wells identified no penetrations of the primary seal exist. The deepest well identified within the calculated AoR has a reported total depth of 1,850 ft MD (1,300 TVDss). A detailed list of these wells has been uploaded to the GSDT tool. In addition to the wells identified to be within the AoR, WCS conducted a survey of the available well records for the region. Based upon the data collected and presented in the tables supplied there are no penetrations of the primary seal within 4 miles of either injection well.

Information concerning the faults and fractures and their spatial relation to the injection wells is discussed the FAULTS and FRACTURES section of this document.

Data concerning the regional geology, primary seal thickness and lateral extent, injection zone thickness and lateral extent and other site-specific geologic characteristics is discussed in the INJECTION and CONFING ZONE DETAILS of this document.
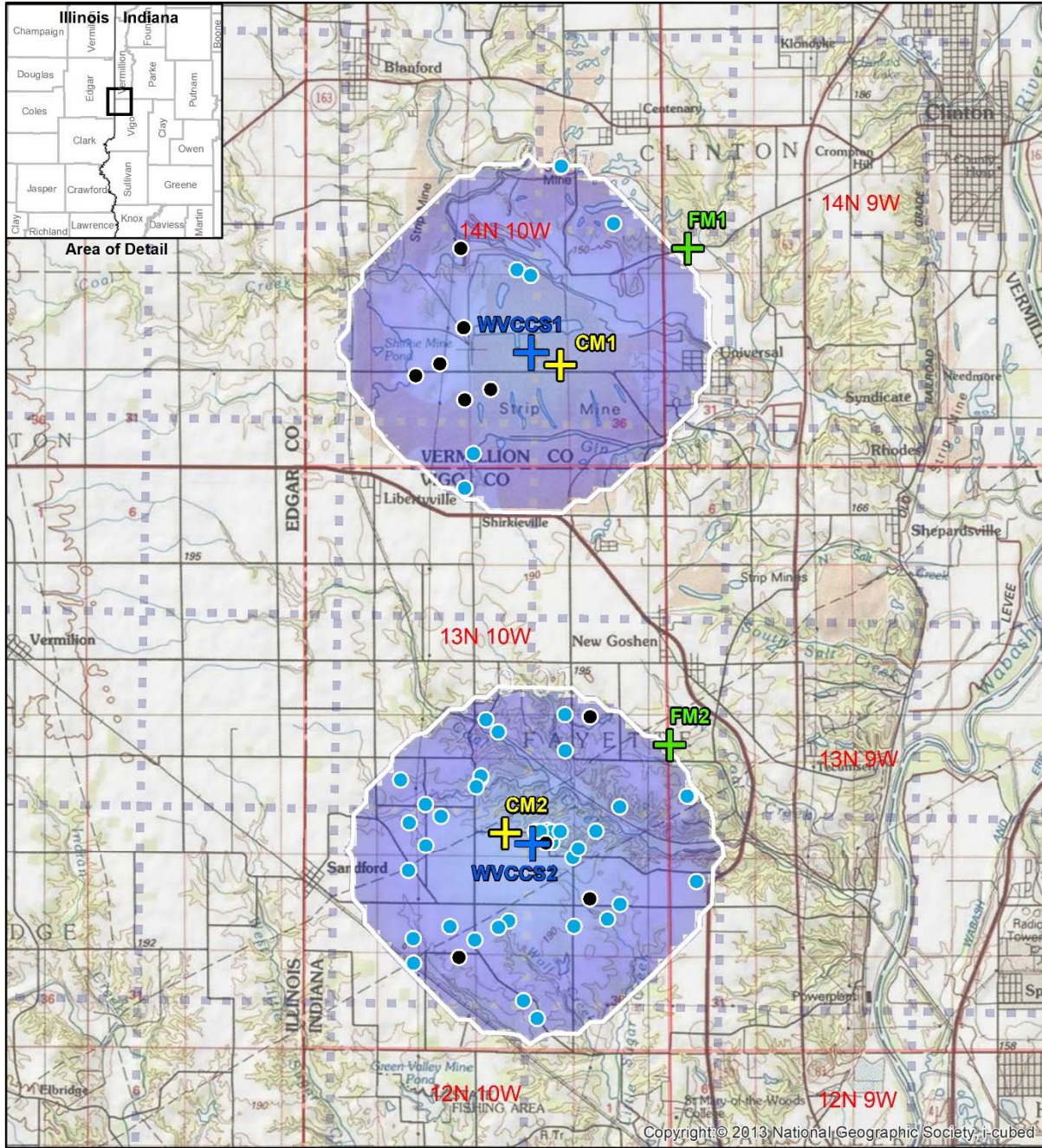
Figure 9 Water and Oil/Gas wells located within the Area of Review (AoR). Well data are from Indiana Department of Natural Resources and Indiana Geological & Water Survey databases. USGS topographic map base shows land surface features, water bodies, and infrastructure through the area.

Faults and Fractures [40 CFR 146.82(a)(3)(ii)]

Evidence for Faults and Fractures

Three 2D seismic reflection profiles were acquired to evaluate structural features and continuity of strata within the Wabash Project Area of Review (AoR) (*Figure 10*). The geologic formation contacts observed in the Wabash #1 well were correlated with the seismic reflections using synthetic seismograms created with sonic and density wireline logs from the Wabash #1 well. The north-south seismic profile (*Figure 11*) shows the correlation of the seismic reflectors with the geologic data acquired from the Wabash #1 well. The seismic reflection data is relatively noisy (high signal to noise ratio) due to near-surface conditions.

The only resolvable faults in the AoR occur in the Precambrian and lower Mt. Simon Sandstone as shown on seismic line 2000 in the circled area (*Figure 12* and *Figure 13*). Figure 12 shows a three-dimensional perspective of the well and seismic data within the Mt. Simon Sandstone. The faults appear to be related to Precambrian structures and terminate within the lower Mt. Simon Sandstone. The northernmost seismic profile WVR 2 has no indication of faulting above the Precambrian (*Figure 14*).

There are no identified faults that transect the Potosi reservoir or in overlying confining units. There is no specific Potosi Dolomite seismic reflector as the 20-foot (6 m) thick, porous Potosi reservoir interval was not resolvable on the seismic data collected. However, there are no faults observed within this sedimentary package including the strata directly overlying or underlying the proposed reservoir.

A Formation Micro Imager (FMI) log acquired in Wabash #1 from the Maquoketa Group to the Oneota Dolomite interval (it did not extend into the Potosi Dolomite) provides information regarding smaller-scale fracturing in the stratigraphic succession above the Potosi Dolomite. In general, the strata have irregular to isolated fractures, with no distinct indication of interconnectedness. Fracture orientations broadly trend along N-NE and S-SW orientations, with dips of 45 degrees or greater.

There were no observed fractures within the upper half of the Maquoketa Group (Brainard Shale) at the Wabash #1 well. The lower portion of the Maquoketa Group (Scales Shale) has occasional fractures on the order of 6 inches or less in visible length which are commonly not connected and occur 1 to 2 ft apart vertically. The bulk of the fractures were interpreted as resistive (closed/healed), although a lesser number were interpreted as conductive (open).

The strata including the Trenton Limestone, Black River Group, and Joachim Dolomite and Dutchtown Formations show some localized fractures that are interspersed with unfractured intervals that may exceed 100 ft in thickness. Fractures in these Ordovician strata tend to terminate at bed boundaries.

Some isolated fractures were observed within the Shakopee Dolomite. In the upper Shakopee, the fractures are relatively short and tend to be confined to individual beds separated by relatively thick non-fractured beds. In the lower part of the Shakopee, the fractures tend to be more numerous and throughgoing (i.e., cutting across multiple beds). The Oneota Dolomite

(above the Potosi Dolomite) is exhibiting more fractures than the Shakopee, but the fractured intervals are separated by non-fractured beds.

Core collected from the Wabash #1 well (61 ft) from the Maquoketa Group exhibited some fractures in the boxed core as examined. Nearly all the fractures are clearly drilling- or handling-induced, based on morphological features such as hackle marks or bullet-shaped "impact marks." Only a few fracture planes do not show drilling-induced fracture patterns; these planar, vertical fractures are not cemented and can extend for several feet. However, artificial fracture initiation in the calcareous shale may have occurred preferentially, along possible pre-existing planes of weakness, producing full core width fractures. Evidence of in situ fracturing was not observed at these depths on the FMI log indicating the bulk of fractures observed are due to coring or handling during core recovery.

Impact on Containment

There are no faults identified seismically in the AoR that transect the storage complex in the Potosi Dolomite (injection target) overlying confining beds or Maquoketa Shale. Fracturing in strata above the Potosi Dolomite is present in some beds as isolated or irregular features without any indication of interconnectedness. There are multiple bedding units that do not have fracturing including several of over 100 ft. The lack of faulting or fracture network in the storage complex indicates containment is not compromised by natural structural features.

Tectonic Stability

The termination of faults in the lower Mt. Simon Sandstone, consistency of stratigraphic thicknesses, and lateral continuity of strata in the AoR suggests there has been no significant active faulting since the early Cambrian period. Basin subsidence continued through the Paleozoic but without apparent reactivation of existing faults. The difference in salinity of hydro-stratigraphic units in the region also supports the lack of any cross-formational migration of fluids and supports a demonstration of hydraulic containment in the stratigraphic succession of the AoR.
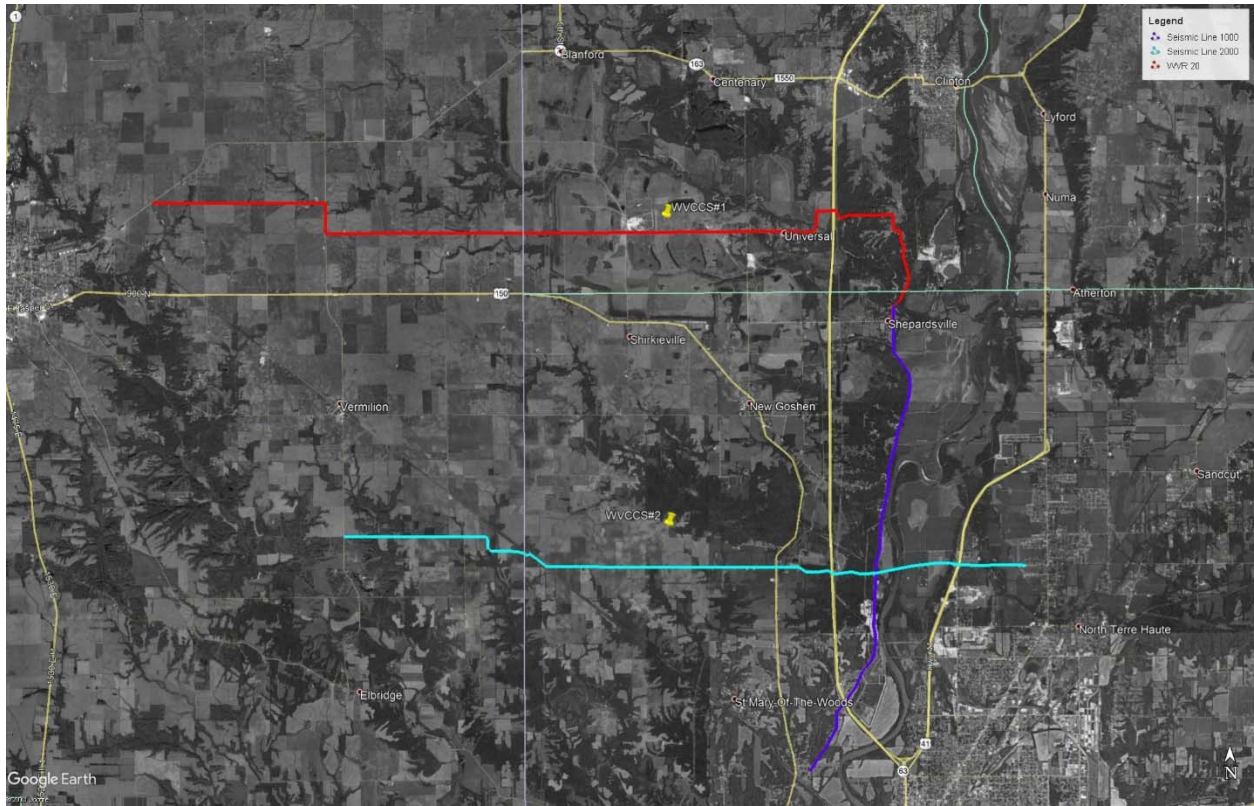
Figure 10. Base map of the Wabash area showing the location of the seismic reflection profiles, injection wells and major roads
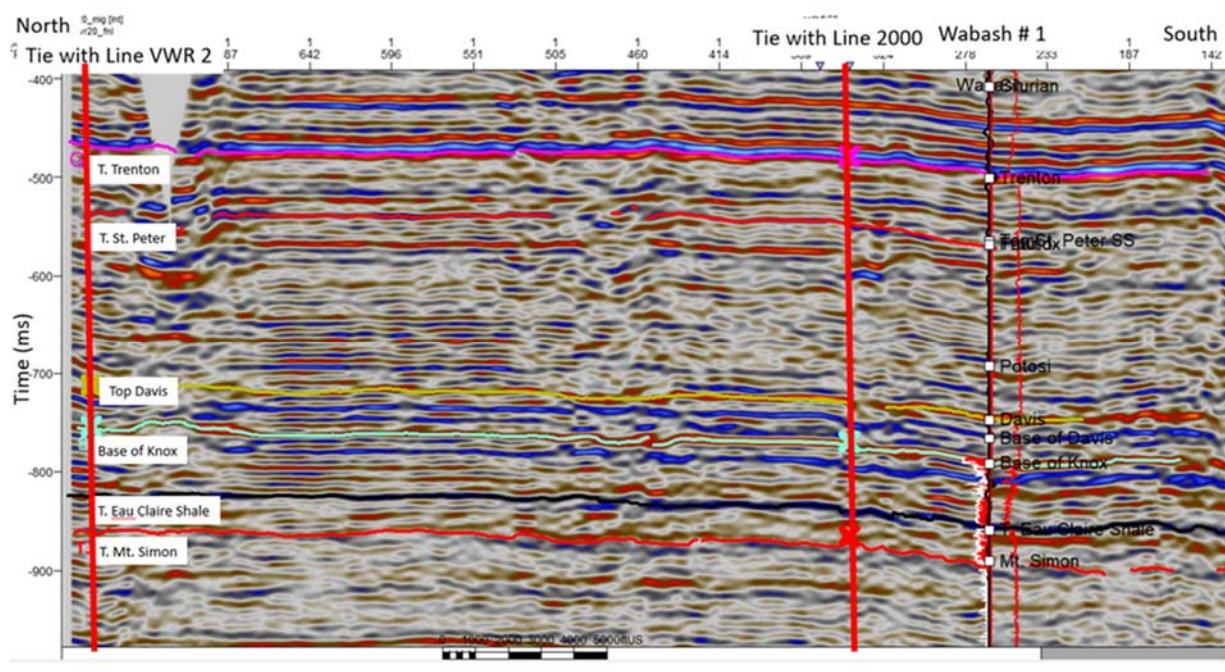

Figure 11. Line 1000 showing correlation of the Wabash #1 with the seismic reflection data. It is difficult to follow the different reflectors across the seismic profile.
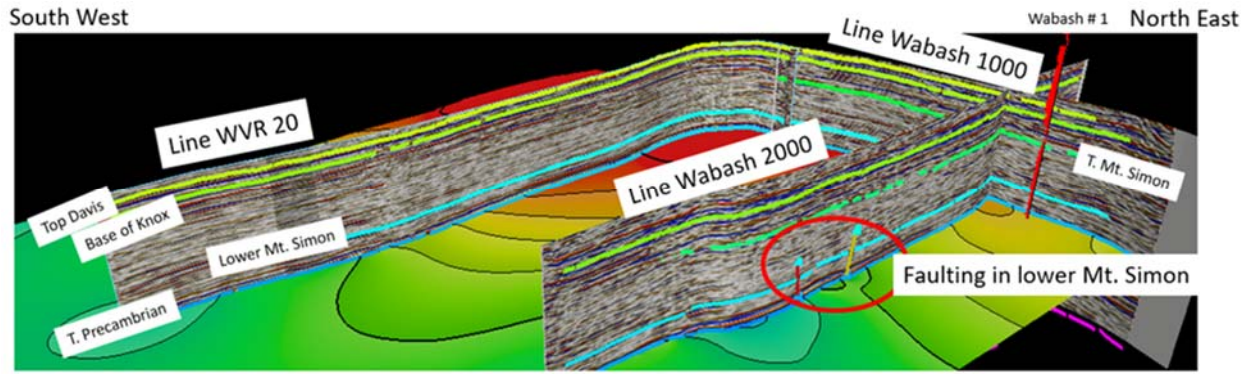
Figure 12. Three-dimensional view of the Precambrian through the Eau Claire formation. The basal surface is the top of the Precambrian correlated from the three seismic lines. The circle on Wabash 2000 is the area with faulting in the lower Mt. Simon and Precambrian
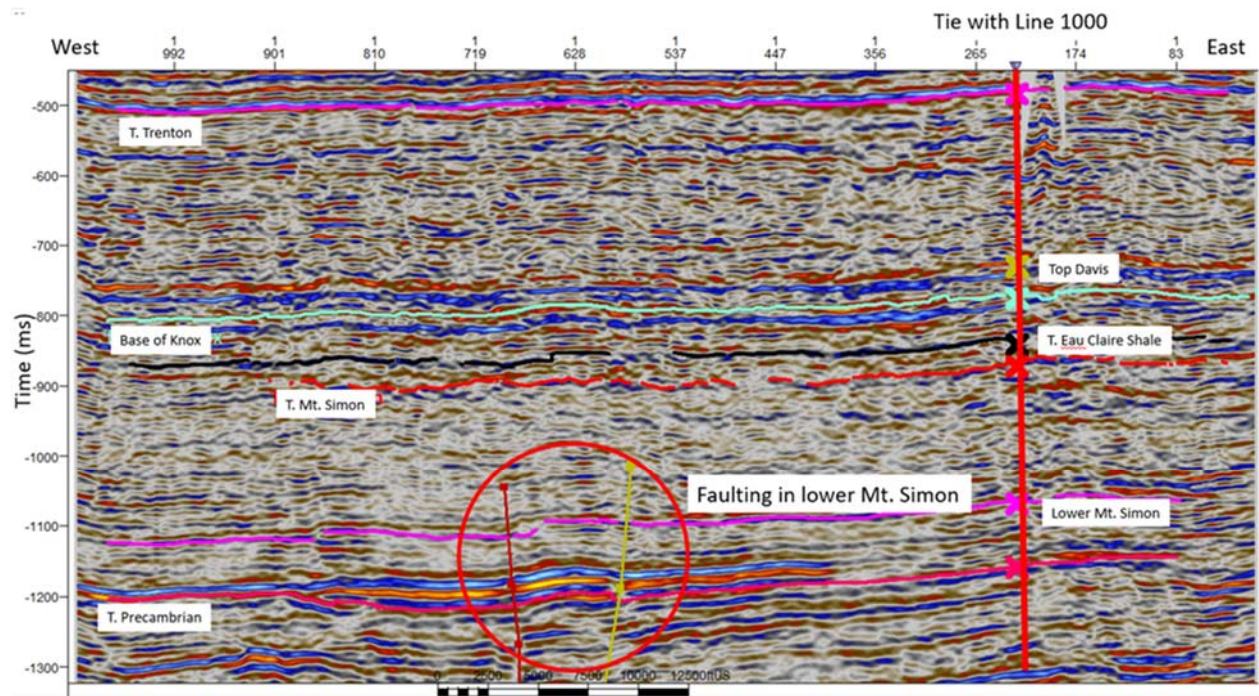
Figure 13. Seismic line 2000 showing faulting in the lower Mt. Simon Sandstone and Precambrian. The interpreted faults do not appear to penetrate through the Eau Claire shale.
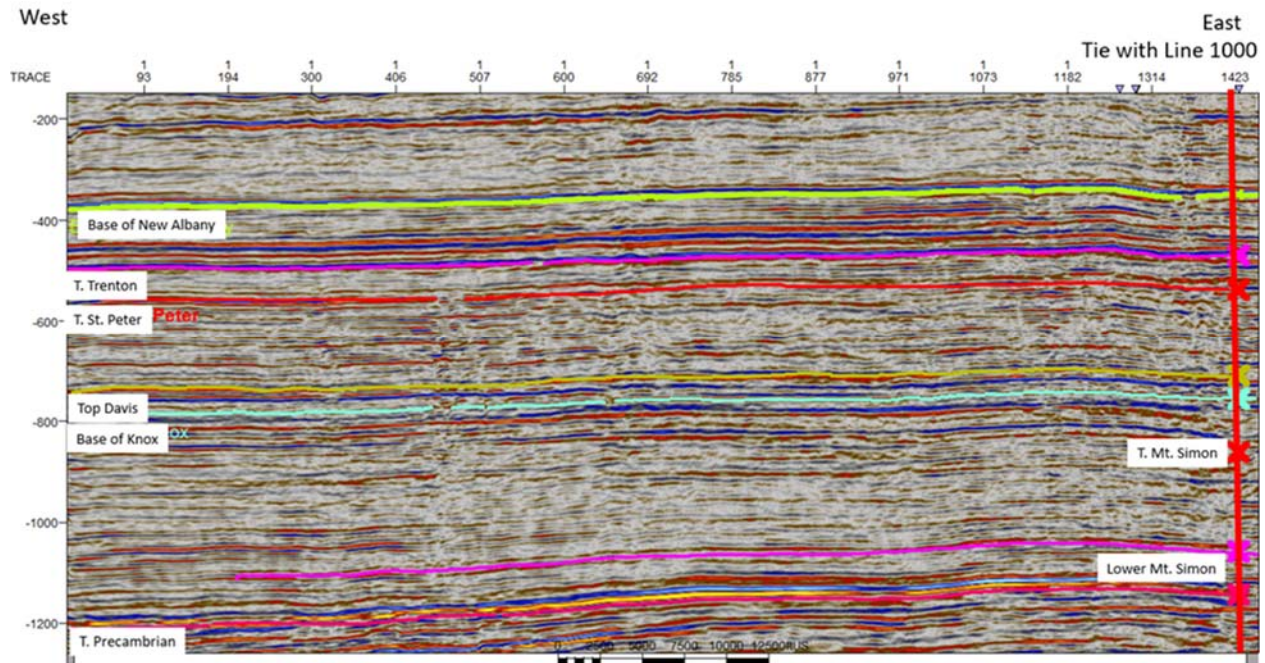
Figure 14. Line WVR line illustrating the stratigraphy and structure in the Ordovician and Cambrian strata. No resolvable faults were observed on this line.

Injection and Confining Zone Details [40 CFR 146.82(a)(3)(iii)]

Depth, areal extent, and thickness of the injection and confining zones

Stratigraphic units that comprise the confining zone for the Potosi dolomite injection interval are cumulatively over 1,900 ft thick and their individual thicknesses and depths are shown in Table 4. All the zones listed in Table 4 contain strata that exhibit characteristics for effective restriction of vertical movement of fluids through negligible permeabilities. The thick shale intervals, however, are considered the most effective seals within this package because these shales are more ductile, have less tendency to fracture and have extremely low vertical permeabilities. The Shakopee dolomite with over 100 ft of shale and the Dutchtown Limestone with over 70 ft of shale are part of the larger geologic group that is considered the Confining Layer that greatly reduces the vertical mobility of the CO_2. The Maquoketa Group has 312 ft of shale and is the primary seal for the Potosi Dolomite injection interval. The thickness and the depth of the Potosi Dolomite that contains the injection zones is provided in Table 5.

The confining and injection zones were identified and located based on downhole wireline logs recovered from the Wabash #1 well (*Figure 15*) and from regional geologic knowledge. The injection zone and confining units have a broad areal extent, well beyond the limits of the study area, based on regional geologic information as discussed in greater detail below. Note that Illinois Basin stratigraphic nomenclature is discussed in the Section entitled REGIONAL GEOLOGY, HYDROGEOLOGY, AND LOCAL STRUCTURAL GEOLOGY, and the names of some regionally extensive units change across the Illinois and Indiana state line boundaries. To be consistent with previous log analysis and reservoir simulation work in Illinois and

throughout the Illinois Basin, the Illinois stratigraphic names will be used preferentially when discussing details about the injection zone, confining zone, and reservoir simulation related to the determination of the Area of Review (AoR).

Variability in thickness of the injection and confining zones within the AoR

The confining zone and the injection zone are present within the AoR as indicated by geological and geophysical data. Regional cross sections show lateral continuity of injection and confining strata across 10's to 100's of miles, with a slight thinning to the east (*Figure 16*) and north (*Figure 17*). Seismic reflection data suggest that within the AoR there is negligible thinning of the confining and injection formations. Thus, thickness variations in confining beds or injection zones will have negligible impact on storage and containment at this site. Seismic reflection data indicate that there are no faults penetrating the confining zones within the AoR.

Injection and confining zone properties

Petrophysical analyses of geophysical logs obtained at the Wabash #1 well are the primary method of determining injection and confining zone properties. A detailed suite of geophysical logs collected in this well permit a continuous evaluation of mineralogical, lithological, and petrophysical characteristics across the injection formation and confining zones. *In situ* well tests were additionally conducted in the Potosi Dolomite injection zone to determine injectivity characteristics. Core samples and rock cuttings are also available for the Maquoketa Group.

Potosi Dolomite well testing

A 20 ft interval (4,505-4,525 ft MD) in the Wabash #1 well was perforated and a series of tests were completed in the Potosi Dolomite. Step rate tests (SRT) were used to estimate fracture gradient. Pressure falloff (PFO) tests were used to estimate permeability, initial pressure, and large-scale geologic features. Multi-rate tests (MRT) were used to estimate permeability. All tests used freshwater as the injection fluid.

An early in situ well test at Wabash #1 provided a permeability value of 2,400 md (millidarcy) for an injection unit within the Potosi Dolomite (24,000 md-ft over 10 ft). Subsequent, longer well testing indicated much higher permeabilities of 45,000 md or greater exist within the Potosi Dolomite. The low permeability value of 2,400 md was used in the present dynamic simulation of CO_2 injection into the Potosi Dolomite. For regional comparison, a Class I well using the Potosi for waste injection near Tuscola, IL, approximately 50 miles west-northwest of the Wabash location, has a permeability of 9,600 md (Texas World Operation, 1995).

Permeability estimation

The permeabilities of the Potosi Dolomite and overlying rocks were estimated using well test data, geophysical well logs, and the method of Lucia (1995; 2007) that links rock fabrics to petrophysical properties. Using Lucia's method, carbonates of the Potosi Dolomite and overlying strata were categorized into three classes (*Figure 18*). The petrophysical classes were initially characterized using core and thin section studies from wells at Decatur, Illinois, then calibrated with well logs from Wabash #1. The equations for estimating the permeability from porosity logs for each petrophysical class are as follows:

Class 1:

$$K = (45.35 \times 10^8) \times \phi_{ip}^{\,8.537}$$

Class 2:

$$K = (1.595 \times 10^5) \times \phi_{ip}^{\,5.184}$$

Class 3:

$$K = (2.884 \times 10^3) \times \phi_{ip}^{\,4.275}$$

Where K = md, ϕ_{ip} = fractional porosity

Permeability estimates of the shale intervals within the Shakopee Dolomite, Dutchtown Limestone and Maquoketa Group were based on routine core analyses results derived from correlative intervals at the Tuscola, Illinois, site which used the Potosi reservoir as the injection zone.

The geophysical log data (porosity and permeability) was scaled-up along the vertical well path to populate grid cells in the 3-D static geological model. The arithmetic method was used for averaging porosity data, and the geometric method was used to average permeability data.

Mineralogy and petrology of the injection and confining zones

Wabash #1 Petrophysical Analysis

Lithologic properties of the injection zone, Potosi Dolomite, and confining zones (Shakopee Dolomite, St. Peter Sandstone, Dutchtown Formation, Platteville Group, Trenton Limestone, and Maquoketa Group (primary seal)) were determined using standard geophysical log analysis techniques from logs obtained at the Wabash #1 well. Measurements of bulk density, neutron porosity, photoelectric (Pe) and acoustic transit time (sonic) were used to estimate matrix density and total porosity. Lithology and porosity range were identified and qualitatively interpreted from neutron-density, Pe-density, and M-N cross plots. The M-N cross plot is based up on the ratio of the porosity data obtained from Sonic and Density logs and the ratio of porosity obtained from the Neutron and Density logs (used to detect the secondary porosity development and provide mineral composition information). The gamma-ray log was used to identify shale intervals.

Potosi Dolomite at the proposed injection interval

The **Potosi Dolomite** is a fine to coarsely crystalline, commonly dense, dolomite, but contains characteristic drusy quartz and intercalations of vugular, brecciated, fractured and/or cavernous intervals. Petrophysical analysis of the wireline log data suggest that only a few intervals in the Potosi Dolomite are porous and permeable. In the Wabash #1 well, there are a total of six porous intervals in the Potosi that range from up to about 20 feet for the tested interval to less than 5 feet in thickness. The evaluation of the 20-foot test interval in Wabash #1 wireline log data (*Figure 19*) shows the zone to be primarily dolomite and quartz (*Figure 20*). The neutron-density porosity in

the tested interval is estimated to be over 30 percent with a permeability determined through well testing of potentially greater than 45,000 md.

The top of the Potosi Dolomite is very difficult to identify using wireline logs. For our petrophysical analysis and reservoir simulation, the top of the Potosi Dolomite is the first porous and permeable interval below the Oneota Dolomite. Note that the top of the Potosi Dolomite in the reservoir simulation model and log interpretations used in static modeling may differ from the top of the Potosi Dolomite as shown in regional map and cross sections.

Overlying and Confining Units

The ***Oneota Dolomite*** consists predominantly of fine-to medium-grained dolomite but includes chert and, particularly near its base in some places, sporadic quartz sand and thin interbeds of green shale. In the Wabash #1 well, the Oneota Dolomite is a primarily carbonate with a few interbedded shale intervals as observed with the Gamma-Ray tool (*Figure 21* and *Figure 22*)

The ***Shakopee Dolomite*** of Indiana is a pure to impure and generally very fine grained to fine-grained dolomite containing some chert and interbeds of shale, siltstone, and sandstone (IGWS 2020). In the Wabash #1 well, the Shakopee Dolomite (*Figure 23*, *Figure 24*, and *Figure 25*) is a dolomitic zone with extensive quartz mineralization. In this report the Shakopee Dolomite has been separated into an upper and lower unit. The lower Shakopee Dolomite also has extensive quartz mineralization present and is defined on this log at below 3,700 ft MD (3,200 ft TVDss).

Generally, the ***St. Peter Sandstone*** in Indiana is composed of fine to medium well-rounded and well-sorted frosted grains of quartz that are weakly cemented (Droste, Abdulkareem, and Patton, 1982; Droste, Patton, and Rexroad, 1986). In Wabash #1, the St. Peter Sandstone (*Figure 26* and *Figure 27*) is primarily a quartz rich zone with some dolomitic carbonates. The zone is 28 ft thick in the Wabash #1 well and has very poor porosity with no reservoir characteristics.

The ***Dutchtown Limestone*** is composed generally of light-gray and brown, partly argillaceous dolomite and some interbeds of green shale (IGWS 2020). The Dutchtown Limestone (*Figure 28* and *Figure 29*; *Table 4*) is primarily a shale in this AoR.

The ***Platteville Group*** and ***Trenton Limestone*** are primarily limestones, dolomitized extensively along the axis of the Kankakee Arch in Indiana with the proportion of dolomite decreasing to the south and southeast of the arch (Yoo et al., 2000). In this report the Platteville Group and Trenton Limestone (*Figure 30*, *Figure 31*, and *Figure 32*) are considered as a single confining interval because the rock properties are similar. In this locale, these two formations are primarily a tightly cemented limestones with little to no measured porosity or permeability.

The ***Maquoketa Group*** in Indiana consists principally of shale (about 80 percent); limestone content is minimal throughout most of Indiana but increases prominently in the southeast, so that parts of the group are in places dominantly limestone (IGWS 2020). The Maquoketa Group (*Figure 33*) is the primary seal for the Potosi Dolomite. It is 314 ft thick at the Wabash #1 well (*Table 4*) that has been shown to be a regional confining unit (Panno et. al 2018).

Geochemical reactions

The proposed CO_2 stream will be greater than 99% pure after dehydration and compression. Expected reactions with brine and injection/confining zone rocks (primarily dolomite) are discussed below, and in the GEOCHEMISTRY Section.

Previous Knox Group analyses identified dissolution of dolomite while exposed to supercritical CO_2 and brine, and that dissolution could occur during the early stages of CO_2 injection operations.

Post batch reaction brines sampled from the Maquoketa Group measured elevated aluminum, barium, calcium, potassium, magnesium, sulfur, silicon, and strontium indicative of feldspar, clay, carbonate, and sulfide mineral dissolution. Computational modeling of a 10-year period indicated no major impact on seal integrity. The most significant observable reaction was alteration of K-feldspar to kaolinite and quartz which would not be expected to significantly impact seal porosity. Modeled dissolution of carbonate minerals estimated a 2.2% decrease in mineral volume at most with carbonate mineral dissolution projected to be less in an actual sequestration scenario due to the lower water-to-mineral ratio being a limiting factor to carbonate dissolution. Based on this information the integrity of the Maquoketa Shale confining layer will be stable throughout the injection and post-injection time periods.

Average, and spatial distribution, of porosity and permeability values within the injection and confining zones

Table 4 and Table 5 summarize the porosity and permeability of each zone. The spatial distribution of the collective confining zones and injection zone is assumed to be relatively uniform within the AoR. However, this interpretation is constrained by a lack of nearby data. As discussed above, the rock properties were based on petrophysics and well testing within the Potosi Dolomite at the Wabash #1 well.

Estimated storage capacity and injectivity of the injection zone, and integrity of the confining zone.

Injection into the Potosi Dolomite was simulated using data from the Wabash #1 well and other wells as described above. Injection into two wells (5 miles apart) was simulated, with each well receiving just over 10 million metric tons of CO_2, based on a rate of 2,286 metric tons of CO_2 per day (834,390 metric tons per year) over a 12-year period. See AREA OF REVIEW documentation for further details.

Integrity of the confining zones is further discussed in the FAULTS AND FRACTURES Section. Interpretation of three 2D seismic reflection profiles acquired within the Area of Review suggests that there were no faults penetrating the Potosi reservoir or confining units. A Formation Micro Imager (FMI) log acquired in Wabash #1 from the Maquoketa Group to the Oneota Dolomite interval (it did not extend into the Potosi Dolomite) shows that, in general, the strata have irregular to isolated fractures, with no distinct indication of interconnectedness.

Additional information required to further characterize the primary seal, the Maquoketa Group, the formations overlying the injection zone, and the injection zone, the Potosi Dolomite, will be gathered during the construction of the injection wells. As discussed in the PRE-OPERATIONAL TESTING PLAN submitted to the GSDT tool, a complete suite of wireline logs, in-situ testing and full core samples will be performed. Whole cores of the Maquoketa, Shakopee and Potosi will be collected and analyzed. Some uncertainty exists concerning the porosity and permeability of the strata directly overlying the injection zone. The uncertainty will be addressed during the testing and coring activities planned for the construction phase of the injection wells. Table 2 and Table 3 summarize the planned open hole logging that will be performed in both the intermediate and long string sections.

Table 2. Intermediate Section Open Hole Testing

Log Performed	Purpose/Comments
Temperature Log	Formation Temperature Profile
1-Arm and 4-Arm Caliper	Bore Hole Diameter/Volume/Condition
Directional Survey	Bore Hole Verticality
Induction	• Characterize basic geology (lithology, mineralogy, porosity, permeability)
Neutron	
Density	
Gamma Ray	
Microlog	
Spontaneous Potential	
Mud Resistivity	
Natural Gamma Ray Spectroscopy	• Enhanced characterization of geologic and geomechanical properties that control injectivity and confining zone/seal integrity
Elemental Spectroscopy	
Formation Micro Imager (FMI)	
Magnetic Resonance	• Dipole Sonic log will also provide data to calibrate surface seismic
Dipole Sonic	
Vertical Seismic Profile (VSP)	• Provide formation depth data and allow refinement of existing 2D and future 3D seismic testing plans

Table 3. Long String Open Hole Testing

Log Performed	Purpose/Comments
Temperature Log	Formation Temperature Profile
1-Arm and 4-Arm Caliper	Bore Hole Diameter/Volume/Condition
Directional Survey	Bore Hole Verticality
Induction	• Characterize basic geology (lithology, mineralogy, porosity, permeability)
Neutron	
Density	
Gamma Ray	
Microlog	
Spontaneous Potential	
Mud Resistivity	
Natural Gamma Ray Spectroscopy	• Enhanced characterization of geologic and geomechanical properties that control injectivity and confining zone/seal integrity
Elemental Spectroscopy	
Formation Micro Imager (FMI)	
Magnetic Resonance	• Dipole Sonic log will also provide data to calibrate surface seismic
Dipole Sonic	
Quantitative ELAN	
Vertical Seismic Profile (VSP)	• Provide formation depth data and allow refinement of existing 2D and future 3D seismic testing plans

Table 4 List of significant confining intervals above the Potosi Dolomite injection zone within the Wabash Area of Review, as identified in the Wabash #1 well. Note that the names of some regionally extensive units change across the Illinois and Indiana state line. For the purpose of being consistent with previous log analysis and reservoir simulation work in Illinois and throughout

the Illinois Basin, the Illinois stratigraphic names will be used preferentially (and/or in shortened notation) here and in subsequent figures.

Confining Zone	Formation Thickness (ft)	Depth MD (ft)	Avg. Porosity (%)	Avg. Permeability (mD)	Shale Thickness (ft)
Maquoketa Group	314	2,386	3.0	0.0001	312
Trenton Limestone	163	2,700	1.3	0.00000273	3.5
Platteville Group	379	2,863	1.2	0.00000475	16
Dutchtown Limestone	84	3,242	2.8	0.0000840	70.5
St. Peter Sandstone	28	3,326	4.0	0.0039	3.5
Shakopee Dolomite (upper)	346	3,354	2.8	0.022360406	101
Shakopee Dolomite (lower)	270	3,700	9.1	0.098032	71
Oneota Dolomite	408	3,970	7.1	2.585488	15

Table 5 Proposed formation for injection reservoir at the Wabash project area, as identified in the Wabash #1 well.

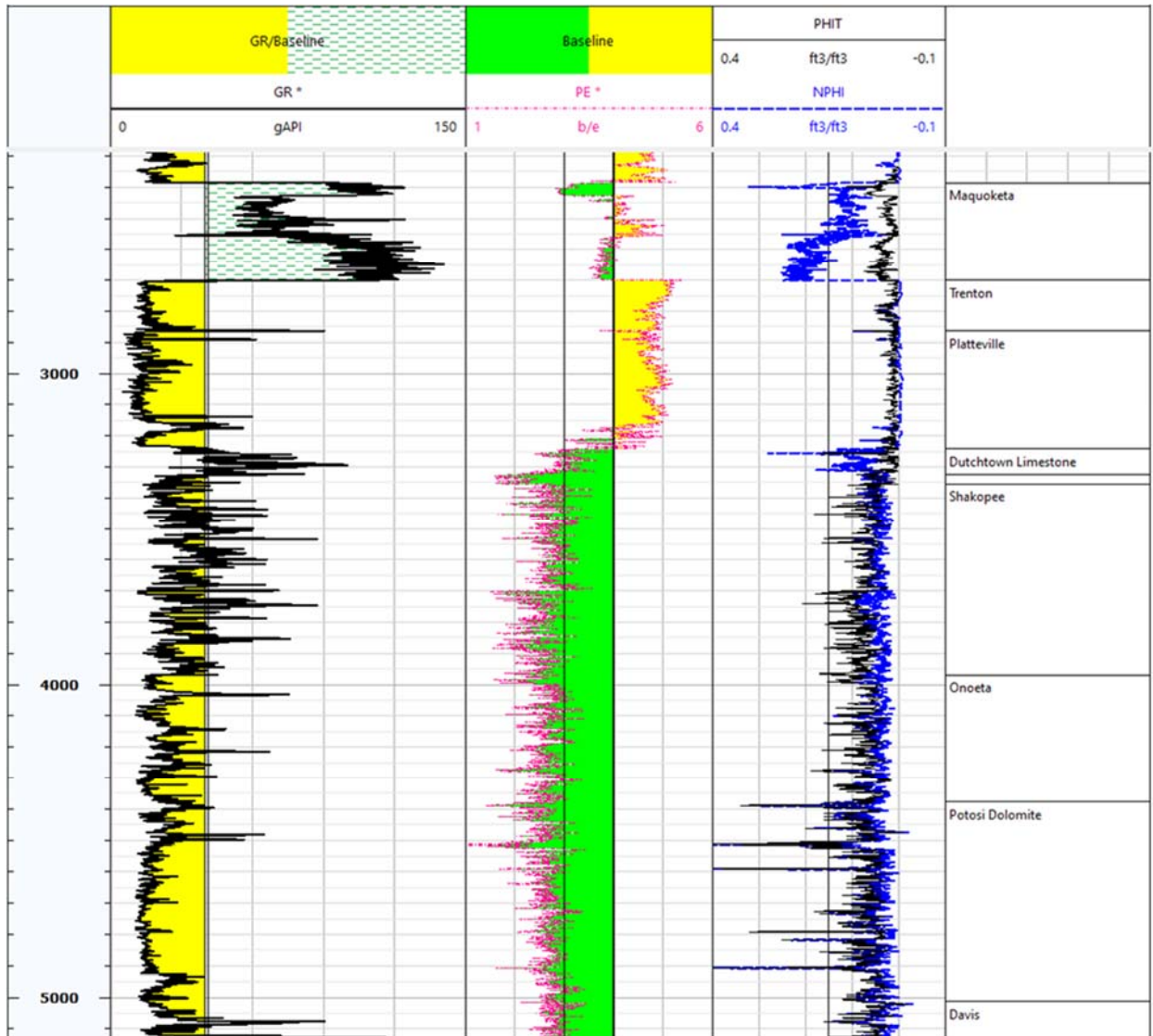| Injection reservoir	Formation Thickness (ft)	Depth MD (ft)	Avg. Porosity %	Avg. Permeability mD	Reservoir Thickness (ft)
Potosi Dolomite	784	4378	30 for tested interval (4,505 to 4,525 ft)	24,000 md-ft over 10 ft (2,400 md) from early short well test* Later and longer well tests suggest 45,000 md or higher.	Total of 149.5 ft greater than 10% porosity

Figure 15 Geophysical log of the Cambro-Ordovician rocks from Davis Formation through Maquoketa Group, Wabash #1 Well, Vigo County, Indiana. The St. Peter Sandstone is not labeled in this figure but is represented in the relatively thin zone above the Shakopee Dolomite.
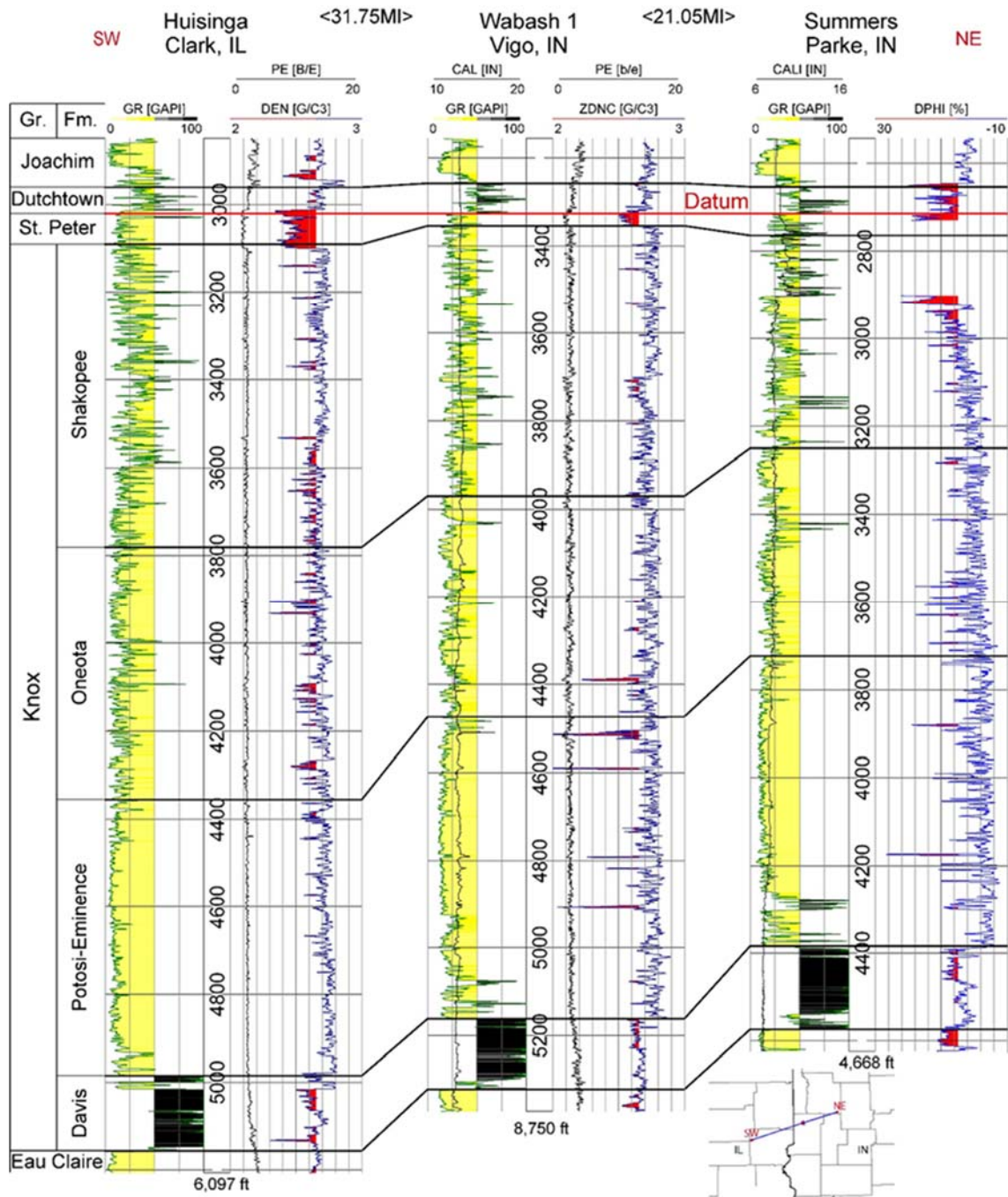
Figure 16 Southwest-northeast correlation of the units in the upper part of the Knox Group from east-central Illinois to west-central Indiana. The Dutchtown Limestone through Davis Formation section is shown to thin eastward, over the 53-mile cross section, from approximately 2,250 ft (685 m) thick to 1,900 ft (580 m) thick.
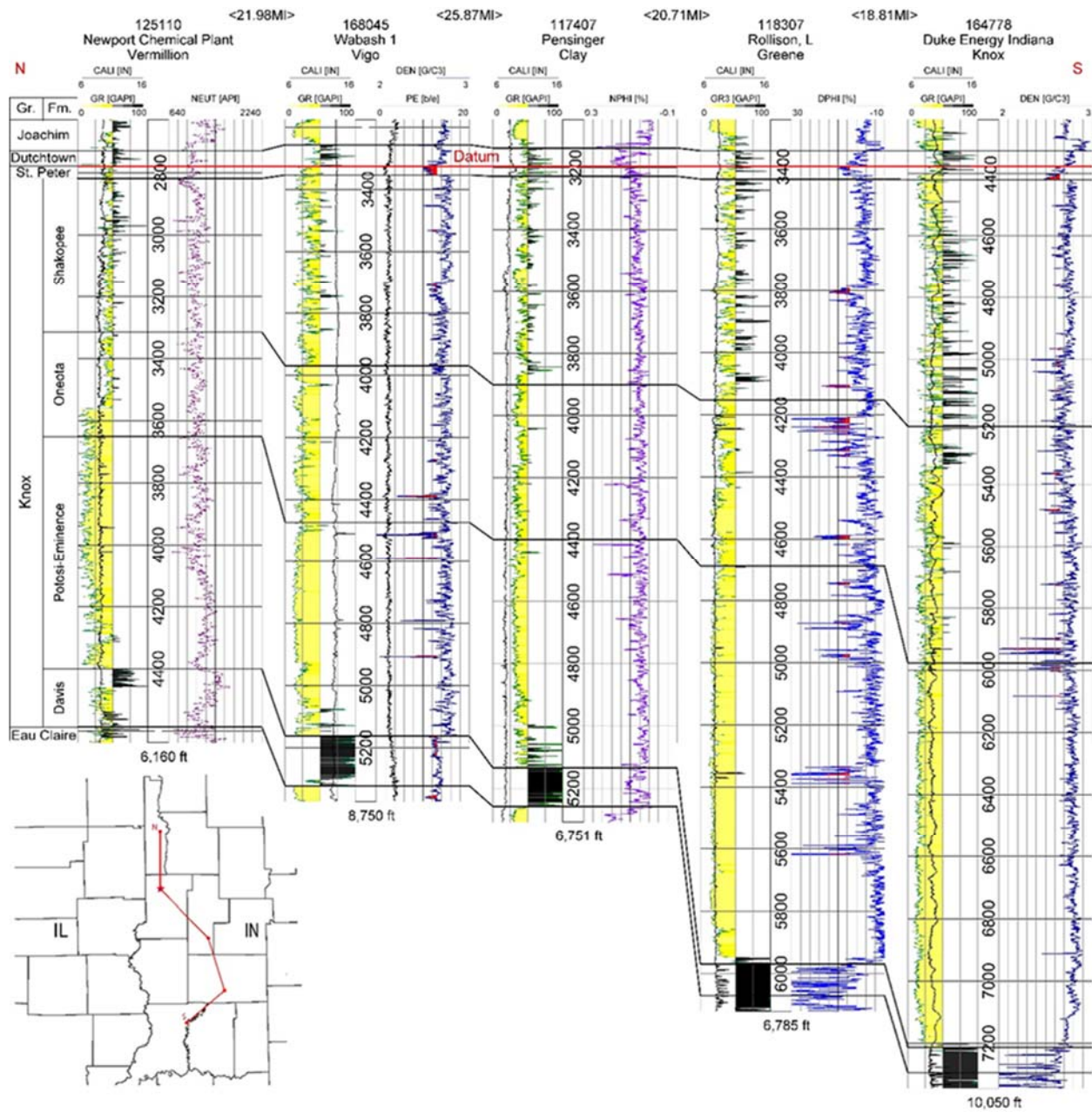
Figure 17 North-south correlation of the units in the upper part of the Knox Group in west-central Indiana. The Dutchtown Limestone through Davis Formation section is shown to thin northward, over the 87-mile cross section, from approximately 2,950 ft (900 m) thick to 1,900 ft (580 m) thick.
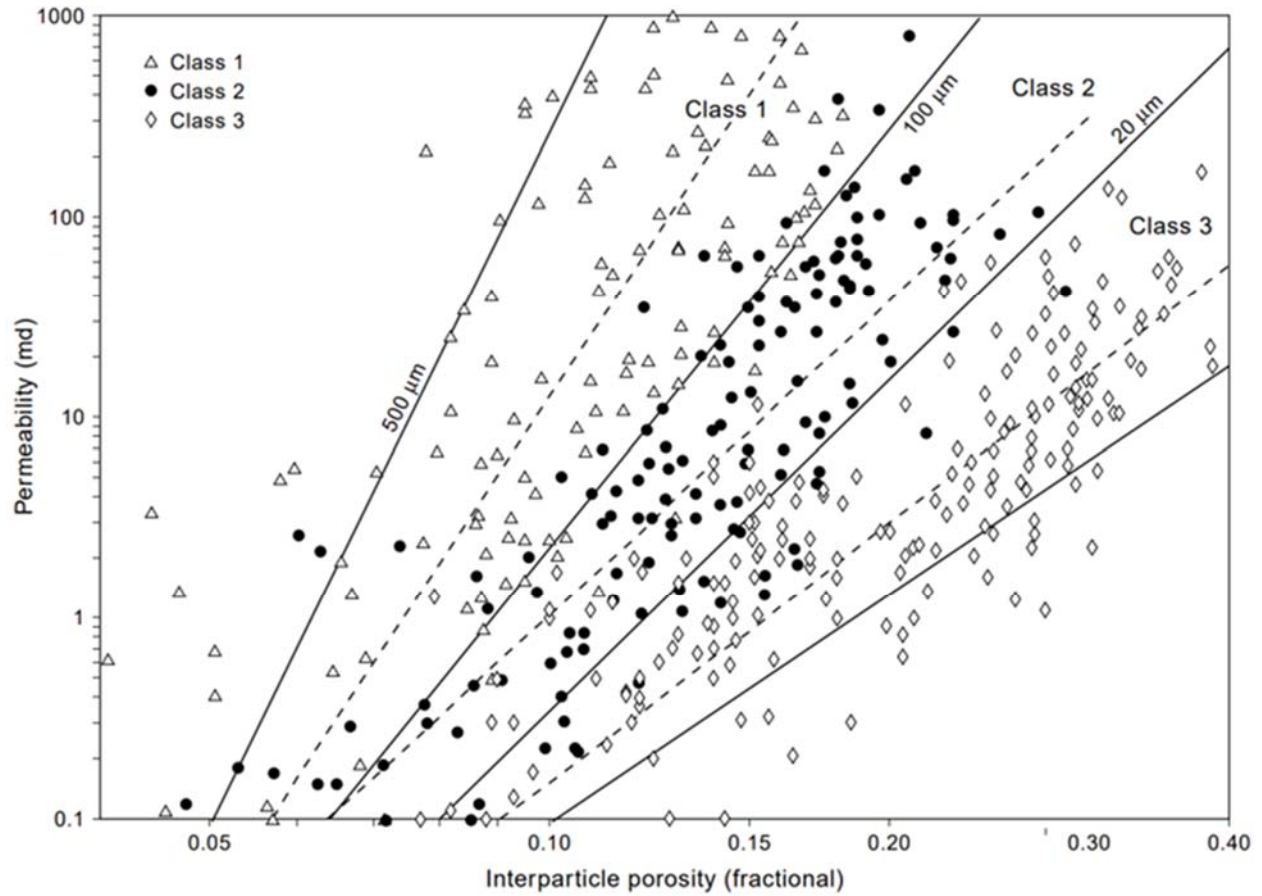
Figure 18 Composite-air permeability cross plot for nonvuggy limestones and dolostones showing statistical reduced-major axis transforms for each class (see text for equations; from Lucia,1995).
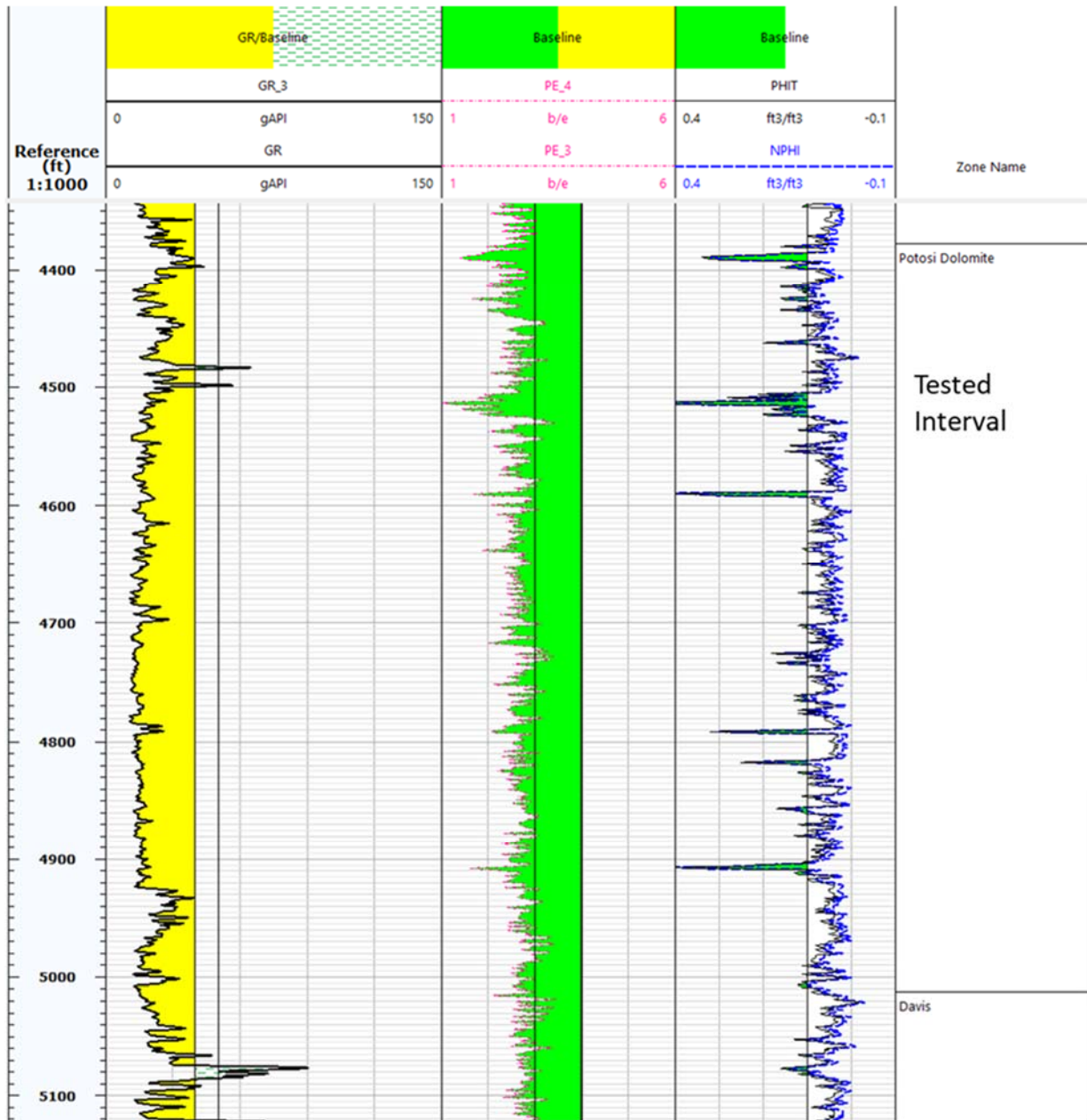
Figure 19. Geophysical log of the Potosi Dolomite in, Wabash #1 Well, Vigo County, Indiana. The green highlighted areas on the right-most porosity column are zones with greater than 10% porosity. Early pressure falloff (PFO) test results were used to estimate 2,400 md (24,000 md-ft over 10 ft) permeability within the tested interval.
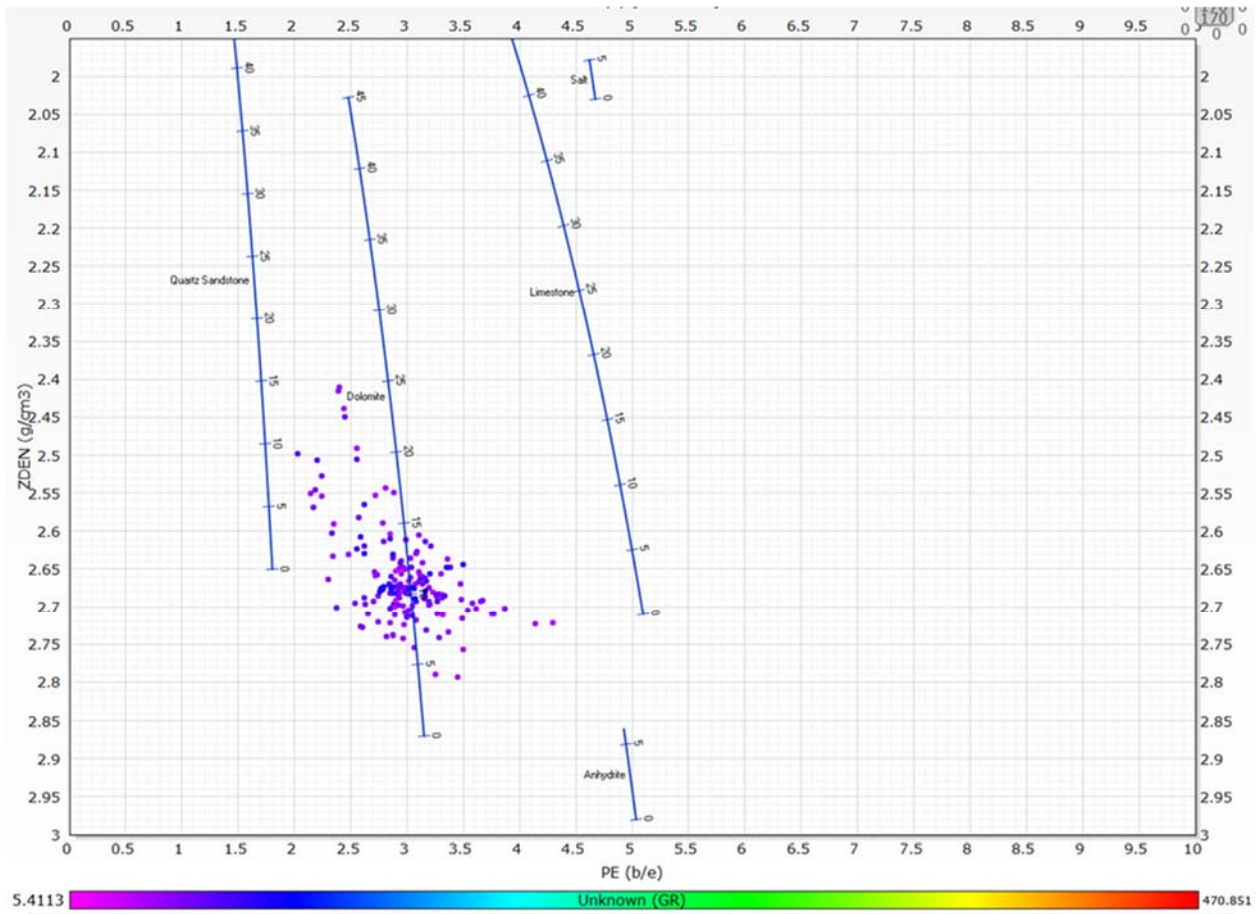
Figure 20. Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Potosi Dolomite tested interval in the Wabash #1 Well, Vigo County, Indiana.
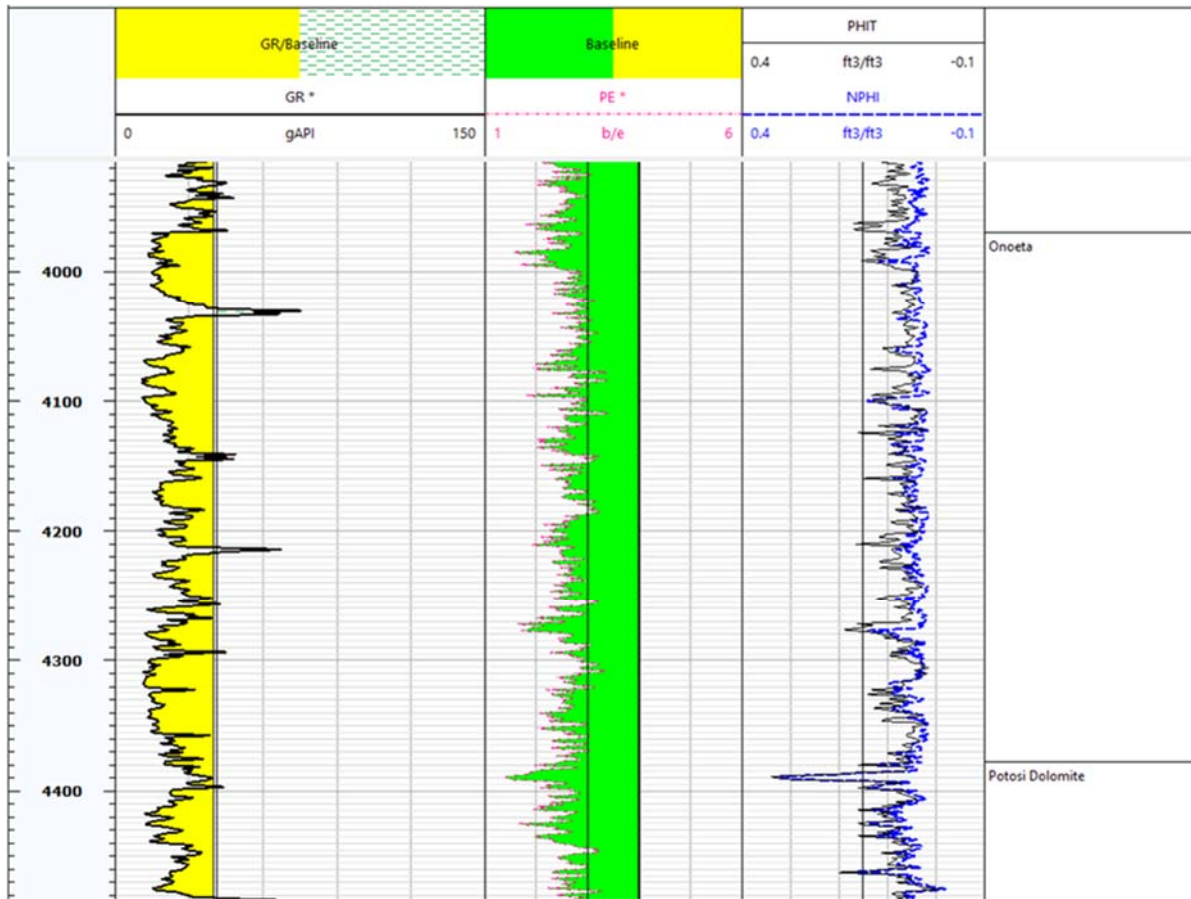
Figure 21 Geophysical log of the Oneota Dolomite in the Wabash #1 Well, Vigo County, Indiana.
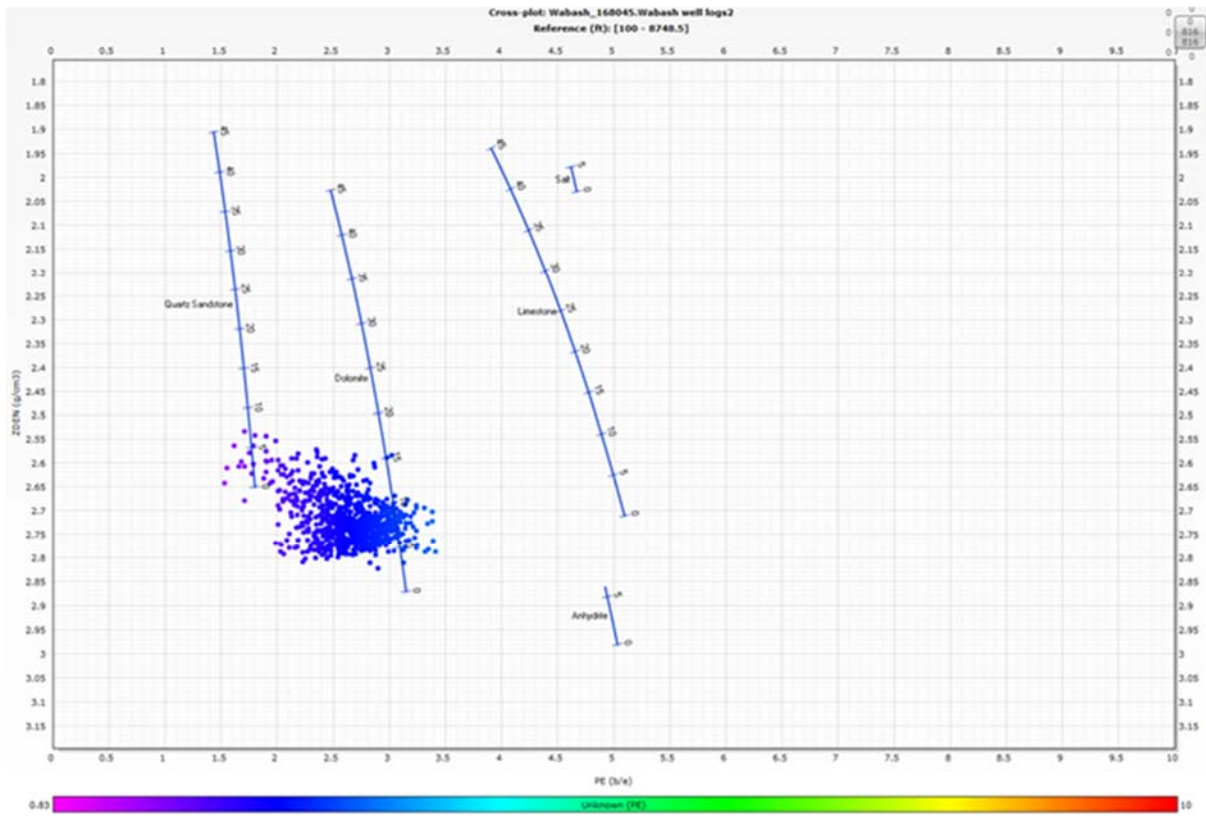
Figure 22 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Oneota Dolomite in the Wabash #1 Well, Vigo County, Indiana.
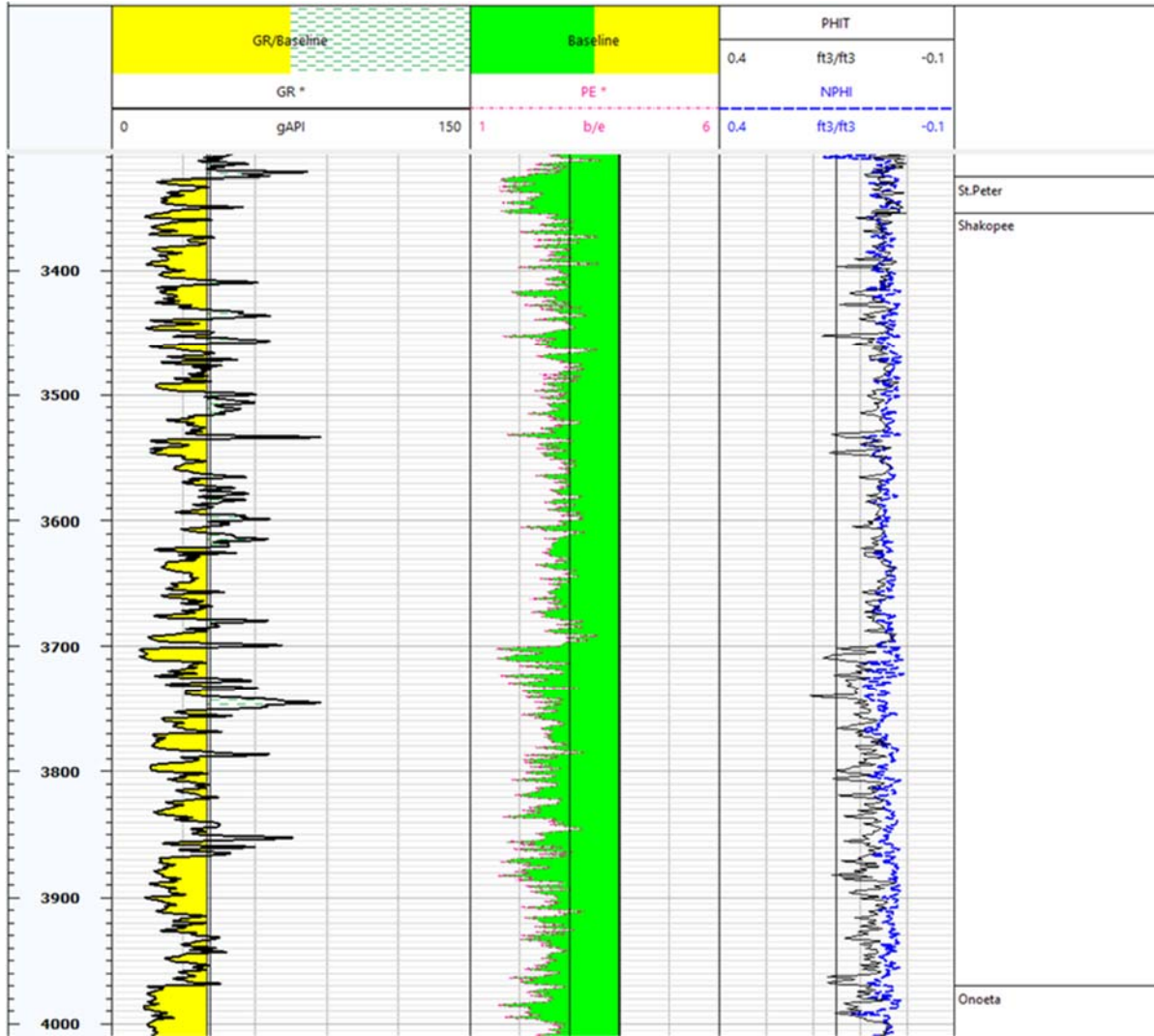
Figure 23 Geophysical log of the Shakopee Dolomite in the Wabash #1 Well, Vigo County, Indiana. Below 3,700 ft the Shakopee Dolomite becomes more quartz rich as can be observed on the PE curve.
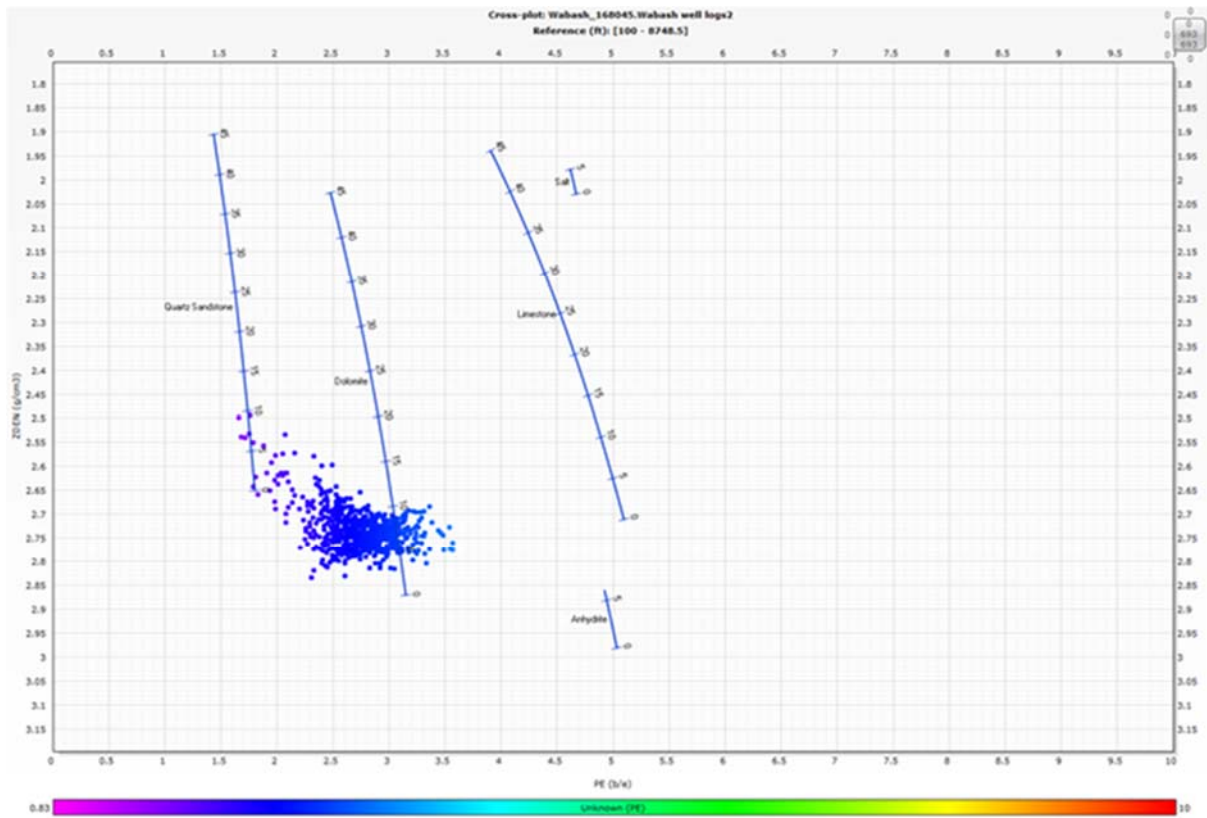
Figure 24 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the lower Shakopee Dolomite in the Wabash #1 Well, Vigo County, Indiana.
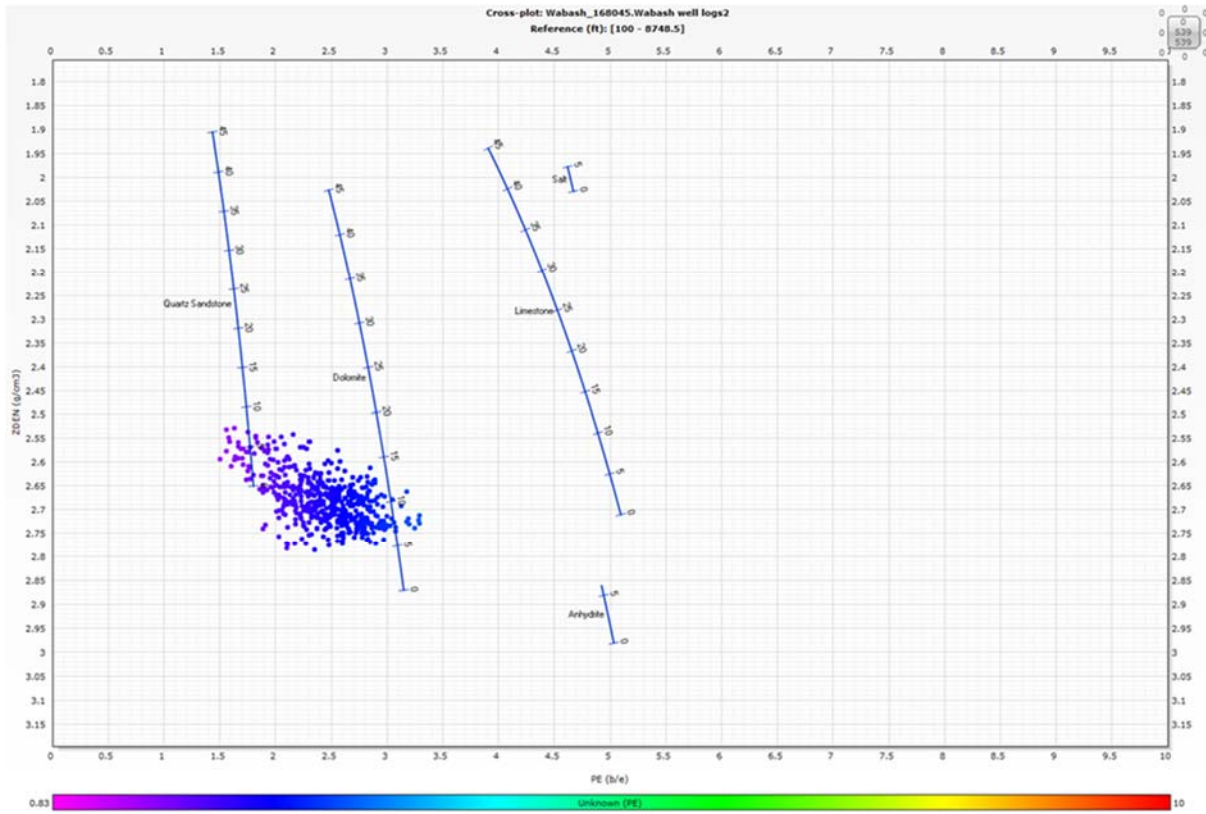
Figure 25 Cross Plot of the density measurements compared with the Pecurve. This plot shows the prorosity and lithology of the upper Shakopee Dolomite in the Wabash #1 Well, Vigo County, IN
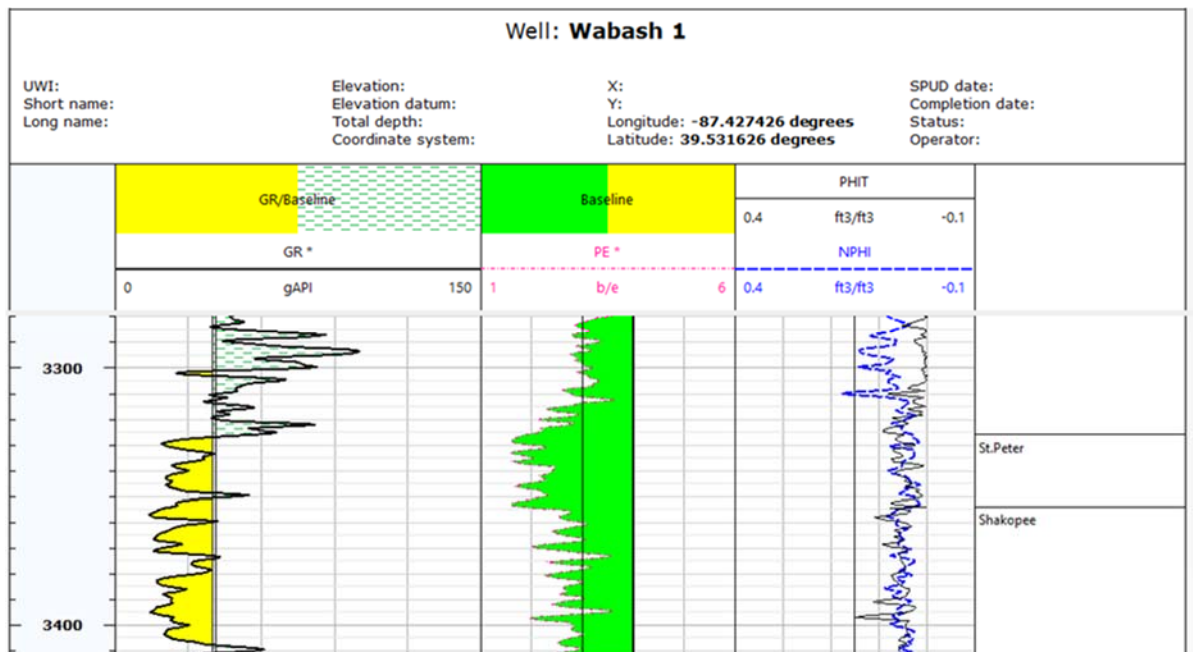
Figure 26 Geophysical log of the St. Peter Sandstone in the Wabash #1 Well, Vigo County, Indiana.
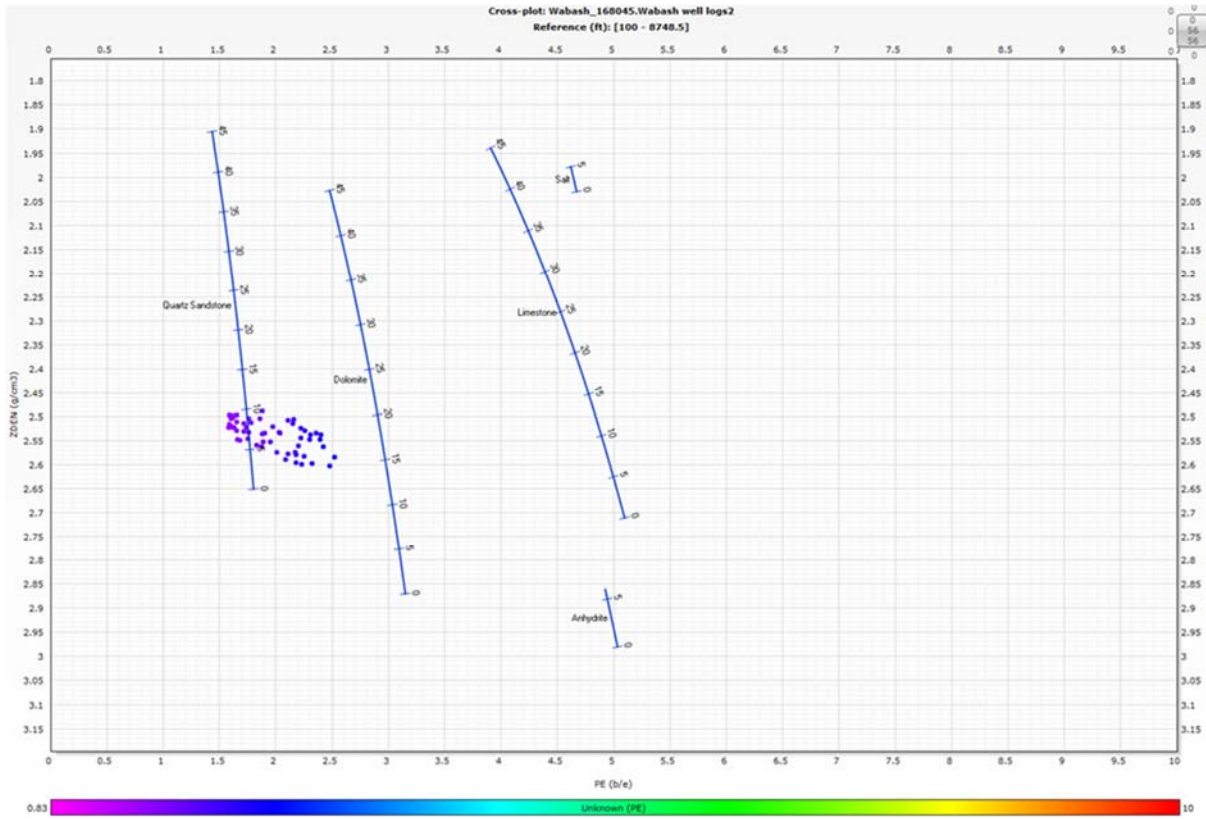
Figure 27 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the St. Peter Sandstone in the Wabash #1 Well, Vigo County, Indiana.
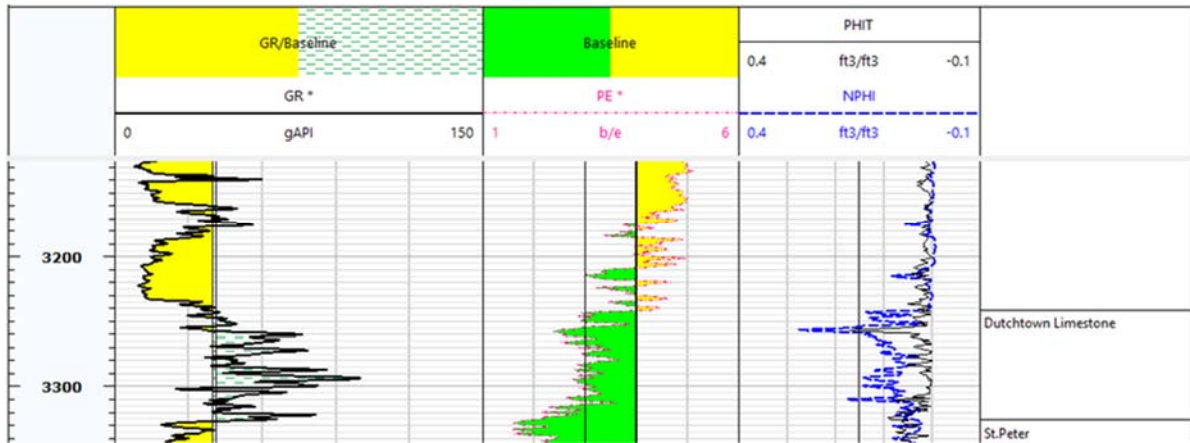
Figure 28 Geophysical log of the Dutchtown Limestone in the Wabash #1 Well, Vigo County, Indiana.
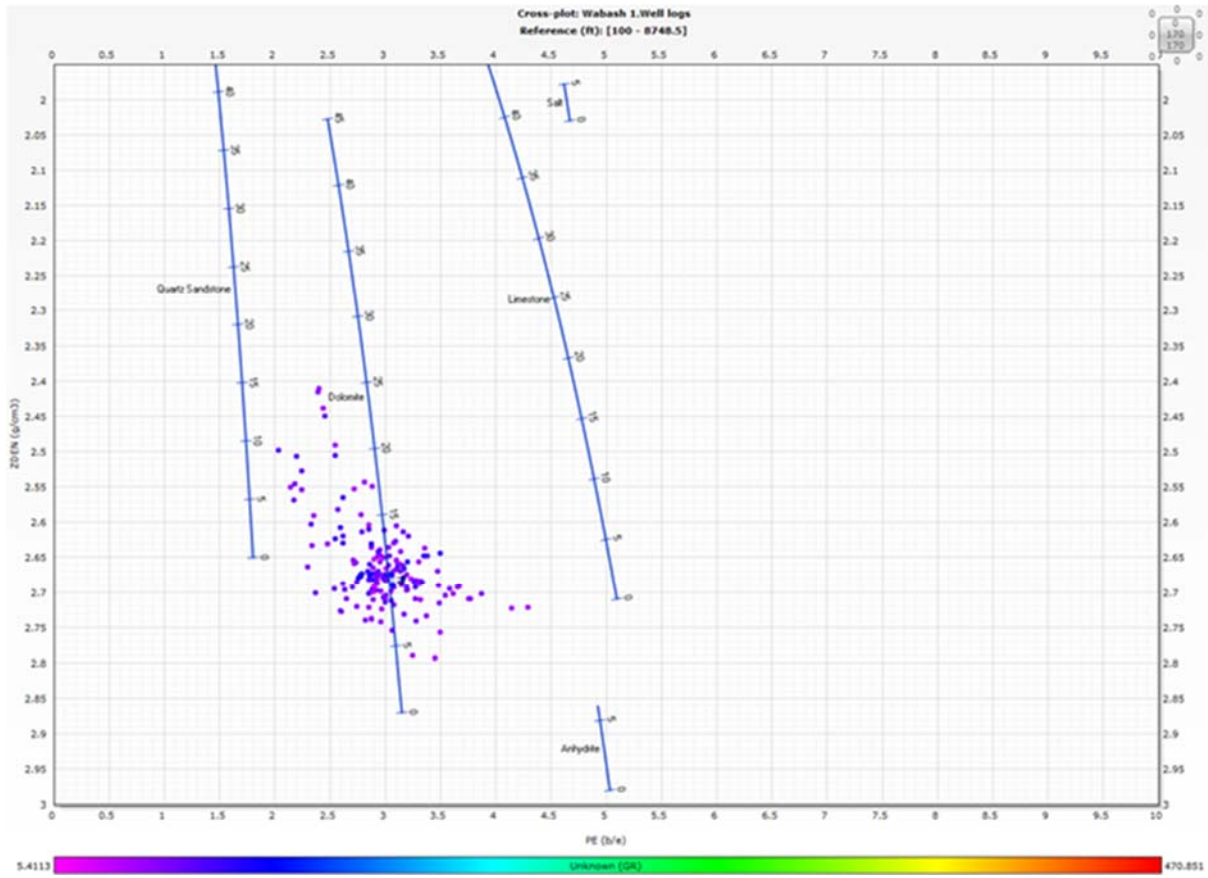
Figure 29 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Dutchtown Limestone in the Wabash #1 Well, Vigo County, Indiana.

Figure 30 Geophysical log of the Platteville Group and Trenton Limestone in the Wabash #1 Well, Vigo County, Indiana.
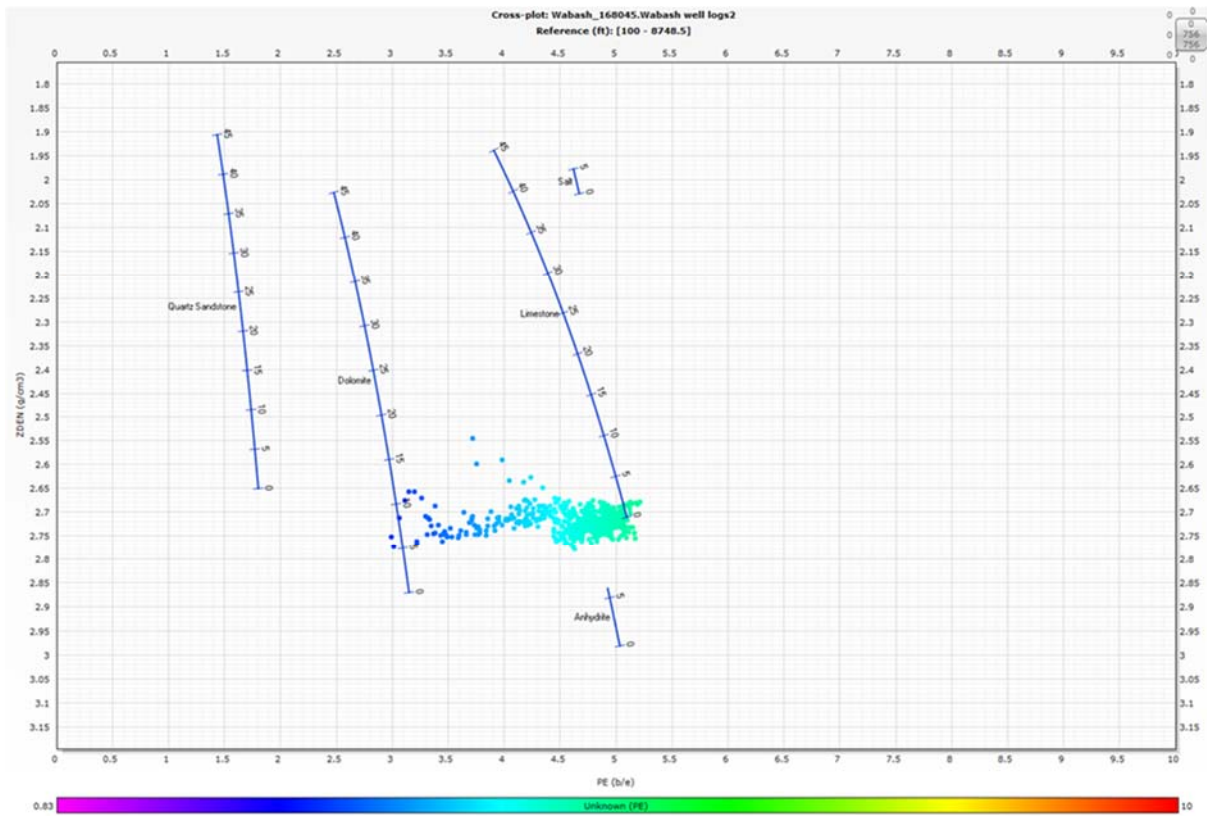
Figure 31 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Platteville Group in the Wabash #1 Well, Vigo County, Indiana.
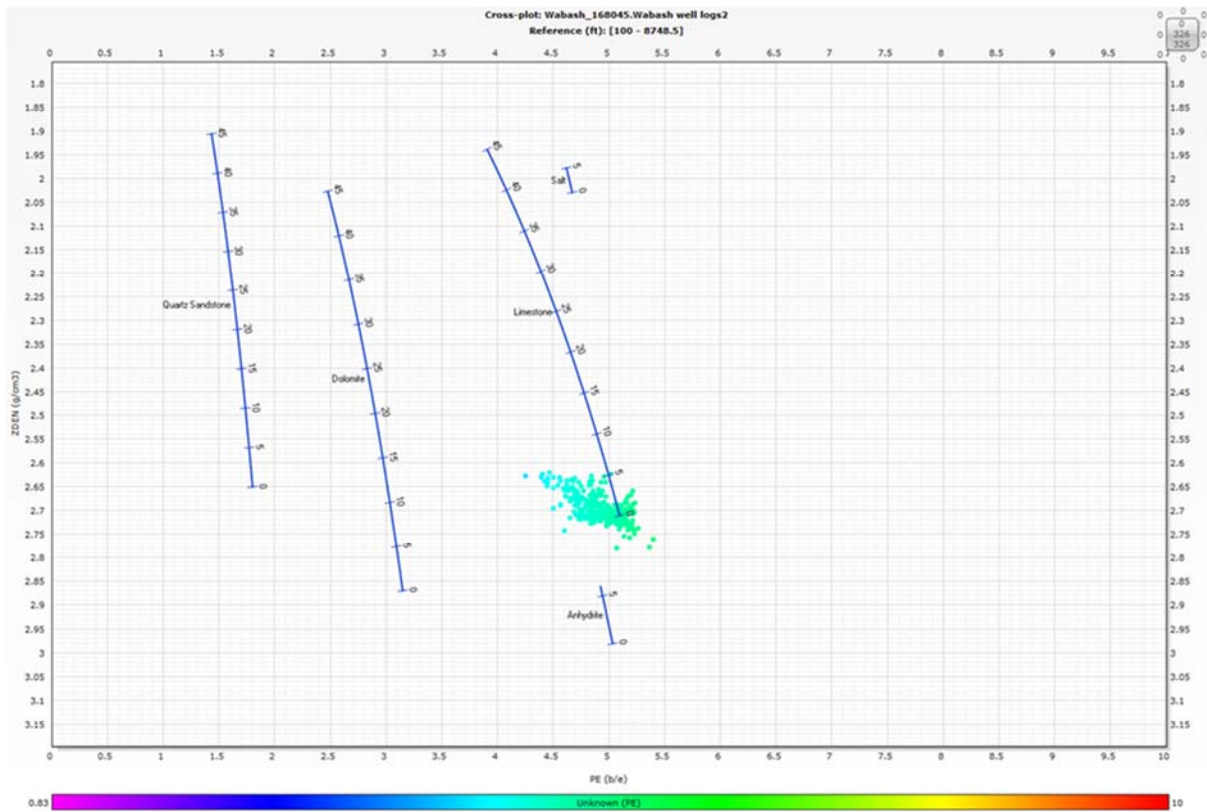
Figure 32 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Trenton Limestone in the Wabash #1 Well, Vigo County, Indiana.
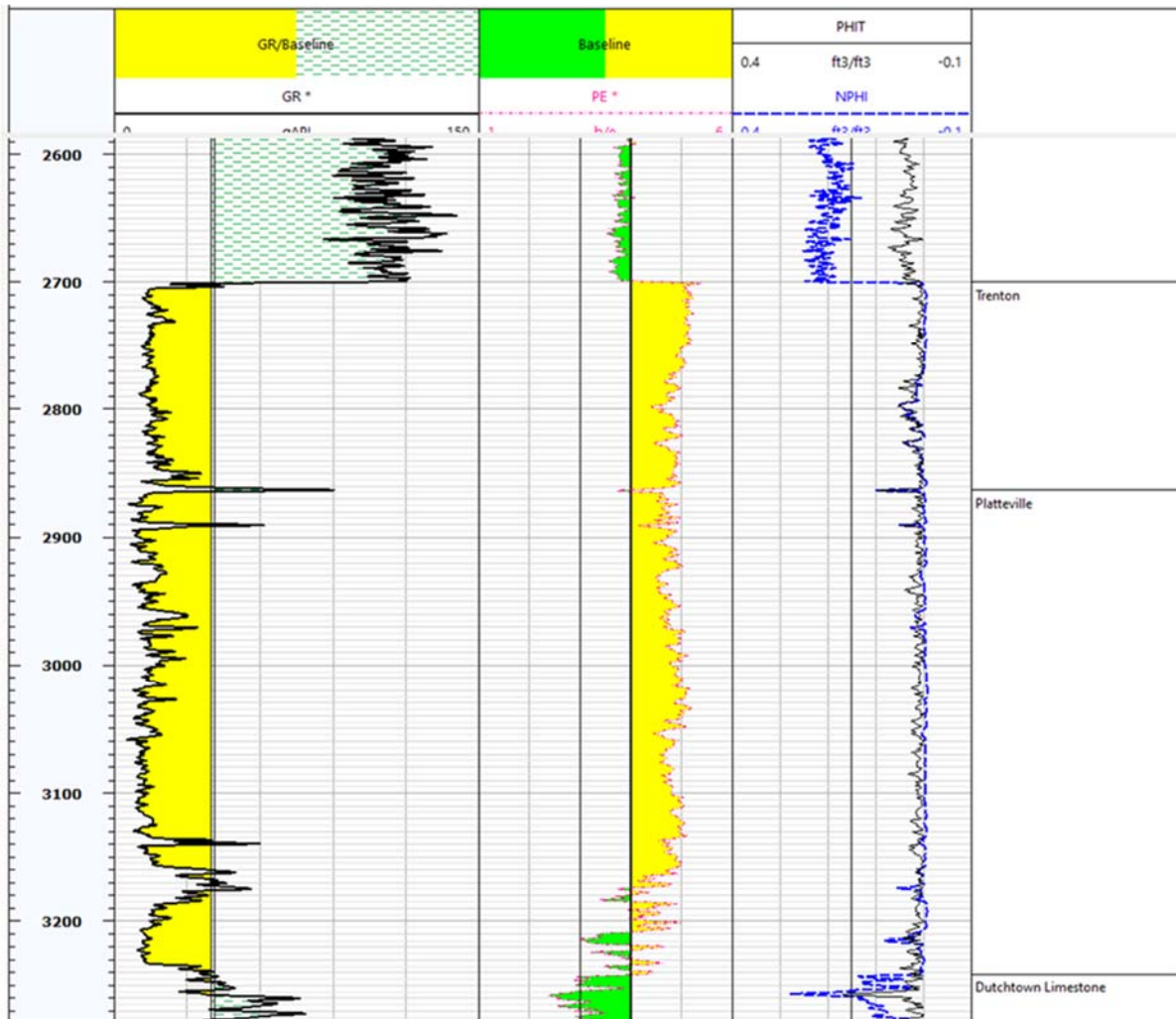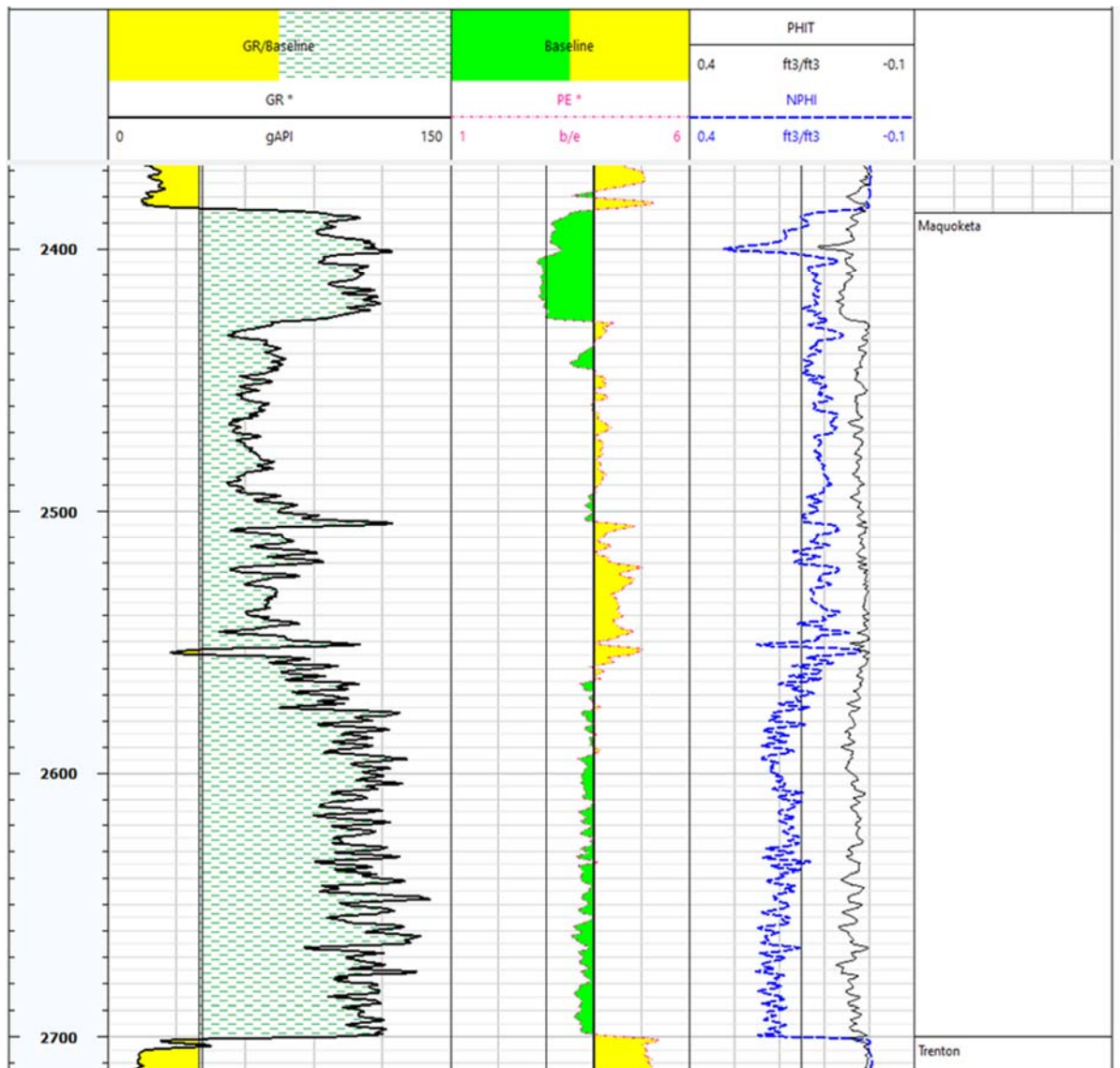
Figure 33 Geophysical log of the Maquoketa Group in the Wabash #1 Well, Vigo County, Indiana.

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Geo-mechanical and Petrophysical Information [40 CFR 146.82(a)(3)(iv)]

Methods used to determine the geo-mechanical and petrophysical characteristics of the confining zone.

Petrophysical characteristics of the confining zones are discussed in the Section INJECTION AND CONFINING ZONE DETAILS and are summarized in Table 6. Lithologic properties of the confining zones including the Shakopee Dolomite, Dutchtown Formation, and the Maquoketa Group (primary seal) were determined using standard geophysical log analysis techniques from logs obtained at the Wabash #1 well. Measurements of bulk density, neutron porosity, photoelectric (Pe) and acoustic transit time (sonic) were used to estimate matrix density, lithologic variability, and total porosity. Lithology and porosity range were identified and qualitatively interpreted from neutron-density, Pe-density, and M-N cross plots (used to detect the secondary porosity development and provide mineral composition information). The gamma-ray log was used to identify clay- and shale-rich intervals that may have more ductile characteristics than adjacent carbonate zones (*Figure 34*, *Table 6*). The Formation Micro Imager (FMI) and caliper logs were used to assess formation integrity, as well as potential drilling induced tensile fractures (DITFs) and wellbore breakouts (WBOs).

Geo-mechanical testing of the Maquoketa Group (primary seal) was performed in September 2020, on wax-preserved core samples obtained from the Wabash #1 well. At the Wabash #1 well, the Maquoketa Group is ~315 ft thick and occurs from 2,386 to 2,700 ft MD in depth. A 61 ft interval was cored (3-1/2 inch diameter) from 2,435 to 2,496 ft MD in depth. A 2 ft section of core was preserved in wax from 2,446.92 to 2,448.45 ft MD (

Table 7).

The waxed core samples were sent to Schlumberger's Reservoir Laboratory (SRL), where three vertical core plugs, one horizontal plug, and one inclined plug (oriented 45-degrees to horizontal) were prepared. Triaxial compressive strength tests and ultrasonic velocity measurements were conducted on the Maquoketa Group core plug samples to determine geo-mechanical (dynamic and static) and petrophysical characteristics. The tests were conducted under confining pressures

of S3 = 675, 1350, and 2025 psi (*Table 8*; ~4.6, ~9.3, and ~14.0 MPa) and results were interpreted based on Mohr-Coulomb failure criteria.

Identification of fractures

Breaks were observed in the computer tomography (CT) scan of the 2 ft section of Maquoketa Group whole core preserved for geo-mechanical testing, and samples MAQ A-6, A-7, and A-8 show evidence of isolated vertical and horizontal fractures. These fractures are likely drilling- or handling-induced, per observations of the overall nature of drilling- and handling-induced fractures observed and described in the 61 ft Maquoketa Group cored interval (SEE FAULTS AND FRACTURES SECTION).

Petrophysical evidence regarding fractures: Formation Micro Imager (FMI) log data acquired in Wabash #1 spanning the confining units from the Oneota Dolomite to the Maquoketa Group (it did not extend into the Potosi Dolomite) shows that, in general, the strata have irregular to isolated fractures, with no distinct indication of interconnectedness.

Some isolated fractures were observed within the Shakopee Dolomite. In the upper Shakopee fractures are short and terminate within individual beds that are interspersed with relatively thick non-fractured beds. In the lower part of the Shakopee fractures are more common and may cut across multiple beds.

Strata of the Dutchtown Formation show some localized fractures that are interspersed with unfractured intervals that may exceed 100 ft (30 m) in thickness (SEE FAULTS AND FRACTURES SECTION). In the Maquoketa Group (primary seal) no significant natural fractures, drilling induced tensile fractures (DITFs) or wellbore breakouts (WBOs) were observed.

Rock strength of the confining zone

Uniaxial or unconfined compressive rock strength (UCS) of ~26,000 psi (~180 MPa) for the Maquoketa Group was extrapolated (based on triaxial testing of 5 cores) from the best fit line to the relationship between σ3 and resulting yield strength (*Figure 35*; Zoback, 2007). The slope (i.e. m = 3) of the best fit line is used to determine a coefficient of internal friction (μ_i) of ~0.58, an angle of internal friction (ϕ) of 30° and a cohesive or shear strength (C_0) of ~7514 psi (~52 MPa). Measurements of compressional velocities (V_p), shear velocities (V_s), dynamic and static Young's modulus (E), and dynamic and static Poisson's ratio (υ) are presented in the *Table 9*. Elastic properties which typically correlates with UCS show nearly consistent values at this depth (see *Figure 37*).

In-situ stress field of the confining zone

General observations of DITFs and WBOs within the intermediate logged interval section in the Wabash #1 well (325–4,426 ft) corresponding to depths above the Potosi Dolomite, and containing the Shakopee Dolomite show the maximum horizontal stress trends W–E (~89°NE) (*Figure 36*) and that the minimum horizontal stress is perpendicular to this direction; this is likely a strike-slip stress regime based on stress estimates from the Wabash #1 well log shown in Figure

37. Seismic reflection data indicate that there are no faults penetrating the confining zones within the AoR (See also FAULTS AND FRACTURES Section).

Average pore pressure of the confining zone

Average hydrostatic pore pressure of the confining zones is estimated to be 0.43 psi/ft.

Anomalies or uncertainties in the data

The UCS value of ~26,000 psi (~180 MPa) determined for the Maquoketa appears higher than expected when comparing data collected and analyzed from the IBDP Maquoketa core.

Uncertainty in measured parameters from the triaxial tests and ultrasonic measurements in the laboratory (*Table 9*) are indicated as a range of values. The uncertainty in measured parameters is likely caused by sedimentary features present in the rock and was addressed by testing cores taken in three different orientations.

Table 6. List of significant confining intervals above the Potosi Dolomite injection zone within the Wabash Area of Review, as identified in the Wabash #1 well. Note that the names of some regionally extensive units change across the Illinois and Indiana state line. For the purpose of being consistent with previous log analysis and reservoir simulation work in Illinois and throughout the Illinois Basin, the Illinois stratigraphic names will be used preferentially (and/or in shortened notation) here and in subsequent figures.

Confining Zone	Formation Thickness (ft)	Depth (ft) MD	Avg. Porosity (%)	Avg. Permeability (mD)	Shale Thickness (ft)
Maquoketa Group	314	2,386	3.0	0.0001	312
Trenton Limestone	163	2,700	1.3	0.00000273	3.5
Platteville Group	379	2,863	1.2	0.00000475	16
Dutchtown Limestone	84	3,242	2.8	0.0000840	70.5
St. Peter Sandstone	28	3,326	4.0	0.0039	3.5
Shakopee Dolomite (upper)	346	3,354	2.8	0.022360406	101
Shakopee Dolomite (lower)	270	3,700	9.1	0.098032	71
Oneota Dolomite	408	3,970	7.1	2.585488	15

Table 7 Wabash #1 Maquoketa Group core preservation notes from Robert Bauer, ISGS, provided June 8, 2020. Sample depths and lengths are in feet.

Sample Depth	Length	Notes
Wax 1a - 2446.92-2447.81	0.89'	Shallowest sample, lowest % limestone from mud log (Impac) chart
Wax 1b - 2447.81-2448.45	0.64'	Send both parts (1a&b) - so enough sample for Brazilian testing

Table 8 Confining pressures used for testing at Schlumberger Reservoir Laboratory.

Formation	Sample depth (ft)	TZSG (psi/ft)	TXSG_ANISO (psi/ft)	TXYSG_ANISO (psi/ft)	PPG (psi/ft)	MES (psi)	MES x 0.5 (psi)	MES x 1.5 (psi)
Maquoketa	2447.25	1.100	0.743	1.114	0.430	1350	675	2025

*TZSG=Vertical stress, TXSG_ANISO=Anisotropic min. horizontal stress, TXYG_ANISO=Anisotropic max. horizontal stress, PPG=Pore pressure gradient, MES=Mean effective stress

Table 9 Measured parameters from the triaxial tests and ultrasonic measurements.

Sample orientation	Petrophysical properties	Ultrasonic velocities		Dynamic elastic properties		Static elastic properties				
	ρ (g/cc)	Vp (km/s)	Vs (km/s)	E (GPa)	υ	E (GPa)	υ	UCS (MPa)	C_0 (Mpa)	φ (°)
Vertical	2.61-2.71	4.9-5.5	2.6-3.0	45-62	0.30	42-46	0.23-0.3	180	51.8	30
45 degrees	2.71	5.5	2.9-3.0	60-62	0.30					
Horizontal	2.63-2.70	5.2-5.7	2.6-3.0	48-63	0.30-0.32					

* (ρ) = Density, (ϕ) = angle of internal friction, (C_0) = cohesive or shear strength, (V_p) = compressional velocities, (V_s) = shear velocities, (E) = dynamic and static Young's modulus, (υ) = dynamic and static Poisson's ratio, (UCS) = uniaxial or unconfined compressive rock strength.
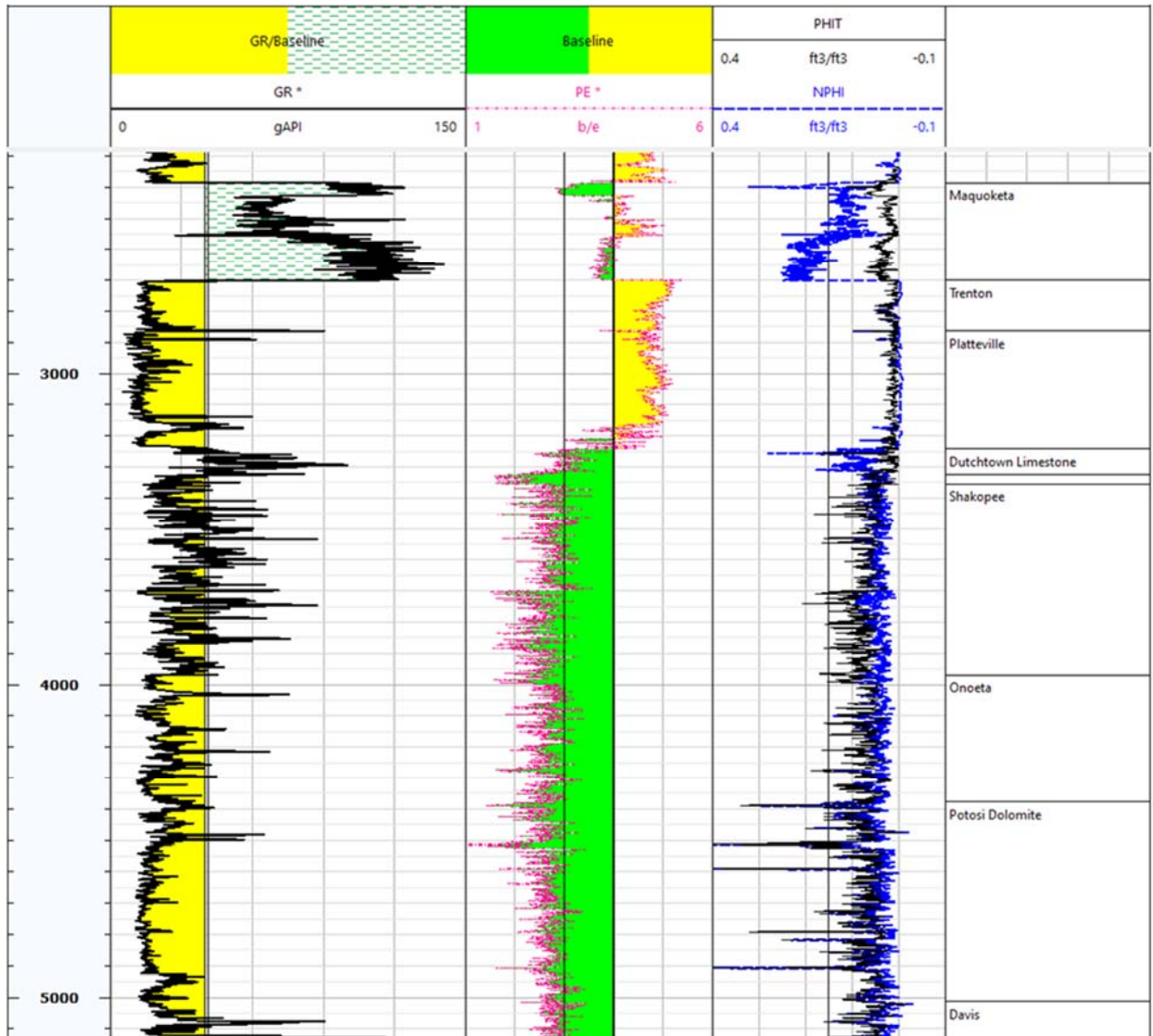
Figure 34. Geophysical log of the Cambro-Ordovician rocks from Davis Formation through Maquoketa Group, Wabash #1 Well, Vigo County, Indiana. The St. Peter Sandstone is not labeled in this figurebut is represented in the relatively thin zone above the Shakopee Dolomite.
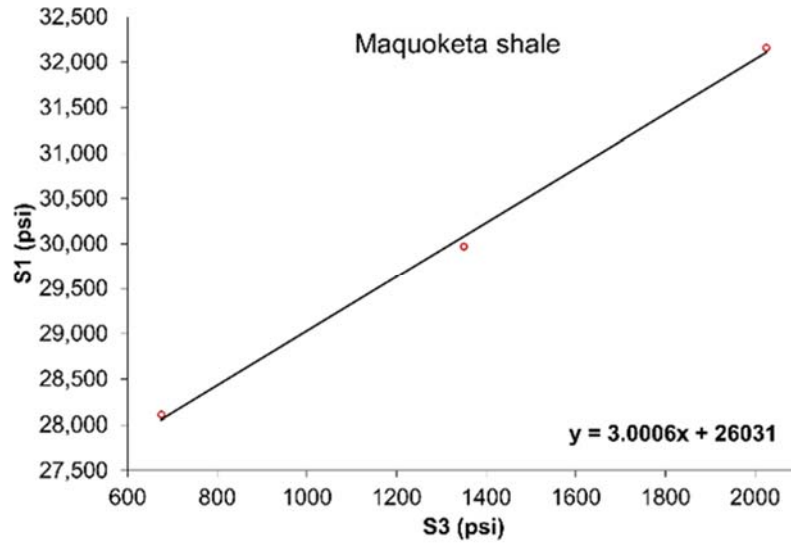
Figure 35. Plot of confining stress versus the resulting yield strength. Note that 3 measurements were used to create a best-fit line.
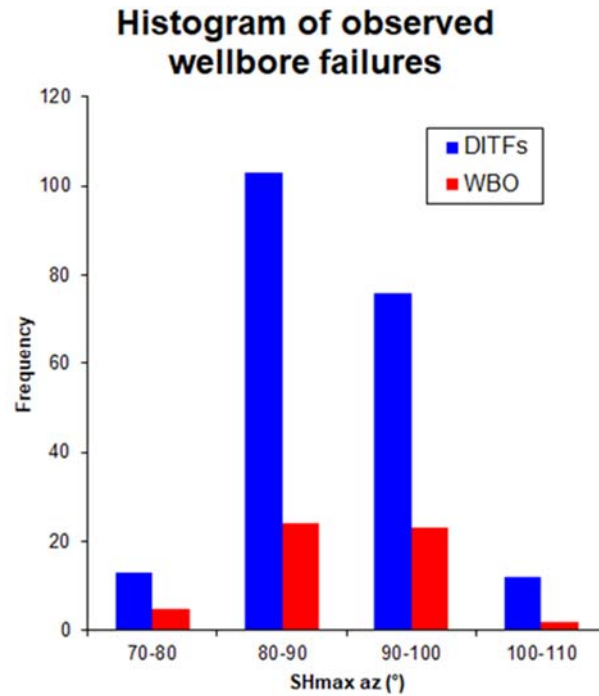
Figure 36. Plot showing the distribution of wellbore failure orientation observed within intermediate logged interval section (325–4426 ft) of the Wabash #1 well. DITFs = drilling induced tensile fractures; WBOs = wellbore breakouts.
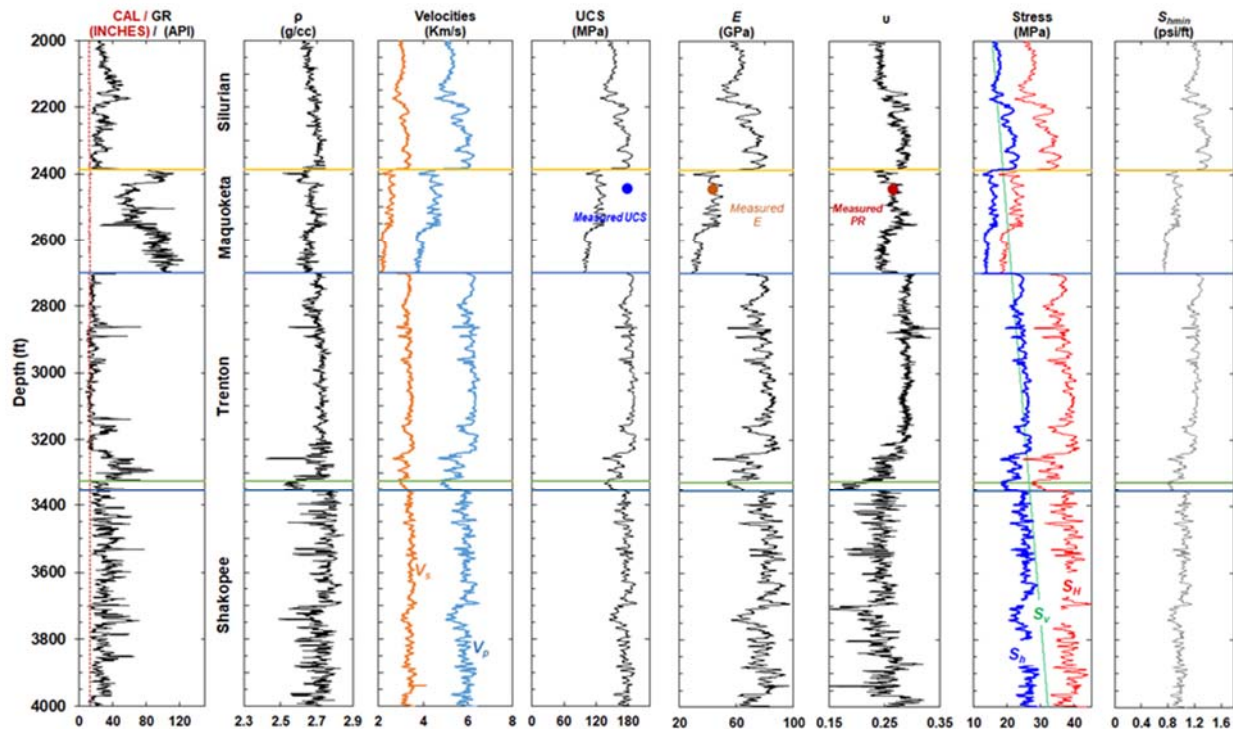
Figure 37 Plots of estimated dynamic elastic properties and in situ stresses. Plots also show measured static elastic properties.

References

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Seismic History [40 CFR 146.82(a)(3)(v)]

Occurrence of earthquakes magnitude 3.0 Mw and larger in central Indiana are typically rare (*Figure 38*). Since 1817 there have been only 44 recorded seismic events greater than 3.0 Mw in the State of Indiana. Table 10 provides a tabulation of this seismic activity and is keyed to Figure 38. Similarly, within East Central Illinois, earthquakes above 3.0 Mw are typically rare. Figure 39 shows a historic record of earthquakes in Illinois between 1795 and 2015. Using the USGS tools available online, a search was done for all seismic activity greater than intensity 2.5 for an area ~100 miles from the injection location in the last 20 years. 80 seismic events were recorded for this time period. The data is presented in Table 11.

Table 10 Seismic Activity Indiana 1817-2012

Map ID	Date	Magnitude Mw		Map ID	Date	Magnitude Mw
1	Jan. 16, 1817	3.3		23	Jan. 7, 1916	3.3
2	Aug. 7, 1827	3.3		24	May 25, 1919	3.9
3	Jul. 5, 1827	4.6		25	Jan. 11, 1922	3.7
4	Aug 7, 1827	3.9		26	Sept. 2, 1925	4.4
5	Jun. 1, 1869	3.3		27	Apr. 27, 1925	4.8
6	Sept. 25, 1876	4.3		28	Feb. 14, 1929	3.1
7	Aug. 12, 1886	4.3		29	Jan. 6, 1931	3.1
8	Aug. 29, 1886	4.3		30	Feb. 12, 1938	3.6
9	Feb. 26, 1889	3.5		31	Dec. 11, 1968	3.3
10	Aug. 15, 1891	4.9		32	Aug. 29, 1984	3.0
11	Dec. 14, 1893	3.4		33	Jul. 28, 1984	3.7
12	Jan. 11, 1893	3.2		34	Jan. 29, 1986	3.0
13	Dec. 20, 1893	3.9		35	Jan. 24, 1990	3.9
14	Apr. 30, 1899	4.4		36	Dec. 20, 1990	3.5
15	Aug. 28, 1899	3.3		37	Dec. 17, 1990	3.3
16	Feb. 11, 1899	4.1		38	Dec. 7, 2000	3.7
17	Sept. 7, 1906	3.0		39	Apr. 14, 2000	3.2
18	May 11, 1906	3.2		40	Jun. 18, 2002	4.4
19	May 8, 1906	3.2		41	Sept. 12, 2004	3.8
20	Jan, 29, 1907	3.3		42	Dec. 30, 2010	3.8
21	Sept. 22, 1909	3.5		43	Jan. 26, 2012	3.0
22	Sept. 27, 1909	4.7		44	May 10, 2012	3.1

Table 11 20 Year record of Earthquake Activity

Date	Mag (Mw)	Mag Type	Location	Depth Ft	Distance AoR (±2.5 miles)
2017-09-19	3.8	mw	13km W of Mount Carmel, Illinois	38320	83.5
2017-09-09	3.06	md	13km W of Mount Carmel, Illinois	38583	83.5
2017-07-01	3.12	mw	16km SW of Vandalia, Illinois	55085	106.1
2015-05-30	3.4	mlg	9km N of Fairfield, Illinois	84810	90.6
2012-11-20	3.6	mlg	13km WNW of Mount Carmel, Illinois	60892	81.3
2012-05-10	3.1	mlg	13km WNW of Bicknell, Indiana	35105	54.0
2012-05-10	2.7	mlg	14km WNW of Bicknell, Indiana	29167	53.3
2011-09-14	2.7	mlg	19km SE of Flora, Illinois	90584	82.8
2010-12-30	3.8	mwr	Indiana	16404	101.6
2008-07-18	3.1	mlg	12km WNW of Mount Carmel, Illinois	59974	82.1
2008-06-24	2.9	md	9km WNW of Mount Carmel, Illinois	48031	81.2
2008-06-05	3.4	mw	8km WNW of Mount Carmel, Illinois	53281	80.6
2008-05-01	3.3	mlg	9km WNW of Mount Carmel, Illinois	46982	80.9
2008-04-30	2.6	md	10km WNW of Mount Carmel, Illinois	50426	81.1

2008-04-25	3.7	mw	10km WNW of Mount Carmel, Illinois	42585	81.2
2008-04-24	2.6	md	12km WNW of Mount Carmel, Illinois	60006	81.3
2008-04-21	4	mw	10km WNW of Mount Carmel, Illinois	60006	81.5
2008-04-20	2.8	mlg	8km WNW of Mount Carmel, Illinois	53248	81.6
2008-04-19	2.8	md	12km WNW of Mount Carmel, Illinois	47506	82.3
2008-04-19	2.7	mlg	11km WNW of Mount Carmel, Illinois	46949	82.2
2008-04-18	4.7	mw	10km WNW of Mount Carmel, Illinois	50722	80.6
2008-04-18	2.7	md	11km WNW of Mount Carmel, Illinois	46489	82.0
2008-04-18	2.5	md	10km WNW of Mount Carmel, Illinois	59974	80.7
2008-04-18	2.6	mblg	Illinois	32808	79.0
2008-04-18	5.2	mw	11km WNW of Mount Carmel, Illinois	46752	81.3
2007-11-28	2.5	mlg	7km NNW of Palestine, Illinois	10367	37.4
2005-12-06	2.7	mlg	11km SSW of Wamac, Illinois	14468	122.3
2004-09-05	2.9	md	16km SSW of Saint Elmo, Illinois	108464	89.3
2004-06-28	4.2	mwr	10km NW of Ottawa, Illinois	32808	149.1
2000-08-26	2.6	mblg	Indiana	16404	103.1
2000-04-14	3.6	mlg	16km NE of Greencastle, Indiana	16404	41.0
2000-03-06	2.7	mlg	0km E of Darmstadt, Indiana	16404	102.9
1996-12-16	3.1	mblg	Indiana	16404	7.7
1995-09-05	2.9	md	12km WNW of Mount Vernon, Illinois	11483	118.9
1994-04-06	3.2	mlg	16km N of Du Quoin, Illinois	50525	135.6
1993-01-29	3.2	mlg	9km NE of Vandalia, Illinois	16404	90.9
1991-11-11	3.8	md	11km SSE of Robinson, Illinois	0	48.6
1991-04-16	2.7	md	16km SSE of Olney, Illinois	22310	74.1
1990-12-20	3.7	md	12km W of Monrovia, Indiana	16404	45.7
1990-12-17	3.2	md	Indiana	32808	40.7
1990-10-24	3.2	md	6km WNW of Mount Vernon, Illinois	3281	117.0
1990-09-03	2.5	md	9km ENE of McLeansboro, Illinois	62336	114.0
1990-04-24	2.9	md	5km SW of Newton, Illinois	60039	58.0
1990-03-09	2.7	md	9km SW of Corydon, Indiana	16404	122.0
1990-03-02	3.4	md	13km SSW of Vandalia, Illinois	328	103.4
1990-03-01	2.5	md	10km E of Grayville, Illinois	49213	95.4

1990-01-29	2.6	md	11km S of Paoli, Indiana	328	96.0
1990-01-27	3.8	md	16km S of English, Indiana	17388	112.4
1990-01-24	3.9	md	21km S of English, Indiana	32808	113.5
1989-01-03	2.8	md	2km SE of Robinson, Illinois	16404	43.1
1988-12-29	2.9	md	1km SSE of Robinson, Illinois	16404	43.2
1988-10-05	3.3	md	9km SE of Olney, Illinois	16404	70.1
1988-03-15	2.8	md	8km WSW of Mount Vernon, Illinois	38714	120.4
1988-01-05	3.3	md	8km W of Sumner, Illinois	17717	65.0
1987-11-17	3.2	md	8km W of Sumner, Illinois	15420	65.0
1987-10-02	2.6	md	7km W of Sumner, Illinois	19685	64.8
1987-07-15	2.6	md	9km S of Newton, Illinois	42323	59.3
1987-06-23	2.8	md	7km W of Sumner, Illinois	16404	64.8
1987-06-11	2.6	md	10km WSW of Sumner, Illinois	16404	68.2
1987-06-10	5.2	md	7km W of Sumner, Illinois	15092	65.5
1987-02-16	2.5	md	14km NNE of Boonville, Indiana	16404	99.0
1987-02-13	2.5	md	10km ESE of Haubstadt, Indiana	16404	97.9
1986-10-29	3	md	11km SE of Wamac, Illinois	16404	115.0
1986-02-26	2.7	md	13km SSE of Wamac, Illinois	16404	119.7
1986-01-29	2.8	md	2km ESE of Princeton, Indiana	16404	85.5
1986-01-10	2.5	md	5km N of Darmstadt, Indiana	32808	99.4
1985-12-29	3.2	md	10km ESE of Centralia, Illinois	3281	111.8
1985-10-12	2.7	md	10km E of Centralia, Illinois	16404	110.5
1985-02-13	3	md	9km NE of Princeton, Indiana	58071	80.7
1984-08-29	2.7	md	7km WSW of Oblong, Illinois	32808	50.1
1984-08-29	3.1	md	4km WNW of Sullivan, Indiana	32808	33.1
1984-07-28	4	md	6km SE of Middlebury, Indiana	32808	33.8
1984-06-12	3.4	mblg	Indiana	9843	46.3
1984-04-17	3.2	md	11km WNW of Fairfield, Illinois	46916	97.2
1983-06-03	2.7	md	12km ENE of McLeansboro, Illinois	72506	111.6
1983-05-16	2.6	md	9km WNW of Sumner, Illinois	66273	63.1
1982-03-27	2.7	md	16km WSW of Louisville, Illinois	48556	87.0
1981-04-08	3.5	md	3km SE of Greenville, Illinois	3609	112.7

Seismic frequency and intensity increase into southern Indiana and Illinois towards multiple seismic zones: The New Madrid seismic zone (NMSZ), the Wabash Valley seismic zone (WVSZ), the Saint Genevieve seismic zone (SGSZ), and the Rough Creek Graben (RCG). NMSZ is well known for a series of three large (magnitudes >7.0) earthquakes that occurred in the winter of 1811 into early 1812 near New Madrid, Missouri (Page and Hough, 2014). McBride et. al. (1997) investigated the potential relationship between basement structures that appeared in high quality seismic reflection profile and a magnitude 5.5 earthquake that occurred in southern Illinois (Hamilton County) in 1968. The 1968 event was the 20th century's largest magnitude earthquake in the southern Illinois region (McBride et al 1997). On June 18, 2002, a magnitude 4.6 earthquake occurred near Mount Vernon, Indiana, 11 miles west of Evansville with an epicenter between Mt. Vernon and West Franklin in Posey County associated with the WVSZ https://igws.indiana.edu/earthquakes/recent.

The United States Geological Survey (USGS) online database (USGS Earthquake Catalog https://earthquake.usgs.gov/earthquakes/search/) was searched in October 2020 and compared with IGWS earthquake map and IGWS recent earthquake compilation list. In September 1909, a magnitude 4.7 event was documented in Vigo County, Indiana approximately 4.5 miles southwest of the Wabash Valley Resource facility in western Terre Haute. Two events occurred in the late summer 1984 within 30 miles of the AoR: magnitude 3.7 event approximately 28 miles to southeast near Middlebury, Clay County, IN and magnitude 3.0 event approximately 28 miles south near Sullivan, Sullivan County, IN. No new earthquakes have been documented within 20 miles of the AoR for over 30 years. The majority of earthquakes in the region have been very deep. Within the past ten years, the shallowest nearby earthquake was over 16,000 feet below the surface. The proposed injection will occur roughly 1/3 that depth.

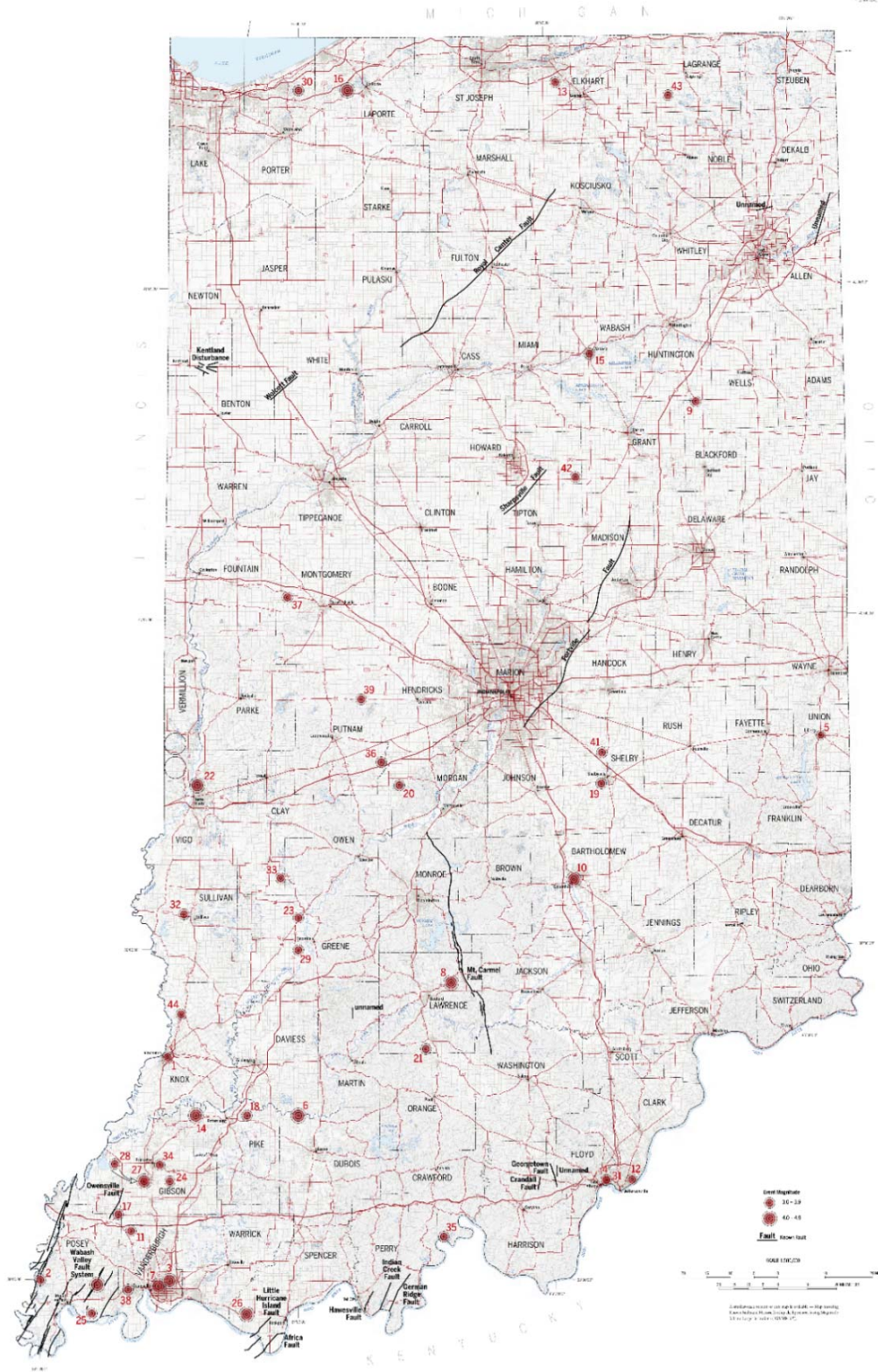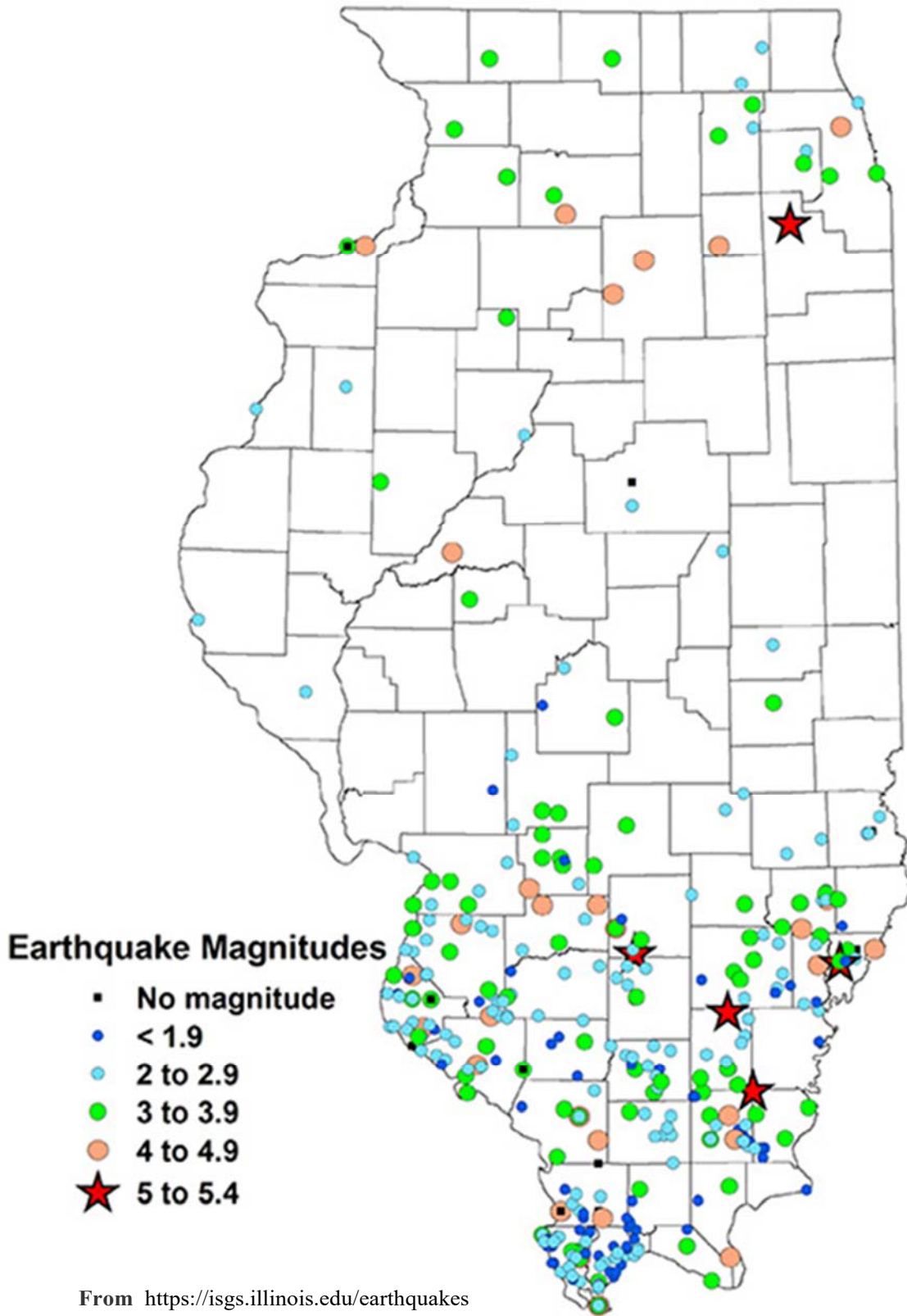*Figure 38 Map of Indiana Faults and Historic Earthquakes*

Earthquake Magnitudes

- ▪ No magnitude
- • < 1.9
- ◦ 2 to 2.9
- ● 3 to 3.9
- ● 4 to 4.9
- ★ 5 to 5.4

From https://isgs.illinois.edu/earthquakes

Figure 39 Map of Historic Illinois Earthquakes 1795-2012

The USGS National Seismic Hazard Map Earthquake hazard map (*Figure 40*) showing peak ground accelerations having a 2 percent probability of being exceeded in 50 years, based on the most recent USGS models that are based on seismicity (event frequency and magnitude) and fault-slip rates (https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map) has been reviewed. The Seismic Hazard Map separates Indiana into three risk zones. Risk of potential occurrence of larger magnitude events increases to the south closer to the WVSZ.
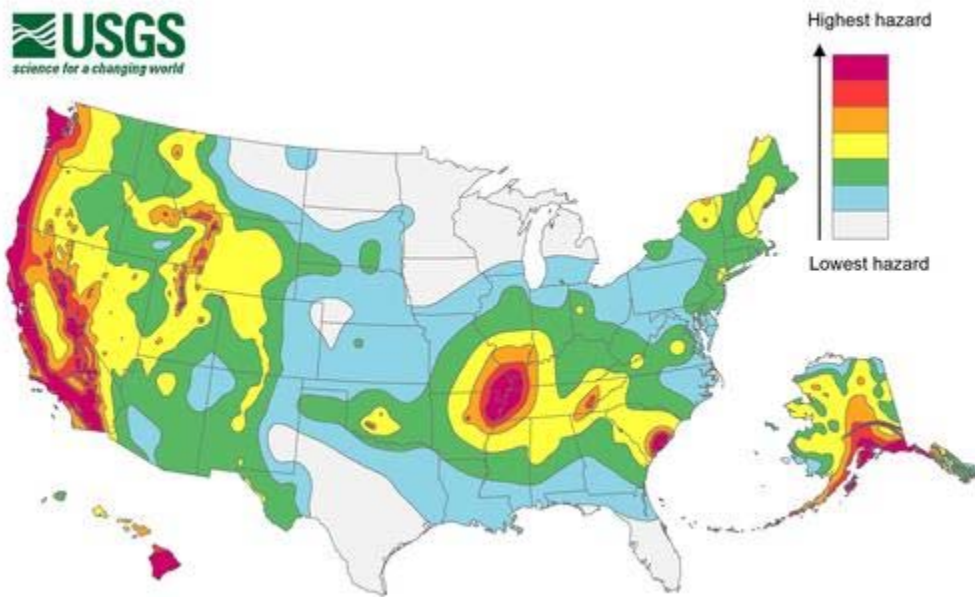

Figure 40 2018 Long-term National Seismic Hazard Map (USGS)

The USGS seismic hazard maps indicate the area around WCS facility and the AoR to be less than 20% (Peak acceleration expressed as a percent of gravity (%g) based on the USGS hazard map Earthquake Hazard and Probability Map tool: https://earthquake.usgs.gov/hazards/interactive/). There is a 2% probability that the Peak Ground Acceleration due to seismic activity would approach 14% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second https://earthquake.usgs.gov/hazards/interactive/). The relative seismic risk at the site is considered minimal.

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Hydrologic and Hydrogeologic Information [40 CFR 146.82(a)(3)(vi), 146.82(a)(5)]

Map of wells and other listed features

A map identifying the location of all wells, subsurface sites, surface water, and other features that are within the AoR is provided under the MAPS and CROSS SECTIONS of AoR section of this document (Figure 9).

Unconsolidated Aquifers

The unconsolidated aquifers are the primary source of drinking water in west central Indiana. The most significant aquifer systems in the Middle Wabash River Basin consist of unconsolidated surficial and buried sand and gravel that originated as outwash and alluvial valley fill and are typically found in recent and relict river valleys (*Figure 41*). Unconsolidated deposits in the area typically range in thickness from 50 to 100 feet (15 to 30 m) with a general thickening trend to the north and northeastern direction in Indiana (*Figure 42*).

The Coal Mine Spoils Aquifer System covers about 5-7 percent of the area in Vermilion and Vigo Counties. Groundwater quality in this system is generally lesser than that in the overburden; high iron and occurrence of low pH (less than 7) can severely limit potential groundwater use.

Bedrock Aquifers

Three bedrock aquifers are present within the Middle Wabash River Basin: the water bearing clastics within the Pennsylvanian System, which are the primary bedrock aquifer in the region, and the Mississippian and Silurian-Devonian carbonate rocks (*Figure 43*,*Figure 44*).

The McLeansboro Group of the Pennsylvanian System is the principal bedrock aquifer in the region, below which lies the Carbondale Group and the Raccoon Creek Group. The unconsolidated and Pennsylvanian deposits are approximately 750 feet (229 m) thick at the Wabash #1 well. A general description of the Pennsylvanian groundwater production in

Vermillion and Vigo Counties has been summarized from narrative text included in Figure 43 (Indiana DNR).

- The thickness of the McLeansboro Group ranges from 50 to up to 200 feet (15 to 61 m) with bedrock occurring from the surface in some areas to a depth of over 125 feet (38 m). The West Franklin Limestone and the Busseron Sandstone are primary aquifers within the McLeansboro Group. Wells generally do not exceed 110 feet (34 m) deep. Static water levels range from 10 to 40 feet (3 to 12 m) below ground surface with production range between 5 to less than 10 gallons per minute (gpm) (19 to 38 liters per minute, lpm).

- The thickness of the Carbondale Group can reach up to 350 feet (107 m). Domestic well production ranges typically less than 10 gpm (38 lpm). Static water levels in the wells vary from less than 10 to 75 feet (3 to 23 m) below the land surface. Most wells produce from the thicker sandstones of the Carbondale Group with greater production in areas with unconsolidated material directly overlying bedrock.

- The thickness of the Raccoon Creek Group can range from approximately 100 to 500 feet (30 to 152 m). Wells in the Raccoon Creek Group Aquifer System generally range from 70 to 250 feet (21 to 152 m) below surface. Static water levels commonly range from 10 to 70 feet (3 to 21 m) below surface. Domestic well production ranges from 2 to 15 gpm (8 to 57 lpm) with a few (pumped) dry holes reported.

The Pennsylvanian-Mississippian erosional contact is at the base of the Raccoon Creek Group. Below the Pennsylvanian, an approximately 1,000 feet (305 m) thick interval of predominately carbonate, Mississippian-aged rock is present to the top of the New Albany Shale at the Wabash #1 well. The Mississippian carbonate aquifers produce groundwater from the fractured limestone with greatly enhanced permeability due to development of solution channels (Palmer 1991). The Mississippian carbonate bedrock aquifer is unpredictable due to permeability differences that are common to carbonate rocks (Fenelon and Bobay 1994).

The Silurian-Devonian carbonate bedrock aquifer is an important groundwater source in Indiana although not a significant groundwater producer in the Middle Wabash River Basin due to the depth and highly mineralized water. The Silurian-Devonian carbonate bedrock aquifer is expected to be the lowermost underground source of drinking water (USDW) through the area (see *Sources of Data* below). Overlying the carbonate rock sequence is the New Albany Shale, a dark, carbon-rich shale that ranges in thickness from 100 to 120 ft (30 to 37 m) in the Middle Wabash River basin (Fenelon and Bobay 1994), and 100 ft (30 m) thick at the Wabash #1 well. Below the Silurian-Devonian carbonates lies the Ordovician Maquoketa Group (314 ft [95 m] thick in the Wabash #1 well), a unit composed of interbedded shale, limestone, and dolomite. The Upper Ordovician Maquoketa Group constitutes a confining unit between the underlying Cambrian-Ordovician and overlying Silurian strata (Panno et. al 2018).

Regional Groundwater Flow

Based on previous work by (McIntosh et al. 2002; Siegel 1989, 1991; Panno et al. 2018), regional groundwater flow occurs towards the center of the Illinois Basin from the northern, eastern, and western margins of the basin and dominantly through the Ordovician St. Peter Sandstone, and carbonate rocks of the Silurian–Devonian and Mississippian strata (Panno et al. 2018). Groundwater flow direction in the majority of Vermillion County, and northwestern Vigo

County, is generally eastward towards the Wabash River and its major tributaries (Indiana DNR, *Figure 45*).

Sources of Data

Potentiometric surface maps of the bedrock aquifers were developed by the Indiana Department of Natural Resources, Division of Water Resources Assessment Section for Vermillion and Vigo Counties. Static water level measurements were collected from available well data to construct the potentiometric surface map surfaces. Potentiometric surface contours are restricted on the map to areas of available data.

Schnoebelen et al. (1998) examined the 10,000 mg/L total dissolved solids (TDS) boundary in the Silurian and Devonian Carbonate-Rock Aquifer in western and southwestern Indiana in a joint regional USGS/IGWS analysis; the data are presented in Schnoebelen et al. (1998 – Table 1 p. 8-12) and displayed in map view in Figure 46. The 10,000 mg/L dissolved solids boundary line has been mapped for the Silurian-Devonian aquifer through an area including Vigo, Vermilion, and Parke Counties (*Figure 46*). The Silurian-Devonian carbonate bedrock aquifer is expected to be the lowermost USDW through the area and overlies the Maquoketa Group confining unit.

Below the Maquoketa Group, the St. Peter Sandstone is not expected to be a USDW in southwestern Vermilion and northwestern Vigo Counties. The nearest brine samples from wells that penetrated the St. Peter are in an adjacent county to the west (Clark County, Illinois) and were measured for ion concentrations (Meents, 1952). Converting chloride concentration into salinity, the resulting salinities for the two samples were 20,800 and 125,000 mg/L TDS.

Panno et al. (2018) developed an IL Basin-wide contour map of chloride concentration for the St Peter Sandstone based on available brine data (*Figure 47*). The authors developed Equations 9 and 10 (as numbered in Panno et al. 2018) to convert TDS concentrations to Cl⁻ concentrations for samples with TDS concentrations less than and greater than or equal to 5000 mg/L, respectively:

$$\text{Eq. 9} \qquad < 5000 \text{ mg/L: } Cl^- = 0.0022 \times TDS^{1.5328} \qquad\qquad (R^2 = 0.895)$$

$$\text{Eq. 10} \qquad \geq 5000 \text{ mg/L: } Cl^- = 0.637 \times TDS \qquad\qquad (R^2 = 0.989)$$

Based on the chloride concentration mapping contours (*Figure 47*) and accompanying cross section (*Figure 48*), the St. Peter Sandstone salinity trend for the area in southwestern Vermillion and northwestern Vigo Counties is expected to be greater than the 10,000 mg/L TDS USDW threshold, and increase with depth through the underlying Cambrian-Ordovician rock units.

Below the St. Peter Sandstone, a swab sample from the Cambrian Potosi Dolomite (see section Geochemistry [40 CFR 146.82(a)(6)]) from the Wabash #1 well was analyzed to be 34,250 mg/L TDS.

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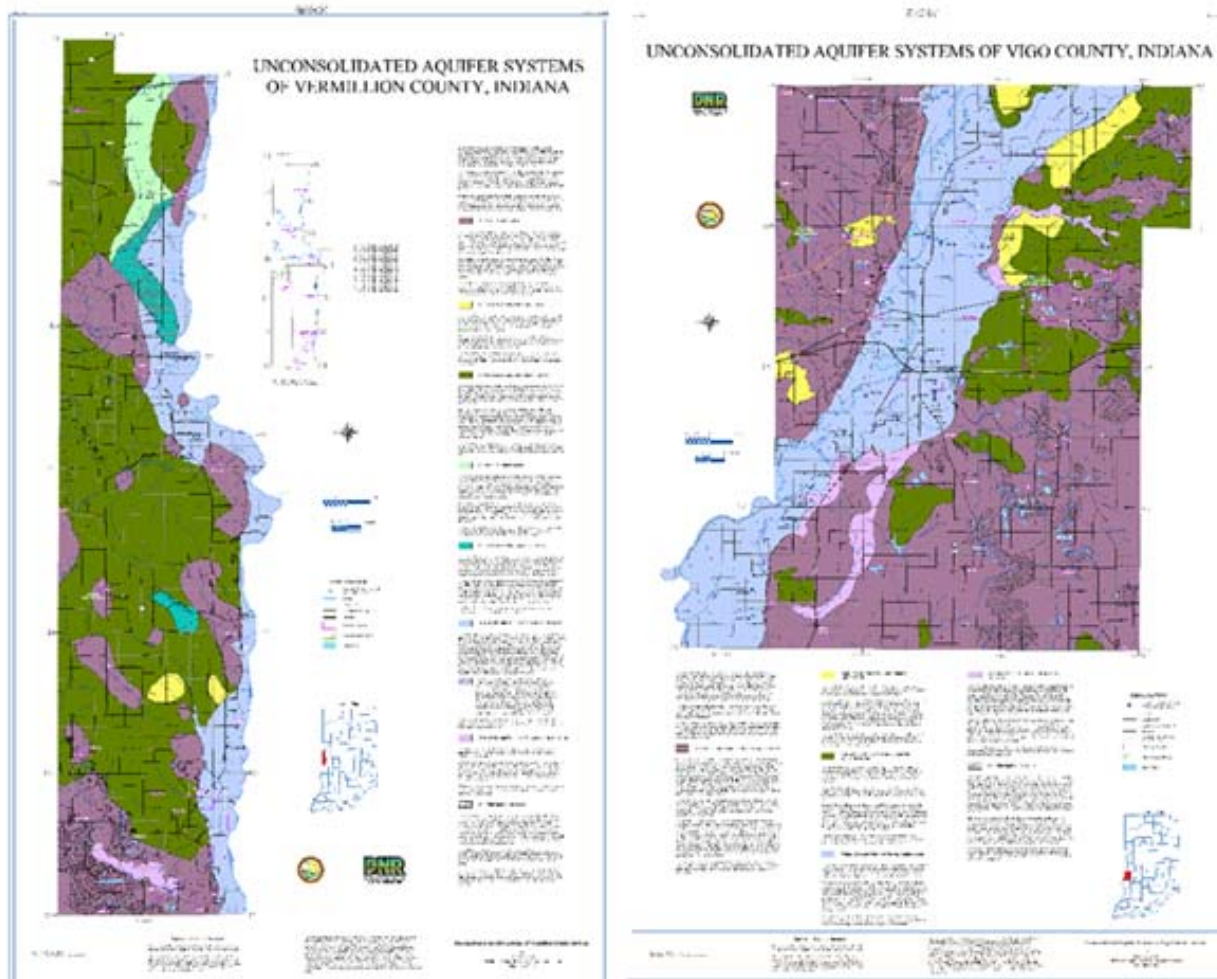
Figure 41 Maps of Unconsolidated Aquifer Systems of Vermillion County and Vigo County, Indiana (Indiana DNR). Available from: https://www.in.gov/dnr/water/5702.htm & https://www.in.gov/dnr/water/5774.htm
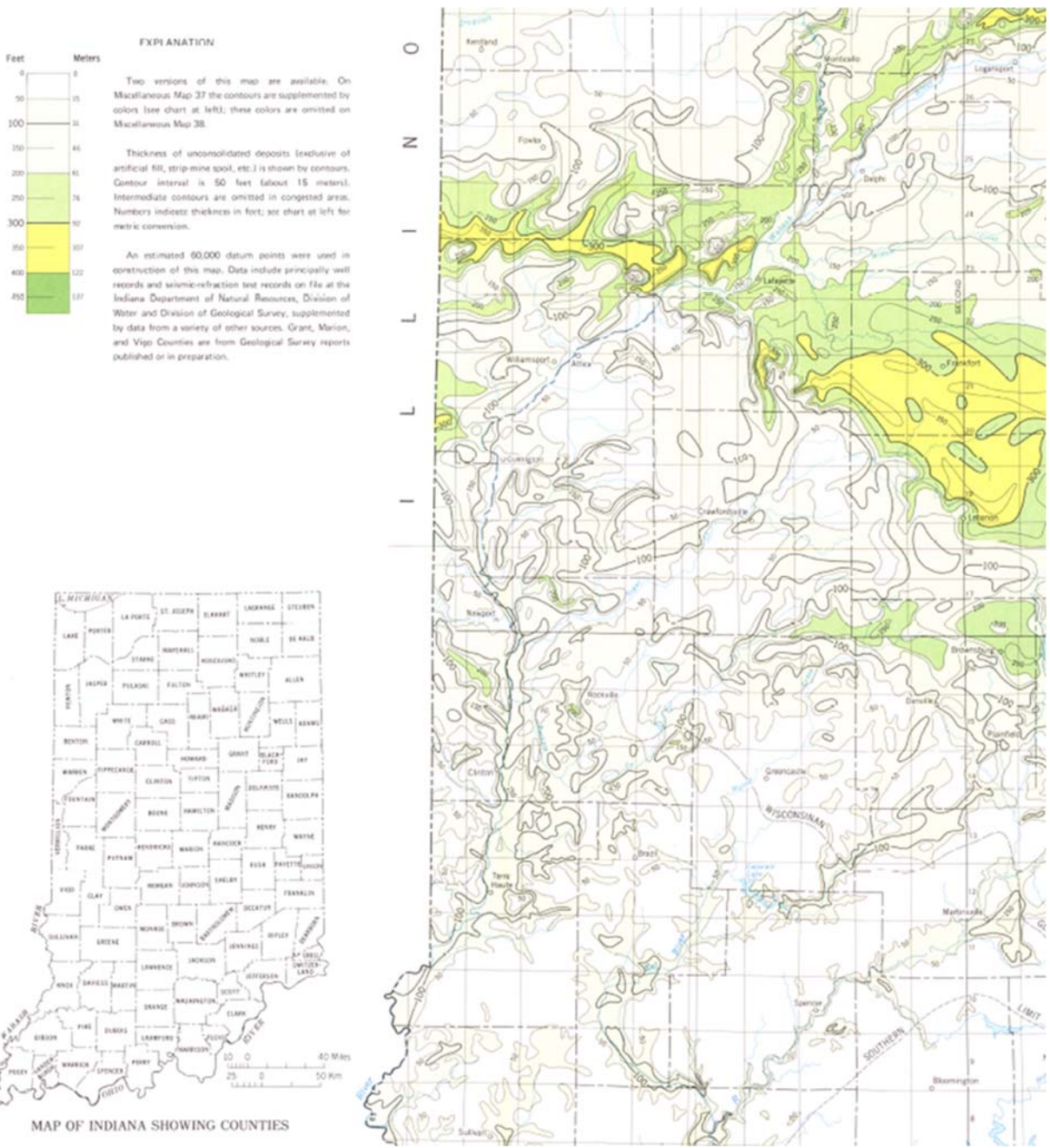
Figure 42 Map of Indiana showing thickness of unconsolidated deposits, excerpt (Gray 1983). Available from:
https://igws.indiana.edu/bookstore/details.cfm?Pub_Num=MM37
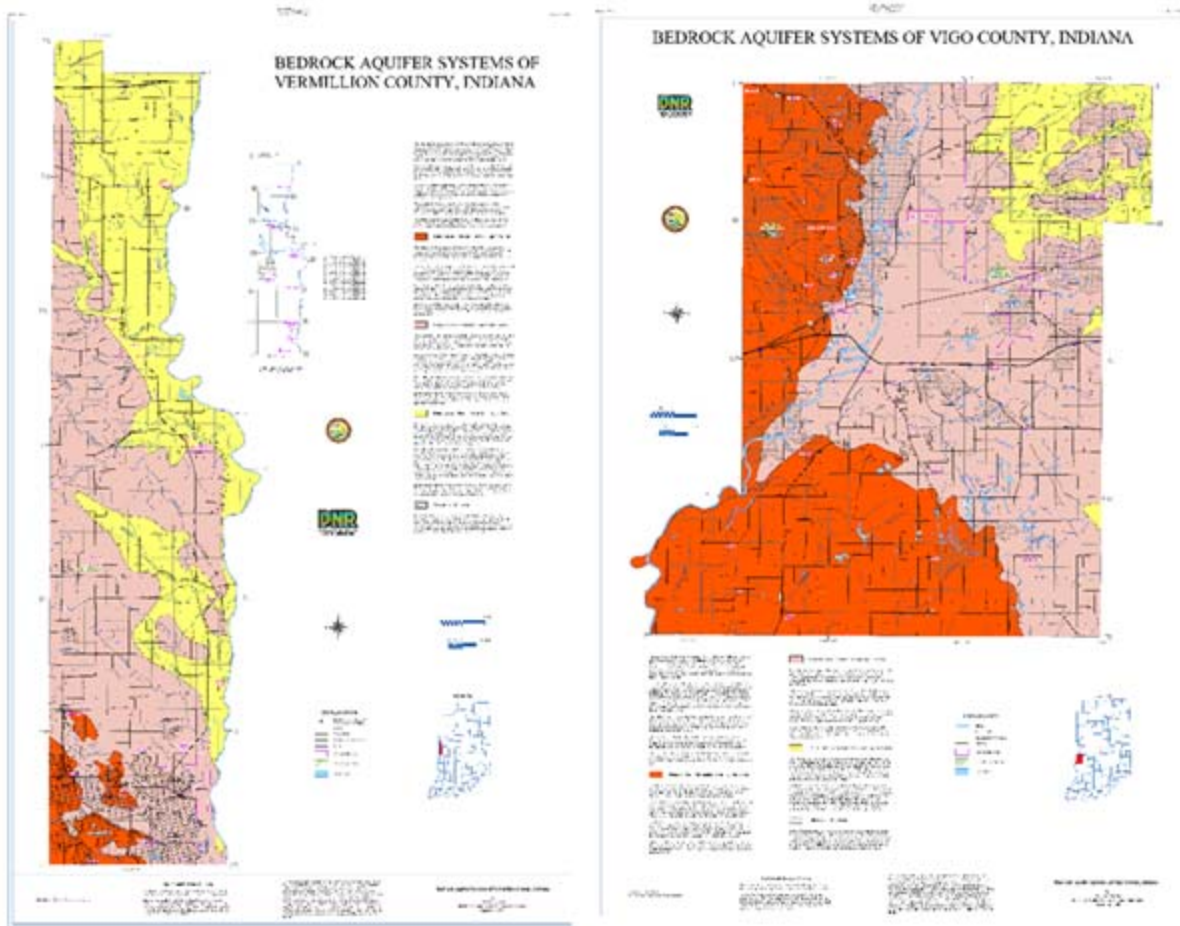
Figure 43 Maps of Bedrock Aquifer Systems of Vermillion County and Vigo County, Indiana (Indiana DNR). Available from:
https://www.in.gov/dnr/water/5702.htm and https://www.in.gov/dnr/water/5774.htm
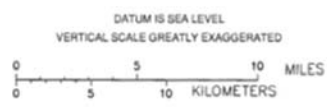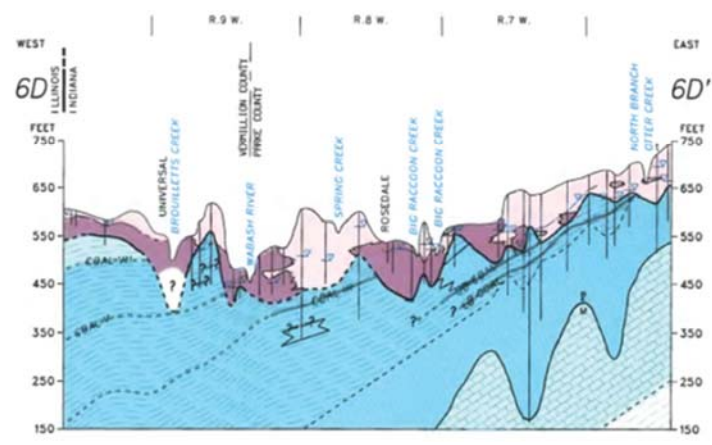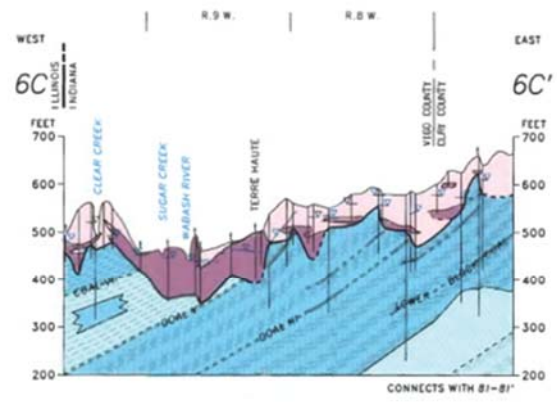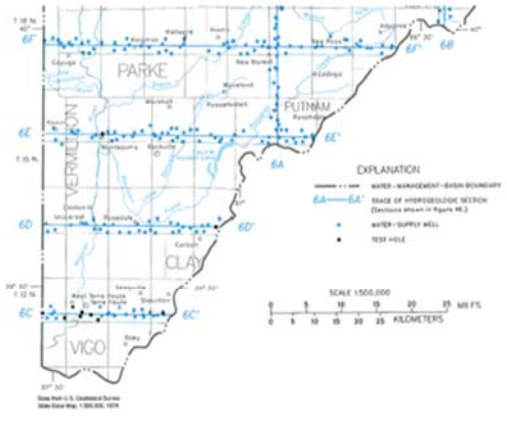
Figure 44 Selected hydrogeologic sections 6C-6C' (Vigo and Clay Counties) and 6D-6D ' (Vermilion and Parke Counties) of the Middle Wabash River basin (modified from Fenelon and Bobay, 1994).
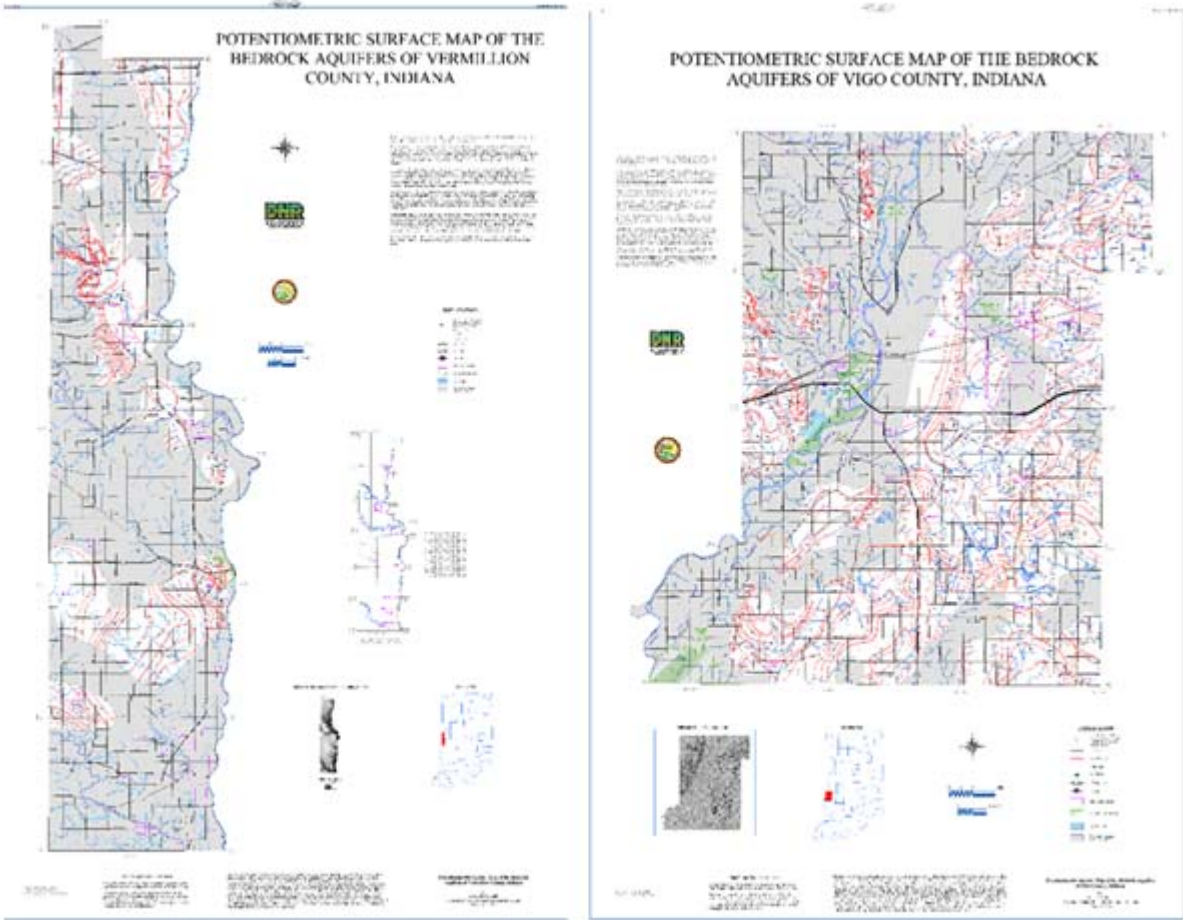
Figure 45 Potentiometric Surfaces Maps of Bedrock Aquifers of Vermillion County and Vigo County, Indiana (Indiana DNR).https://www.in.gov/dnr/water/8660.htm https://www.in.gov/dnr/water/8718.htm

*Figure 46 Location of the 10,000 mg/L dissolved solids boundary in the Silurian and Devonian carbonate aquifer systems (Schnoebelen et al. 1998).*
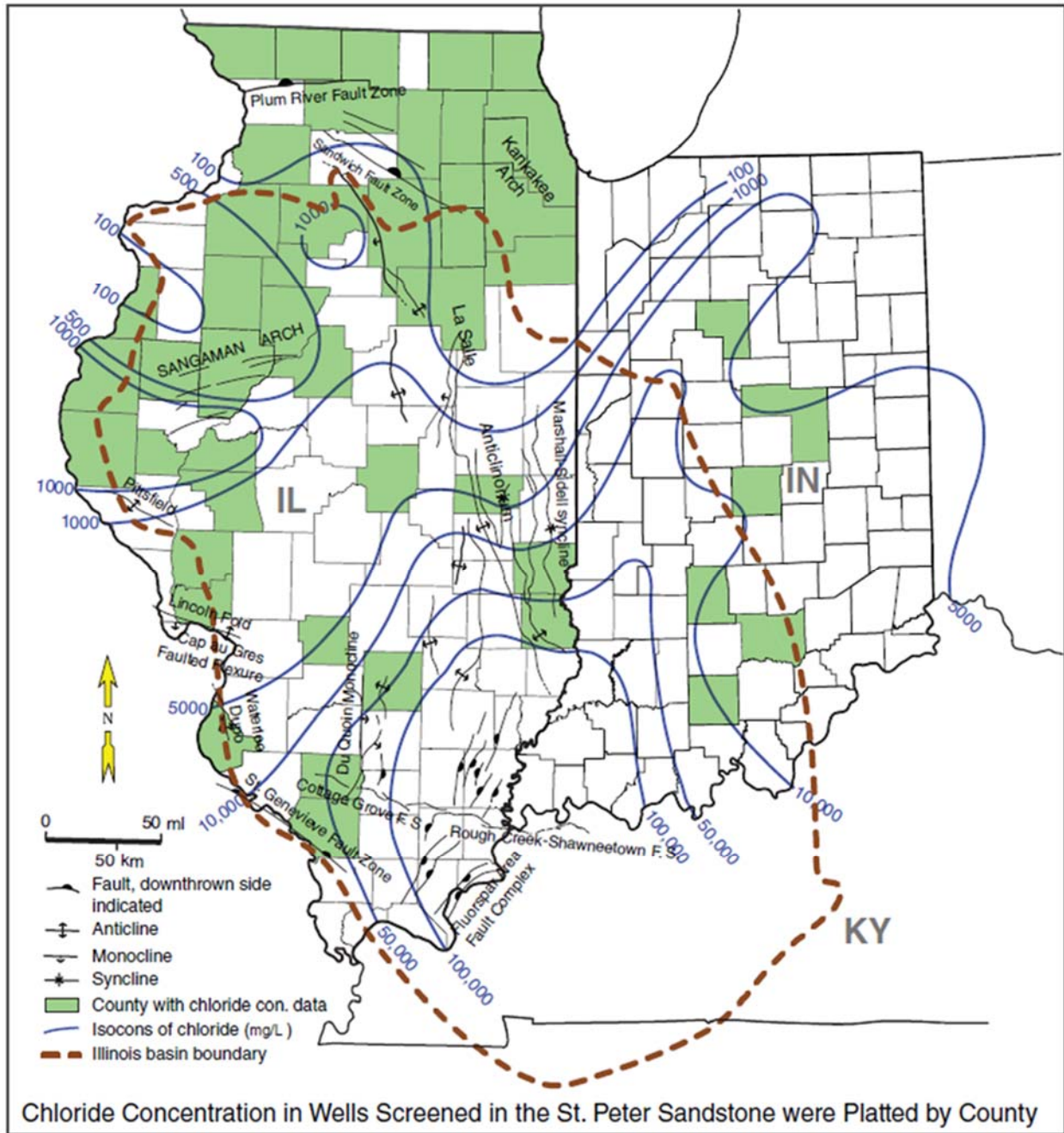
Figure 47 Chloride isocons in groundwater for the St. Peter Sandstone. Water quality data are from groundwater samples from wells screened in the St. Peter Sandstone. All chloride concentrations are from published data and were plotted by county and may be converted to total dissolved solids using Equations 9 and 10 (in Panno et al. 2018).
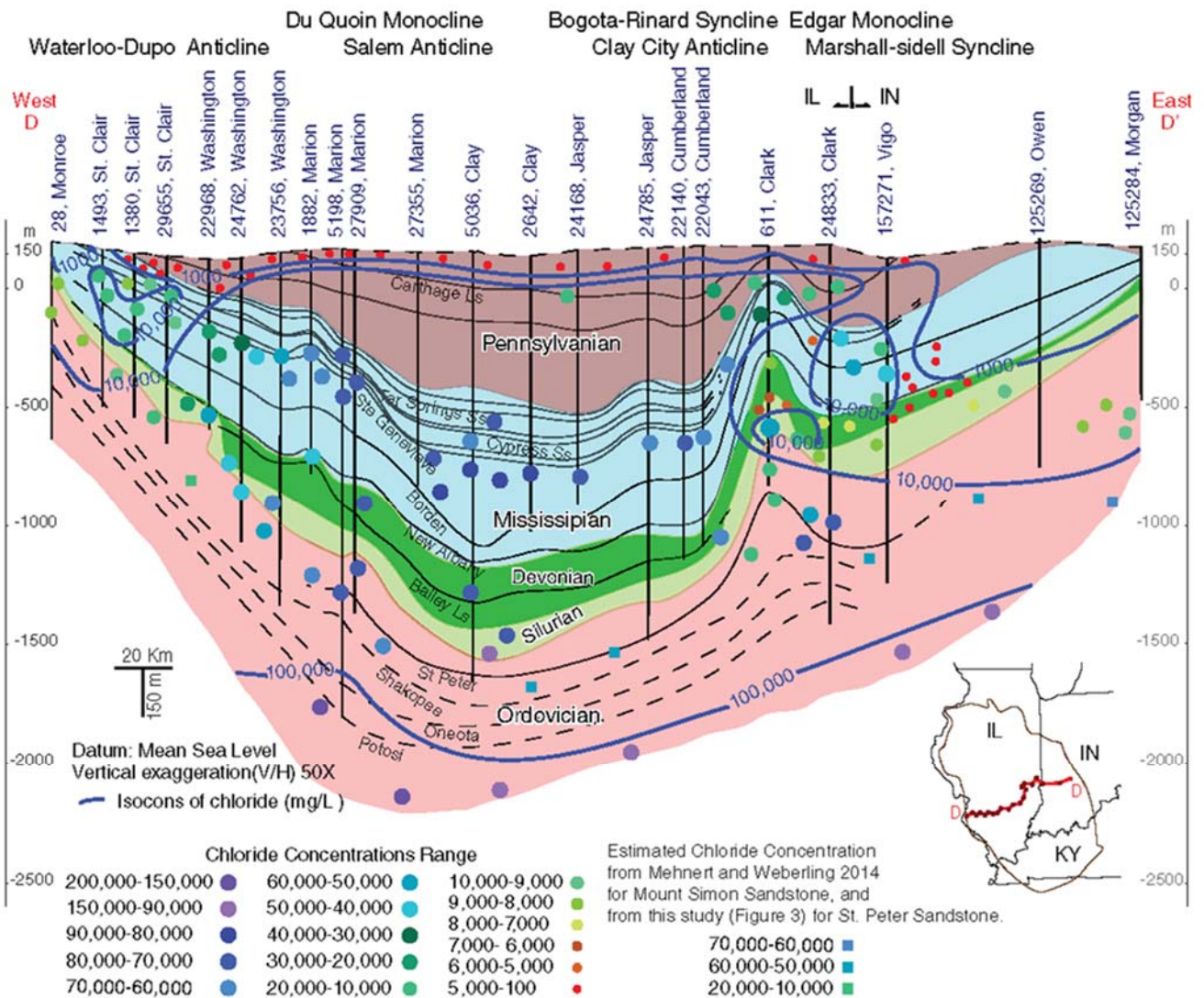
Figure 48 Cross section D-D' extending east-west across southern Illinois and southern Indiana, showing general chloride (Cl−) concentration in Illinois Basin aquifers (Panno et al. 2018).

Geochemistry [40 CFR 146.82(a)(6)]

Data Sources, Samples, and Analyses

A test well, Wabash #1, provided data regarding fluid and rock composition for this project site. Fluid samples were collected at Wabash #1 stratigraphic well for the Potosi Dolomite well test interval (4,505 to 4,525 ft) on June 8 and 9, 2020. Produced fluids were collected at the well head approximately every 10 minutes and density measurements were recorded on unfiltered samples. A total of 24 swab runs were completed prior to collection of the final swab sample (approximately 3 liters). The final swab sample was filtered, preserved, and submitted for

analysis (Locke et al. 2013) at the Illinois State Water Survey Analytical Laboratory (*Table 2*). The sample was analyzed for major, minor and trace element composition using Ion Chromatography (IC) and Inductively Coupled Plasma-atomic Emission Spectrometry (ICP-ES). The Potosi fluid sample had a Total Dissolved Solids (TDS) of 34,250 mg/L.

Rock cuttings, full diameter core, sidewall core, and geophysical logs provided information regarding the solid and fluid-phases at this site. Full diameter and sidewall core were not collected over all intervals. Geophysical logs including density, photoelectric index, conductivity (resistivity) and spectral gamma ray provided measurements that can be used to evaluate major and minor phases in the rock matrix.

Rock cores could not be collected over all intervals in the Wabash #1 well; however, there is considerable regional understanding of the geochemistry of fluids and rock lithology within the Illinois Basin. There may be local variations in depositional fabrics, but there is high confidence in the bulk mineralogy (lithology) of the injection zone and confining zone in the AoR.

<u>Solid-Phase Geochemistry</u>

The injection zone, the Potosi Dolomite, is primarily dolomite ($CaMg(CO_3)$) with minor quartz (often lining vugs and voids) and clay minerals (SEE INJECTION AND CONFINING ZONE DETAILS). A general summary of the overlying and/or confining zones is as follows:

X-Ray diffraction (XRD) data from the Cabot No. 3 well in Tuscola, IL showed the Oneota Dolomite averaged 68.3% carbonate material, 2.0% clays, and 30.3% other minerals, while the Shakopee Dolomite averaged 84.4% carbonate material, 3.7% clays, and 12.7% other minerals. The carbonate materials consisted of over 95% dolomite, the clay was primarily illite, and the other minerals were mostly quartz and feldspar with minor pyrite and ankerite (Texas World Operation, 1995).

A neutron-density cross plot from the Wabash #1 well shows the Dutchtown Formation data scattered around quartz sandstone, limestone, and dolomite values; combined with high gamma ray values (25 to 100 API) in the formation, the cross-plot data indicate that the Dutchtown interval in the well contains a mixture of shale and shaly carbonates (SEE INJECTION AND CONFINING ZONE DETAILS).

The Black River Group and Trenton Limestone are primarily limestones, dolomitized extensively along the axis of the Kankakee Arch in Indiana; the proportion of dolomite decreases to the south and southeast of the arch, influenced by multiple stages of dolomitization involving different fluids (Yoo et al., 2000). Litho-scanner log analysis from the Wabash #1 well identified predominantly calcite to dolomite (roughly averaging 70% and 20%, respectively) with minor quartz, feldspars, and clay minerals. Comparatively, to the south-southwest in White County, IL, Medina el at. (2020) identified a sample of the Trenton Limestone as nearly 98% calcite, with trace amounts of dolomite, quartz, albite, and illite.

The Maquoketa Group is a heterogeneous succession composed of clastics and carbonates. Medina et al. (2020) assessed mineral content (and five predominant/interpreted lithofacies intervals) including: high calcite (limestones); high clay content and quartz (silty clay); high clay content and carbonate-rich intervals (calcareous/dolomitic shale); high calcite and moderate clay

(muddy limestone); and high clay (shale). X-ray diffraction (XRD) analyses of the Maquoketa Group over multiple depths within a White County, IL, well indicate an overall predominance of quartz and illite throughout the section, with dolomite decreasing with depth and calcite only a major component in the basal Maquoketa; minor minerals (averaging < 10%) throughout the section include chlorite, albite, rutile, microcline, and pyrite.

Geochemical Data and Modeling

Experimental reaction and modeling information for the Potosi Dolomite and Maquoketa Group was obtained from previous ISGS studies and reports, based on core from wells in Missouri and Illinois—discussed below. A previous Kentucky Geological Survey study used test well data as inputs for reaction simulation modeling in the predominantly dolomitic upper Knox Group rocks in western Kentucky. Based on these experiments and modeling results discussed below, the CO_2 is expected to have negligible to no reaction with the minerals in the formation water and with the minerals in the Maquoketa Group. Dissolution of dolomite while exposed to supercritical CO_2 and brine was previously identified in Potosi Dolomite batch reactor experiments (Yoksoulian et al., 2014) and upper Knox Group reaction simulations (Zhu et al. 2013).

High-pressure, high-temperature batch reactor experiments were conducted using samples from the Potosi Dolomite (southwest Missouri outcrop), Maquoketa Group (Illinois Basin-Decatur Project [IBDP] core), and sandstone units not recognized in Indiana. Core flood experiments were conducted using the Potosi Dolomite (IBDP site) and sandstone units, using either laboratory produced synthetic brine or deionized water to identify the reaction mechanisms, kinetics, and solid-phase products likely to occur when exposed to supercritical CO_2 (Yoksoulian et al., 2014).

Knox Group analyses identified dissolution of dolomite while exposed to supercritical CO_2 and brine. Dissolution was confirmed through scanning electron microscope (SEM) analysis of dolomite (showing reduction in bulk volume of dolomite ranging from 12 to 47%) and brine analysis. Post-reaction brine analysis from sandstone samples as well as the Potosi Dolomite showed all samples contained elevated concentrations of calcium, magnesium, strontium, and barium, indicative of dolomite dissolution. No measurable amount of new solid-phase products was observed during the 1- to 4-month batch reactor studies. Post-reaction brine chemistry and modeling indicated that equilibrium was reached before the end of the 4-month experimental trials, suggesting dissolution could occur during the early stages of CO_2 injection operations; additionally, equilibrium was corroborated with subsequent short-term (approximately 6-hour) core flood experiments.

Post batch reaction brines sampled from the Maquoketa Group measured elevated aluminum, barium, calcium, potassium, magnesium, sulfur, silicon, and strontium indicative of feldspar, clay, carbonate, and sulfide mineral dissolution. Results of computational modeling of a 10-year period indicated no impact on seal integrity. The most significant observable reaction was alteration of K-feldspar to kaolinite and quartz which would not be expected to significantly impact seal porosity. Modeled dissolution of carbonate minerals estimated a 2.2% decrease in mineral volume at most with carbonate mineral dissolution projected to be less in an actual sequestration scenario due to the lower water-to-mineral ratio being a limiting factor to carbonate

dissolution. Based on this information, the integrity of the Maquoketa Shale primary seal will be stable throughout the injection and post-injection time periods.

Post-reaction brine chemistry results for all experiments (in Yoksoulian et al., 2014) were compared to established United States Environmental Protection Agency (USEPA) drinking water standards (discussed in detail in Yoksoulian et al. 2014); results of the Potosi Dolomite, Maquoketa Group, and other batch experiments indicated that the concentrations of the analytes were generally less than the USEPA minimum contaminant levels (MCLs) and in some cases results were inconclusive because analytical method detection limits (MDLs) were up to 150 times greater than the USEPA MCLs.

Geochemical Reactions and Mineral Trapping

Zhu et al. (2013) used TOUGHREACT kinetic batch models to simulate long-term chemical and physical interaction of formation rocks, brines, and pure CO_2 in the predominately dolomitic sequence of the upper Knox Group in western Kentucky which is consistent with mineralogy in the AoR. Rock core, fluid samples, and geophysical logs were acquired from a carbon storage test well which was used to inject 626 metric tons of CO_2 into the entire Knox Group interval; datasets from the well provided inputs for the modeling. The most significant reactions simulated from CO_2 injection were dissolution of dolomite and precipitation of quartz and dawsonite. For the permeable sections of the model dominated by dolomite, simulated mineral trapping capacity for CO_2 was small and even less in the absence of dawsonite precipitation.

Table 12 Concentration ranges of selected analytes in swab sample taken from the Potosi Dolomite for Wabash #1. Analyses performed by the Illinois State Water Survey.

Analysis Date	Analyte	Method Detection Limit (mg/L)	Concentration (mg/L)
6/16/2020	Al	0.93 ‡(brine); 0.037 (fresh)	< 0.37 ‡
6/16/2020	As	1.1 ‡(brine); 0.11 (fresh)	< 1.1 ‡
6/16/2020	B	0.58 ‡(brine); 0.023 (fresh)	4.71
6/16/2020	Ba	0.021 ‡(brine); 0.00085 (fresh)	0.391
6/16/2020	Be	0.0055 ‡(brine); 0.00055 (fresh)	< 0.0055 ‡
6/16/2020	Ca	0.29 ‡(brine); 0.029 (fresh)	1901
6/16/2020	Cd	0.12 ‡(brine); 0.012 (fresh)	< 0.12 ‡
6/16/2020	Co	0.13 ‡(brine); 0.013 (fresh)	< 0.13 ‡
6/16/2020	Cr	0.058 ‡(brine); 0.0058 (fresh)	0.066
6/16/2020	Cu	0.040 ‡(brine); 0.0016 (fresh)	< 0.016 ‡
6/16/2020	Fe	0.24 ‡(brine); 0.024 (fresh)	< 0.24 ‡
6/16/2020	K	0.40 ‡(brine); 0.016 (fresh)	213
6/16/2020	Li	2.8 ‡(brine); 0.11 (fresh)	5.8
6/16/2020	Mg	0.27 ‡(brine); 0.027 (fresh)	516
6/16/2020	Mn	0.015 ‡(brine); 0.0015 (fresh)	0.368
6/16/2020	Mo	0.22 ‡(brine); 0.022 (fresh)	< 0.22 ‡
6/16/2020	Na	0.36 ‡(brine); 0.036 (fresh)	9671
6/16/2020	Ni	0.43 ‡(brine); 0.043 (fresh)	< 0.43 ‡
6/16/2020	P	0.73 ‡(brine); 0.073 (fresh)	< 0.73 ‡
6/16/2020	Pb	0.41 ‡(brine); 0.041 (fresh)	< 0.41 ‡
6/16/2020	S	2.2 ‡(brine); 0.22 (fresh)	888
6/16/2020	Sb	1.5 ‡(brine); 0.059 (fresh)	< 0.59 ‡
6/16/2020	Se	1.3 ‡(brine); 0.13 (fresh)	< 1.3 ‡
6/16/2020	Si	1.7 ‡(brine); 0.066 (fresh)	18.9

6/16/2020	Sn	0.86 ‡(brine);0.086 (fresh)	< 0.86 ‡
6/16/2020	Sr	0.0037 ‡(brine); 0.00037 (fresh)	43.8
6/16/2020	Ti	0.0056 ‡(brine); 0.00056 (fresh)	0.0207
6/16/2020	Tl	1.2 ‡(brine); 0.047 (fresh)	< 0.47 ‡
6/16/2020	V	0.47 ‡(brine); 0.047 (fresh)	< 0.47 ‡
6/16/2020	Zn	0.097 ‡(brine); 0.0097 (fresh)	< 0.097 ‡
6/19/2020	TDS	7	34250
6/17/2020	F	7 ‡(brine); 0.07 (fresh)	< 40 *
6/17/2020	Cl	480 ‡(brine); 0.16 (fresh)	18900
6/11/2020	NO$_3$-N	4 ‡(brine); 0.04 (fresh)	< 4 *
6/11/2020	SO$_4$	21 ‡(brine); 0.21 (fresh)	1845
6/11/2020	Br	8 ‡(brine); 0.08 (fresh)	88
6/10/2020	pH	-----	7.65
6/10/2020	Alkalinity	4	446

‡ = MDL elevated and estimated due to difficult matrix

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Other Information (Including Surface Air and/or Soil Gas Data, if Applicable)

During the construction and testing of Wabash #1 (the stratigraphic test well), gas testing was incorporated as part of the mud logging protocol. The testing was performed primarily as an effort to identify any petroleum bearing formations or potential for recoverable oil and gas. The results of the gas monitoring indicated that there was no presence of recoverable oil and gas at the Wabash #1 site.

Site Suitability [40 CFR 146.83]

Based upon on all available information and the research presented in this document, the selected site meets the suitability requirements set forth in the regulations. The proposed injection zone, the Potosi Dolomite, is an extensive formation that underlies most of Illinois and Indiana, except in parts of northern Illinois. Its thickness ranges from 100 ft in northern Illinois to more than 1,500 ft in southernmost Indiana. Data collected at the Wabash #1 well indicates the injection zone is 689 ft thick at the Wabash #1 well site (*Figure 4*) and occurs at 4,473 ft MD in the Wabash #1 well. The areal extent of the Potosi formation far exceeds the predicted area required for the storage of the proposed volume of CO_2.

Early testing performed on the Wabash #1 well provided a permeability value of 2,400 md across an injection unit within the Potosi Dolomite (24,000 md-ft over 10 ft). This value was applied during the dynamic modeling of the entire injection period. The resulting modeling showed that the injection zone is capable of accepting all the CO_2 that will be injected for the duration of the project. As a further assurance of the capacity of the injection zone, secondary testing of the injection interval revealed that higher permeabilities of 45,000 md exist within the Potosi Dolomite. The usage of the much lower value of 2,400 md ensures that no limitation on injection capacity will be encountered.

The primary seal identified for this project is the Maquoketa Group. In the Wabash #1 well the Maquoketa Group is 314 ft thick, from 2,386 to 2,700 ft MD, and is composed of interbedded shale, argillaceous limestone, and dolomite. The shale intervals are considered to be the most effective seals within this rock package because these shales are more ductile, have less tendency to fracture and have extremely low vertical permeabilities. The Maquoketa Group is found over the entire Illinois Basin and extends into parts of Michigan and Iowa. Across the Basin, the Maquoketa Group ranges from 100 ft in thickness near the Mississippi River to greater than 800 ft at the eastern edge. Extensive 2D seismic evaluations were performed in the area of interest. Analysis of the seismic data revealed that no transmissive faults or fractures exist within the injection zone or any of the identified confinement layers. Regional mapping and 2D seismic information indicate that the identified confining layer is continuous across the AoR.

A record survey was performed for all oil and gas wells and water wells in the AoR. It was determined that no manmade penetrations of the primary confining layer exist within the expected AoR. The lack of manmade penetrations into the primary seal, along with the lack of

transmissive faults and fractures ensures that no leakage pathways are currently existing that threaten the LUSDW or could result in the release of CO_2 to atmosphere.

WCS has chosen Dual Refrigerant CO_2 Fractionation (DRCF) as the CO_2 capture technology. Due to the nature of this process the CO_2 produced will be dry. The absence of water in the CO_2 stream provides an extra layer of protection against corrosion as it relates to the CO_2 transport equipment (pipeline) and the well head. It is recognized within industry that carbon steel and stainless steel exposed to supercritical CO_2 with moisture levels below the saturation point experience little or no corrosion. The injection well itself has been designed using proven techniques and CO_2 compatible materials (high chrome casing and tubing, CO_2 resistant cements) to ensure no adverse interactions are experienced.

Within the injection zone, the CO_2 and brine are expected to have some interaction with dolomite resulting in some dissolution of the base material. This dissolution did not result in the precipitation of new solids during lab scale testing, thus posing no risk of loss of porosity or permeability during the injection operations due to interactions of the CO_2 and brine with the dolomite present in the injection zone. The reaction between the dolomite and the CO_2 also reached equilibrium within the 4-month experimentation period, indicating the reaction was relatively short lived in comparison to the injection time frame. There are no adverse effects expected due to the interaction of the CO_2 with injection zone material.

The primary seal layer, the Maquoketa Group, is composed of interbedded shale, argillaceous limestone, and dolomite. High-pressure, high-temperature batch reactor experiments were conducted using samples from the Maquoketa Group using either laboratory produced synthetic brine or deionized water to identify the reaction mechanisms, kinetics, and solid-phase products likely to occur when exposed to supercritical CO_2. Post batch reaction brines sampled from the Maquoketa Group measured elevated aluminum, barium, calcium, potassium, magnesium, sulfur, silicon, and strontium indicative of feldspar, clay, carbonate, and sulfide mineral dissolution. Computational modeling projected no impact on seal integrity. The most significant observable reaction was alteration of K-feldspar to kaolinite and quartz which would not be expected to significantly impact seal porosity. Modeled dissolution of carbonate minerals estimated a 2.2% decrease in mineral volume at most with carbonate mineral dissolution projected to be less in an actual sequestration scenario due to the lower water-to-mineral ratio being a limiting factor to carbonate dissolution.

The WCS project has identified the Maquoketa Group as the primary seal layer based upon core analysis, wire line logs and regional understanding of existing geology. In addition to this primary seal, there are several distinct units that exist between the Maquoketa Group and the Potosi Dolomite injection zone. These formations, the Shakopee and the Dutchtown, among others, exhibit confining zone characteristics such as low porosity, interbedded shale layers and a lack of faults and fractures. While not considered the primary seal, they will act as restriction zones, greatly reducing the dependance on the Maquoketa Group. Model results indicate that no CO_2 reaches the Shakopee due to the low permeability of the dolomite formations above the Potosi. The existence of these extensive restricting formations greatly improves the efficacy of Maquoketa Group and ensures the LUSDW is protected.

AoR and Corrective Action

To determine the AoR and any potential Corrective Actions that may need to be carried out per 40 CFR 146.84 WCS partnered with the Illinois State Geological Survey (ISGS) and Pacific Northwest National Laboratory (PNNL). Illinois State Geological Survey (ISGS) and Pacific Northwest National Laboratory (PNNL) authored this model using Subsurface Transport of Multiple Phase (STOMP) dynamic subsurface simulation software, Version 3.0. The model was built to dynamically simulate the flow of water and CO_2 throughout a twelve-year injection period and a subsequent 50-year Post Injection Site Care (PISC) period. The model accounts for multiphase (brine and CO_2) flow and reactive transport.

The dynamic model simulation is based on porous media theory (Darcy's Law) and uses internal lookup tables to define gas properties vs. pressure. The CO_2 properties are based on an equation of state (Span and Wagner, 1996); the CO_2/H_2O phase equilibria are based on a model developed by Spycher and Pruess, et al (Spycher et al., 2003; Spycher and Pruess, 2010). The multiphase flow of water and CO_2 was modeled to predict the movement of water, CO_2, and pressure evolution within the reservoir. Carbon dioxide saturation and spatial pressure differentials over time were used to estimate and delineate the Area of Review (AoR). The selection of modeled processes is unlikely to change during AoR reevaluations.

Within the calculated AoR, no artificial penetrations of the Maquoketa Group (primary seal) were identified. Table 1 provides a tabulation of all oil & gas and water wells located within the AoR for both WVCSS1 and WVCCS2. Tabulations of all wells within a 4-mile radius of each injection well have been uploaded to the GSDT tool to provide further assurance that no Corrective Actions will be required.

AoR and Corrective Action GSDT Submissions

GSDT Module: AoR and Corrective Action
Tab(s): All applicable tabs

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☒ Tabulation of all wells within AoR that penetrate confining zone *[40 CFR 146.82(a)(4)]*
☒ AoR and Corrective Action Plan *[40 CFR 146.82(a)(13) and 146.84(b)]*
☒ Computational modeling details *[40 CFR 146.84(c)]*

Financial Responsibility

To determine the financial responsibility as required by 40 CFR 146.82(a)(14) and 146.85, WCS contracted Keramida, a global Environmental Health and Safety company with experience working in the Midwest, to develop a site remediation plan in the event of contamination of the USDW due to: acidification due to CO_2 migration; toxic metals dissolution; and displacement of groundwater with brine due to CO_2 injection.

In addition to the estimate of Emergency and Remedial Response costs provided by Keramida, WCS developed cost estimates for the following required areas:

- Plugging of Injection Wells
- Post Injection Site Care and Closure
- Corrective Action on existing wells

The costs estimates are based upon historic price data from other projects performed by WCS, cost quotes from third-party companies, and professional judgment about the level of effort required to complete an activity. The estimated costs for each required activity are summarized in Table 13 below. A more detailed spreadsheet containing the breakdown of these costs, along with supporting quotes from 3rd party vendors has been uploaded to the GSDT tool.

Table 13 Financial Responsibility Cost Estimates

Item	Cost in Millions
Corrective Action	0
Injection Well Plugging (2 wells)	.88
PISC and Site Closure	3.64
Emergency and Remedial Response	9.37
Total	13.90

Within the calculated AoR, no wells penetrate the primary seal. In fact, within a 4-mile radius of each injection well, only one (1) installation exists that reaches the depth of the primary seal. This well does not fully penetrate the primary seal, with a reported Total Depth of 2,500 ft MD, it does not extend beyond the base of the Maquoketa Group which has a MD of 2,700 ft. For estimating purposes, WCS has assumed that no Corrective Action on existing wells will be required.

Post Injection Site Care (PISC) and Site Closure costs were estimated using a PISC time period of 4 years (See ALTERNATE POST-INJECTION SITE CARE TIMEFRAME).

WCS will be using a Trust Fund as the Financial Responsibility Instrument. The Trust Fund will be funded per Table 14. All required information concerning the Trust Fund has been uploaded to the GSDT tool.

Table 14 Trust Fund Schedule

Funding	Activities	Cost
Pre-Injection (*within 7 days of final permit issuance*)	Plugging Injection and Monitoring Wells	$1,935,602
	Emergency and Remedial Response	$9,378,796
Injection and Post-Injection (*within 1 year of final permit issuance, or at least 7 days prior to injection, whichever comes first*)	Post-Injection Site Care and Closure	$2,590,928

Financial Responsibility GSDT Submissions
GSDT Module: Financial Responsibility Demonstration *Tab(s):* Cost Estimate tab and all applicable financial instrument tabs Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Demonstration of financial responsibility *[40 CFR 146.82(a)(14) and 146.85]*

Injection Well Construction

WCS will be constructing all new fit-for-purpose injection facilities for this project. Injection wells WVCCS#1 and WVCCS#2 will be constructed per the information in this section.

Proposed Stimulation Program [40 CFR 146.82(a)(9)]

The need for stimulation to enhance the injectivity potential of the Potosi Dolomite formation is not anticipated at this time. If it is determined that stimulation techniques are needed, a stimulation plan will be developed and submitted to EPA Region 5 for review and approval prior to conducting any stimulation.

Construction Procedures [40 CFR 146.82(a)(12)]

The construction of WVCCS#1 and WVCCS#2 will be performed following industry best practices. All materials used in the construction of the well will conform to API (American Petroleum Institute) and NACE (National Association of Corrosion Engineers) standards.

The proposed well design will be drilled ~150 feet into the Eau Claire Shale formation to define the base of the Potosi with open-hole and cased hole well logs. Based on the Wabash #1 stratigraphic test well, the well depth will be ~5,500 feet MD (~4900 feet TVDss) and the casing and cementing program is designed for this depth. Actual well depth will be supplied in the completion report.

The Wabash #1 well data suggests that the top of the Potosi will occur at ~4,400 feet MD (3,900 feet TVDss). A swab sample of formation fluid collected during the testing of the Wabash #1 well indicate that the Potosi Dolomite formation fluid has a total dissolved solids (TDS) value of 34,250 mg/L. A Potosi pressure gradient of 0.431 psi/ft (1940 psig) was measured in the Wabash #1 stratigraphic test well at 4,505 feet MD. Using this pressure gradient, the pressure at the top of the Potosi should be approximately 1887 psi. The actual pressure and static level will be determined after the well is fully cased and perforated.

The well will be cased to total depth (TD) and cemented back to ground level with a CO_2 -resistant cementing system. CO_2 resistant cement will cover the entire open hole section from TD and be placed approximately 500 feet back into the 10-3/4" casing. One intermediate casing string is planned; it will also be cemented to surface.

The subsurface and surface design (casing, cement, and wellhead designs) reflects the necessary requirements to sustain the integrity of the caprock to ensure no movement of CO_2 out of the

target reservoir. For reasons such as equipment or supply availability, or changes to the supplemental monitoring program, the final well design will meet or exceed these requirements in terms of strength and CO_2 compatibility. The well design also has the objective of maintaining life cycle well integrity (through the drilling, injection/operations, and the abandonment phases) of the CO_2 injection well(s). The design of the casing string provides a minimum of two layers of protection (2 casing layers) between the CO_2 and the surrounding formations. The use of the minimum 2 casing layer design and constant monitoring of well integrity (annular fluid level, annular pressure, mechanical integrity testing) ensures the protection of the USDW and prevention of fluid movement between sections. To provide further protection of the primary sources of drinking water (Pennsylvanian formation) during drilling operations, surface casing will be set to a depth of ~350 feet well below the average water well depth of ~66 feet.

The wellbore trajectory of each of the deep wells will be tracked. The wells will be drilled to an inclination standard of less than 5 degrees and will be surveyed at least every 1,000' to ensure compliance.

Note that depths given are based on anticipated drilling conditions and estimated depths of formations and are subject to change. Final depths will be reported in the well completion report.

MD/TVD	Section	Casing Size	Open Hole Size	Formation Tops
	Conductor			
100		24"	30"	
	Surface			
350		16"	20"	
				1,960 Silurian LUSDW
	Intermediate			2,380 Maquoketa Confining Layer
				3,320 St. Peter
3,400		10 3/4"	14 3/4"	3,350 Shakopee
				4,380 Potosi
	Production			Injection Interval
5,400		7 5/8"	9 1/2"	5,300 Eu Claire
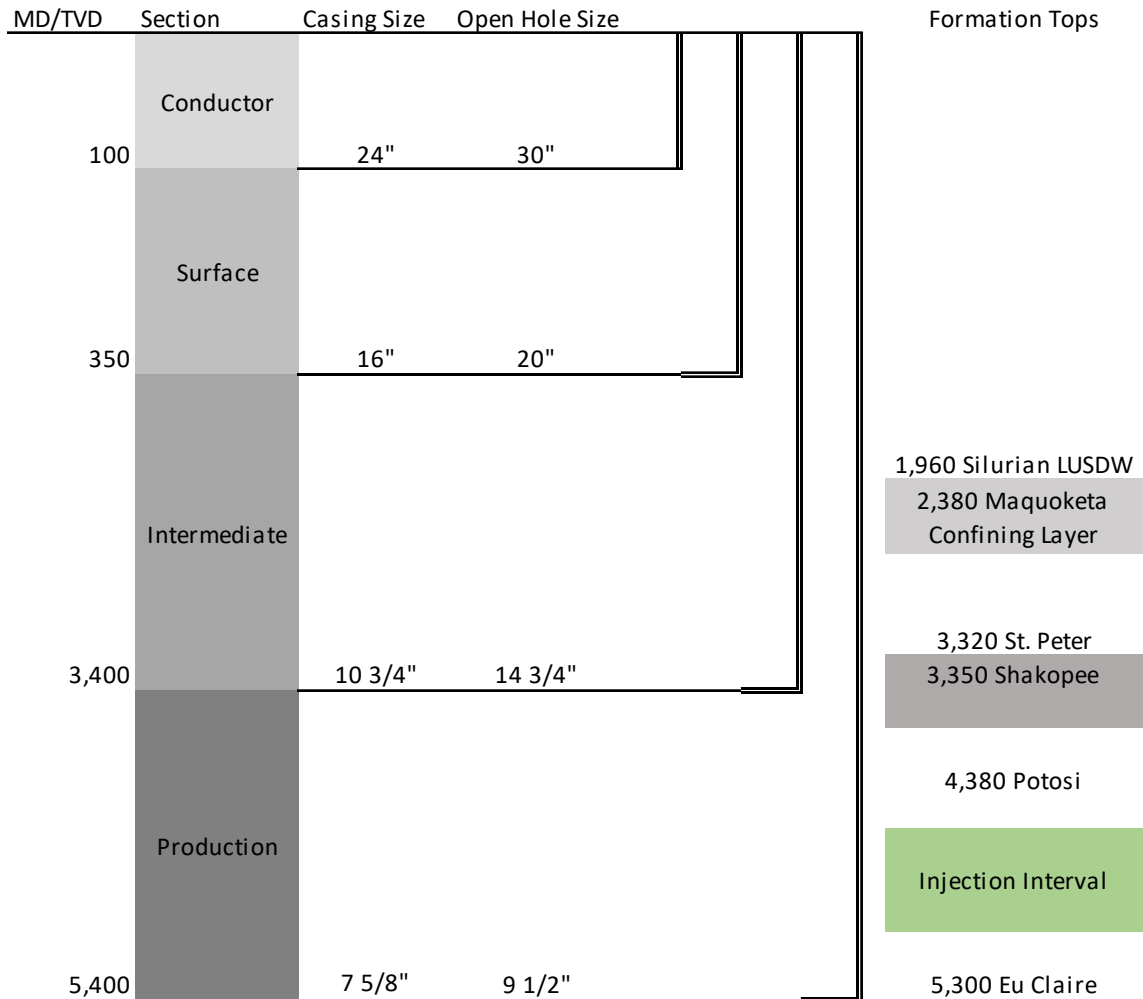
Figure 49 WVCCS #1 and #2 Casing Details

Casing and Cementing

The casing and cementing of the proposed injection wells will follow industry standards for CO2 resistance within the injection zone. Table 15 and Table 16 provides information concerning the proposed casing plan and materials of construction to achieve the required compatibility with the envisaged downhole conditions.

To ensure compatibility with the CO_2 environment WCS will be utilizing CO_2 resistant casing (13% Cr or other appropriate metallurgy) for the long string from ~3,200 Ft MD (2,650 TVDss) to ~5,500 Ft MD (4,950 TVDss) (TD). The interface from API Carbon Steel to 13 Cr or equivalent will occur ~200 feet within the intermediate casing above the Shakopee. This ensures

that only CO2 resistant material is exposed to any potential CO_2 in the surrounding formation stream.

Table 15 Casing details

Casing String	Casing Depth (feet - MD)	Borehole Diameter (inches)	Wall Thickness (inches)	External Diameter (inches)	Casing Material
Conductor	0-100	30	1.094	24	H40, Welded Coupling
Surface	0-350	20	0.495	16	84 #/ft, J55, STC coupling
Intermediate	0-~3,400	14 3/4	0.350	10 ¾	40.5 #/ft, J55, BTC coupling
Long String (API Carbon Steel)	0-~3,200	9 1/2	0.75	7.625	26.4 #/ft, N80, BTC coupling
Long String (Chrome)	~3,200-~5,400	9 1/2	0.75	7.625	24 #/ft, L-80, 13Chrome Alloy, Special Coupling. A corrosion-resistant alloy such as 13Cr (13 % chromium) having strength properties equal to or greater than 26.4#/ft N-80 and having premium connections will be used for this section.

Table 16 Casing details

Casing String	Lb/Ft	String Weight Lbs	Burst Pressure PSI	Collapse Pressure PSI	Tension Data Lbs Pipe	Thread
Conductor	125.5	12,550	2005	442		
Surface	84	29,400	2980	1410	1,326,000	817,000
Intermediate	40.5	137,700	3130	1580	629,000	700,000
Long String (Carbon)	26.4		6020	3400	602,000	659,000
Long String (Chrome)	24	147840	5508	2816	602,000	317,000

In order to ensure proper cementing of the injection well the following cementing plan has been developed. The casing centralizer design and placement will be determined utilizing actual drilling and log data including trajectory and borehole dimensions for all casing strings to optimize casing centralization and mud removal.

The cement plan incorporates use of a one-stage cementing technique for each string if hole conditions allow. A casing float shoe will be placed on the bottom of the casing string and a float collar placed one to two joints of casing above the bottom. A bottom wiper plug will be used to wipe the mud film from the casing ahead of the cement job. The bottom of the casing will be set a few feet off the bottom of the hole. Actual cement pumping and displacement rates will be determined using well specific parameters such as mud properties and circulation rates determined during the actual drilling process. A custom spacer will be pumped ahead of the cement system to assist in mud removal.

Although single stage cement jobs are planned for all casing strings, information learned during the drilling process (e.g., lost drilling returns) may lead to a decision to use a two-stage cementing technique on any or all of the strings. It is anticipated that the long string will be cemented back to surface through a single stage system, however, should a two-stage cement system be required for the long string, the lower cement stage will cover the Potosi and come up to a few hundred feet above the Shakopee. A stage cementing tool will be run on the 7-5/8" casing string allowing the second stage or upper section to be cemented after the lower cement stage has reached approximately 500 psi compressive strength. The designed lead system will cover the upper hole section and a small amount of the CO_2 resistant cement may be tailed in and placed across the stage cementing collar. The stage cementing collar will be drilled out and casing integrity test performed.

Integrity of the cement used for each section will be verified before moving forward to the next phase of well construction. The use of proper annular fluids (cement or completion brine) ensures isolation of the well from the surrounding USDW and prevents movement of fluids from one geological zone to another. Each well casing section will have the following annular fluid used with the associated integrity test performed.

Table *17* contains more information related to the cementing plan.

- 24" casing inside 30" hole cemented to surface with excess. Topped out if full returns are not obtained.
- 16" casing inside 20" hole cemented to surface. Cement top and quality to be determined by USIT (Ultrasonic Imaging Tool) or CBL (Cement Bond Log)
- 10 3/4" casing inside 14 ¾" hole to be cemented to surface. Cement top and quality to be determined by USIT or CBL
- 7 5/8" casing inside 9 ½" hole to be cemented to surface. Cement top and quality to be determined by USIT or CBL
- 4 ½" tubing and 7 5/8" casing above the packer will have a NaCl or equivalent completion brine with a density of at least 9.4 lbs/gallon (ppg) and very low solids.

Table 17 Cementing Details

Casing String	Cement Type	Additive	Cement lb/gal	Cement Amount Sacks	Slurry Amount bbl	Bottom hole static temp (BHST) degF	Bottom hole circulating temp.(BHCT) degF
Conductor	Class A	NA	15.60	274	58.3	71	80
Surface	Class A	NA	15.60	412	87.7	73.5	80
Intermediate Lead	TXI Lightweight	Extender, Antifoam, Accelerator, LCM Dispersant	12	1062	340	113	96.6
Intermediate Tail	Class G		15.60	465	98	113	96.6

Long Lead	TXI Lightweight	Antifoam, Dispersant, Fluid Loss + antisettling (tail)	12	414	120.7	123.2	102
Long Tail	EverCRETE or similar		12.77	440	89.4	123.2	102

Tubing and Packer

Table 18 Tubing and packer details.

Material	Setting Depth	Tensile Strength	Burst Strength/Internal Yield (psi)	Collapse Strength (psi)	Material
Tubing 4.5" 12.6#/ft Chrome Alloy (EUE – external upset end)	0 - ~5,322	Special	2630	2870	Chrome Alloy
Packer	~4,500	Packer details will be provided after final selection of tool and vendor			Type III Service Tool, 13 Chrome

Pre-Operational Logging and Testing

The Pre-operational logging and testing plan submitted through the GSDT system covers all requirements of 40 CFR 146.87. The proposed plan covers the testing to be performed and samples to be collected during the construction of WVCCS1. A thorough logging plan has been developed that incorporates all mandated logs along with other geophysical test that will help inform future modeling work and reservoir development. The testing regime for the entire well bore can be found in the Pre-operational testing plan.

Per 40 CFR 146.87(b) whole cores will be collected from the Potosi Dolomite formation, Shakopee formation and Maquoketa Group formation during the construction of WVCCS1. The core collected from WVCCS1 will be compared to the core samples collected from Wabash1 test well. No coring will be performed during the construction of WVCCS2 given its proximity to core collection sites.

Pre-Operational Logging and Testing GSDT Submissions

GSDT Module: Pre-Operational Testing
Tab(s): Welcome tab

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☒ Proposed pre-operational testing program *[40 CFR 146.82(a)(8) and 146.87]*

Well Operation

Operational Procedures [40 CFR 146.82(a)(10)]

Maintaining proper operational procedures is critical to ensure the protection of the USDW and the integrity of the injection well and associated equipment. To determine the maximum allowable injection pressure of the Potosi formation a fracture gradient of 0.710 psig/ft was used as a baseline. This value was verified during the testing of the Wabash #1 stratigraphic test well. To determine the maximum allowable downhole pressure an injection depth of 4,300 Ft was assumed. Given a fracture gradient of 0.710 psig/ft and an injection pressure limit of 90% of fracture pressure, per 40 CFR 146.88(a), a resulting maximum allowable pressure of 2,747 psig was derived. These values will be finalized after construction of the actual injection wells due to final setting depths affecting both CO_2 density and available head pressure.

Using a supercritical CO_2 density of 712 Kg/M^3 the head pressure of the fluid column was calculated. To determine the head pressure in feet the following conversion was performed:

$$2.3 \text{ Feet } H_2O = 1 \text{ PSIG}$$

$$H_2O = 1000 \text{ Kg/M}^3$$

$$\text{Supercritical CO2} = 712 \text{ Kg/M}^3$$

$$712/1000 = 0.712 \text{ percent of } H_2O \text{ Density}$$

$$2.3/0.712 = 3.2 \text{ Feet } CO_2 \text{ per PSIG}$$

$$4300 \text{ ft} / 3.2 \text{ Feet } CO_2 \text{ per psig} = 1343 \text{ psig static head}$$

2747 psig maximum downhole pressure – 1343 psig static head = 1404 psig surface wellhead injection pressure limit.

The operating conditions proposed are based upon the average steady state condition. Actual operating conditions will vary due to Carbon Capture Plant throughputs and routine plant maintenance outages.

Proposed Carbon Dioxide Stream [40 CFR 146.82(a)(7)(iii) and (iv)]

The source of the CO_2 stream supplied to the injection site will be the Wabash Valley Resources facility located approximately 12 miles to the South East. The CO_2 will be captured using a Dual Stage Refrigeration unit as part of the generation of H_2 for power production. The capture technology creates a liquid CO_2 stream that is then pumped via pipeline to the injection site. The CO_2 will be delivered to the sequestration wells as a supercritical fluid containing less than 400 PPM (*Table 19*). Based on existing literature concerning the handling of supercritical CO_2 "Field experiences and laboratory experiments indicated that as long as the water content contained in the SC CO2/H2O system was below the solubility limit at the corresponding pressure and

temperature, carbon steels were not corroded during the transporting CO_2 process" (L. Wei et al. 2014).

Table 19 Proposed CO₂ Stream Composition

Component	% VOLUME
CO_2 (Carbon Dioxide)	99.88504
O_2 (Oxygen)	0 PPM
N_2 (Nitrogen)	0.00203
CO (Carbon Monoxide)	0.00353
CH_4 (Methane)	0.02538
H_2S (Hydrogen Sulfide)	<1000 PPM
$H2O$ (Water)	<400 PPM
Ar (Argon)	.00961
$H2$ (Hydrogen)	0.00106

Table 20 Proposed operational procedures.

Parameters/Conditions	Value	Unit
Maximum Injection Pressure		
Downhole	2747	PSIG
Average Injection Pressure		
Surface	Surface Injection Pressure to be established after final injection tubing depth/size is determined	PSIG
Downhole	2110	PSIG
Maximum Injection Rate	834,390 per well	T/Yr
Average Injection Rate	834,390 per well	T/Yr
Annulus Pressure	To be determined based on on-site conditions	PSIG
Annulus Pressure/Tubing Differential	To be determined based on on-site conditions	PSIG

References

Liang Wei, Yucheng Zhang, Xiaolu Pang and Kewei Gao 2014. Corrosion behaviors of steels under supercritical CO_2 conditions. Corrosion Reviews, July 2015.

Testing and Monitoring

WCS has submitted via the GSDT system a Testing and Monitoring plan that meets all requirements of 40 CFR 146.82 (a)(15) and 146.90. The T&M plan includes the testing

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protocols of the CO_2 stream, operating parameters for the injection well, injection well mechanical integrity, ground water quality monitoring and CO_2 plume tracking. The T&M plan will be executed in conjunction with the Quality Assurance and Surveillance Plan (QASP) that has been submitted through the GSDT system.

<table>
<tr><td>Testing and Monitoring GSDT Submissions</td></tr>
<tr><td>GSDT Module: Project Plan Submissions
Tab(s): Testing and Monitoring tab

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☒ Testing and Monitoring Plan [40 CFR 146.82(a)(15) and 146.90]</td></tr>
</table>

Injection Well Plugging

WCS has uploaded into the GSDT tool the plugging plans for both WCCS1 and WCCS2. The individual plugging plans meet the requirements set forth in 40 CFR 146.92(b). The files submitted provide detailed descriptions, job plans and schematics of the proposed plugging process. Each of the following activities are covered in detail:

- Bottomhole pressure determination
- Casing mechanical integrity evaluations
- Well plug type and number
- Setting depth of each placed plug
- Material of construction of each plug, including plugs that require CO_2 resistance
- Methods employed to place the plugs

At the time of final abandonment, these plans will be revised to reflect the current State of Indiana Oil and Gas requirements along with current EPA regulations, as well as utilizing current technology applicable to the condition of the well at the time. These agencies will be notified in sufficient time to witness the abandonment operation.

Understandably, specific action plans may change since perforation intervals and perhaps tubular sizes may vary, depending upon how the well construction/well intervention/injection processes proceed. Also, the type, grade and quantity of cement used will depend on the wellbore geometry and physical conditions existing at the time of each abandonment operation. At closure a rig will remove most of the tubing, and place the appropriate cement plugs.

<table>
<tr><td>Injection Well Plugging GSDT Submissions</td></tr>
<tr><td>GSDT Module: Project Plan Submissions
Tab(s): Injection Well Plugging tab

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☒ Injection Well Plugging Plan [40 CFR 146.82(a)(16) and 146.92(b)]</td></tr>
</table>

Post-Injection Site Care (PISC) and Site Closure

To meet the requirements set forth in 40 CFR 146.93 WCS developed a Post-Injection Site Care and Site Closure plan. The PISC modeling period details the behaviors of the Pressure Front and CO_2 Plume for 50 years post-injection. Detailed images describing these behaviors are provided along with Site Closure procedures.   WCS will be proposing an alternative PISC timeframe of 4 years which is justified through the information submitted to the GSDT tool and contained within the PISC and Site Closure Plan.

PISC and Site Closure GSDT Submissions

GSDT Module: Project Plan Submissions
Tab(s): PISC and Site Closure tab

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☒ PISC and Site Closure Plan *[40 CFR 146.82(a)(17) and 146.93(a)]*

GSDT Module: Alternative PISC Timeframe Demonstration
Tab(s): All tabs (only if an alternative PISC timeframe is requested)

Please use the checkbox(es) to verify the following information was submitted to the GSDT:
☒ Alternative PISC timeframe demonstration *[40 CFR 146.82(a)(18) and 146.93(c)]*

Emergency and Remedial Response

A Emergency and Remedial Response Plan (ERRP) has been uploaded to the GSDT tool. This plan meets all the requirements put forth in 40 CFR 146.82(a)19 and 146.94(a). Specifically, the plan covers the response required to the following emergency situations:

- Injection or monitoring (verification) well(s) integrity failure

- Injection well monitoring equipment failure (e.g., shut-off valve or pressure gauge, etc.)

- A natural disaster (e.g., earthquake, tornado, lightning strike)

- Fluid (e.g., brine) leakage to a USDW

- CO_2 leakage to USDW or land surface

Response plans, communication plans, contact numbers for local authorities and the review schedule of the ERRP are included within this document.

Emergency and Remedial Response GSDT Submissions
GSDT Module: Project Plan Submissions *Tab(s):* Emergency and Remedial Response tab Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☒ Emergency and Remedial Response Plan *[40 CFR 146.82(a)(19) and 146.94(a)]*

Injection Depth Waiver and Aquifer Exemption Expansion

No Injection Depth Waiver or Aquifer Exemption Expansion will be filed as part of this project. All injection will occur below the identified USDW.

Injection Depth Waiver and Aquifer Exemption Expansion GSDT Submissions
GSDT Module: Injection Depth Waivers and Aquifer Exemption Expansions *Tab(s):* All applicable tabs Please use the checkbox(es) to verify the following information was submitted to the GSDT: ☐ Injection Depth Waiver supplemental report *[40 CFR 146.82(d) and 146.95(a)]* ☐ Aquifer exemption expansion request and data *[40 CFR 146.4(d) and 144.7(d)]*