CLASS VI PERMIT APPLICATION NARRATIVE
40 CFR 146.82(a)

Wabash CCS Project

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 yellow highlighted text 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 before 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.

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. However, 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) in the Wabash #1 well.

The Potosi injection zone is primarily within the Potosi Dolomite (Upper Cambrian)—the basal unit of the Knox Supergroup—and includes the bottom 95 feet of the overlying Oneota Dolomite. Overlying the injection zone, multiple units exist with low enough permeabilities to serve as barriers or baffles which may inhibit vertical fluid movement; at the top of these units overlying the injection zone lies the Maquoketa Group confining unit. Core samples of the Maquoketa shale were collected and analyzed. Based on 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 injection zone 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—and includes the bottom 95 feet of the overlying Oneota Dolomite (as described below). 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 Dolomite is 689 ft thick at the Wabash #1 well site (*Figure 4*) and occurs at 4,473 ft MD (3,921 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).

The top of the Potosi Dolomite is difficult to identify using wireline logs. For the petrophysical analysis (and subsequent reservoir simulation), the top of the Potosi injection interval is considered to be a porous and permeable zone in the lower Oneota Dolomite. Note that the top of the Potosi injection interval from log interpretations used in reservoir modeling differs from the top of the Potosi Dolomite as shown in regional stratigraphic column and cross sections; the top of the Potosi injection interval described herein includes 95 feet of the lower Oneota Dolomite.

Oneota Dolomite

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

Overlying Units

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 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 argillaceous dolomites are characterized by high gamma ray, low density, and high porosity values. However, the porosity values of the intervals shown in figures 2 and 3 are not considered as an effective porosity. The clay contents of the intervals as well as shale intervals contains small pore spaces which are not connected to each other; therefore, these intervals have very low effective porosity.

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 SW-NE cross section prepared for three wells in Illinois and Indiana depicts the Shakopee Dolomite is composed of fine-grained argillaceous dolomite and thin bedded shale intervals throughout the area with a thickness range of 400 to 600 ft (122 to 182 m; Fig 2). The N-S cross section prepared for the Knox Group in Indiana indicates the Shakopee primarily consists of dolomite with thin intervals of shale and argillaceous dolomite in the northern part changing to thick intervals of argillaceous dolomite and thin intervals of shale in southern parts (Fig 3). Furthermore, the thickness of Shakopee increases from 600 ft (180 m) in northern Indiana to 800 ft (243 m) in southern Indiana. 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*).

St. Peter Sandstone

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 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.

Dutchtown Formation

The argillaceous carbonate rocks of the Ancell Group (Dutchtown Formation and Joachim Dolomite) and Black River Group (Platteville Group of Illinois). 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 higher neutron signatures of this interval is likely due to clay content in the carbonate layers.

Platteville Group* and *Trenton Limestone

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 are described together 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.

CONFINING UNIT

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).

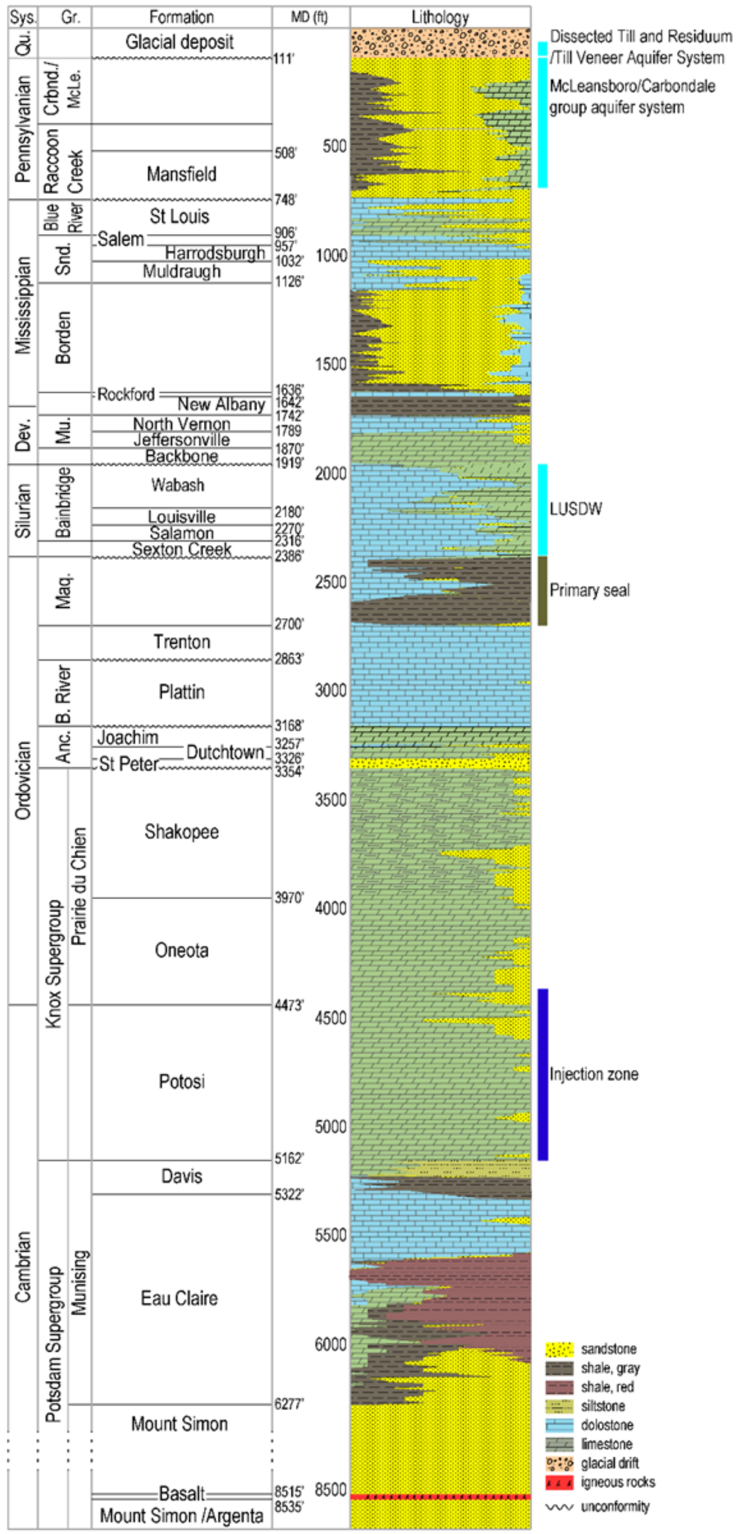

Figure 1. Stratigraphic column of the Wabash #1 well, Vigo County, Indiana. Note: dashed vertical lines indicate where the Mt. Simon Sandstone section (above the basalt layer) has been condensed in this graphic. Abbreviations: Sys: System, Gr: Group, MD: Measured depth, Qu: Quaternary, Dev: Devonian, Crbnd: Carbondale,McLe: McLeansboro, B. River: Black River, Mu: Muscatatuck, Maq: Maquoketa, Anc: Ancell.

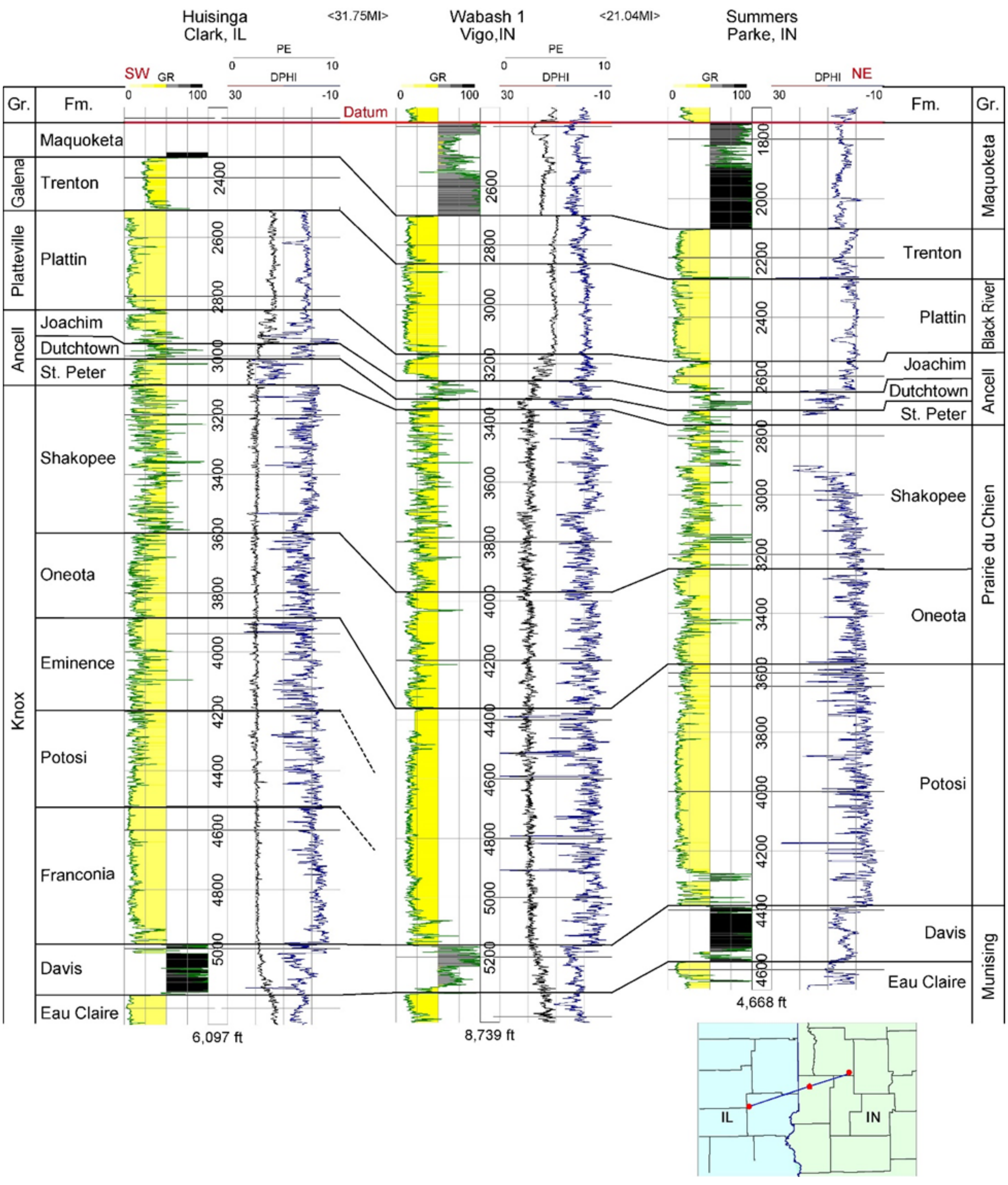

Figure 2. Southwest-northeast correlation of the units in the upper part of the Knox Group from east-central Illinois to west-central Indiana.

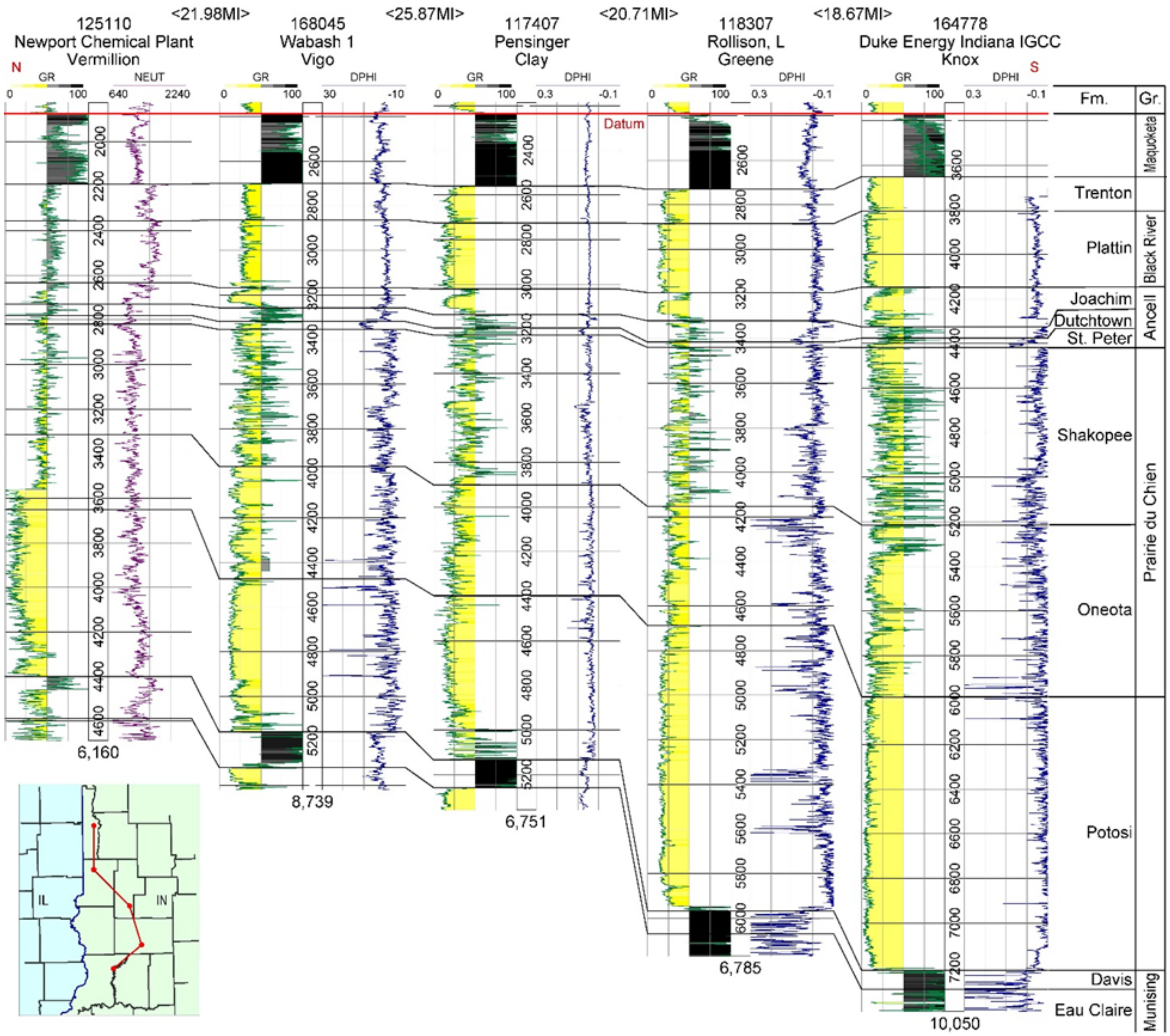

Figure 3. North-south correlation of the units in the upper part of the Knox Group in Indiana.

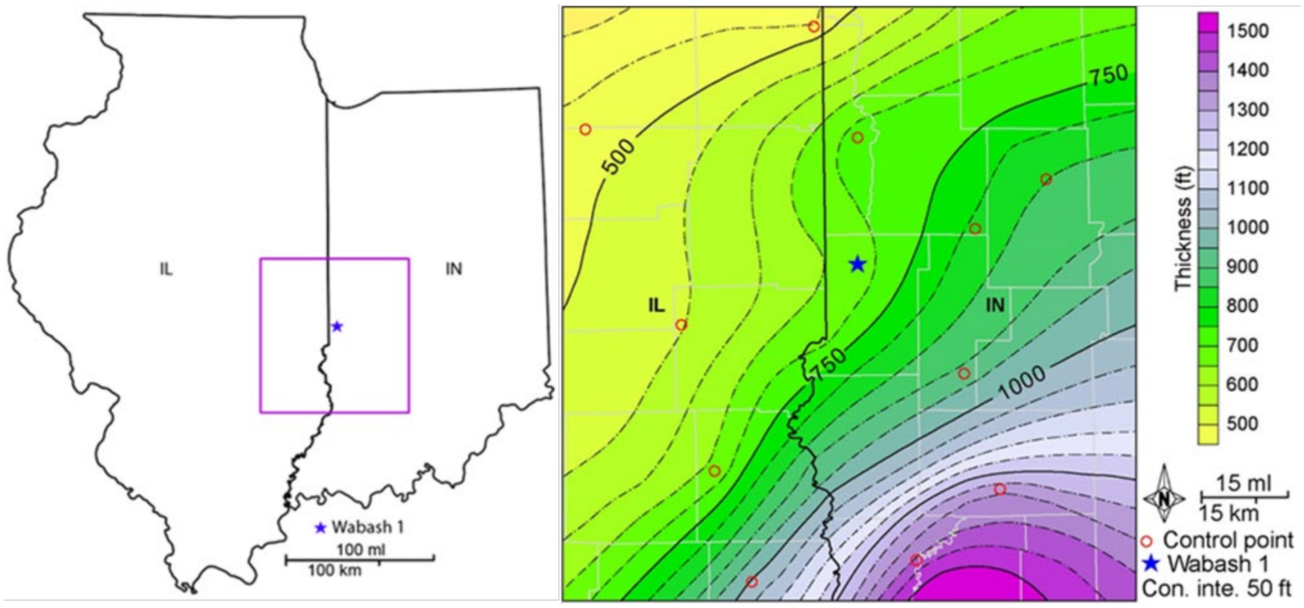

Figure 4. Thickness (in feet) of the Potosi Dolomite around the study area of the Wabash Well # 1 (denoted by the star). The Potosi generally thickens southeastward across the area.

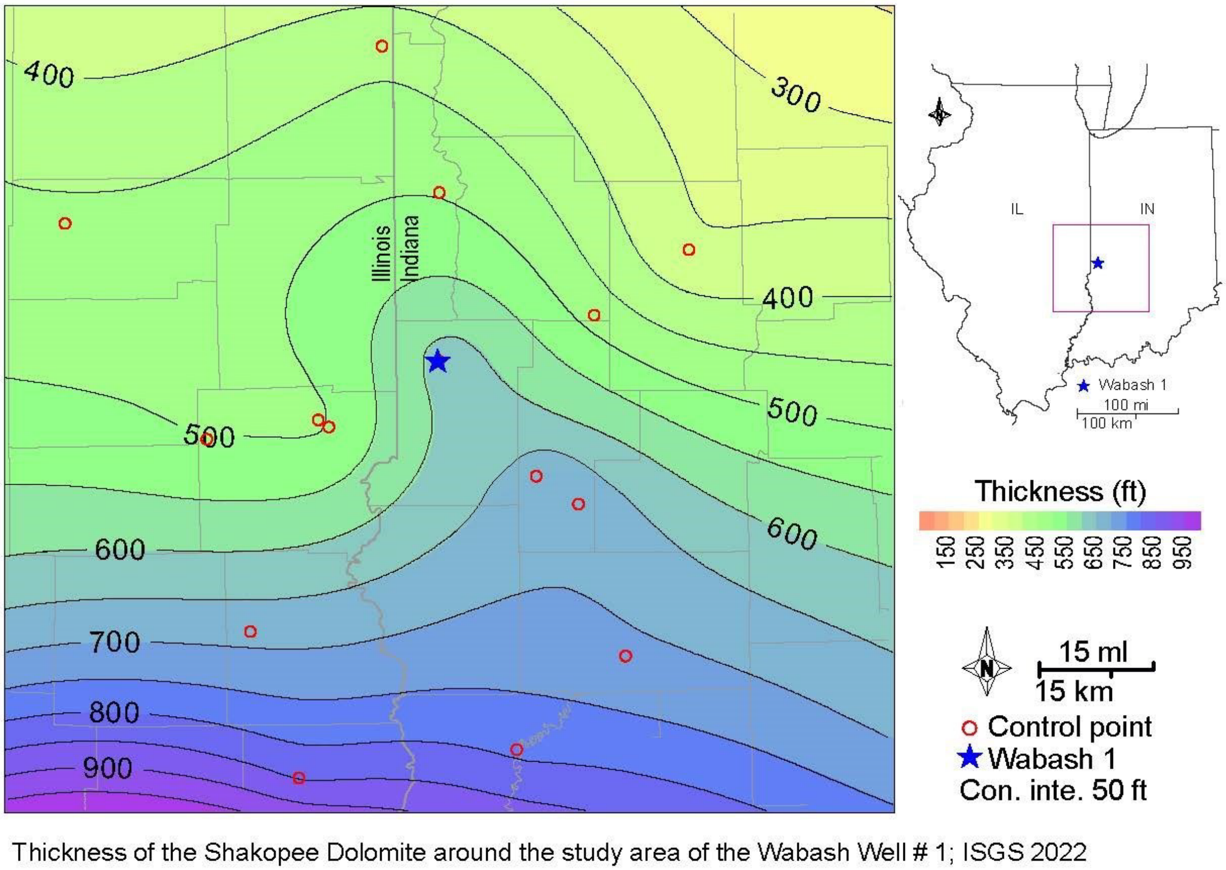

Figure 5. Thickness (in feet) of the Shakopee Dolomite around the study area of the Wabash Well # 1 (denoted by the star). The Shakopee generally thickens toward the south across the area.

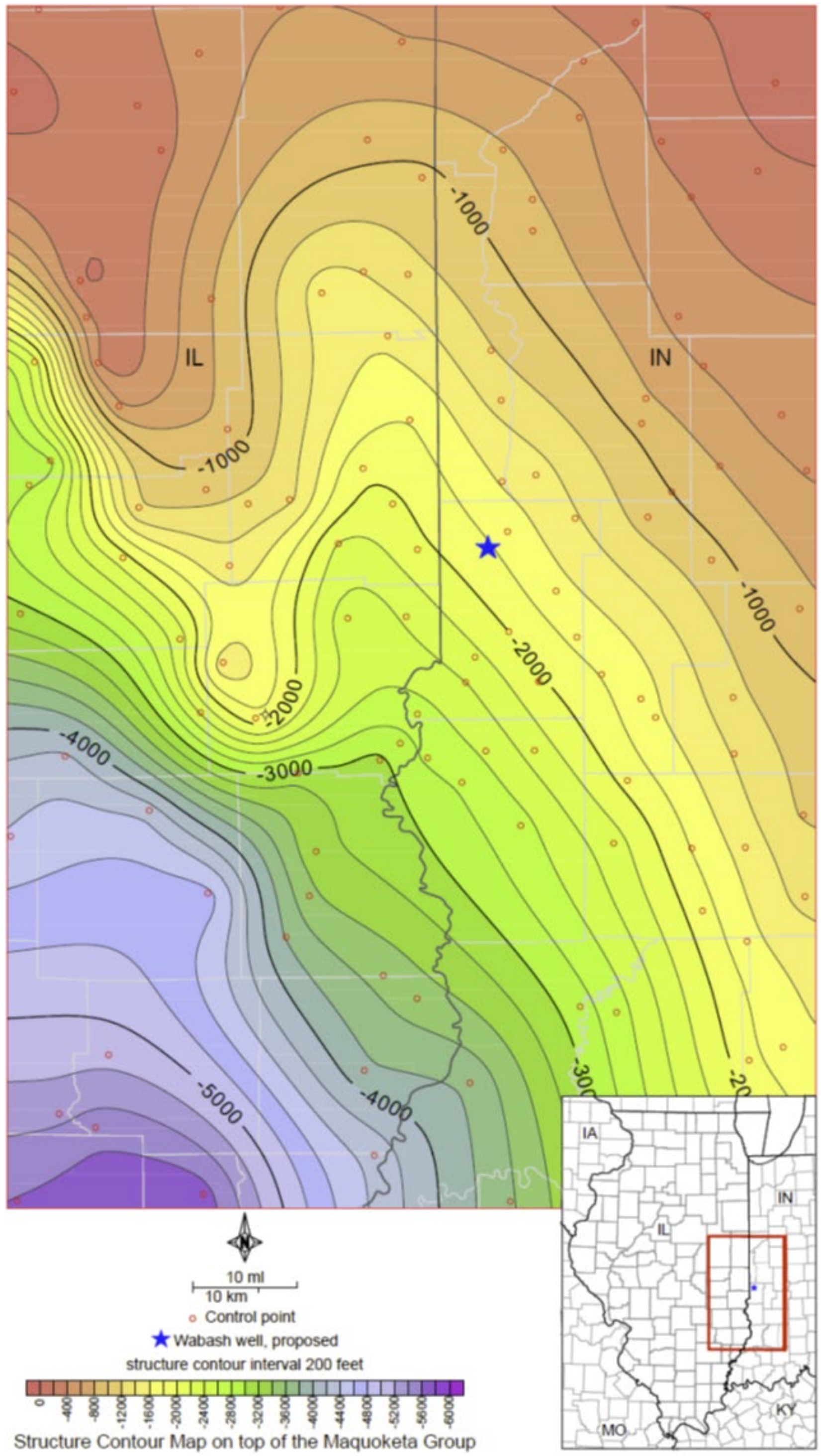

Figure 6. Regional structure map of the top of the Maquoketa Group. The Wabash #1 well is denoted by the star.

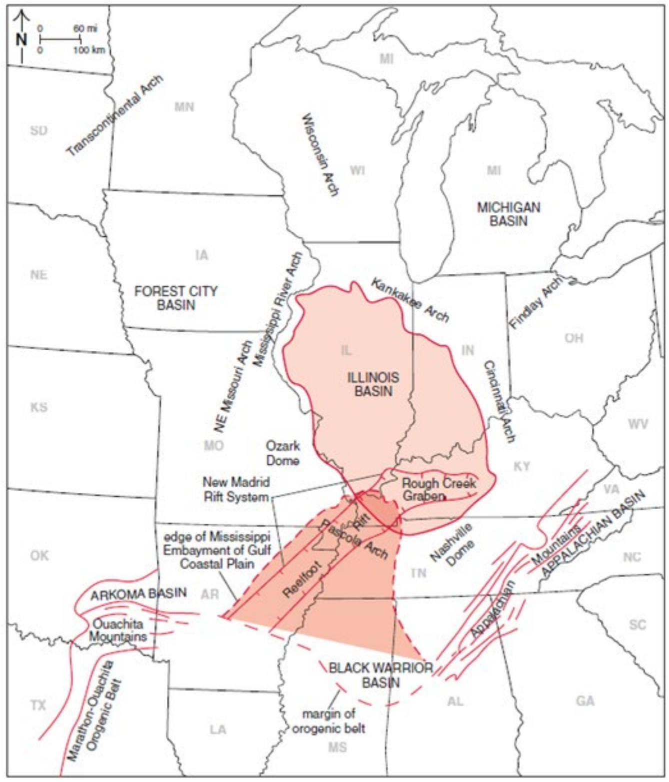

Figure 7. Regional map of the central United States showing the major tectonic features surrounding the Illinois Basin from various sources (Finley, 2005).

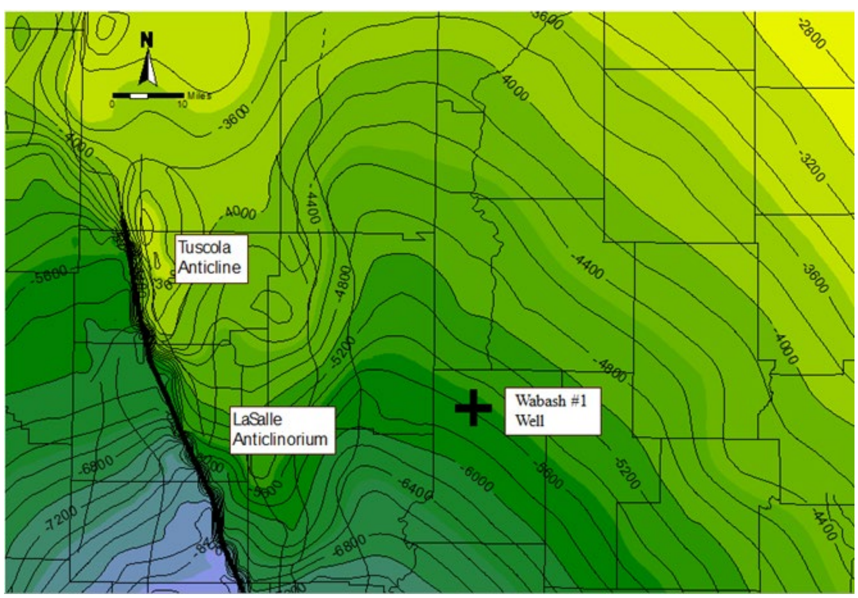

Figure 8. Structure on the Mt. Simon Sandstone in east-central Illinois and west-central Indiana. The Wabash #1 well in Vigo County, Indiana, is shown as a black cross. The nearest known structure is the LaSalle Anticlinorium approximately 20 miles west of the well location.

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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 AoR's all pre-existing wells have been identified (water/oil & gas). The type of well and depth of penetration of all wells located within the AoR's is detailed below:

Table 1 Total Count of Wells in AoR

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

Well Type	Depth of Penetration (FT)	Well Type	Depth of Penetration (FT)
Oil and Gas	1,407	Water	33
Oil and Gas	197	Water	30
Oil and Gas	1,116	Water	60
Oil and Gas	1,850	Water	51
Oil and Gas	1,827	Water	45
Oil and Gas	917	Water	45
Oil and Gas	879	Water	150
Oil and Gas	356	Water	31
Oil and Gas	1,768	Water	72
Oil and Gas	294	Water	40
Water	45	Water	45
Water	31	Water	45
Water	36	Water	47
Water	47	Water	45
Water	33	Water	
Water	100	Water	
Water	50	Water	
Water	95	Water	47
Water	88	Water	53
Water	60	Water	35
Water	47	Water	36
Water	40	Water	180
Water	80	Water	34

Water	42	Water	30
Water	30	Water	49
Water	125	Water	46
Water	45	Water	60
Water	373	Water	46
Water	89	Water	46
Water	81	Water	42
Water	166		

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 are discussed in the INJECTION and CONFING ZONE DETAILS of this document.

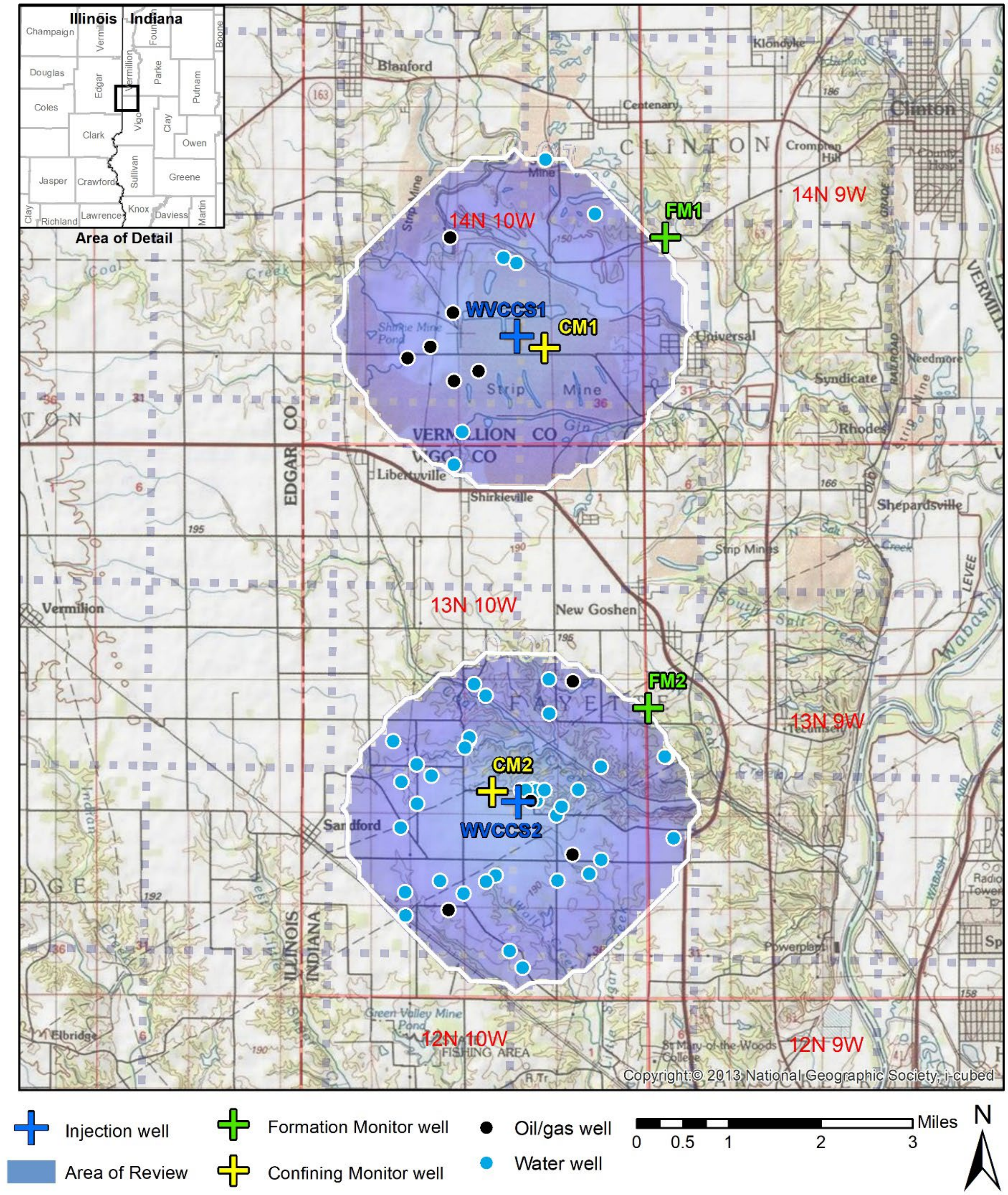

Figure 9 Water and oil/gas wells located within the Area of Review (AoR). Well data are from Indiana Department of Natural Resources and Indiana Geological & Water Survey databases. USGS topographic map base shows land surface features, water bodies, and infrastructure through the area.

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 9*). 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 10*) shows the correlation of the seismic reflectors with the geologic data acquired from the Wabash #1 well. The seismic reflection data are 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 11* and *Figure 12*). Figure 11 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 13*).

There are no identified faults that transect the Potosi reservoir, overlying units, or the confining unit. There is no specific Potosi Dolomite seismic reflector as the 20-ft (6 m) thick, porous Potosi reservoir injection test 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) exhibits 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 were 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 Potosi Dolomite injection zone, overlying beds, or the Maquoketa confining unit. 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.

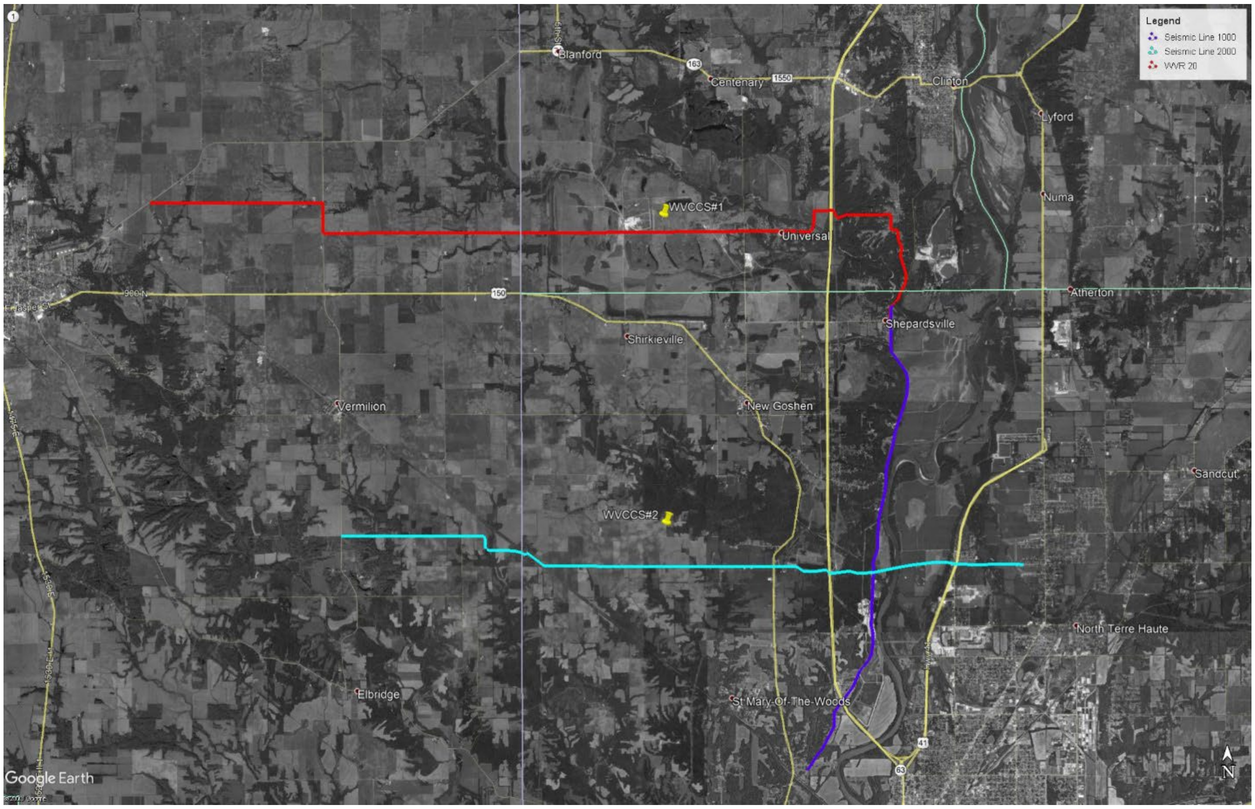

Figure 10. Base map of the Wabash area showing the location of the seismic reflection profiles, injection wells and major roads

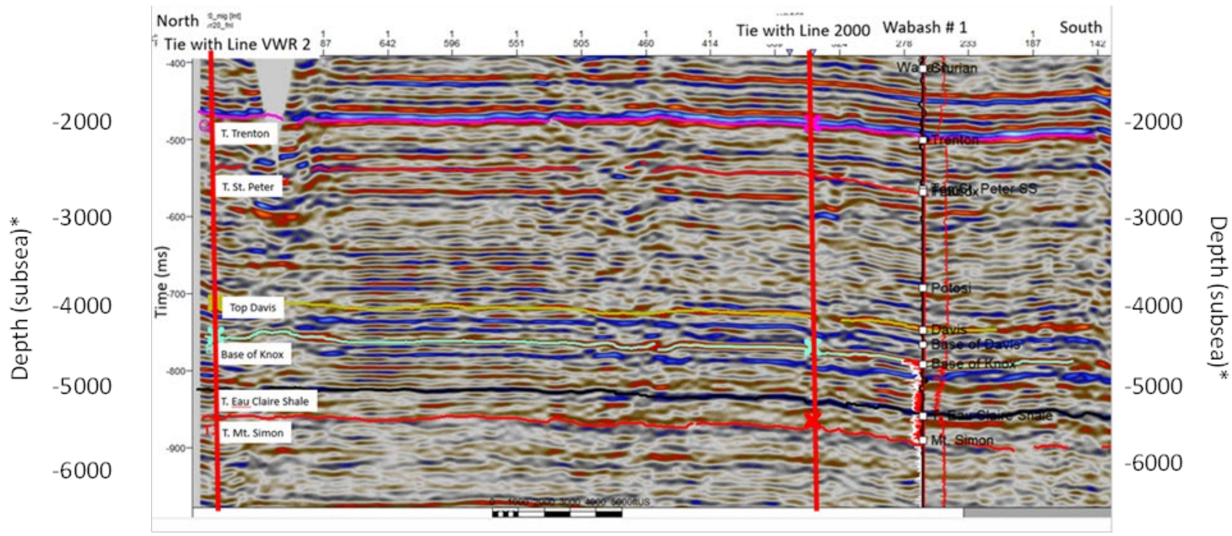

Figure 11. Line 1000 showing correlation of the Wabash #1 with the seismic reflection data. It is difficult to follow the different reflectors across the seismic profile.

* Note: Depth intervals are not identical since the seismic is in time

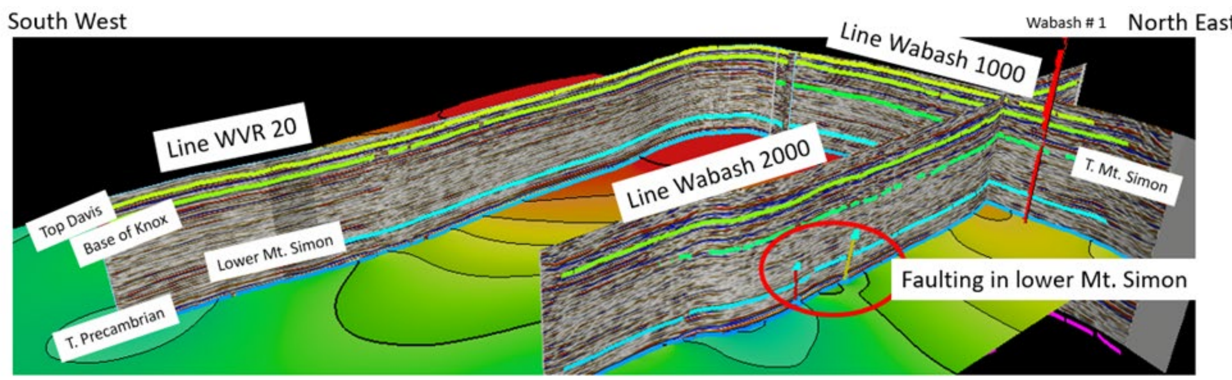

Figure 11. Three-dimensional view of the Precambrian through the Eau Claire Formation. The basal surface is the top of the Precambrian correlated from the three seismic lines. The circle on Wabash 2000 is the area with faulting in the lower Mt. Simon and Precambrian

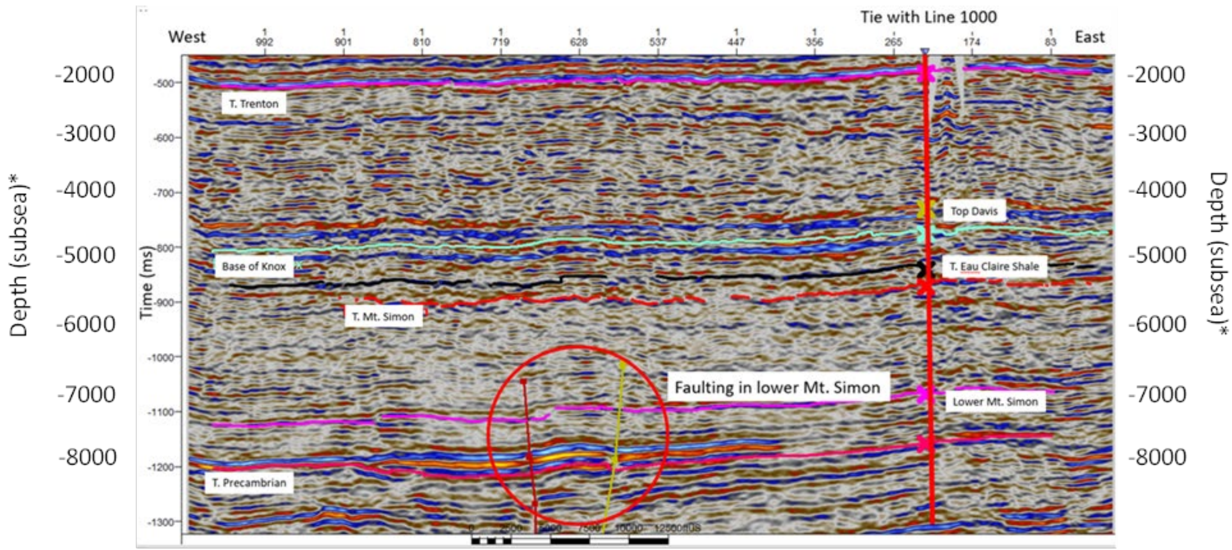

Figure 13. Seismic line 2000 showing faulting in the lower Mt. Simon Sandstone and Precambrian. The interpreted faults do not appear to penetrate through the Eau Claire shale.

* Note: Depth intervals are not identical since the seismic is in time

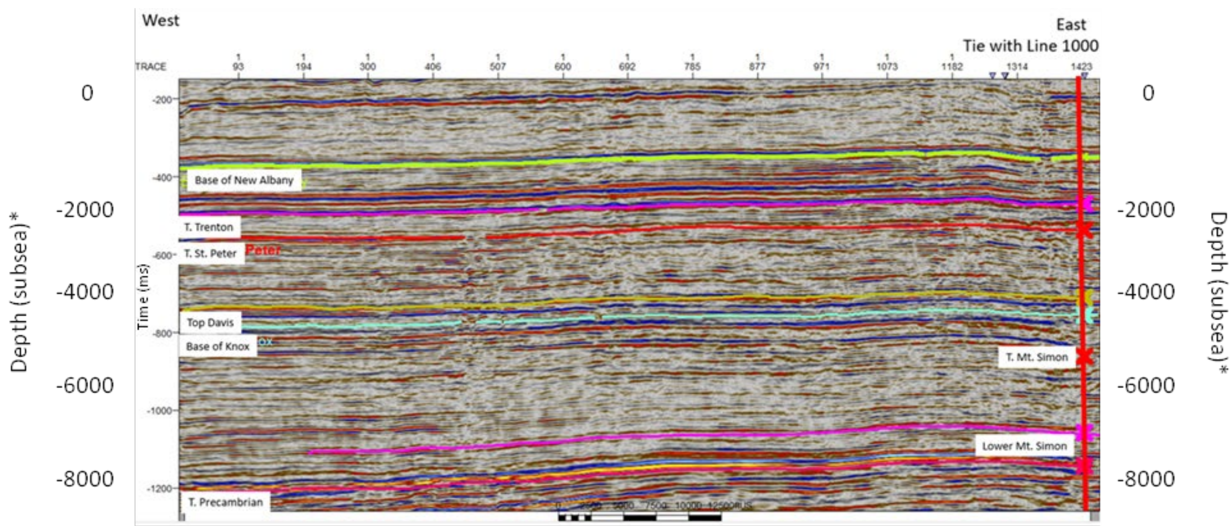

Figure 14. Line WVR line illustrating the stratigraphy and structure in the Ordovician and Cambrian strata. No resolvable faults were observed on this line.

* Note: Depth intervals are not identical since the seismic is in time

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 overlying units and confining unit 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 within this package, however, are considered the most effective barriers to vertical movement 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 of units overlying the injection zone that reduces the vertical mobility of the CO_2. The Maquoketa Group (gross thickness of 314 ft) 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 injection zone (that includes the lower 95 feet of Oneota Dolomite) is provided in Table 5.

The injection zone, overlying units, and confining unit were identified and located based on downhole wireline logs recovered from the Wabash #1 well (*Figure 15*) and from regional geologic knowledge. The units described herein 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, overlying units, confining unit, and reservoir simulation related to the determination of the Area of Review (AoR).

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

The injection zone and overlying zones are present within the AoR as indicated by geological and geophysical data. Regional cross-sections show lateral continuity of injection and overlying 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 formations. Thus, thickness variations in the injection zone or overlying zones will have negligible impact on storage and containment at this site. Seismic reflection data indicate that there are no faults penetrating the overlying units and confining unit (Maquoketa Group) 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 unit 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 overlying 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 confining unit.

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*). Because there are no core data recovered from Wabash #1 in the Potosi, the gamma ray log values were used as a proxy to estimate the dolomite crystal sizes. Based on this assumption, the Potosi dolomites with non-vuggy porosities were categorized into 3 classes with a gamma range of: class 1: less than 25 API; class 2: 25-50 API; class 3: over 50 API. The equations for estimating the permeability from porosity logs for each petrophysical class are as follows:

Class 1:

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

Class 2:

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

Class 3:

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

Where K= mD, $\phi_{ip=}$ fractional porosity

The geophysical log data (porosity and permeability) were scaled-up along the vertical well path to populate grid cells in the 3-D static geological model.

Mineralogy and petrology of the injection and overlying zones

Wabash #1 Petrophysical Analysis

Lithologic properties of the Potosi injection zone and overlying 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-porosity and total porosity. Matrix density of 2.65 g/cc, 2.71 g/cc, and 2.87 g/cc were used for sandstone, limestone, and dolomite intervals, respectively. 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 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 suggests 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-ft 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.

Across the basin the top of the Potosi Dolomite is difficult to identify using wireline logs. For the petrophysical analysis (and subsequent reservoir simulation), the top of the Potosi injection interval is considered to be a porous and permeable zone in the lower Oneota Dolomite. Note that the top of the Potosi injection interval from log interpretations used in reservoir modeling differs from the top of the Potosi Dolomite as shown in regional stratigraphic column and cross sections; the top of the Potosi injection interval described herein includes 95 feet of the lower Oneota Dolomite.

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*)

Overlying Units

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 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 described together 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.

Confining Unit

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 injection interval. It is 314 ft thick at the Wabash #1 well (*Table 4*) and 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 overlying zones

Table 4 and Table 5 summarize the porosity and permeability of each zone. The spatial distribution of the injection zone and overlying units 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 injection zone 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 overlying units and confining zone 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 Potosi Dolomite injection zone 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. The petrophysical logs were calibrated with routine core analysis data. However, 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 • Dipole Sonic log will also provide data to calibrate surface seismic
Elemental Spectroscopy	
Formation Micro Imager (FMI)	
Magnetic Resonance	
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 Neutron Density Gamma Ray Microlog Spontaneous Potential Mud Resistivity	• Characterize basic geology (lithology, mineralogy, porosity, permeability)
Natural Gamma Ray Spectroscopy Elemental Spectroscopy Formation Micro Imager (FMI) Magnetic Resonance Dipole Sonic Quantitative ELAN	• Enhanced characterization of geologic and geomechanical properties that control injectivity and confining zone/seal integrity • Dipole Sonic log will also provide data to calibrate surface seismic
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 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.

Overlying Zone	Formation Thickness (ft)	Depth MD (ft)	Avg. Porosity (%) derived from logs	Estimated Avg. Permeability (mD)	Shale Thickness (ft)	Cumulative Shale Thickness (ft)	Source of data
Maquoketa Group (confining unit)	314	2,386	3.0	0.0001	314	314	Porosity form well log; Permeability from core analysis of Marvin Blan #1 well (KY)
Trenton Limestone	163	2,700	1.3	0.00000273	3.5	317.5	Porosity form well log; Permeability by using Lucia equations

Platteville Group	379	2,863	1.2	0.00000475	16	333.5	“
Dutchtown Limestone	84	3,242	2.8	0.0000840	70.5	404	“
St. Peter Sandstone	28	3,326	4.0	0.0039	3.5	407.5	“
Shakopee Dolomite (upper)	346	3,354	2.8	0.022360406	101	508.5	“
Shakopee Dolomite (lower)	270	3,700	9.1	0.098032	71	579.5	“
Oneota Dolomite	408	3,970	7.1	2.585488	15	594.5	“
Total Thickness	1992	-	-	-	592.5	592.5	

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

Injection zone	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

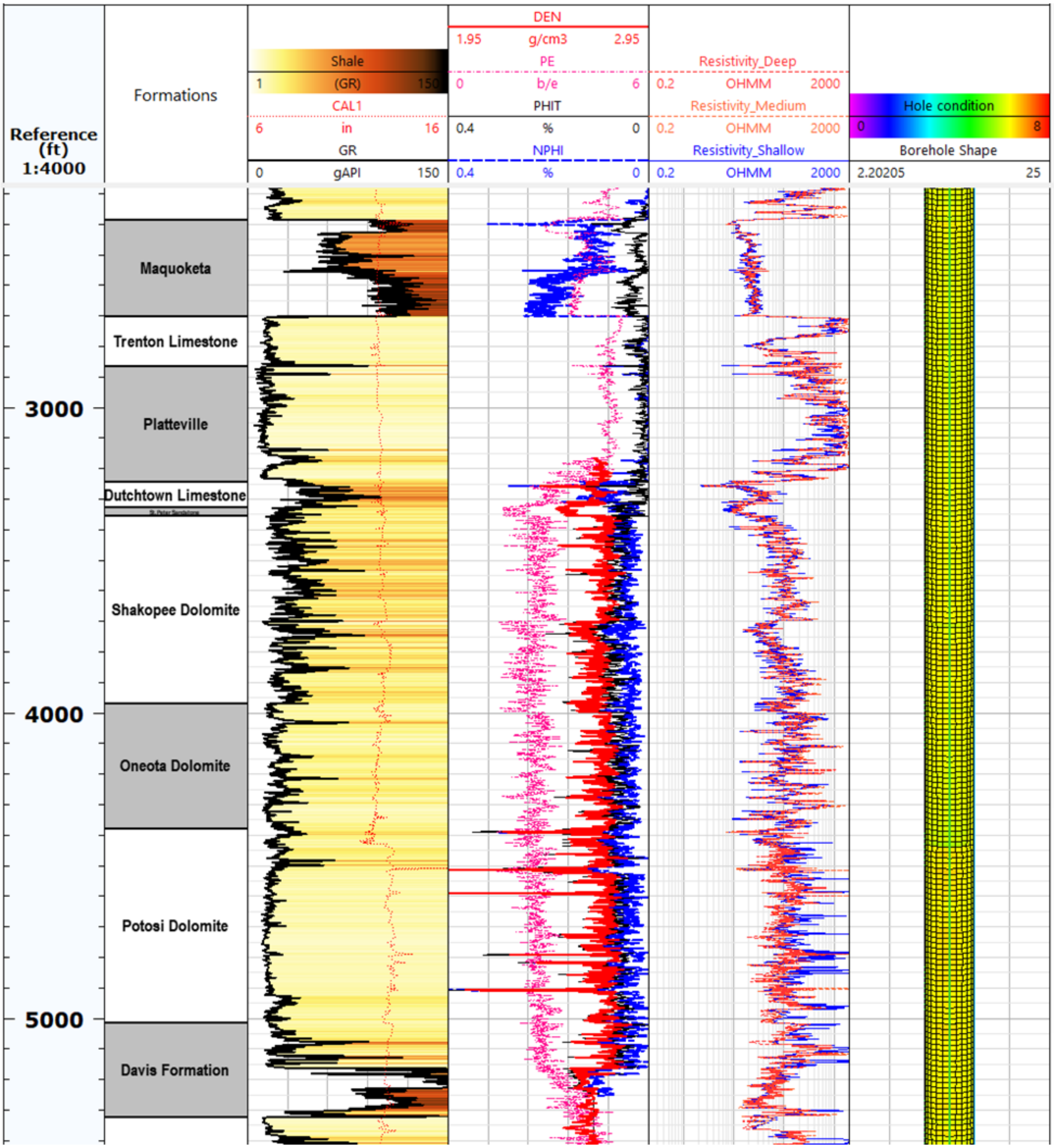

Figure 12 Geophysical log of the Cambro-Ordovician rocks from Davis Formation through Maquoketa Group, Wabash #1 Well, Vigo County, Indiana. The St. Peter Sandstone is not labeled in this figure but is represented in the relatively thin zone above the Shakopee Dolomite.

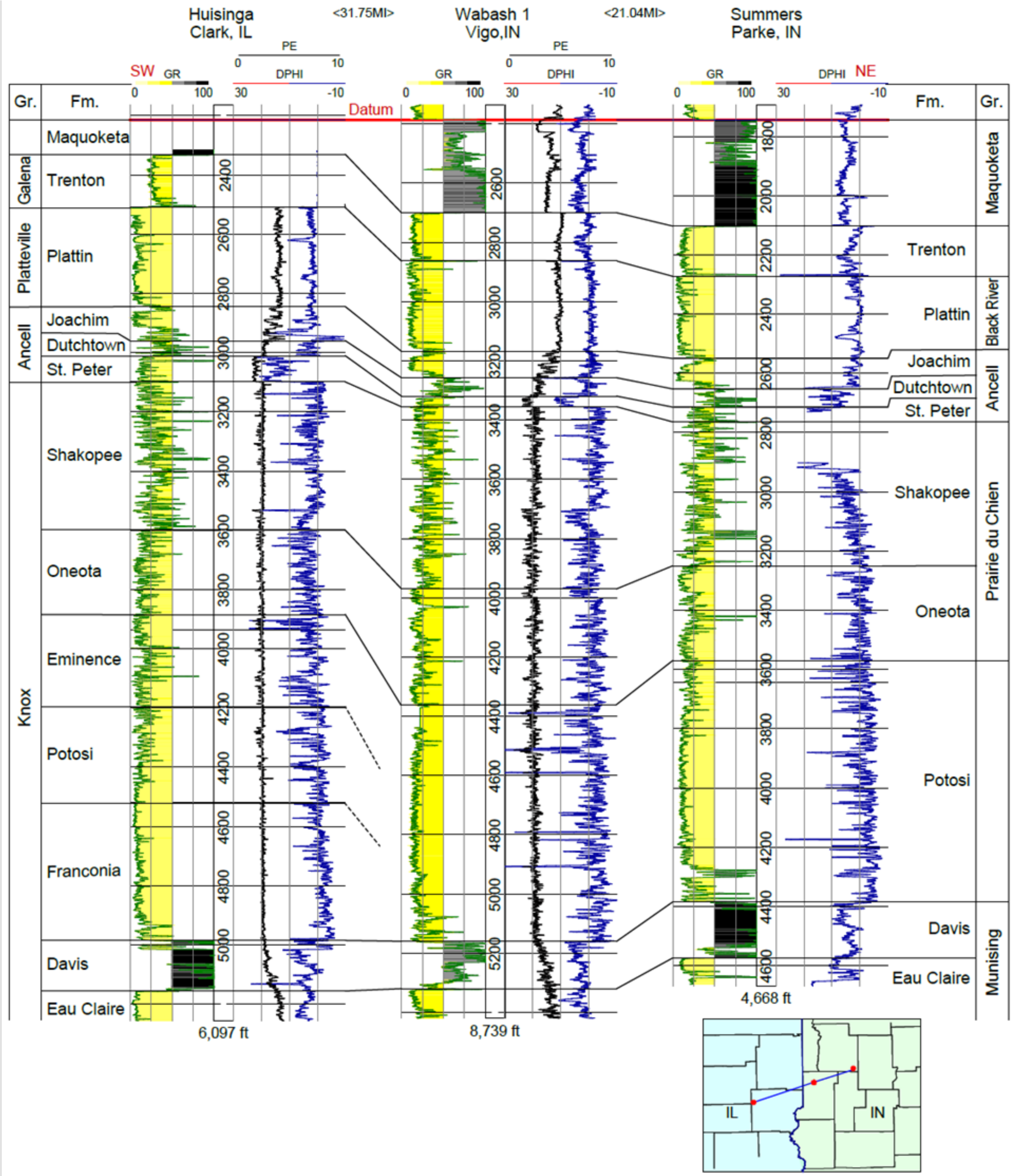

Figure 13 Southwest-northeast correlation of the units in the upper part of the Knox Group from east-central Illinois to west-central Indiana. The Dutchtown Limestone through Davis Formation section is shown to thin eastward, over the 53-mile cross section, from approximately 2,250 ft (685 m) thick to 1,900 ft (580 m) thick.

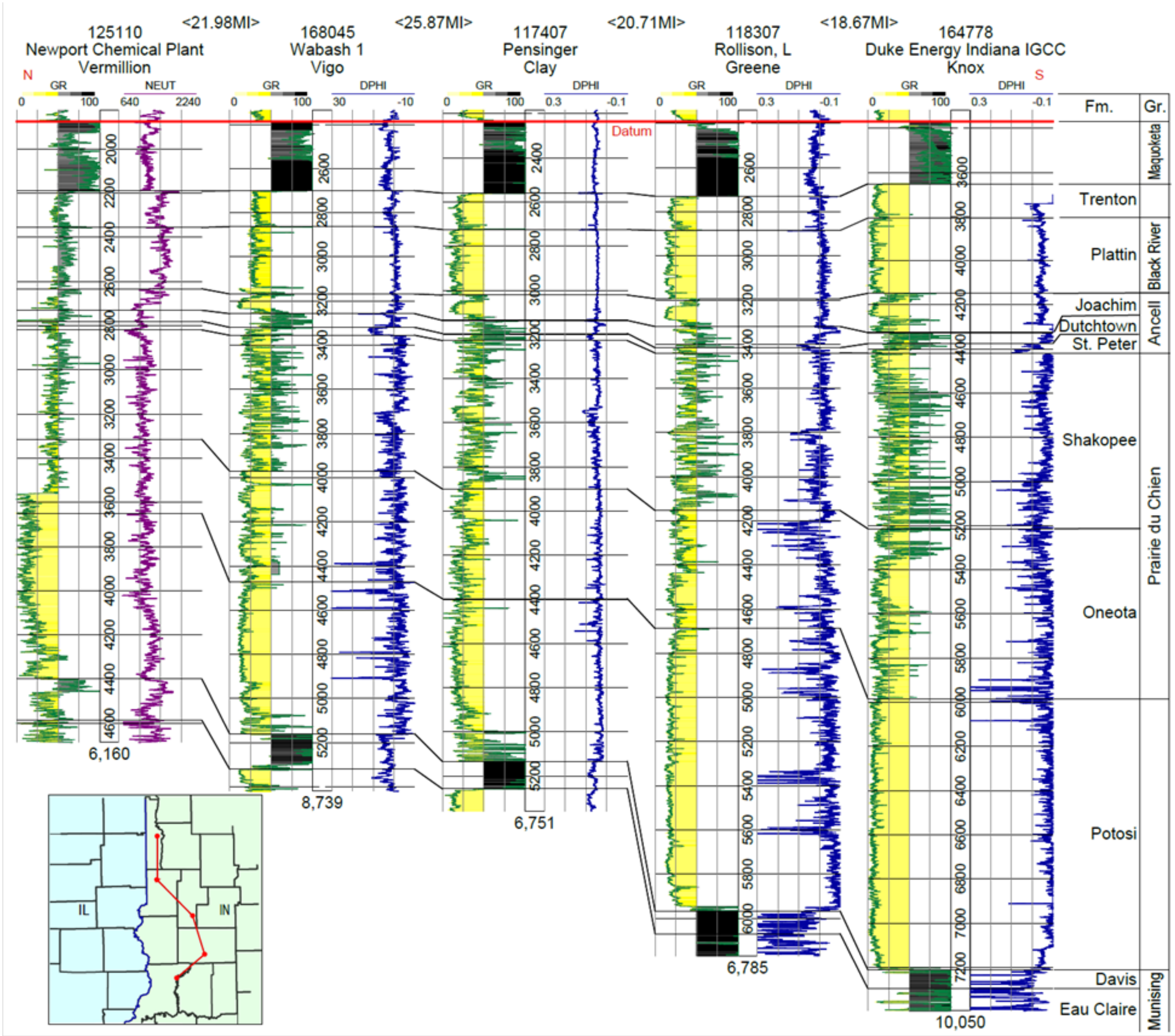

Figure 14 North-south correlation of the units in the upper part of the Knox Group in west-central Indiana. The Dutchtown Limestone through Davis Formation section is shown to thin northward, over the 87-mile cross section, from approximately 2,950 ft (900 m) thick to 1,900 ft (580 m) thick.

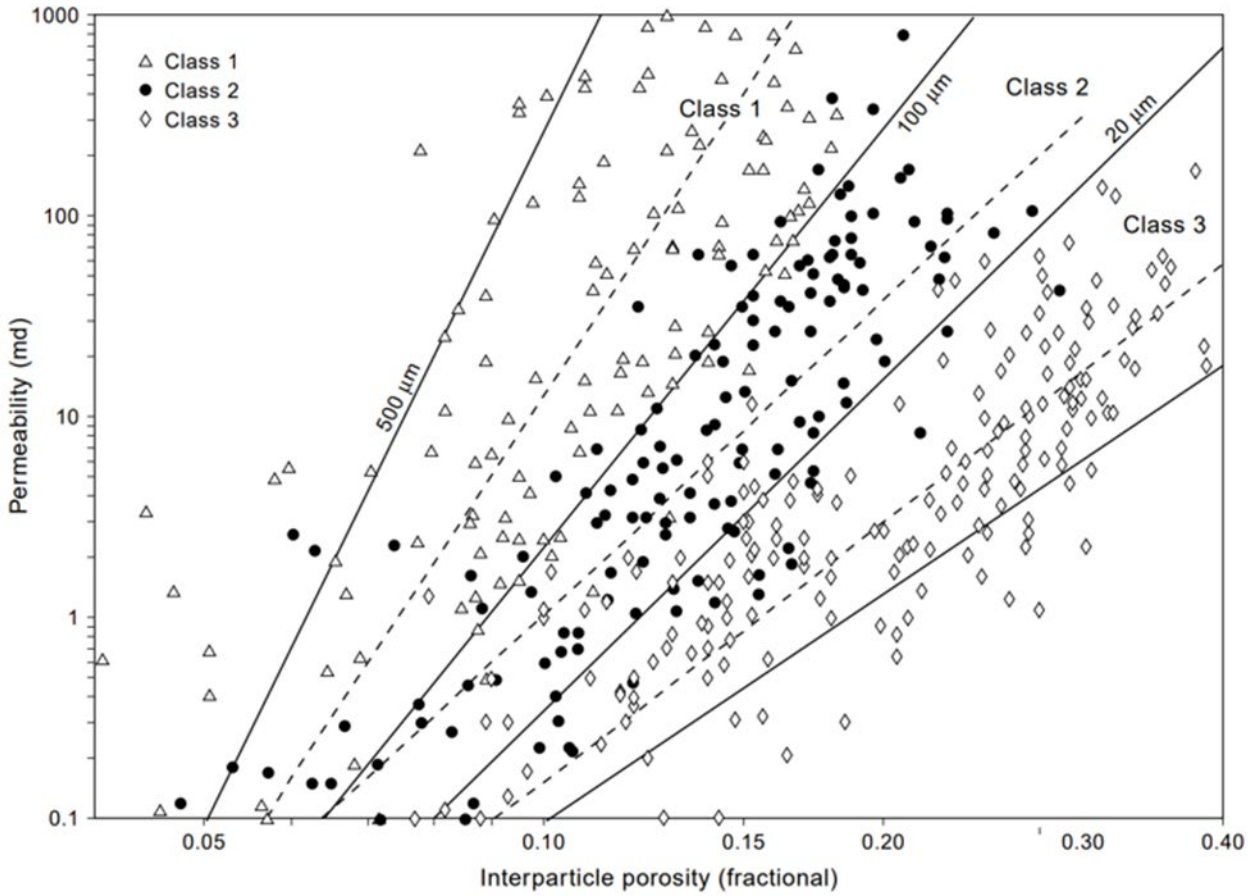

Figure 15 Composite-air permeability cross plot for nonvuggy limestones and dolostones showing statistical reduced-major axis transforms for each class (see text for equations; from Lucia,1995).

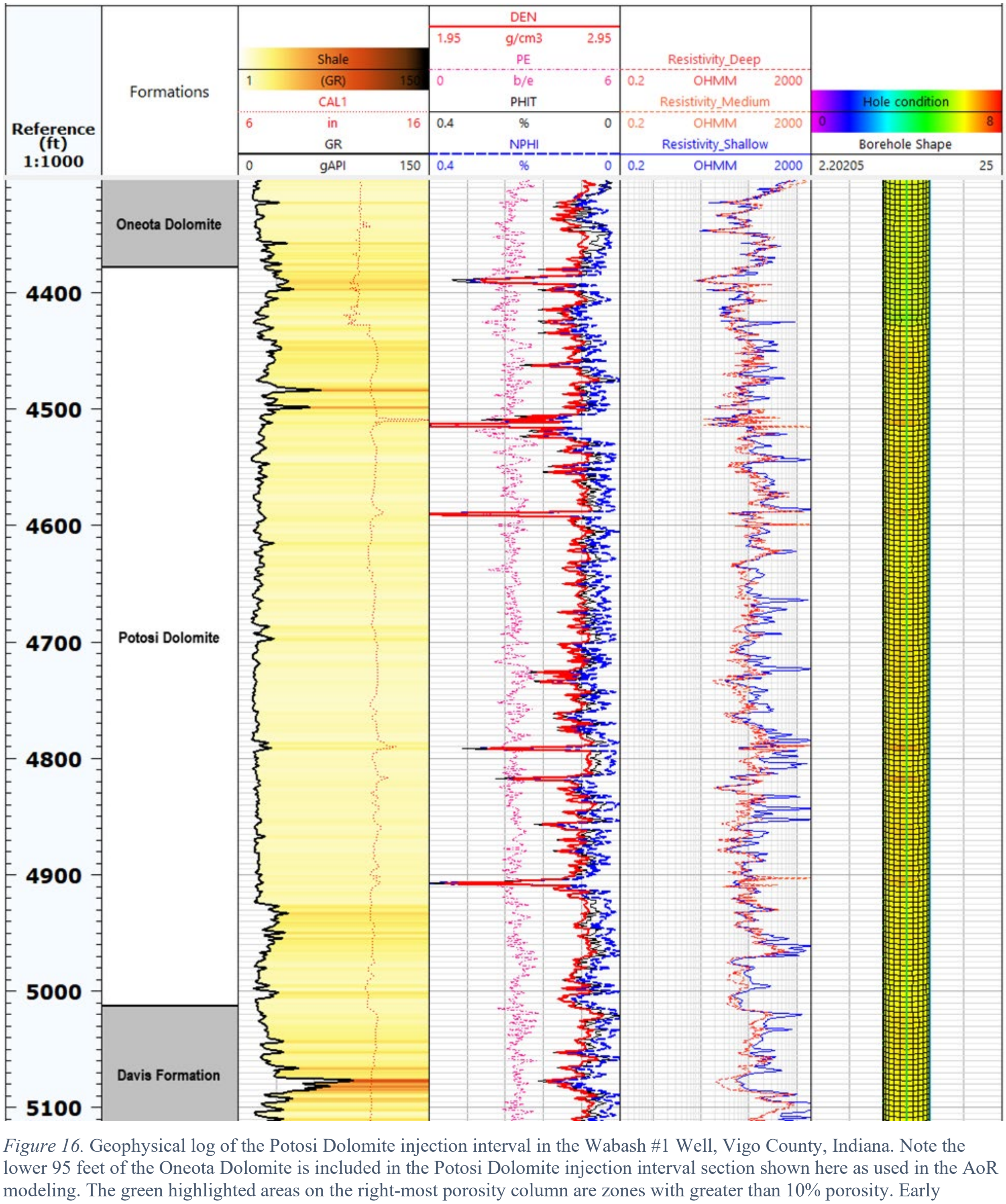

Figure 16. Geophysical log of the Potosi Dolomite injection interval in the Wabash #1 Well, Vigo County, Indiana. Note the lower 95 feet of the Oneota Dolomite is included in the Potosi Dolomite injection interval section shown here as used in the AoR modeling. The green highlighted areas on the right-most 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 from 4,505-4,525 ft MD.

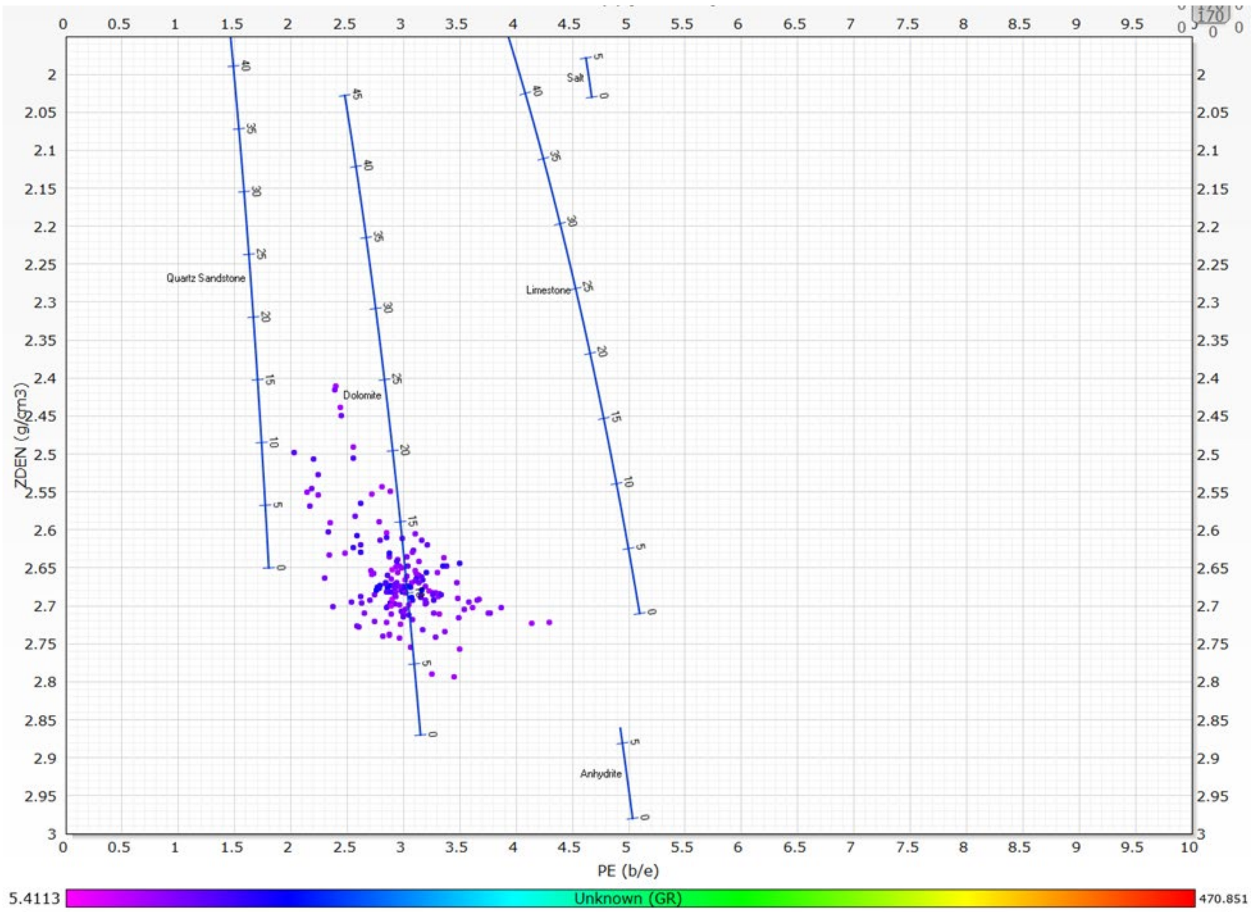

Figure 17. Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Potosi Dolomite tested interval (4,505-4,525 ft MD) in the Wabash #1 Well, Vigo County, Indiana.

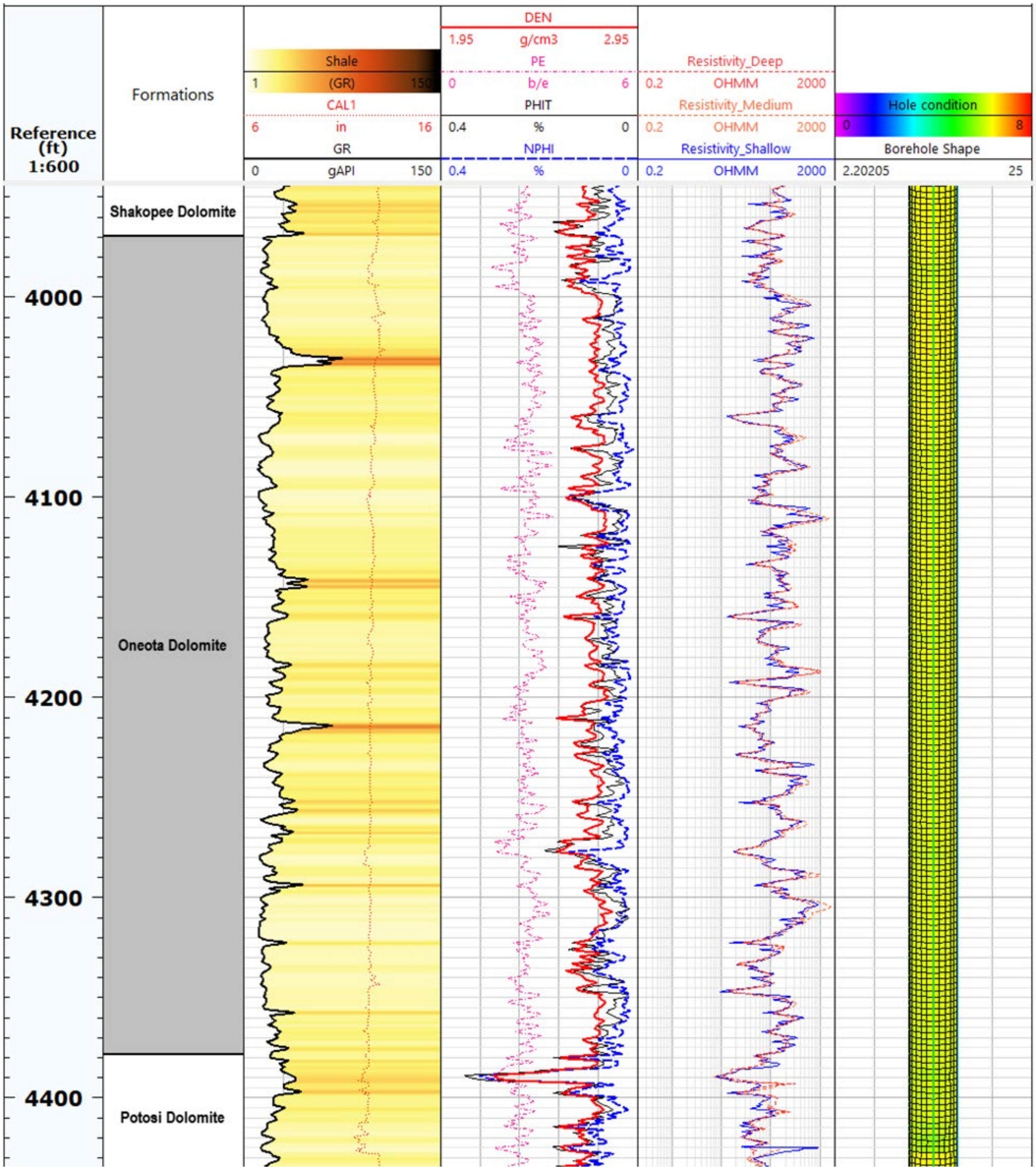

Figure 18 Geophysical log of the Oneota Dolomite in the Wabash #1 Well, Vigo County, Indiana. Note the lower 95 feet of the Oneota Dolomite is included in the Potosi Dolomite (injection interval) section.

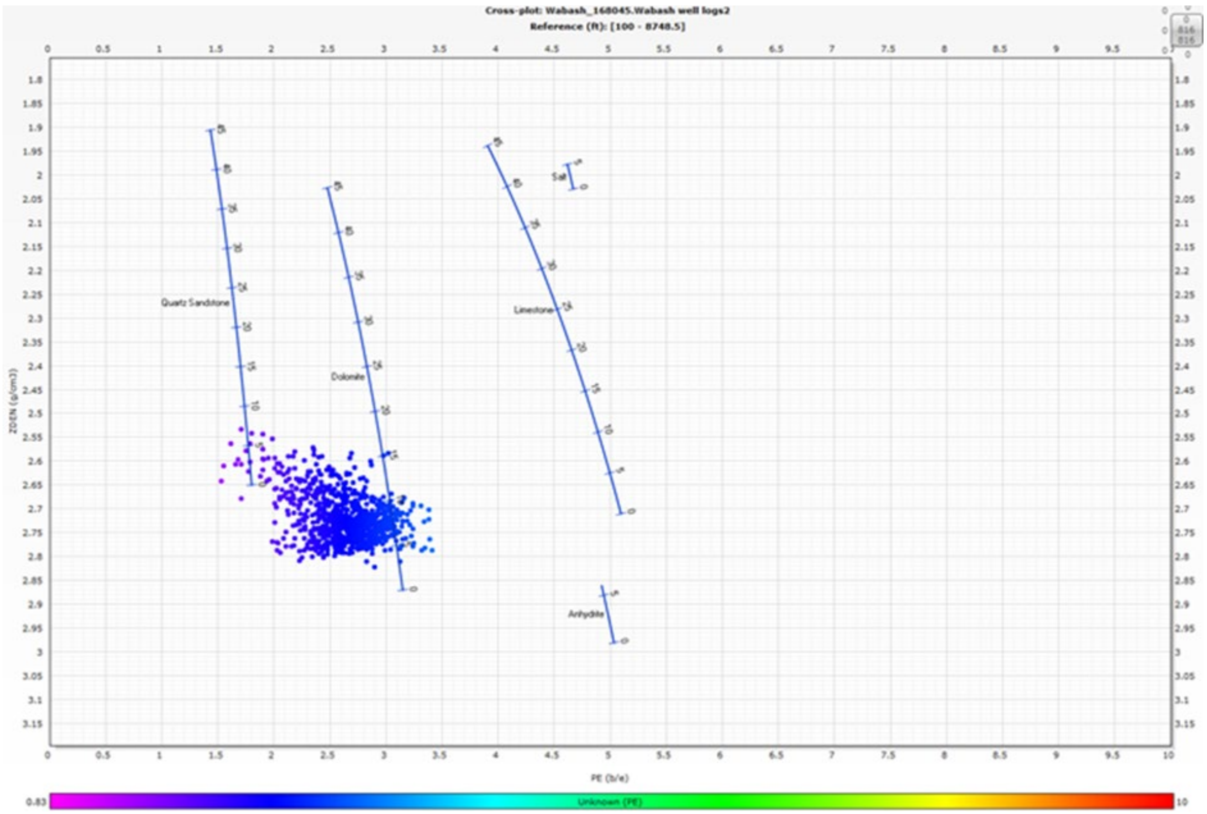

Figure 19 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Oneota Dolomite in the Wabash #1 Well, Vigo County, Indiana.

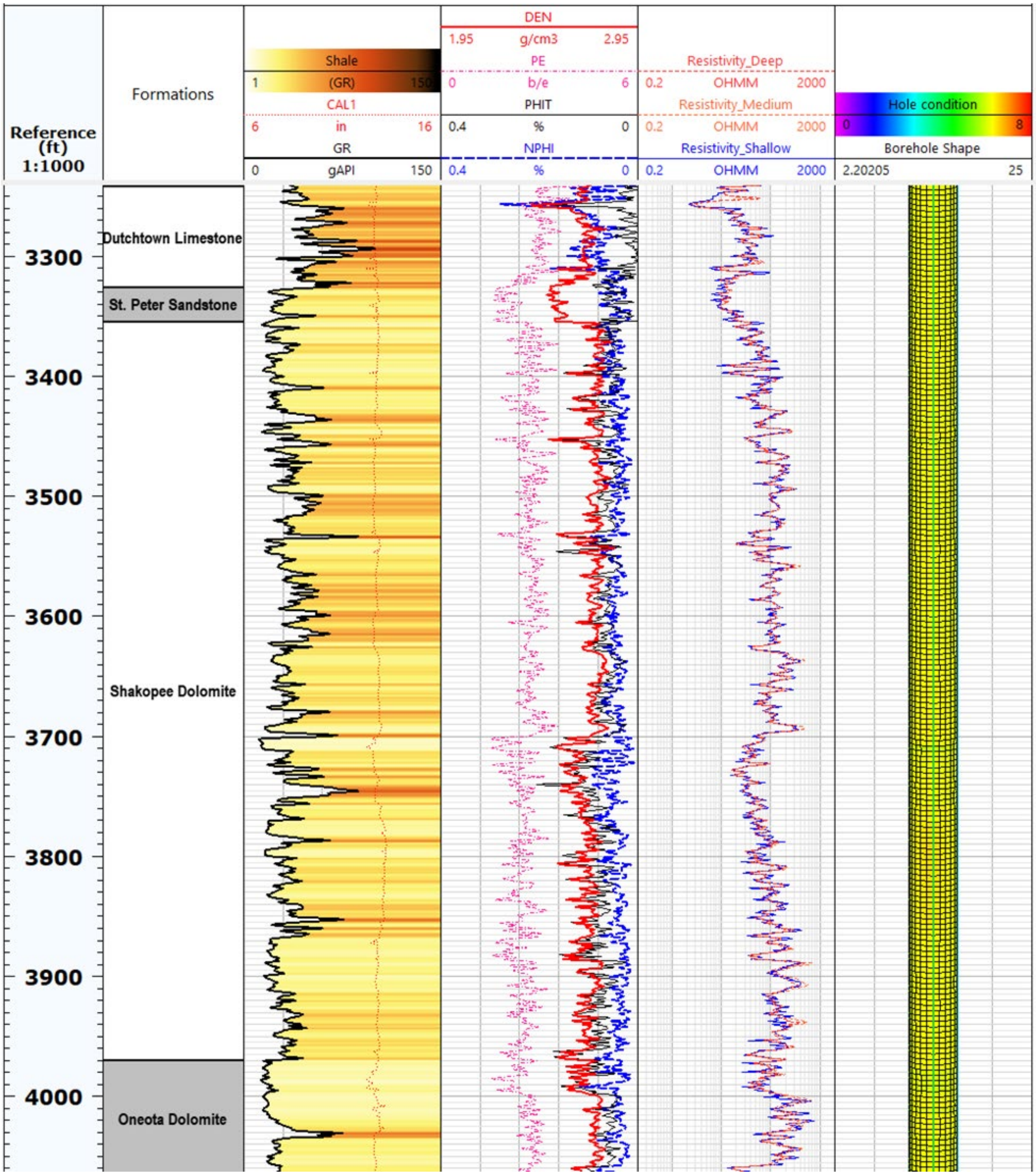

Figure 20 Geophysical log of the Shakopee Dolomite in the Wabash #1 Well, Vigo County, Indiana. Below 3,700 ft the Shakopee Dolomite becomes more quartz rich as can be observed on the PE curve.

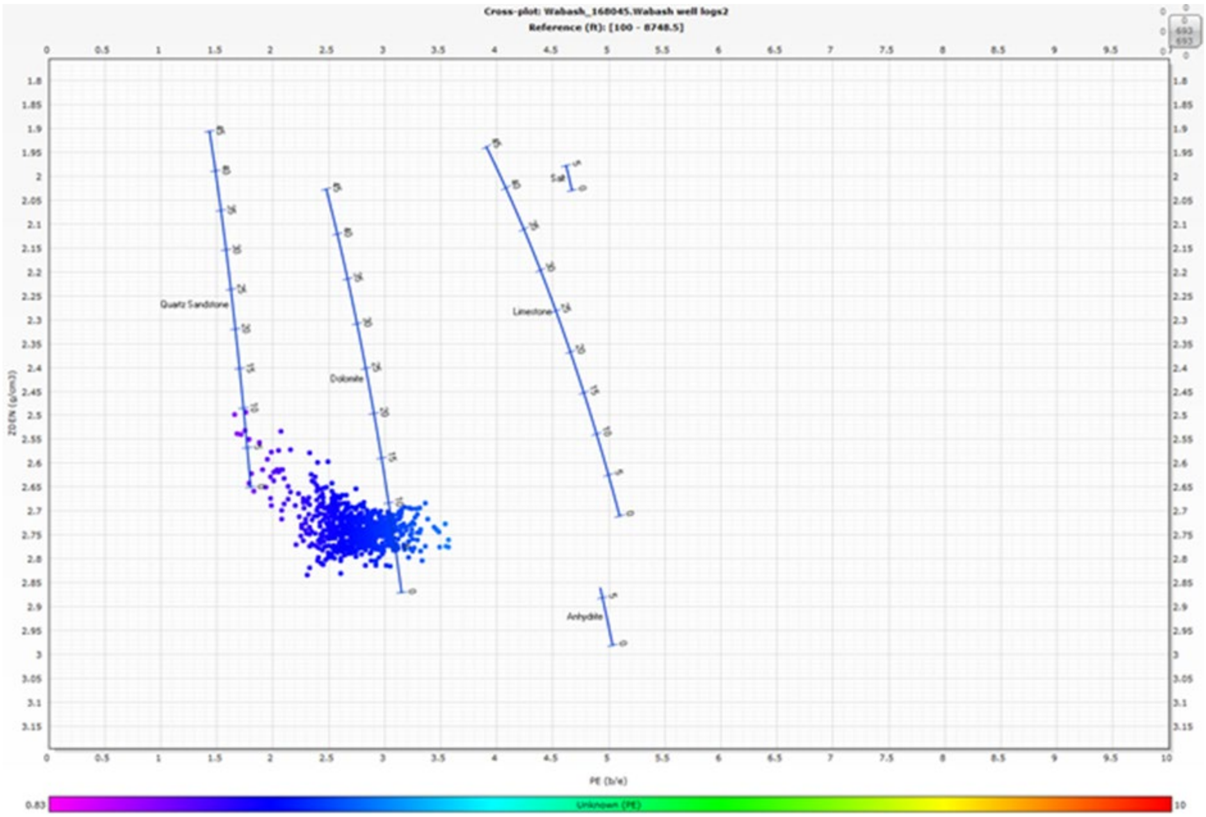

Figure 21 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the lower Shakopee Dolomite in the Wabash #1 Well, Vigo County, Indiana.

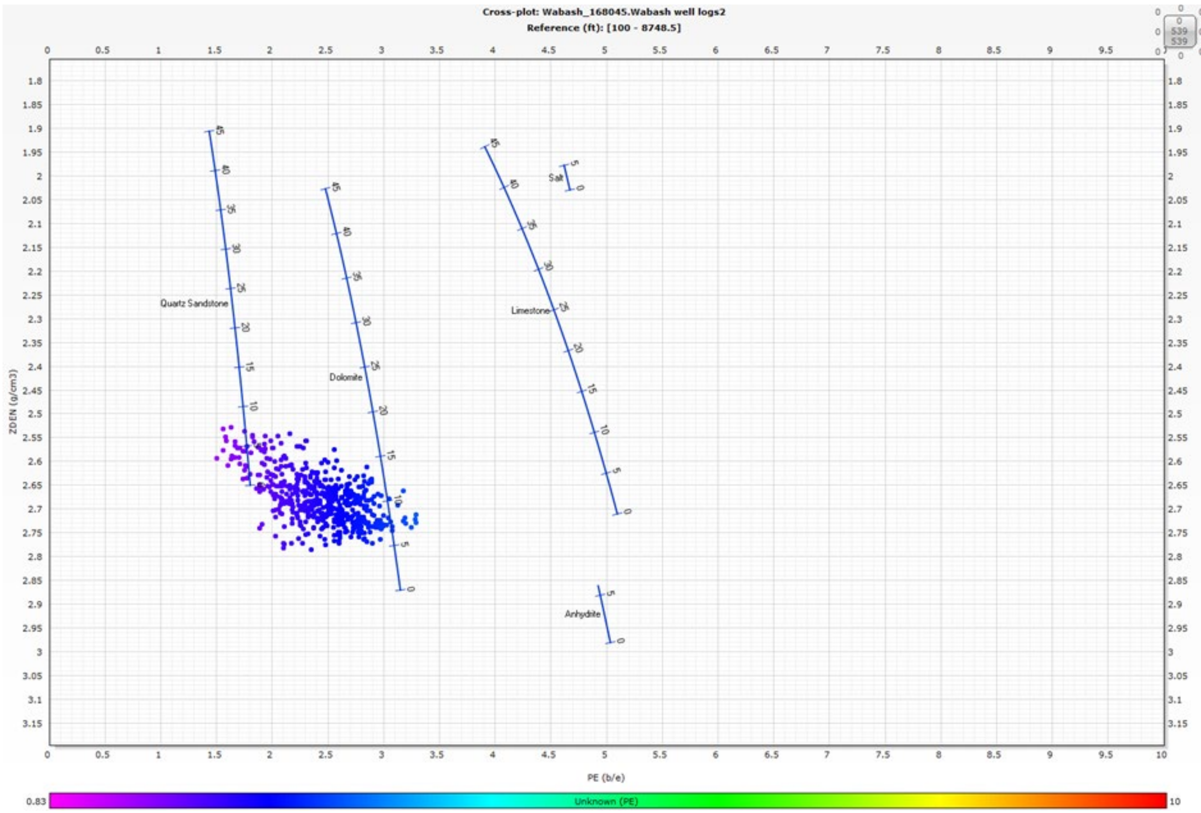

Figure 22 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the upper Shakopee Dolomite in the Wabash #1 Well, Vigo County, IN

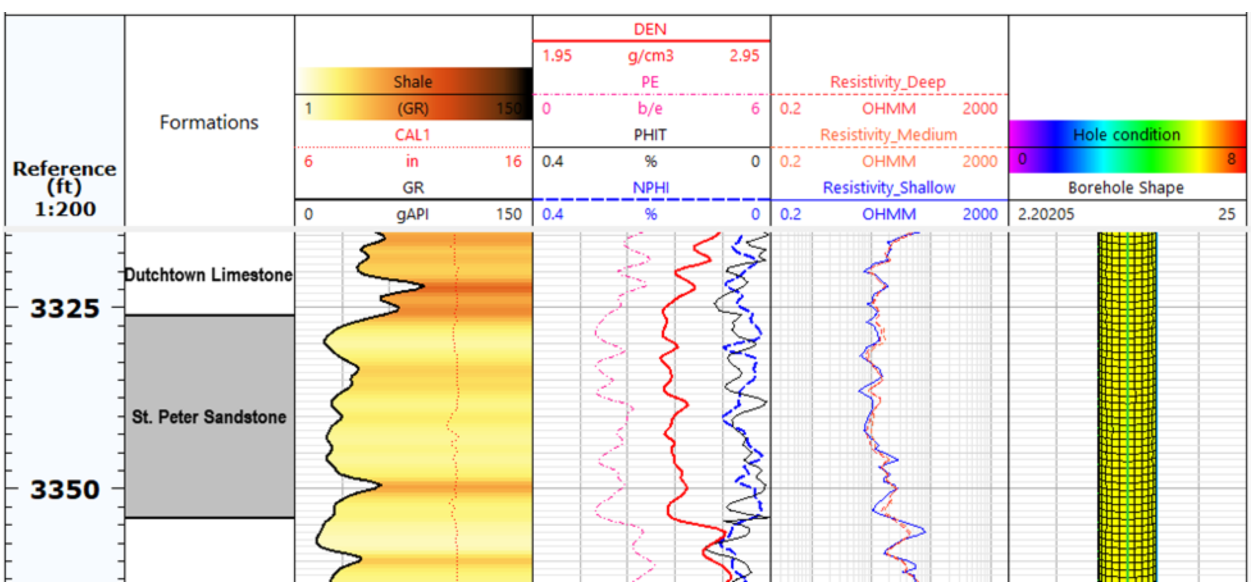

Figure 23 Geophysical log of the St. Peter Sandstone in the Wabash #1 Well, Vigo County, Indiana.

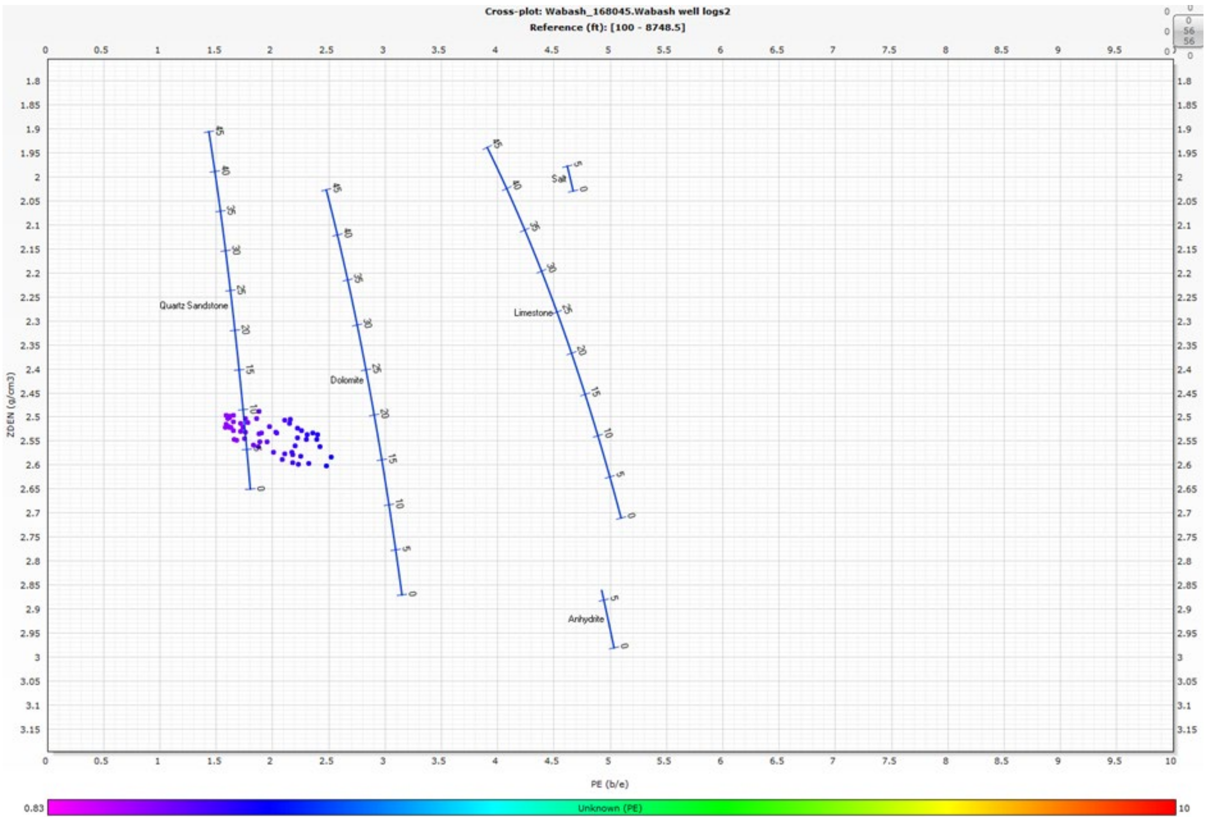

Figure 24 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the St. Peter Sandstone in the Wabash #1 Well, Vigo County, Indiana.

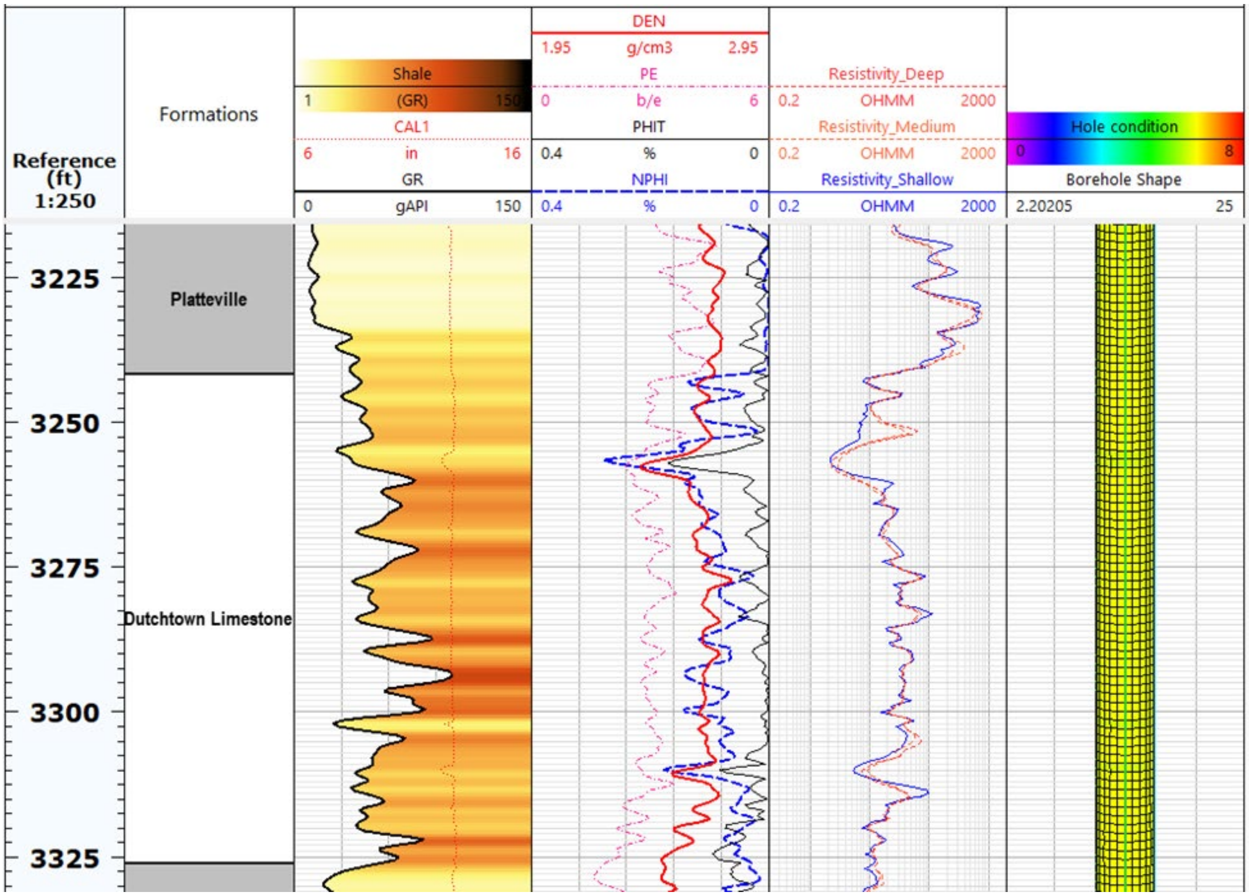

Figure 25 Geophysical log of the Dutchtown Limestone in the Wabash #1 Well, Vigo County, Indiana.

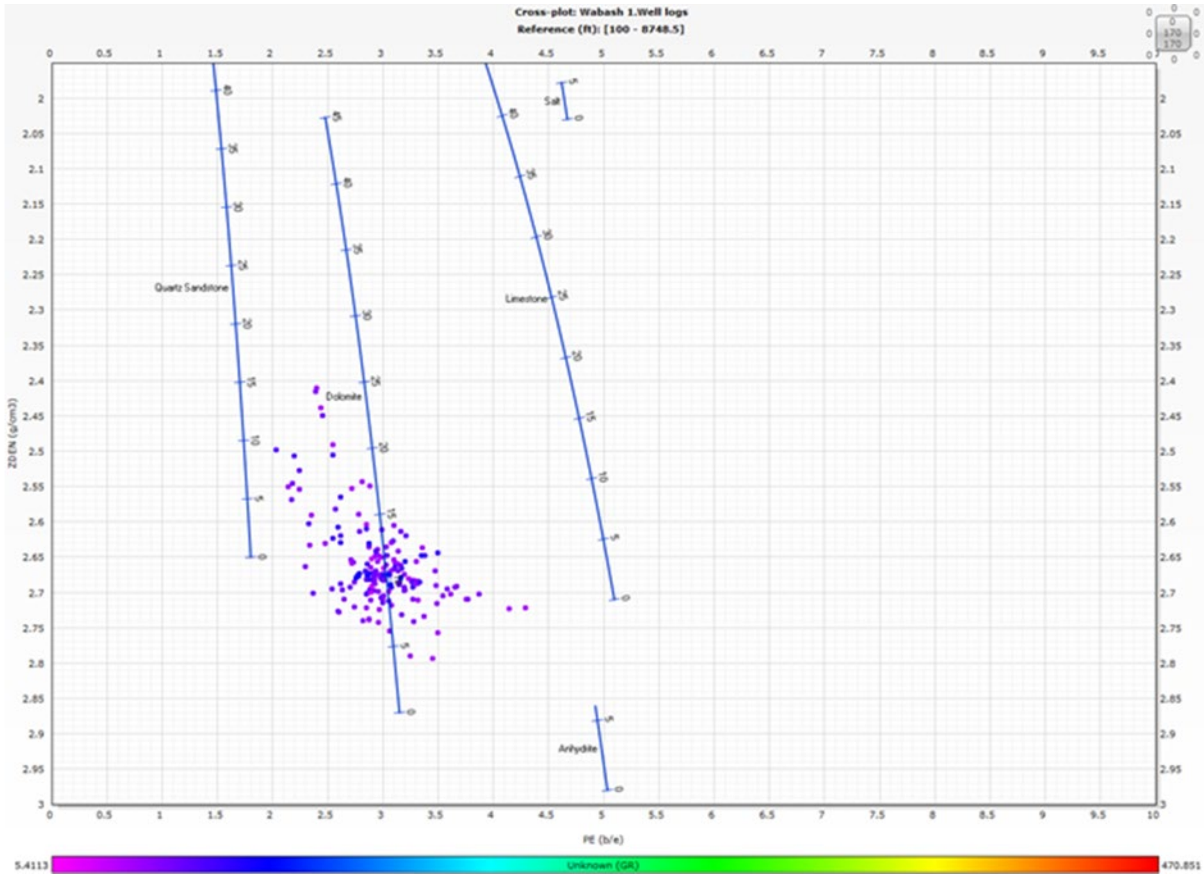

Figure 26 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Dutchtown Limestone in the Wabash #1 Well, Vigo County, Indiana.

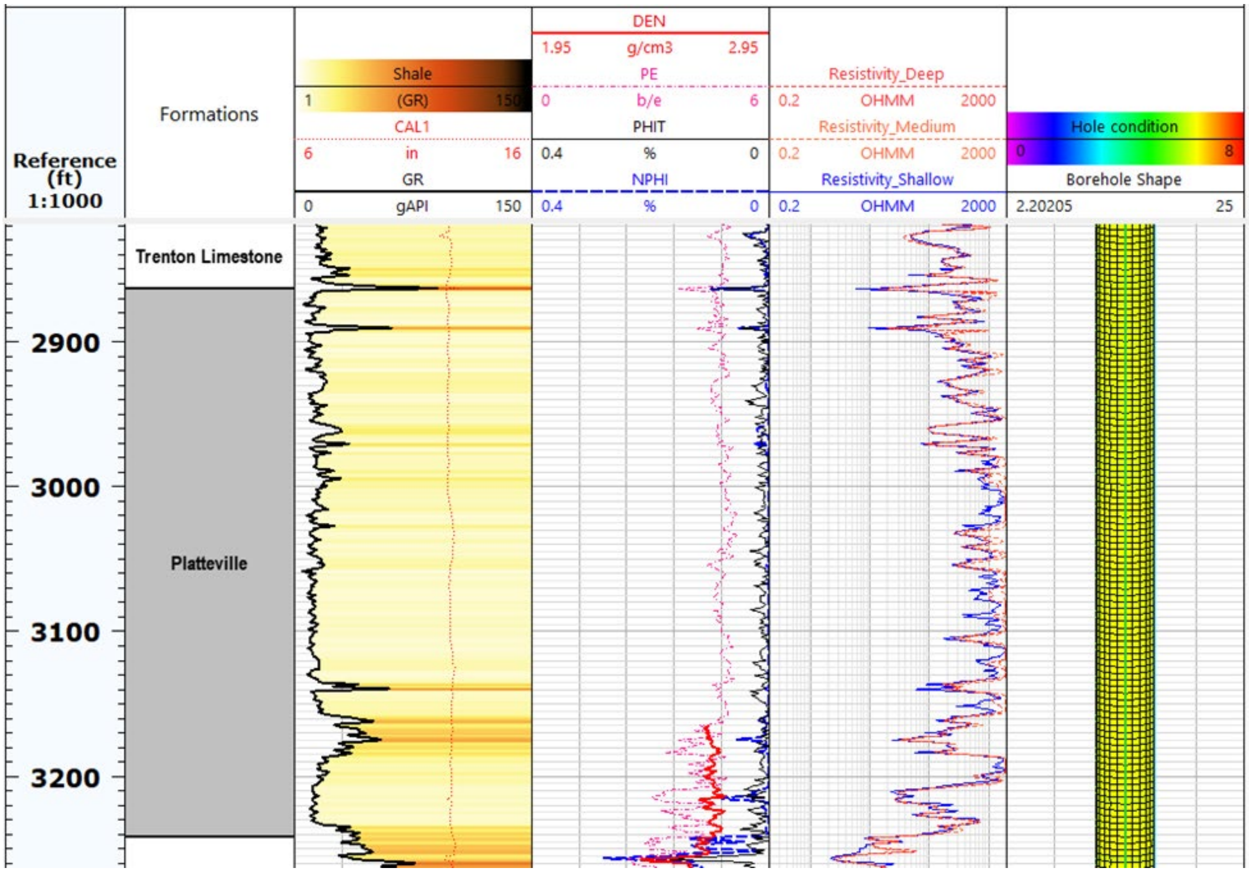

Figure 27 Geophysical log of the Platteville Group and Trenton Limestone in the Wabash #1 Well, Vigo County, Indiana.

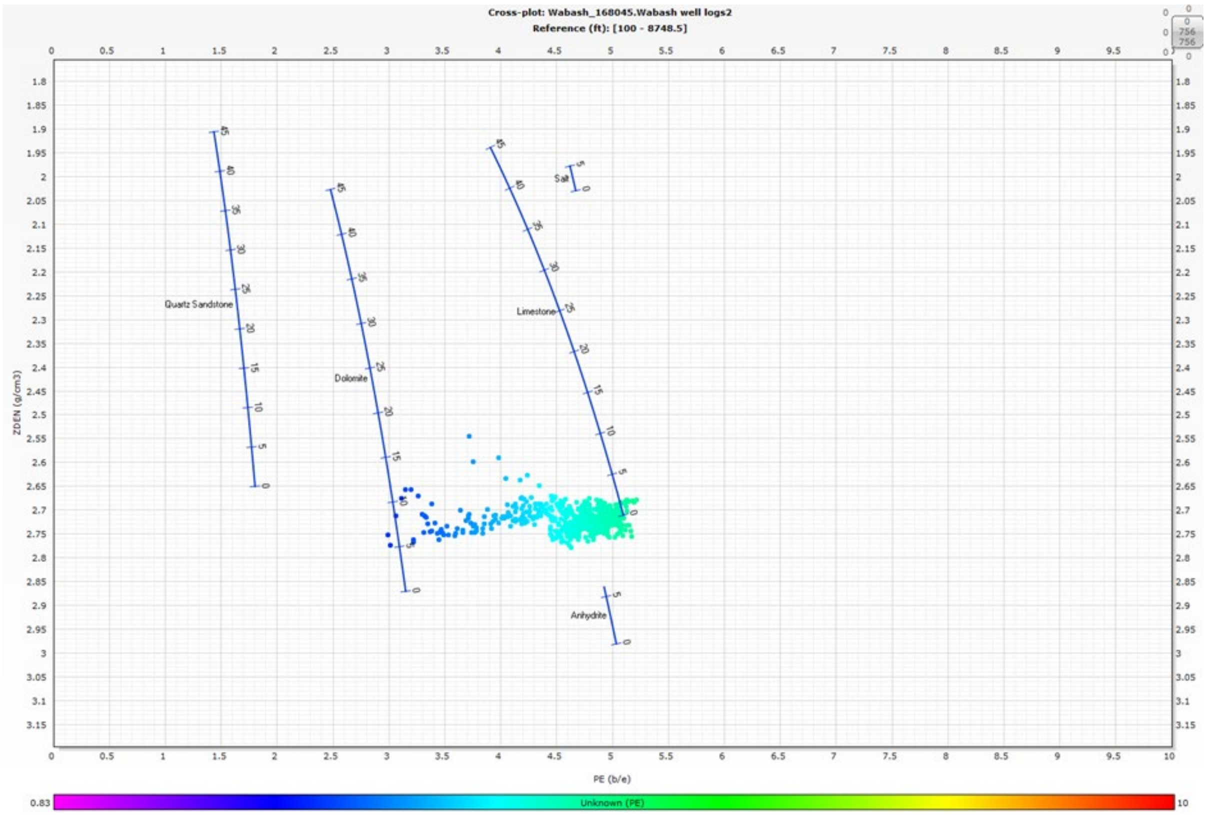

Figure 28 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Platteville Group in the Wabash #1 Well, Vigo County, Indiana.

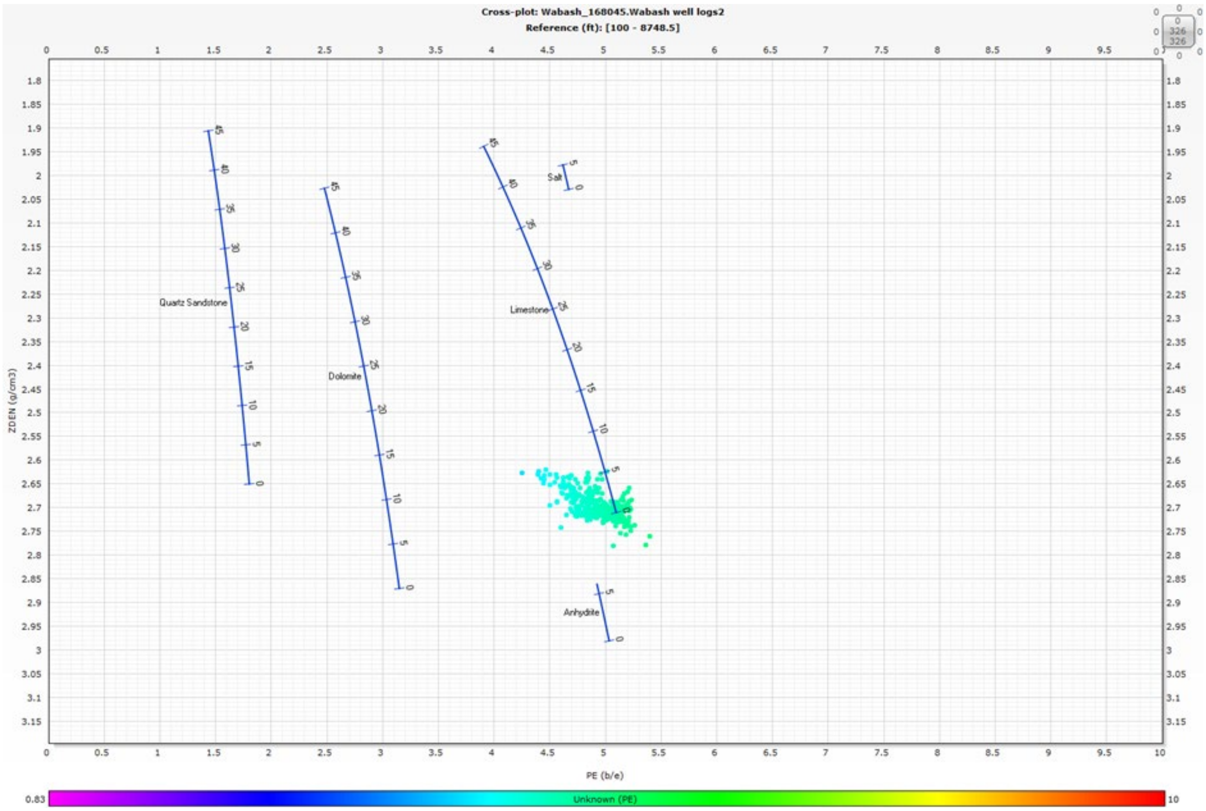

Figure 29 Cross plot of the density measurements compared with the Pe curve. This plot shows the porosity and lithology of the Trenton Limestone in the Wabash #1 Well, Vigo County, Indiana.

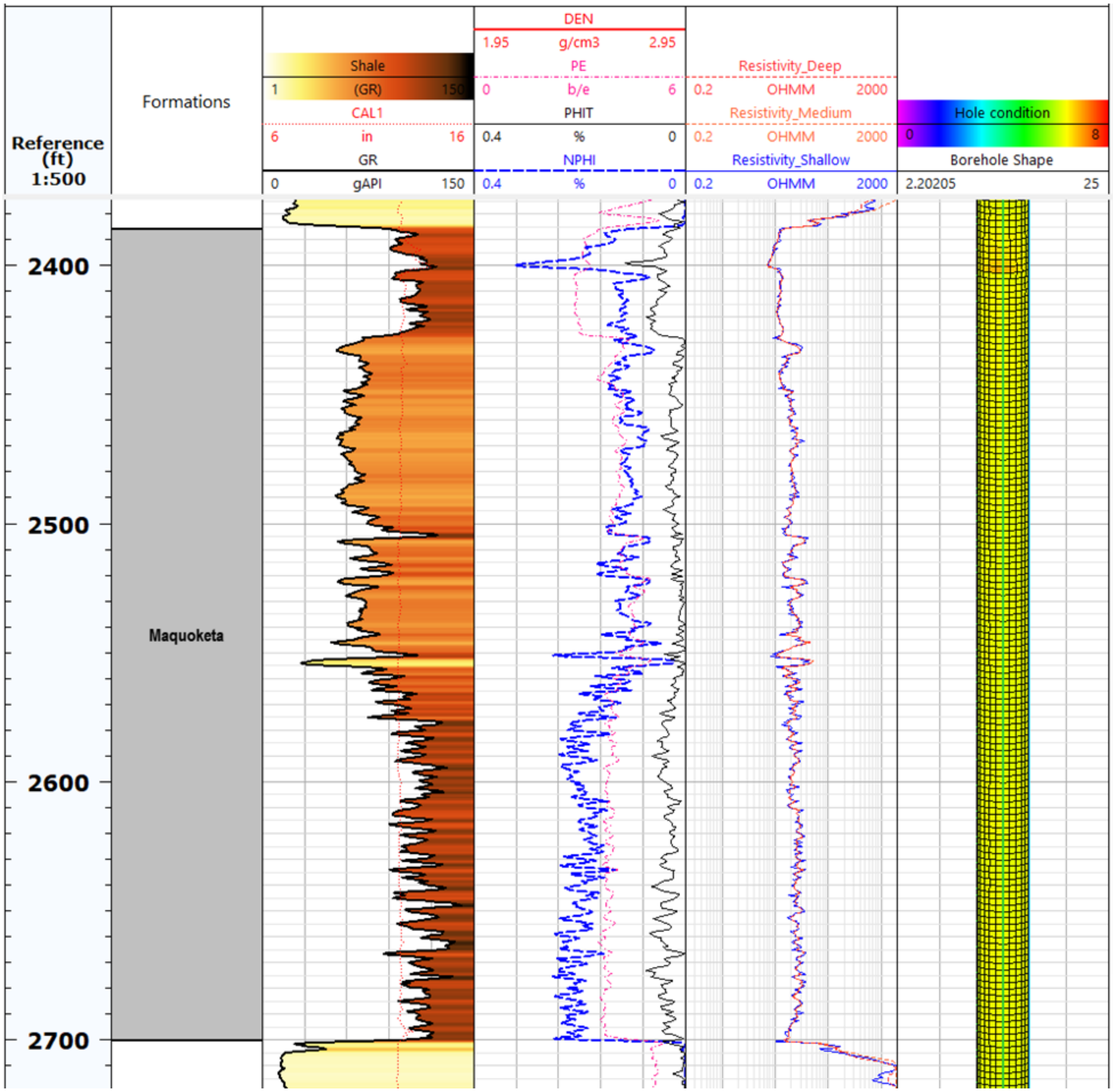

Figure 30 Geophysical log of the Maquoketa Group in the Wabash #1 Well, Vigo County, Indiana.

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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 zone is discussed in the Section INJECTION AND CONFINING ZONE DETAILS and are summarized in Table 6. Lithologic properties of the overlying 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. A full suite of petrophysical logs including triple combo logs (gamma-ray, porosity, and resistivity logs), density, sonic, caliper, SP, FMI, NMR, and CBL were utilized to assess the geo-mechanical and petrophysical characteristics of overlying zones. 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 ~314 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 7*; ~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) show 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 (duplicated from Table 4). 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.

Overlying Zone	Formation Thickness (ft)	Depth MD (ft)	Avg. Porosity (%) derived from logs	Estimated Avg. Permeability (mD)	Shale Thickness (ft)	Cumulative Shale Thickness (ft)
Maquoketa Group (confining unit)	314	2,386	3.0	0.0001	314	314
Trenton Limestone	163	2,700	1.3	0.00000273	3.5	317.5
Platteville Group	379	2,863	1.2	0.00000475	16	333.5
Dutchtown Limestone	84	3,242	2.8	0.0000840	70.5	404
St. Peter Sandstone	28	3,326	4.0	0.0039	3.5	407.5
Shakopee Dolomite (upper)	346	3,354	2.8	0.022360406	101	508.5
Shakopee Dolomite (lower)	270	3,700	9.1	0.098032	71	579.5
Oneota Dolomite	408	3,970	7.1	2.585488	15	594.5

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.

	Petrophysical properties	Ultrasonic velocities		Dynamic elastic properties		Static elastic properties				
Sample orientation	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.

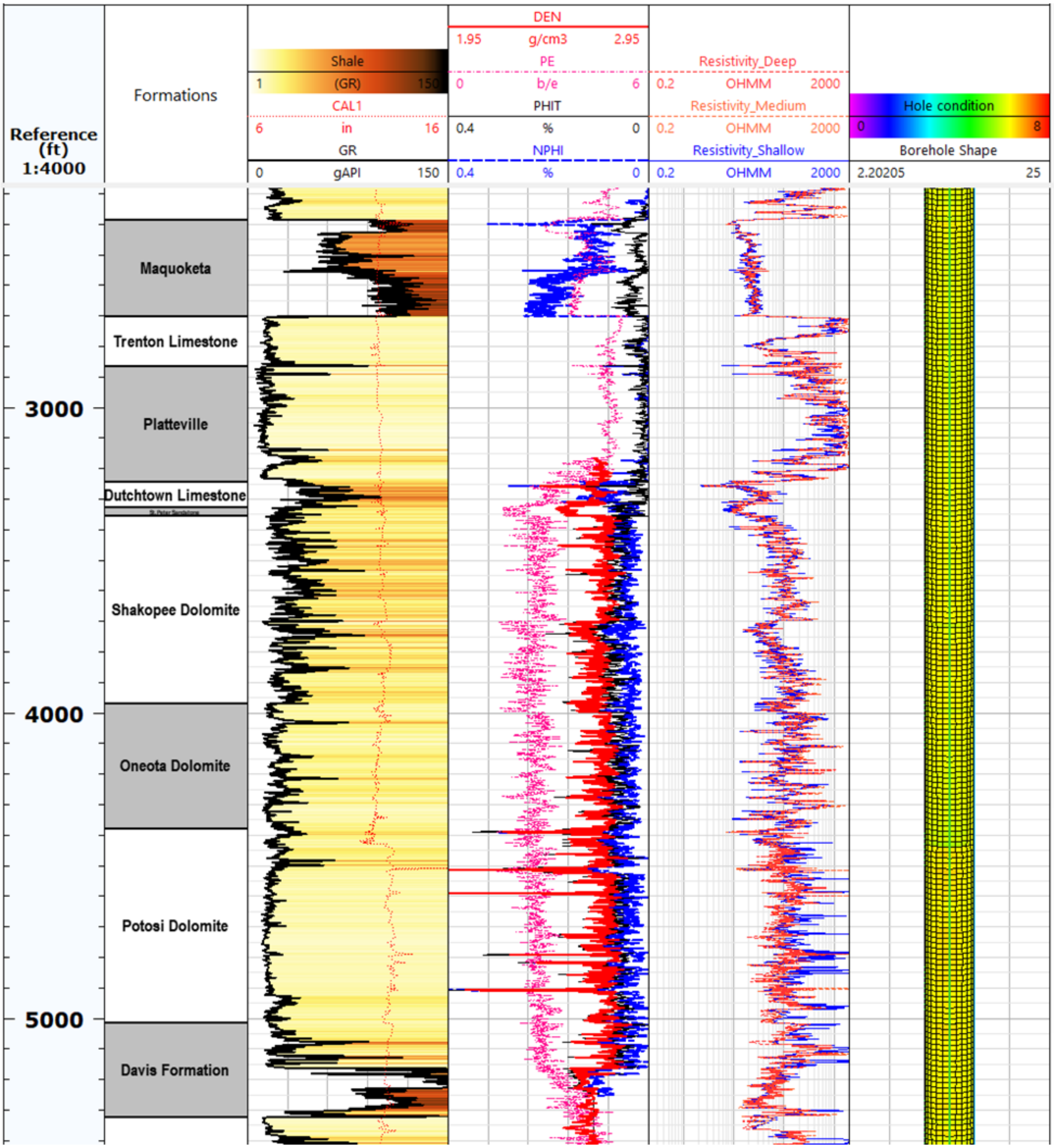

Figure 31. Geophysical log of the Cambro-Ordovician rocks from the Davis Formation through Maquoketa Group, Wabash #1 Well, Vigo County, Indiana. The St. Peter Sandstone is not labeled in this figure but is represented in the relatively thin zone above the Shakopee Dolomite.

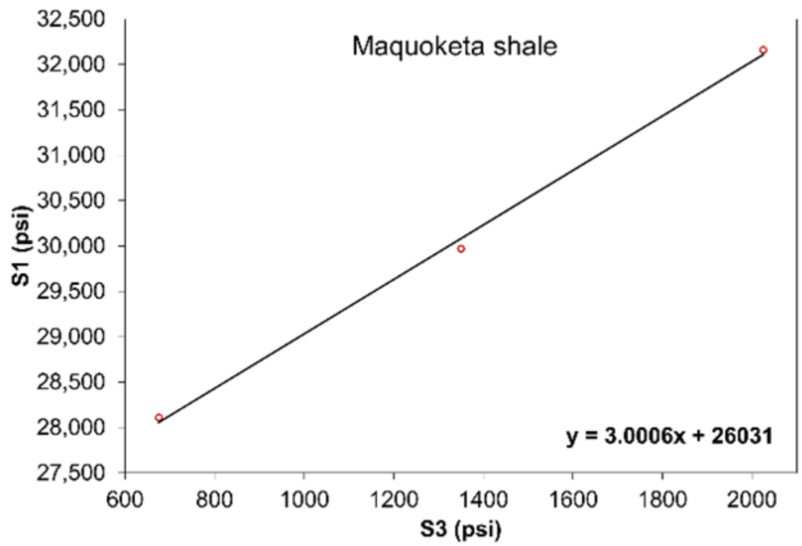

Figure 32. Plot of confining stress versus the resulting yield strength. Note that 3 measurements were used to create a best-fit line.

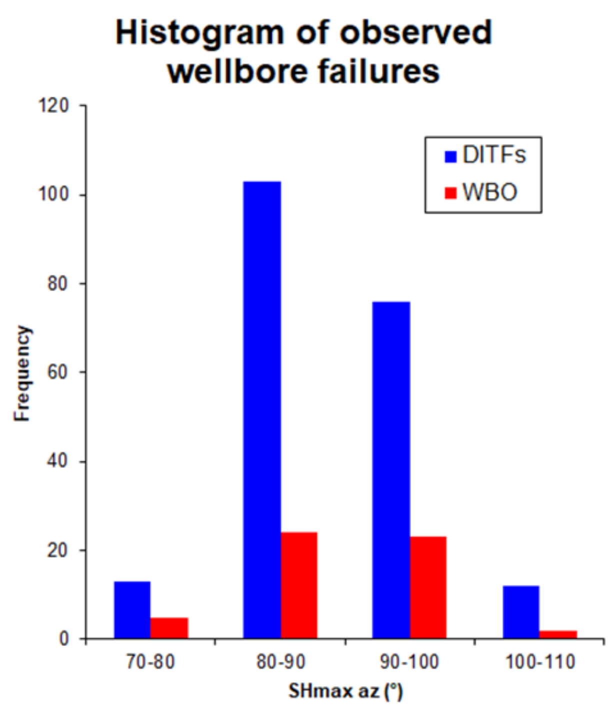

Figure 33. Plot showing the distribution of wellbore failure orientation observed within intermediate logged interval section (325–4426 ft) of the Wabash #1 well. DITFs = drilling induced tensile fractures; WBOs = wellbore breakouts.

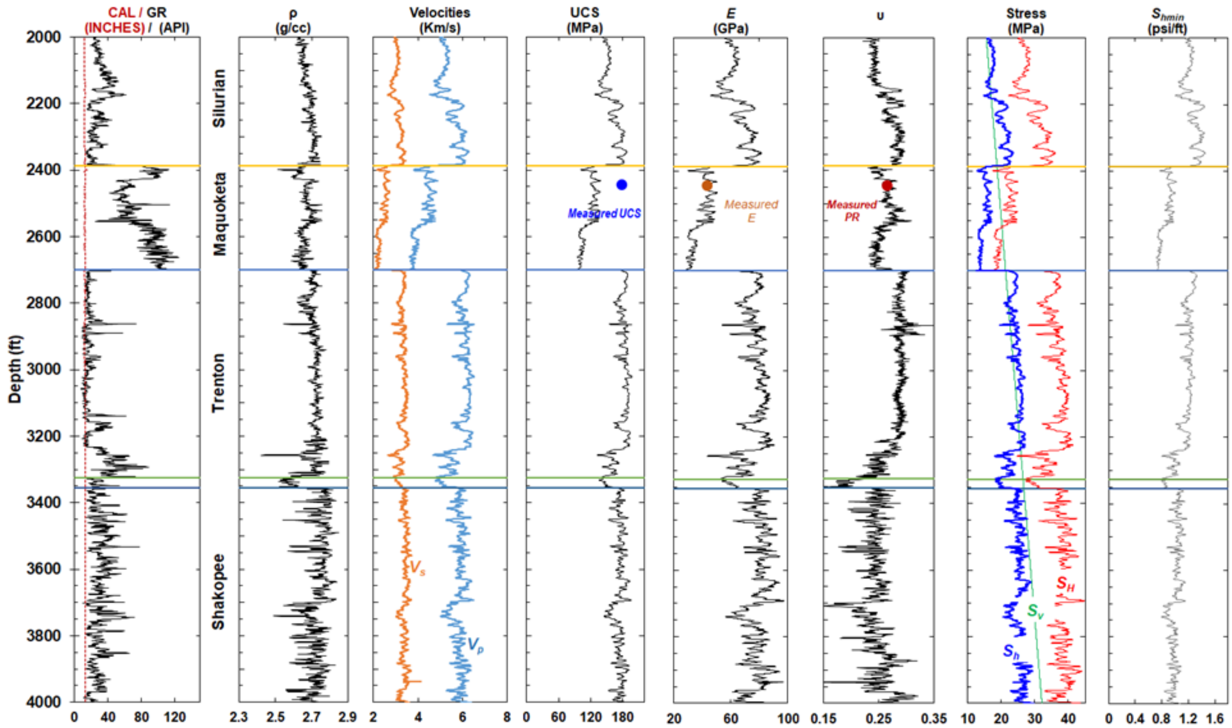

Figure 34 Plots of estimated dynamic elastic properties and in situ stresses. Plots also show measured static elastic properties.

<u>References</u>

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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. Eighty seismic events were recorded for this time period. The data are 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.

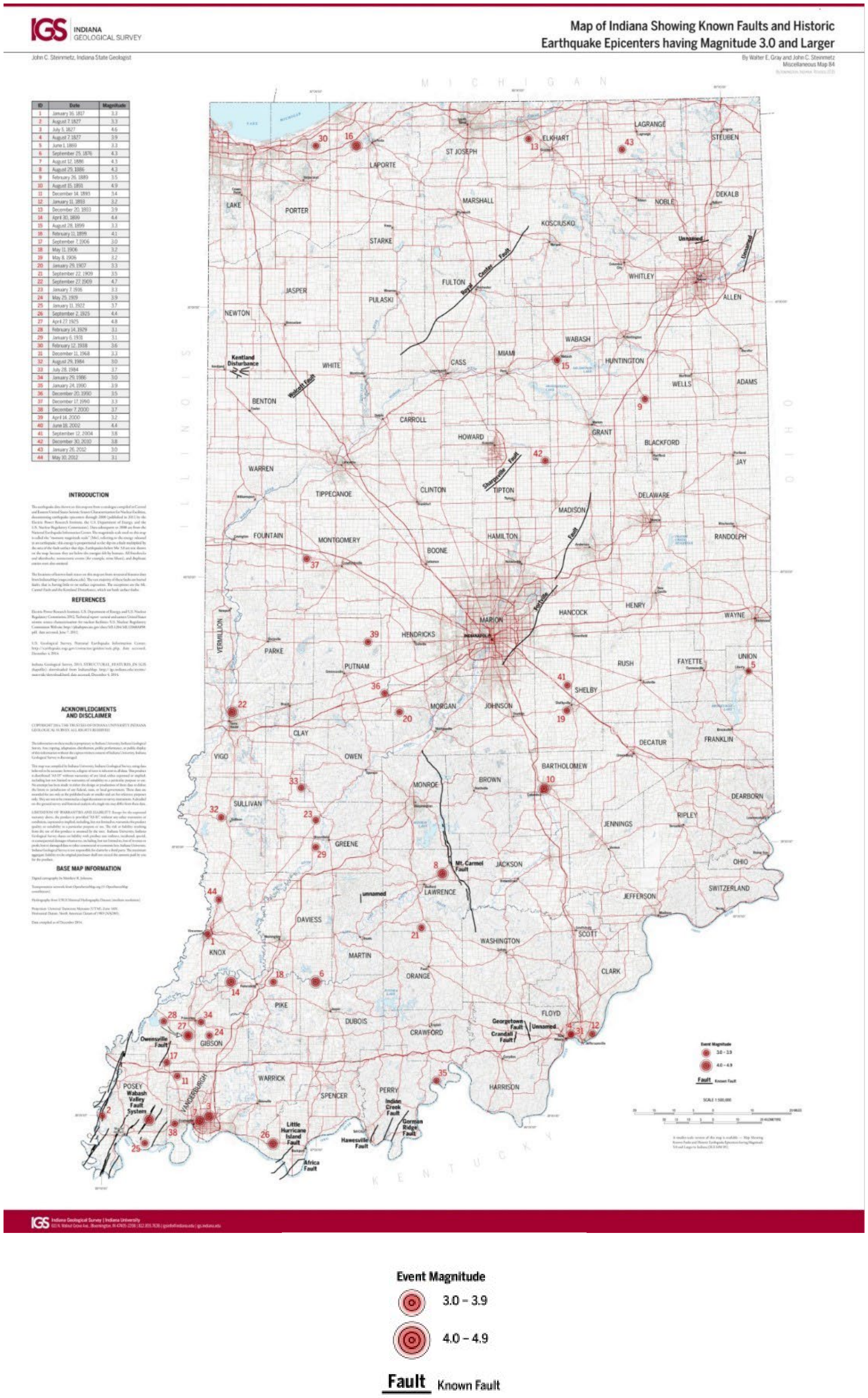
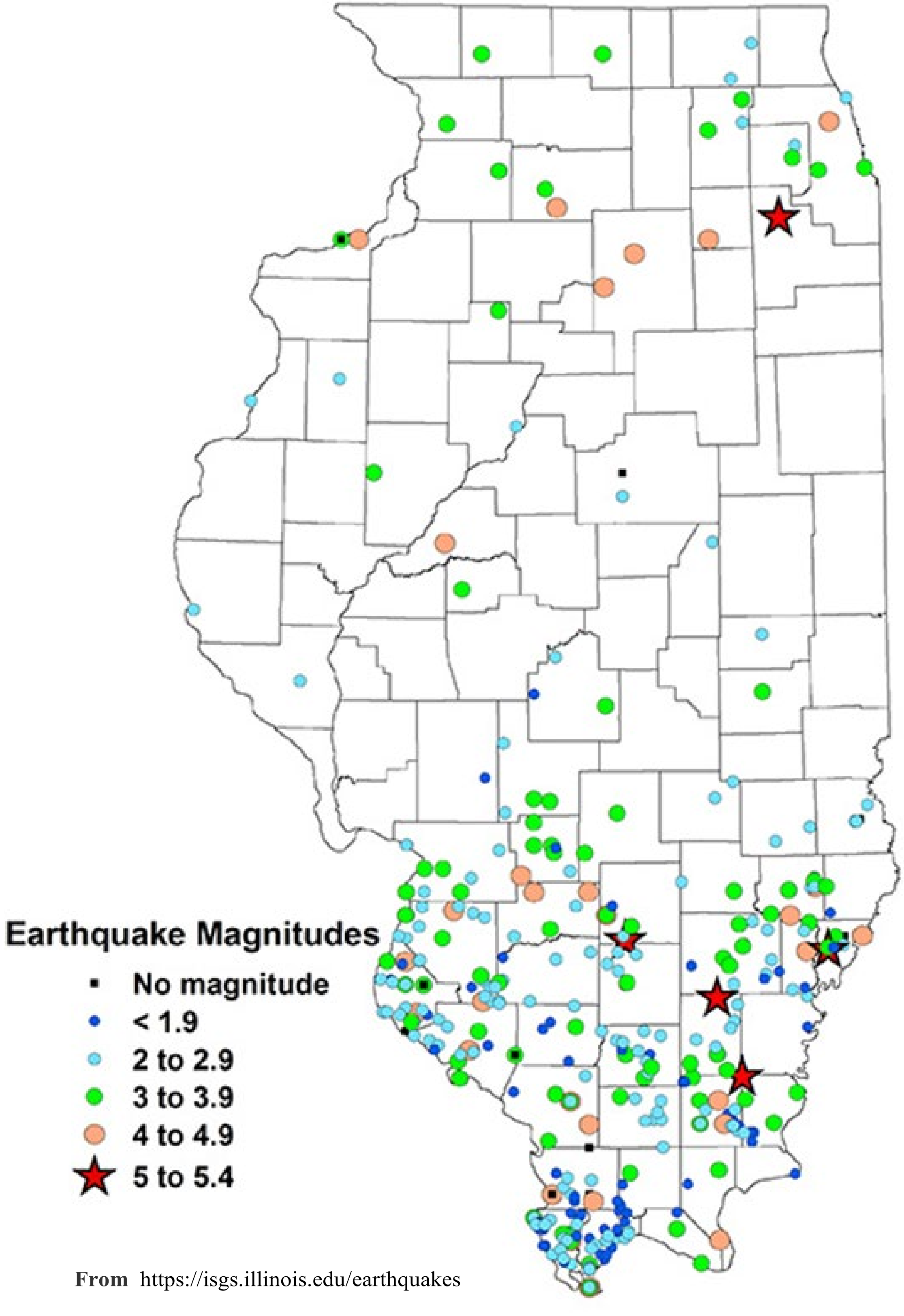


Figure 35 Map of Indiana Faults and Historic Earthquakes



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

Figure 36 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.

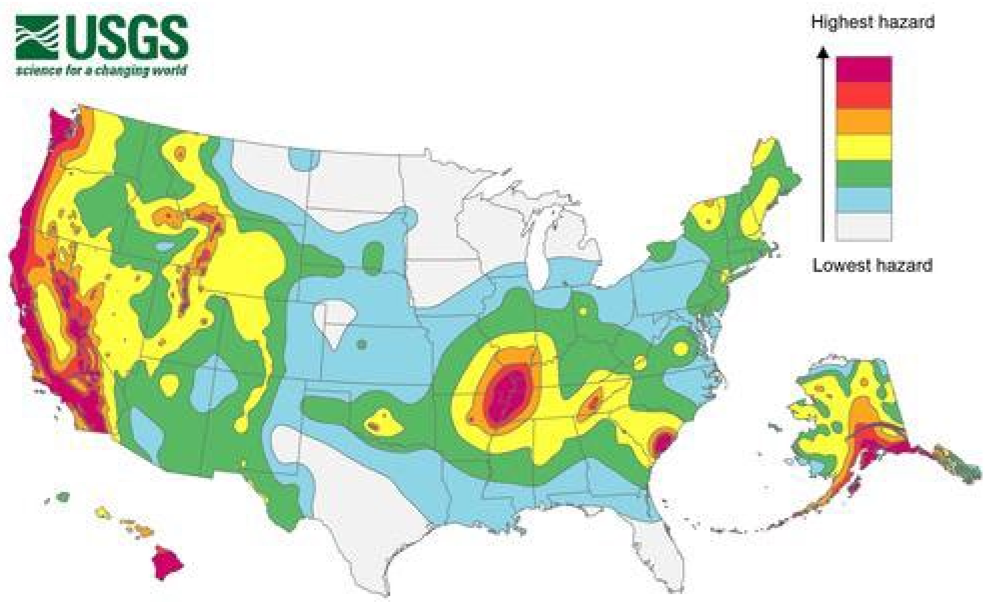


Figure 37 2018 Long-term National Seismic Hazard Map (USGS)

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 2018 USGS Long-Term Seismic Hazard Map (Figure 40) https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map . There is a 2% probability that the Peak Ground Acceleration due to seismic activity would approach 13% G (Figure 41) within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second, for location Lat. 39.55103, Lon. -87.48794 degrees (WVCCS2 south well), https://earthquake.usgs.gov/hazards/interactive/). The relative seismic risk at the site conveyed by the blue-green colors (map in Figure 40) is considered to be on the lower half of the seismic hazard color scale (Figure 40).

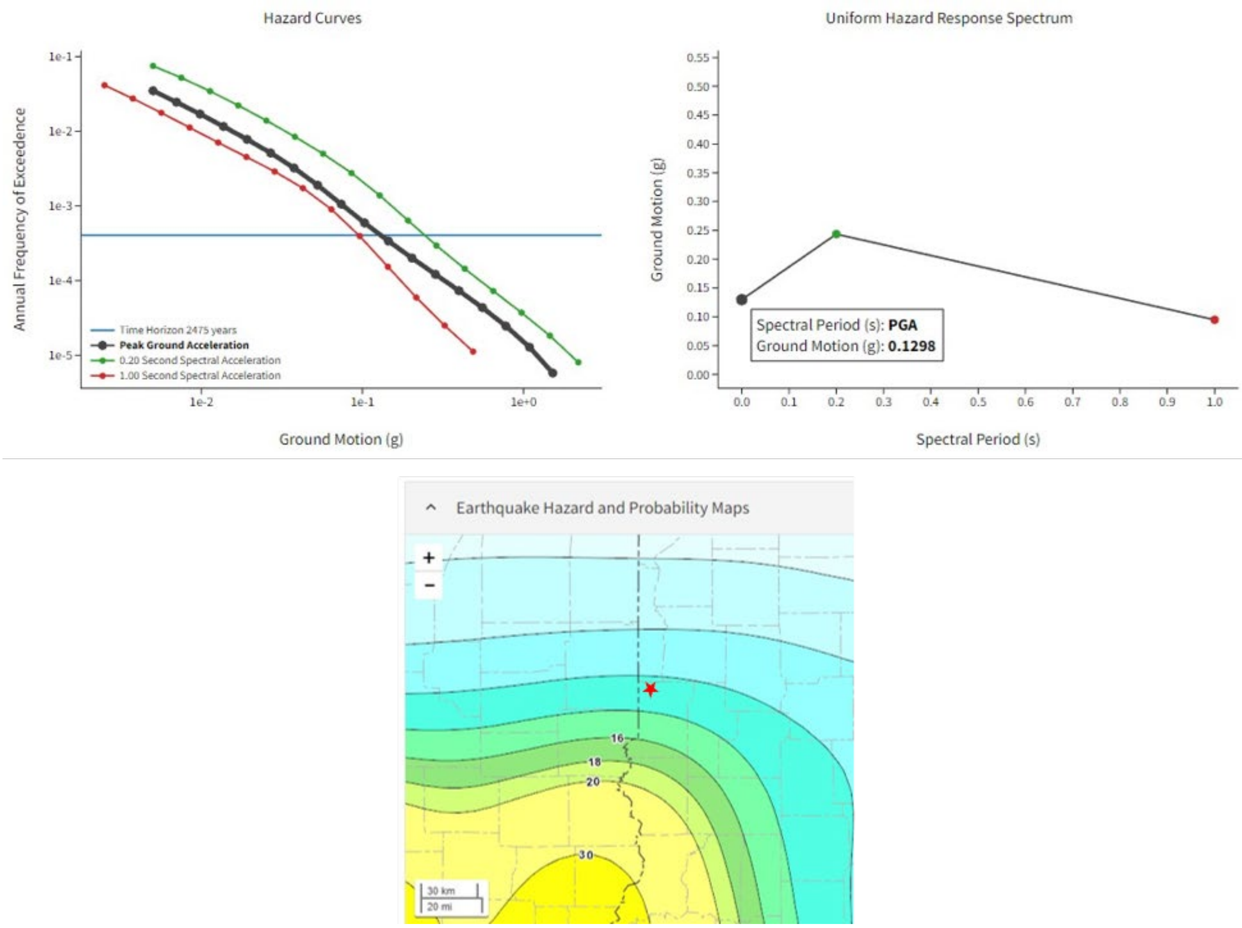


Figure 38. Hazard curves and response spectrum (top panels) depicting Peak Ground Acceleration (PGA) of 12.96% for the AoR (approximated by using WVCCS2 south well location: Lat. 39.55103, Lon. -87.48794 degrees). Bottom panel shows Wabash #1 well location (red star) overlain on 2014 USGS Seismic Hazard Map (https://earthquake.usgs.gov/hazards/interactive/).

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https://igws.indiana.edu/earthquakes/ Earthquake resources compiled by the Indiana Survey

https://igws.indiana.edu/Bedrock/Wabash - Seismic interpretation (U.S. Geological Survey Professional Paper 1538-O)

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 in West Central Indiana

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 (*44*). 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 (*46*).

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 in West Central Indiana

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 47*, *Figure 48*).

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).

Unconsolidated Aquifers in East Central Illinois

Glacial sand and gravel aquifers were identified stratigraphically and mapped in 50 by 80-mile rectangular area of east-central Illinois (Figure 42) for the purpose of assessing the unconsolidated sand and gravel aquifers for potential municipal use (Kempton et al. 1982).

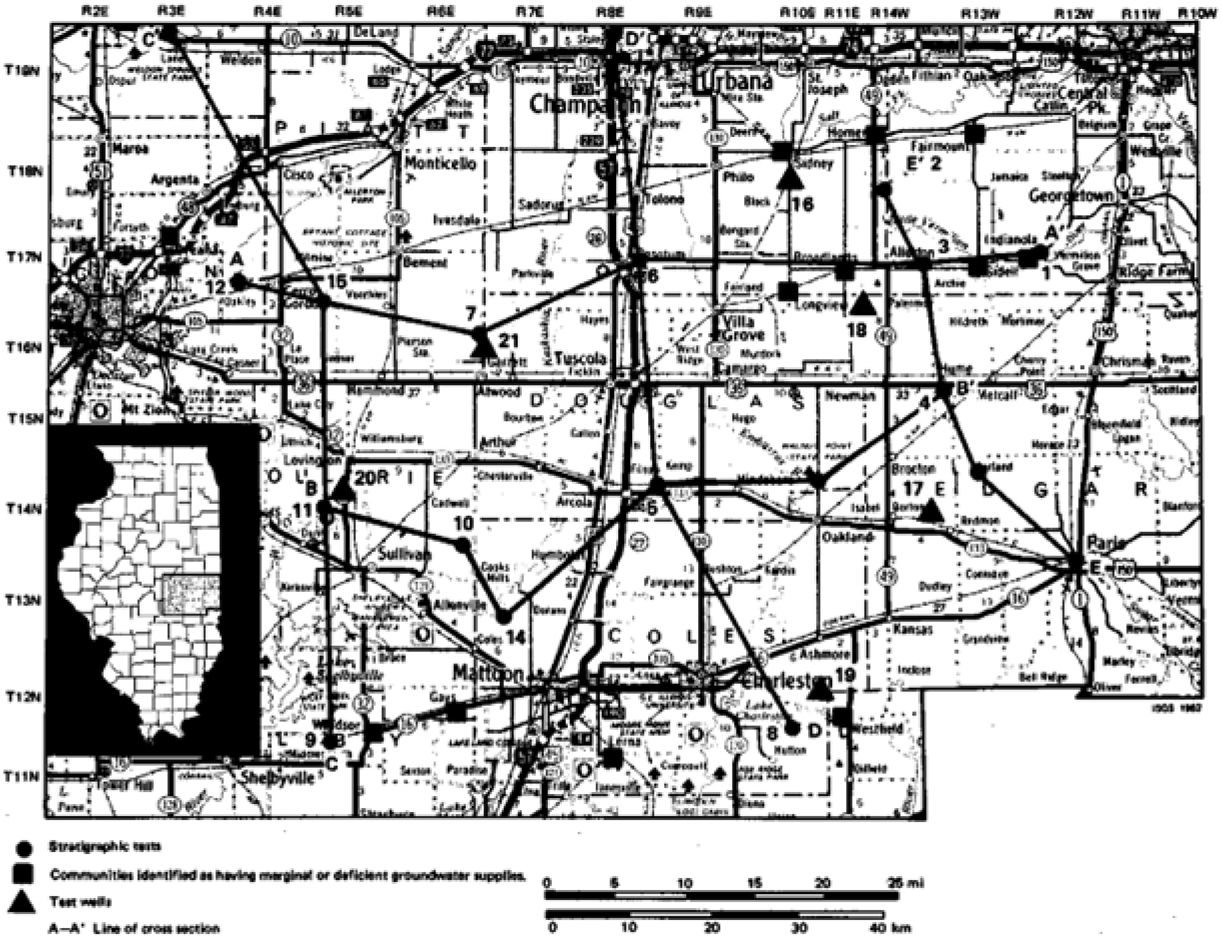

Figure 42. Location of study area, stratigraphic test holes, and lines of section used in Kempton et al. 1982.

Unconsolidated aquifers in east-central Illinois are unevenly distributed with principal aquifers concentrated in the western half of the study area, while aquifers with limited extent and thickness, which are separated with unproductive areas, occupy eastern half of the east-central Illinois assessment area (Figure 42; Kempton et al. 1982).

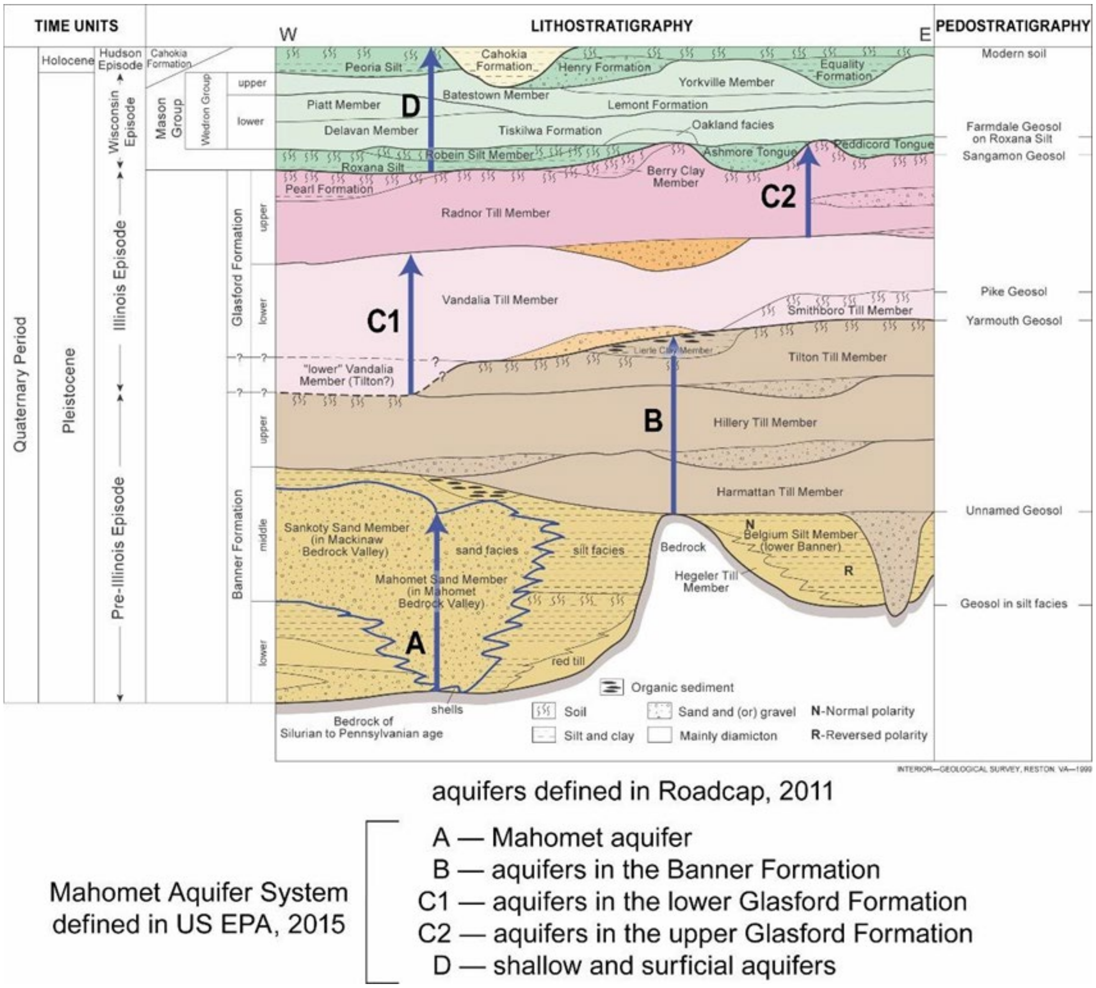

Figure 43. Stratigraphic column and correlation of glacial deposits (Soller et al. 1999). Hydrogeologic framework recreated from Roadcap et al., 2011. The Sole Source Aquifer designation of the Mahomet aquifer, the Mahomet aquifer system (US EPA, 2015), includes all the hydrogeologic units of Roadcap et al., 2011. The Mahomet Sand Member and the Sankoty Sand Member of the Banner Formation are outlined in blue.

The uppermost sediments of Quaternary Period are assigned to the Wisconsin and Hudson Episodes these thin, discontinuous sand and gravel deposits assigned to the Henry Formation and sand and gravel assigned to the Ashmore Tongue of the Henry Formation make up these aquifers.

These shallow sands and gravels are used as sources of drinking water for many households within the region.

The sediments assigned to the Illinois Episode include the Upper and Lower Glasford formations. The Glasford formations contain extensive sand and gravel aquifers, primarily in the Lower Glasford, in the western and northern parts of the study area (Kempton et al. 1982).

The pre-Illinois Episode Banner Formation contains the most significant aquifer in east-central Illinois, the Mahomet Sand Member (Kempton et al. 1982). The Mahomet Sand Member or the Mahomet Aquifer (Figure 44) extends across portions of 14 counties in east-central Illinois producing an average daily groundwater withdrawal rate estimated to be 210 million gallons a day (Roadcap et al. 2011).

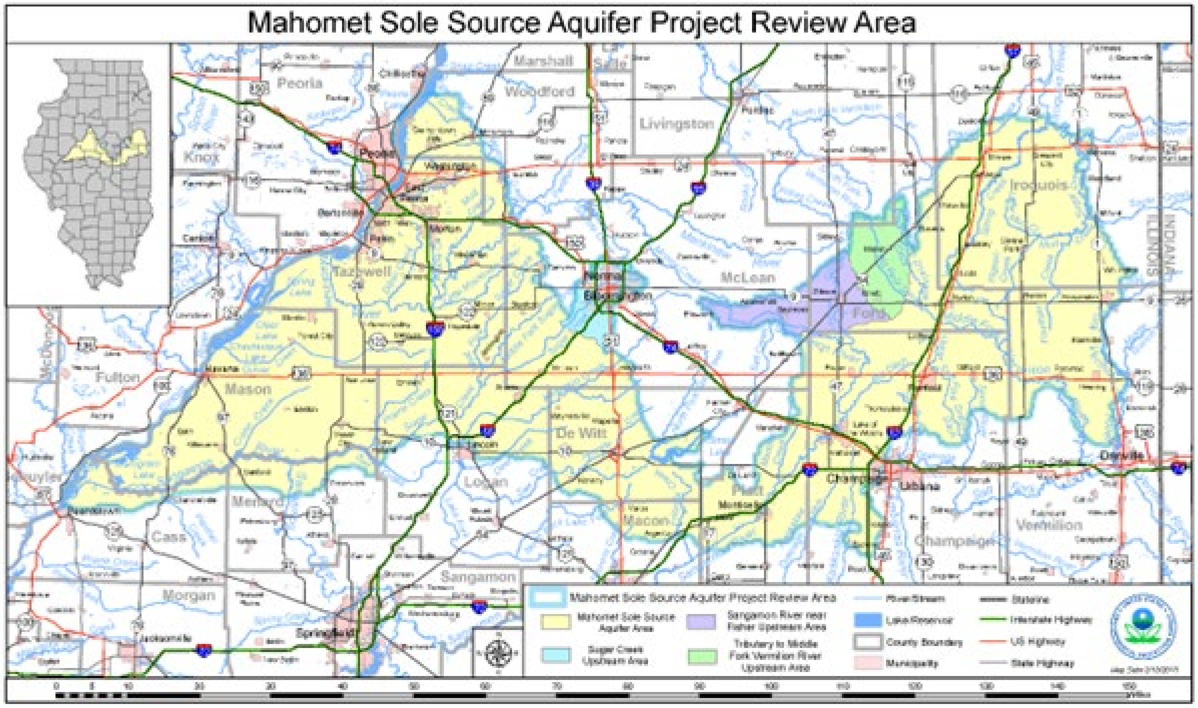

Figure 44. Mahomet Sole Source Aquifer in yellow (USEPA 2015) distributed across central Illinois.

Bedrock Aquifers in Aquifers in East Central Illinois

A generalized geology of hydrostratigraphic units and non-aquifer units in east-central Illinois (Selkregg and Kempton 1958) is presented in Figure 52. Cambrian and Ordovician-age rocks are predominantly sandstones, Silurian through Mississippian-age rocks are predominantly carbonates, and Pennsylvanian-age rocks are shales, sandstones, and coal measures (Kelly et al. 2018).

The Pennsylvanian Sandstones have the capacity to supply groundwater and are sourced in east-central Illinois, but water quality usually becomes poor with depth. Csallany (1966) provides a statewide summary of the production potential of the Pennsylvanian and Mississippian strata by county. Figure 52 provides a general summary of the bedrock production potential for strata underlying the Pennsylvanian. In the northern extent of Kempton et al. 1982 study area the St. Peter Sandstone is the lowermost underground source of drinking water.

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 49*).

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.

The Silurian-Devonian carbonate bedrock aquifer is expected to be the lowermost USDW through the area. 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 50. 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*).

Panno et al. (2018) produced five east-west and one north-south cross section to map the distribution of chloride (Cl^-) in the subsurface within the Illinois Basin. 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:

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

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

According to Panno et al. (2018) and referencing Figure 52:

"The eastern portion of the cross section (D-D') within Indiana reveals greater recharge from the east within Silurian through Mississippian strata. This is supported by McIntosh et al. (2002) who found that the Silurian-Devonian strata provided a hydrologic pathway for recharging Pleistocene meltwater to depths up to 1 km across the eastern margin of the basin, and recharge from Mississippian strata, through underlying fractured New Albany Shale, and into Silurian-Devonian strata in the southeastern part of the Illinois Basin."

Below the Silurian-Devonian is the Maquoketa Group regional seal and underlying this is the St. Peter Sandstone. The St. Peter Sandstone is defined as the LUSDW in north-central Illinois; it is an important underground source of water in Illinois but 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 Sandstone 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) at the ISGS had developed an Illinois Basin-wide contour map of chloride concentration for the St. Peter Sandstone based on available brine data; a later update of the Panno work by the ISGS (2021, unpublished) has produced a regional map of estimated total dissolved solids for the St. Peter Sandstone waters (*Figure 51*). 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.

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.

Units below the Potosi Dolomite are not expected to be USDWs in the AoR, and salinities in the deep Cambrian strata are generally expected to increase with depth (*Figure 51*). Swab and Drill Stem Test (DST) samples were obtained from the Mt. Simon Sandstone in the Wabash #1 well during well testing operations. The sample analyses show generally increasing TDS concentrations with increasing depth within the Mt. Simon Sandstone as well as confirm the high TDS concentration trends in the Mt. Simon Sandstone shown in the regional map (Figure 54) for the Vigo County, Indiana, area. The Wabash #1 fluid samples were analyzed for major, minor, and trace element composition using Ion Chromatography (IC) and Inductively Coupled Plasma-atomic Emission Spectrometry (ICP-ES) by the Illinois State Water Survey.

The Wabash #1 Drill Stem Tests performed in the Upper/Middle Mt. Simon (sample interval from 6,710 – 6,912 ft MD) resulted in a TDS concentration of 154,460 mg/L. For the Lower Mt. Simon, TDS concentrations of 150,540 mg/L (swab sample from 7,976 – 7,996 ft MD) along with 169,700 mg/L and 168,490 mg/L (one DST sample from 7,696 – 8,121 ft MD, analyzed twice) were recorded. The deepest swab sample from beneath the basalt, obtained in the Mt. Simon/Argenta from 8,661 – 8,671 ft MD, yielded a TDS concentration of 270,890 mg/L.

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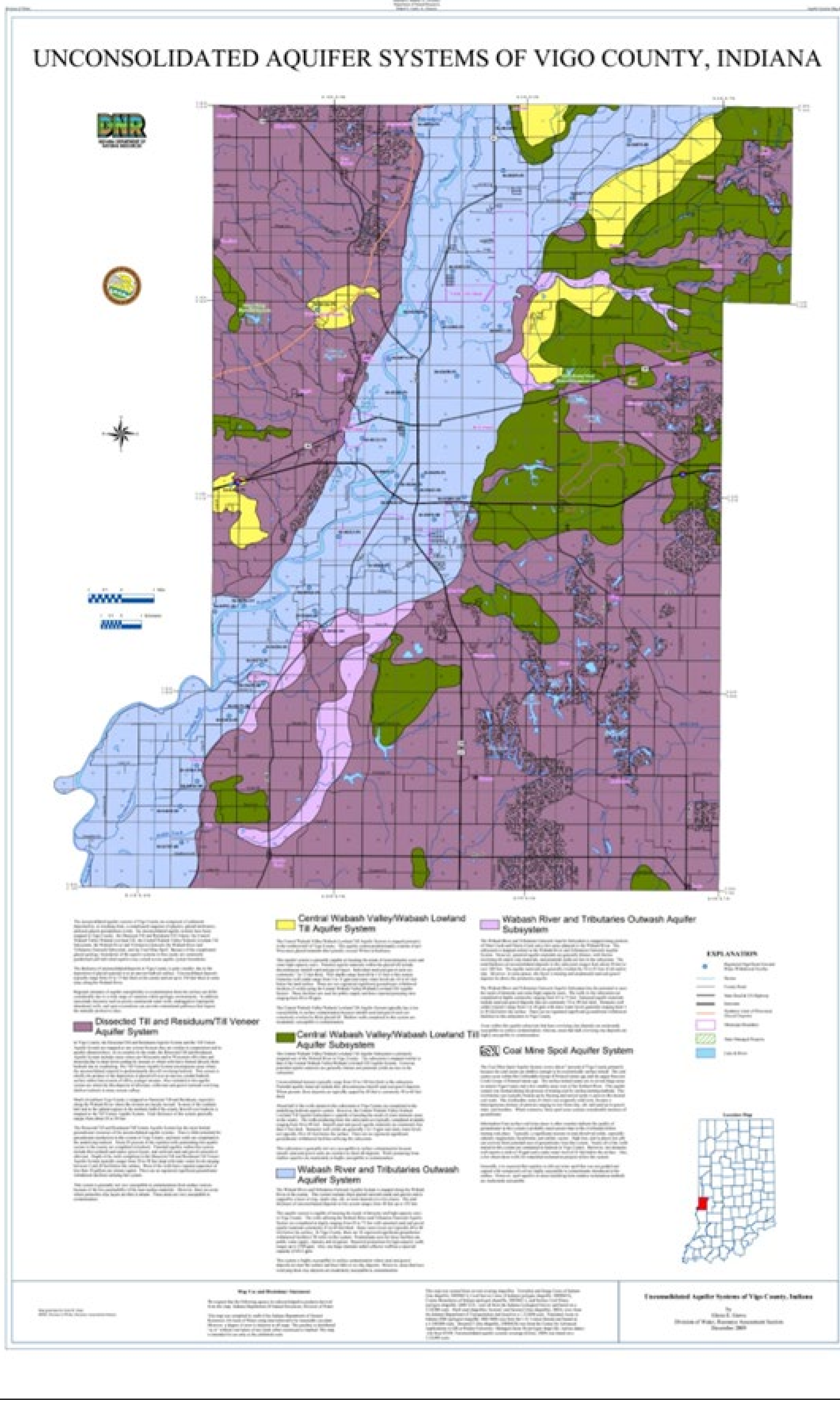
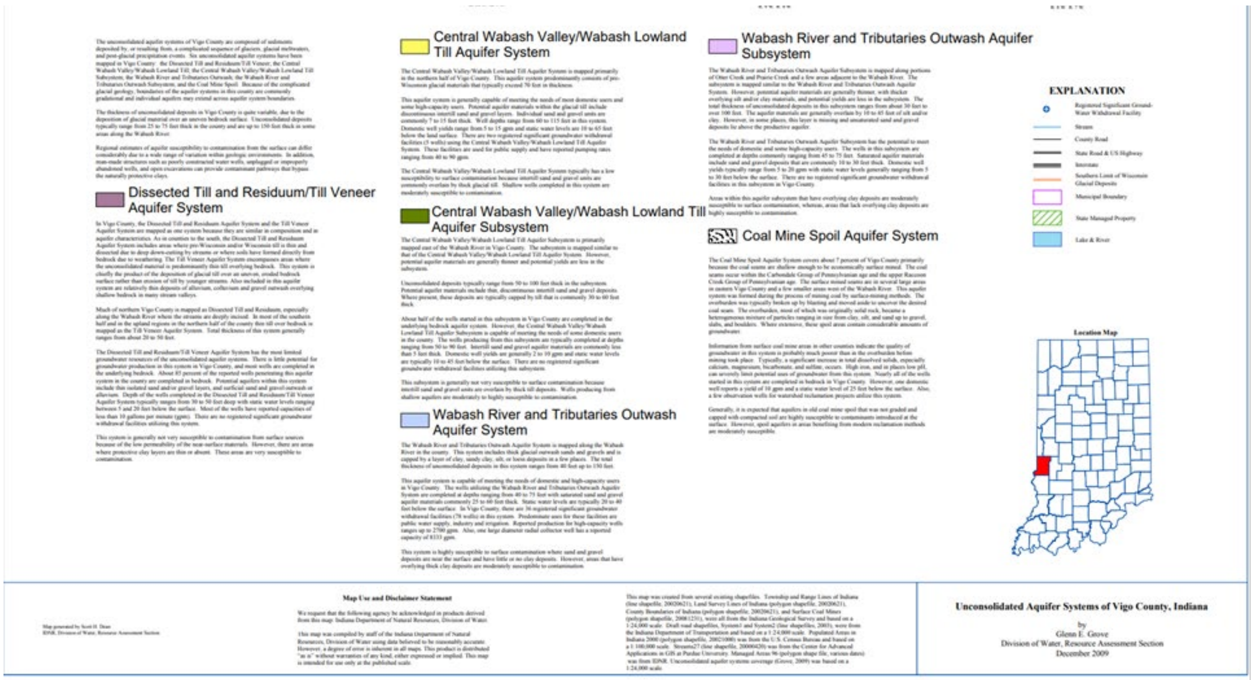

UNCONSOLIDATED AQUIFER SYSTEMS OF VIGO COUNTY, INDIANA
DNR
Central Wabash Valley/Wabash Lowland Till Aquifer System
Wabash River and Tributaries Outwash Aquifer Subsystem
Dissected Till and Residuum/Till Veneer Aquifer System
Central Wabash Valley/Wabash Lowland Till Aquifer Subsystem
Coal Mine Spoil Aquifer System
Wabash River and Tributaries Outwash Aquifer System
EXPLANATION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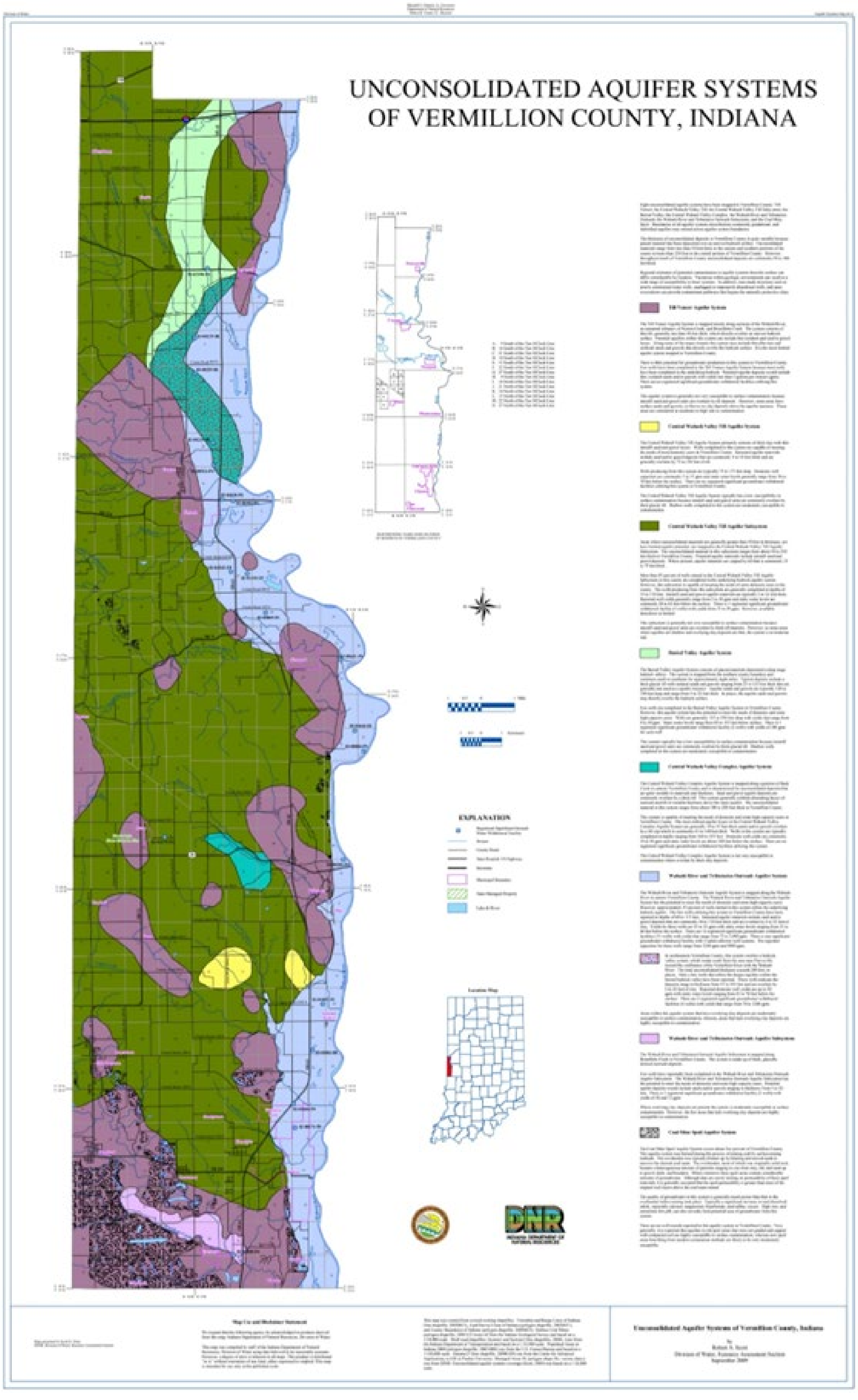
Coal Mine Spoil Aquifer System
Location Map
Wabash River and Tributaries Outwash Aquifer System
Map Use and Disclaimer Statement
Unconsolidated Aquifer Systems of Vigo County, Indiana
by
Glenn E. Grove
Division of Water, Resource Assessment Section
December 2009


UNCONSOLIDATED AQUIFER SYSTEMS
OF VERMILLION COUNTY, INDIANA
EXPLANATION

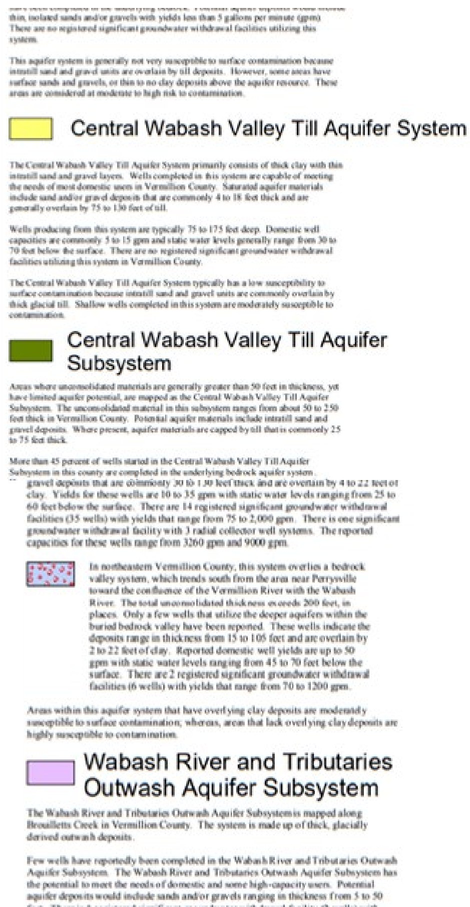
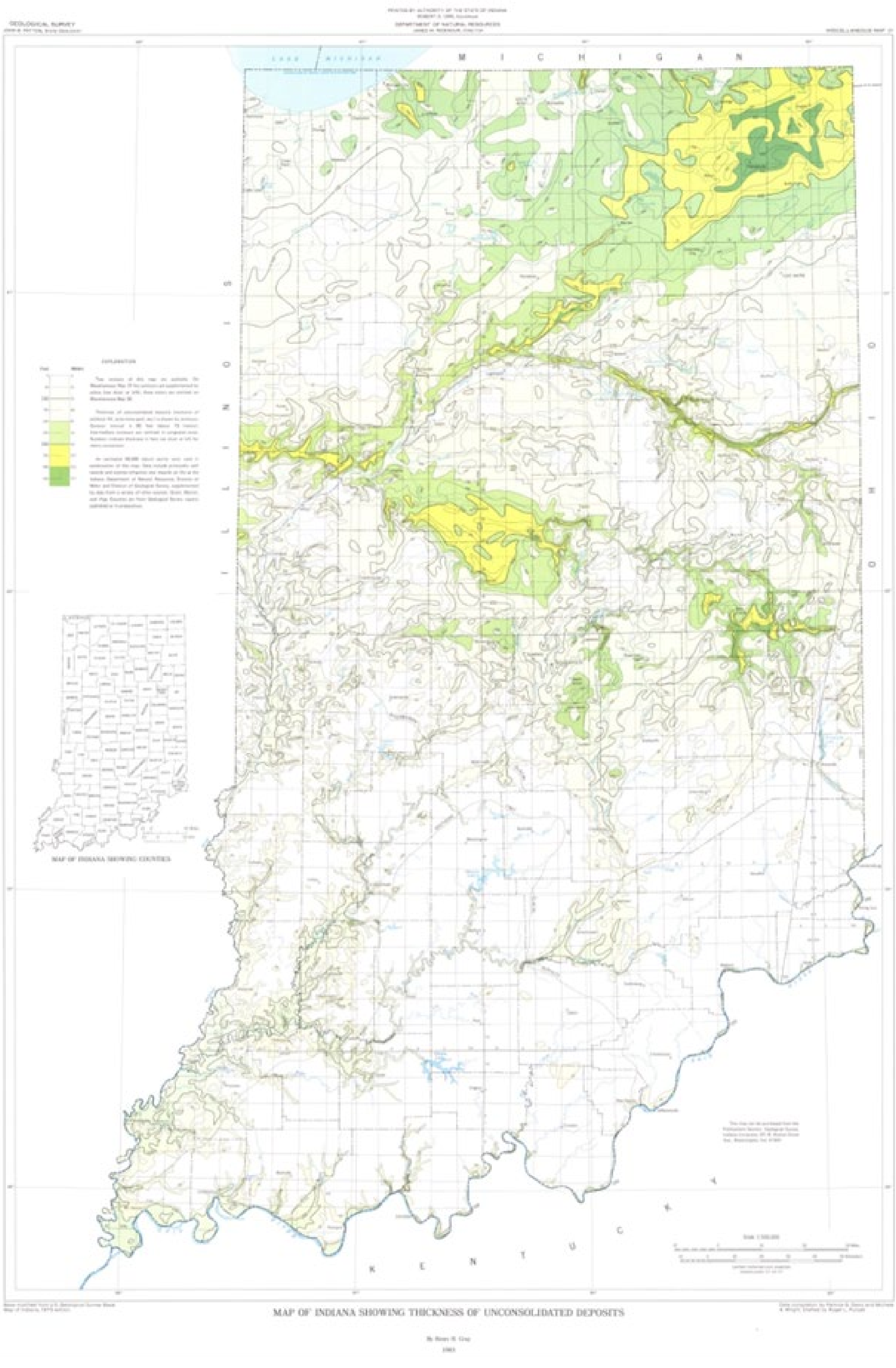
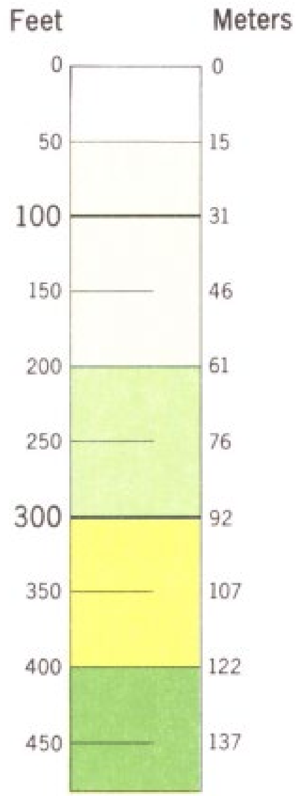


Figure 45 Maps of Unconsolidated Aquifer Systems of Vermillion County and Vigo County, Indiana (Indiana DNR). Available from: https://www.in.gov/dnr/water/5702.htm & https://www.in.gov/dnr/water/5774.htm


GEOLOGICAL SURVEY
MICHIGAN
ILLINOIS
OHIO
KENTUCKY
EXPLANATION
MAP OF INDIANA SHOWING COUNTIES
MAP OF INDIANA SHOWING THICKNESS OF UNCONSOLIDATED DEPOSITS
By Henry H. Gray
1983

EXPLANATION

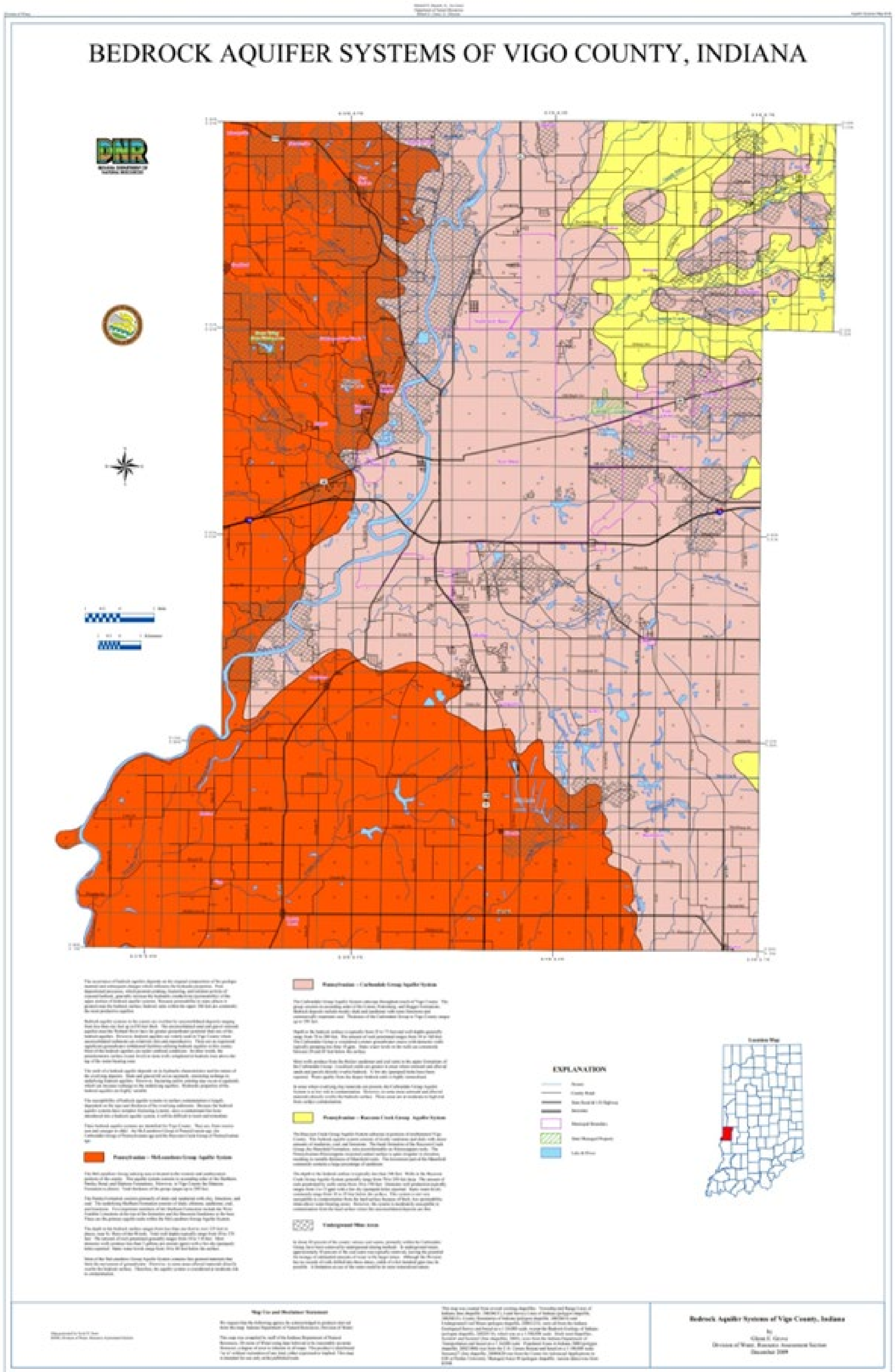


Two versions of this map are available. On Miscellaneous Map 37 the contours are supplemented by colors (see chart at left); these colors are omitted on Miscellaneous Map 38.

Thickness of unconsolidated deposits (exclusive of artificial fill, strip-mine spoil, etc.) is shown by contours. Contour interval is 50 feet (about 15 meters). Intermediate contours are omitted in congested areas. Numbers indicate thickness in feet; see chart at left for metric conversion.

An estimated 60,000 datum points were used in construction of this map. Data include principally well records and seismic-refraction test records on file at the Indiana Department of Natural Resources, Division of Water and Division of Geological Survey, supplemented by data from a variety of other sources. Grant, Marion, and Vigo Counties are from Geological Survey reports published or in preparation.

Figure 46 Map of Indiana showing thickness of unconsolidated deposits, excerpt (Gray 1983). Available from: https://igws.indiana.edu/bookstore/details.cfm?Pub_Num=MM37


BEDROCK AQUIFER SYSTEMS OF VIGO COUNTY, INDIANA
DNR
EXPLANATION

of bedrock aquifers depends on the original composition of the geologic
bsequent changes which influence the hydraulic properties. Post-
cesses, which promote jointing, fracturing, and solution activity of
k, generally increase the hydraulic conductivity (permeability) of the
f bedrock aquifer systems. Because permeability in many places is
e bedrock surface, bedrock units within the upper 100 feet are commonly
ctive aquifers.

r systems in the county are overlain by unconsolidated deposits ranging
one foot up to150 feet thick. The unconsolidated sand and gravel outwash
e Wabash River have far greater groundwater potential than any of the
s. However, bedrock aquifers are widely used in Vigo County where
sediments are relatively thin and unproductive. There are no registered
ndwater withdrawal facilities utilizing bedrock aquifers in this county.
lrock aquifers are under confined conditions. In other words, the
surface (water level) in most wells completed in bedrock rises above the
-bearing zone.

edrock aquifer depends on its hydraulic characteristics and the nature of
eposits. Shale and glacial till act as aquitards, restricting recharge to
rock aquifers. However, fracturing and/or jointing may occur in aquitards,
ase recharge to the underlying aquifers. Hydraulic properties of the
s are highly variable.

ity of bedrock aquifer systems to surface contamination is largely
e type and thickness of the overlying sediments. Because the bedrock
have complex fracturing systems, once a contaminant has been
a bedrock aquifer system, it will be difficult to track and remediate.

aquifer systems are identified for Vigo County. They are, from west to
er to older: the McLeansboro Group of Pennsylvanian age, the
oup of Pennsylvanian age and the Raccoon Creek Group of Pennsylvanian

Pennsylvanian -- McLeansboro Group Aquifer System

oro Group subcrop area is located in the western and southwestern
county. This aquifer system consists in ascending order of the Shelburn,
nd Mattoon Formations. However, in Vigo County the Mattoon
sent. Total thickness of the group ranges up to 200 feet.

mation consists primarily of shale and sandstone with clay, limestone, and
rlying Shelburn Formation consists of shale, siltstone, sandstone, coal,
Two important members of the Shelburn Formation include the West
tone at the top of the formation and the Busseron Sandstone at the base.
rimary aquifer units within the McLeansboro Group Aquifer System.

e bedrock surface ranges from less than one foot to over 125 feet in
Mary-of-the-Woods. Total well depths typically range from 50 to 170
nt of rock penetrated generally ranges from 10 to 110 feet. Most
produce less than 5 gallons per minute (gpm) with a few dry (pumped)
Static water levels range from 10 to 40 feet below the surface.

Leansboro Group Aquifer System contains fine-grained materials that
nent of groundwater. However, in some areas alluvial materials directly
rock surface. Therefore, the aquifer system is considered at moderate risk
n.

Pennsylvanian -- Carbondale Group Aquifer

The Carbondale Group Aquifer System subcrops throughout much of Vi
group consists in ascending order of the Linton, Petersburg, and Dugger
Bedrock deposits include mostly shale and sandstone with some limesto
commercially important coal. Thickness of the Carbondale Group in Vi
up to 350 feet.

Depth to the bedrock surface is typically from 25 to 75 feet and well dep
range from 70 to 200 feet. The amount of rock penetrated ranges from 1
The Carbondale Group is considered a minor groundwater source with d
typically pumping less than 10 gpm. Static water levels in the wells are
between 20 and 65 feet below the surface.

Most wells produce from the thicker sandstone and coal units in the upp
the Carbondale Group. Localized yields are greater in areas where outw
sands and gravels directly overlie bedrock. A few dry (pumped) holes h
reported. Water quality from the deeper bedrock units is highly mineral

In areas where overlying clay materials are present, the Carbondale Gro
System is at low risk to contamination. However, in some areas outwas
materials directly overlie the bedrock surface. These areas are at moder
from surface contamination.

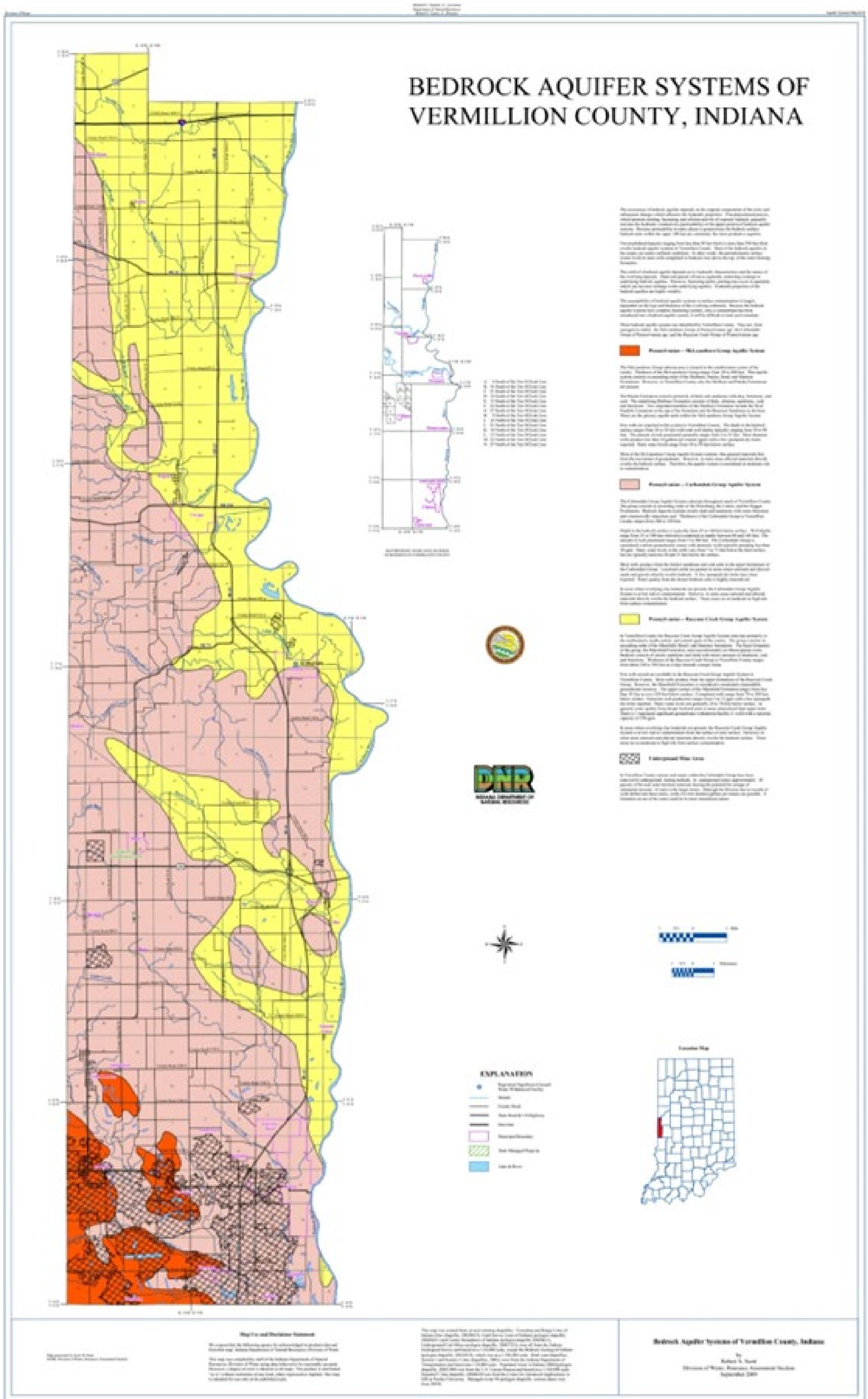
Pennsylvanian -- Raccoon Creek Group Aq

The Raccoon Creek Group Aquifer System subcrops in portions of north
County. This bedrock aquifer system consists of mostly sandstone and s
amounts of mudstone, coal, and limestone. The basal formation of the R
Group, the Mansfield Formation, rests unconformably on Mississippian
Pennsylvanian-Mississippian erosional contact surface is quite irregular
resulting in variable thickness of Mansfield rocks. The lowermost part c
commonly contains a large percentage of sandstone.

The depth to the bedrock surface is typically less than 100 feet. Wells in
Creek Group Aquifer System generally range from 70 to 250 feet deep.
rock penetrated by wells varies from 10 to 150 feet. Domestic well prod
ranges from 2 to 15 gpm with a few dry (pumped) holes reported. Static
commonly range from 10 to 55 feet below the surface. This system is nc
susceptible to contamination from the land surface because of thick, low
strata above water-bearing zones. However, the system is moderately su
contamination from the land surface where the unconsolidated deposits a

Underground Mine Areas

In about 20 percent of the county various coal seams, primarily within th
Group, have been removed by underground mining methods. In undergr
approximately 50 percent of the coal seam was typically removed, leavin
for storage of substantial amounts of water in the larger mines. Although
has no records of wells drilled into these mines, yields of a few hundred g
possible. A limitation on use of the water could be its more mineralized


BEDROCK AQUIFER SYSTEMS OF
VERMILLION COUNTY, INDIANA
DNR
EXPLANATION

Few wells are reported in this system in Vermillion County. The depth to the bedrock surface ranges from 10 to 30 feet with total well depths typically ranging from 50 to 90 feet. The amount of rock penetrated generally ranges from 5 to 35 feet. Most domestic wells produce less than 10 gallons per minute (gpm) with a few (pumped) dry holes reported. Static water levels range from 10 to 30 feet below surface.

Most of the McLeansboro Group Aquifer System contains fine-grained materials that limit the movement of groundwater. However, in some areas alluvial materials directly overlie the bedrock surface. Therefore, the aquifer system is considered at moderate risk to contamination.

Pennsylvanian – Carbondale Group Aquifer System

The Carbondale Group Aquifer System subcrops throughout much of Vermillion County. The group consists in ascending order of the Petersburg, the Linton, and the Dugger Formations. Bedrock deposits include mostly shale and sandstone with some limestone and commercially important coal. Thickness of the Carbondale Group in Vermillion County ranges from 300 to 350 feet.

Depth to the bedrock surface is typically from 45 to 140 feet below surface. Well depths range from 35 to 300 feet with most completed at depths between 60 and 160 feet. The amount of rock penetrated ranges from 5 to 280 feet. The Carbondale Group is considered a minor groundwater source with domestic wells typically pumping less than 10 gpm. Static water levels in the wells vary from 7 to 75 feet below the land surface, but are typically between 20 and 55 feet below the surface.

Most wells produce from the thicker sandstone and coal units in the upper formations of the Carbondale Group. Localized yields are greater in areas where outwash and alluvial sands and gravels directly overlie bedrock. A few (pumped) dry holes have been reported. Water quality from the deeper bedrock units is highly mineralized.

Figure 47 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

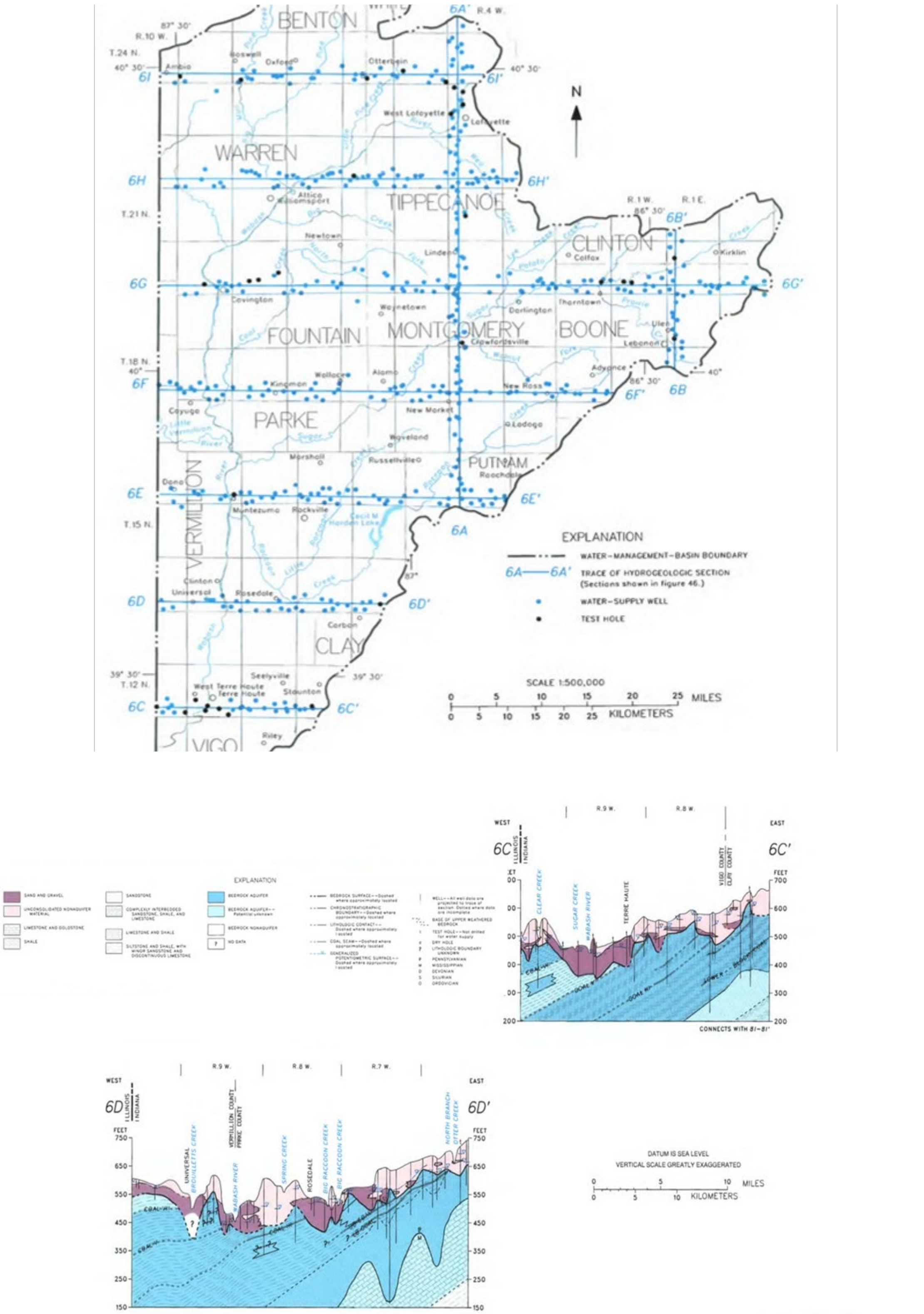


Figure 48 Selected hydrogeologic sections 6C-6C' (Vigo and Clay Counties) and 6D-6D ' (Vermilion and Parke Counties) of the Middle Wabash River Basin (modified from Fenelon and Bobay, 1994).

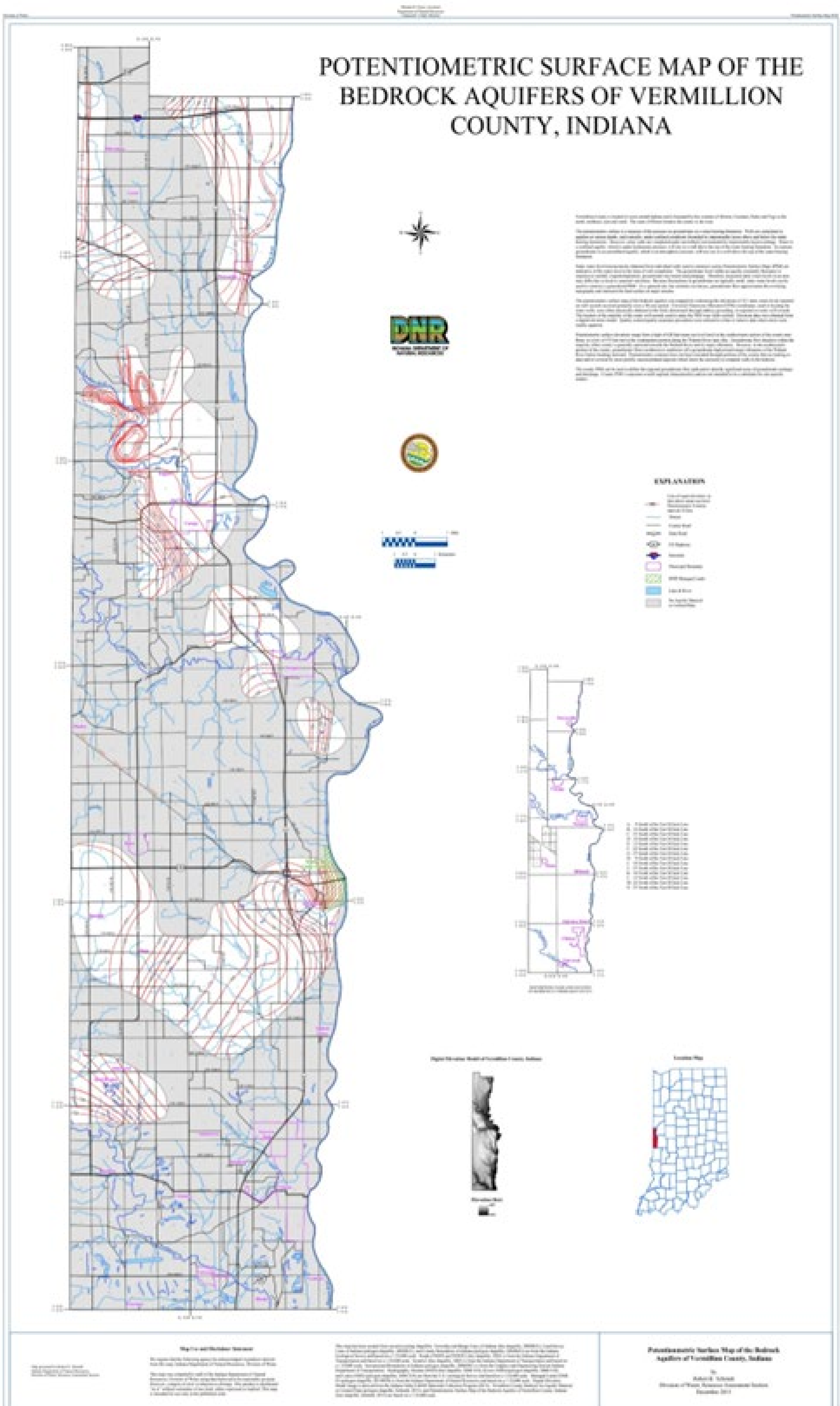

POTENTIOMETRIC SURFACE MAP OF THE BEDROCK AQUIFERS OF VERMILLION COUNTY, INDIANA
DNR

*Figure 49 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

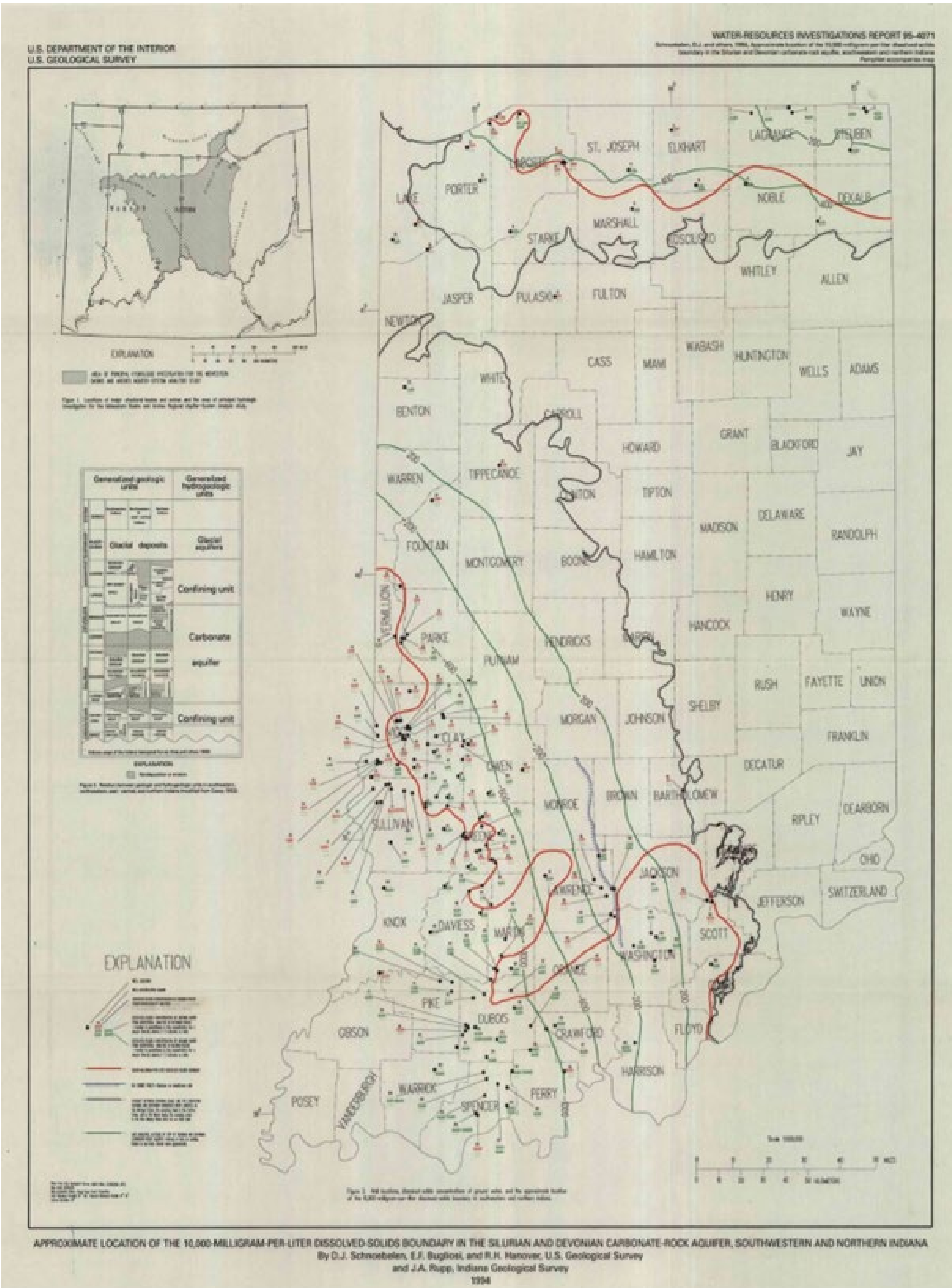


Figure 50 Location of the 10,000 mg/L dissolved solids boundary in the Silurian and Devonian carbonate aquifer systems (Schnoebelen et al. 1998).

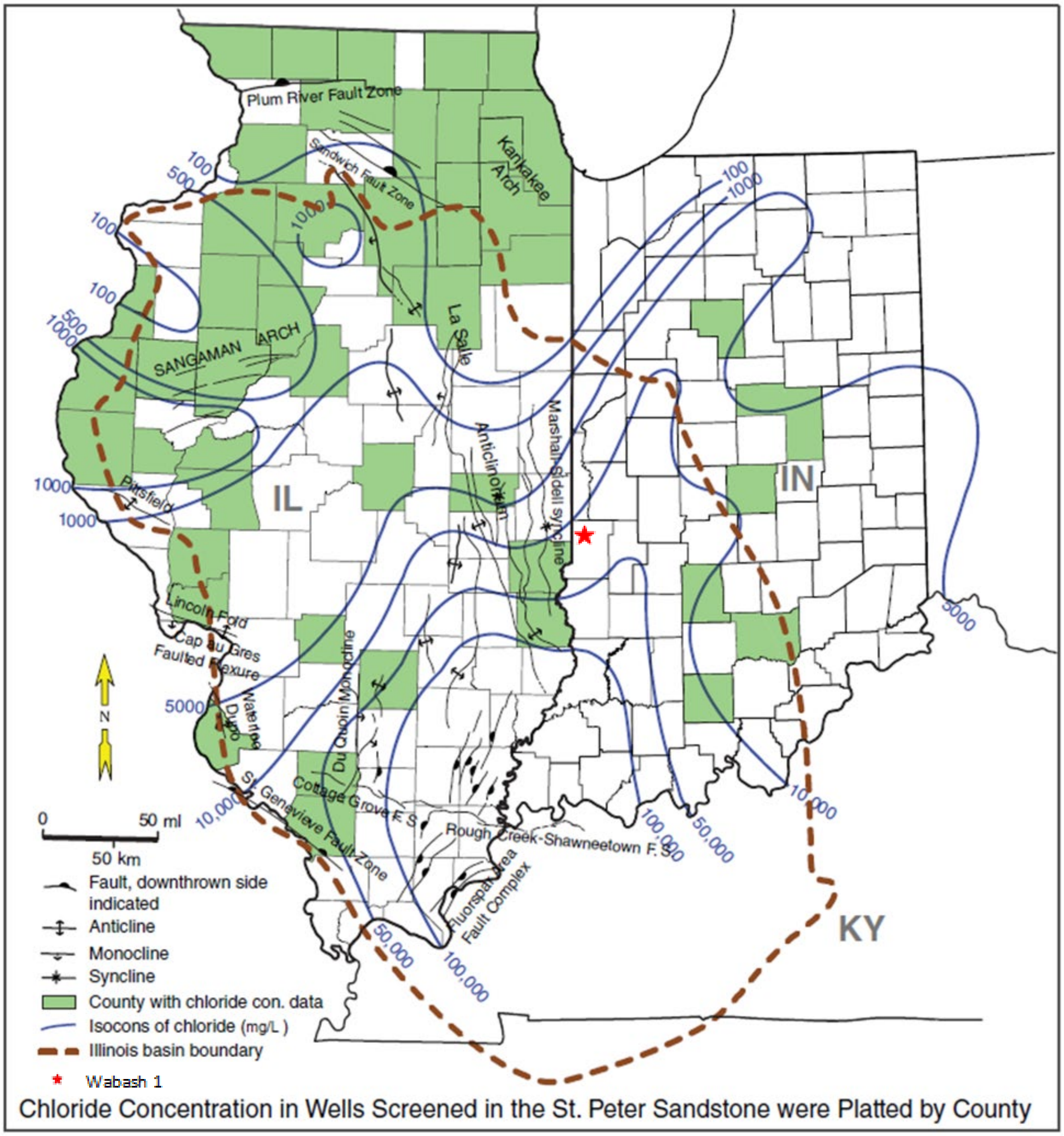


Figure 51 Chloride isocons in groundwater for the St. Peter Sandstone. Water quality data are from groundwater samples from wells screened in the St. Peter Sandstone. All chloride concentrations are from published data and were plotted by county and may be converted to total dissolved solids using Equations 9 and 10 (in Panno et al. 2018).

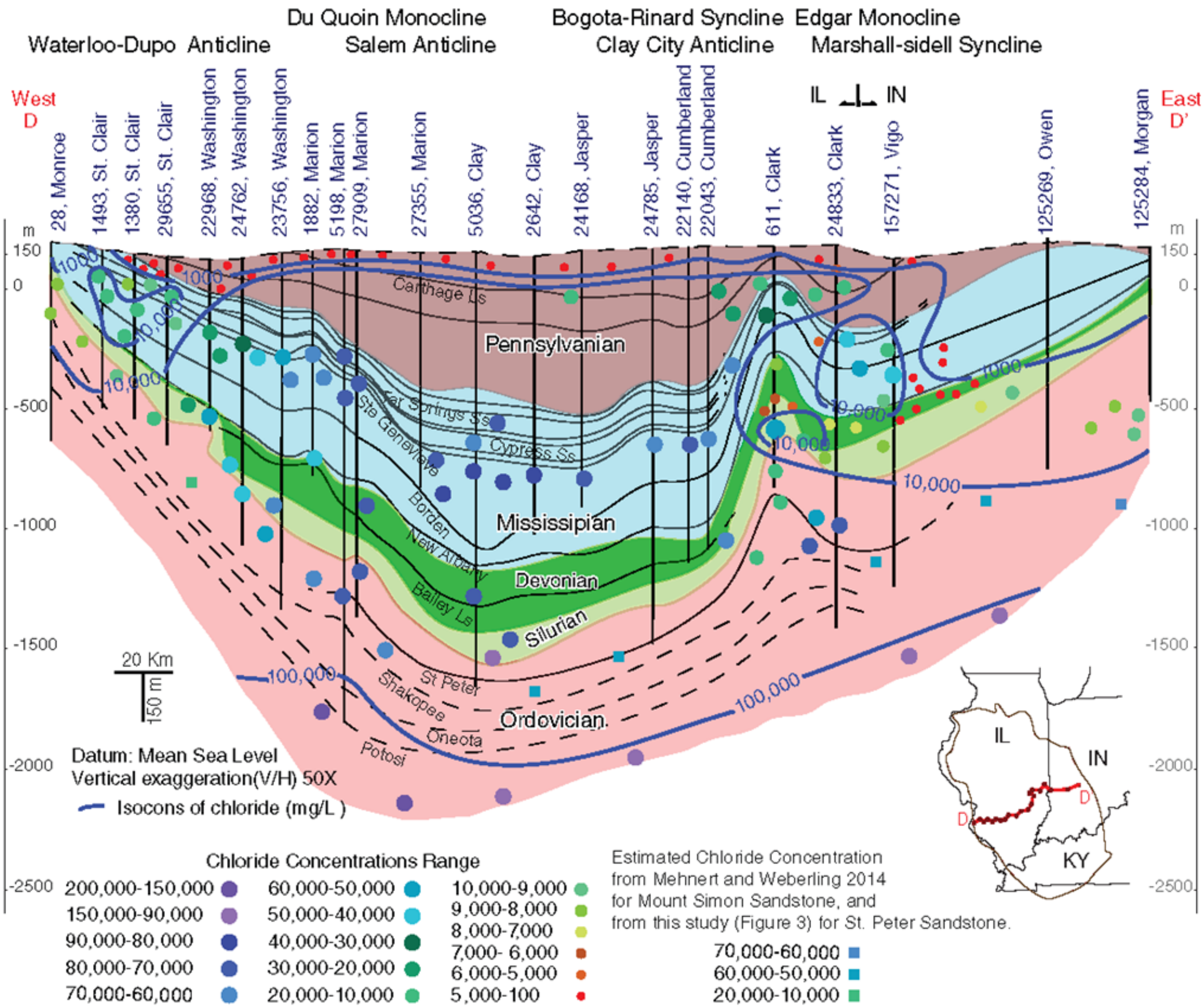


Figure 52 Cross section D-D’ extending east-west across southern Illinois and southern Indiana, showing general chloride (Cl−) concentration in Illinois Basin aquifers (Panno et al. 2018).

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 1*). 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 (see sections *Solid-Phase Geochemistry*, *Geochemical Data and Modeling*, and *Geochemical Reactions and Mineral Trapping* below). There may be local variations in depositional fabrics, but there is high confidence in the bulk mineralogy (lithology) of the injection zone and overlying zones in the AoR.

Solid-Phase Geochemistry

The Potosi Dolomite injection zone (including the lower Oneota) 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 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 confining unit 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.

<u>Geochemical Data and Modeling</u>

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 (Yoksoulian et al., 2014).

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 (Yoksoulian et al., 2014). Based on this information, the integrity of the Maquoketa Group 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 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. The proposed injection zone is primarily within the Potosi Dolomite and includes a porous and permeable zone in the bottom 95 feet of the overlying Oneota Dolomite. Data collected at the Wabash #1 well indicate the injection zone is 784 ft thick at the Wabash #1 well site (*Figure 4*) and occurs at 4,378 ft MD in the Wabash #1 well. The areal extent of the Potosi Dolomite 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 and confining unit 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 overlying layers. Regional mapping and 2D seismic information indicate that the identified confining unit 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 characteristics that may inhibit the vertical movement of CO2 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 the 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 and Spycher 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	4.92
Emergency and Remedial Response	9.37
Total	15.18

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 10 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	$3,873,512

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 suggest 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 13 3/8" 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.

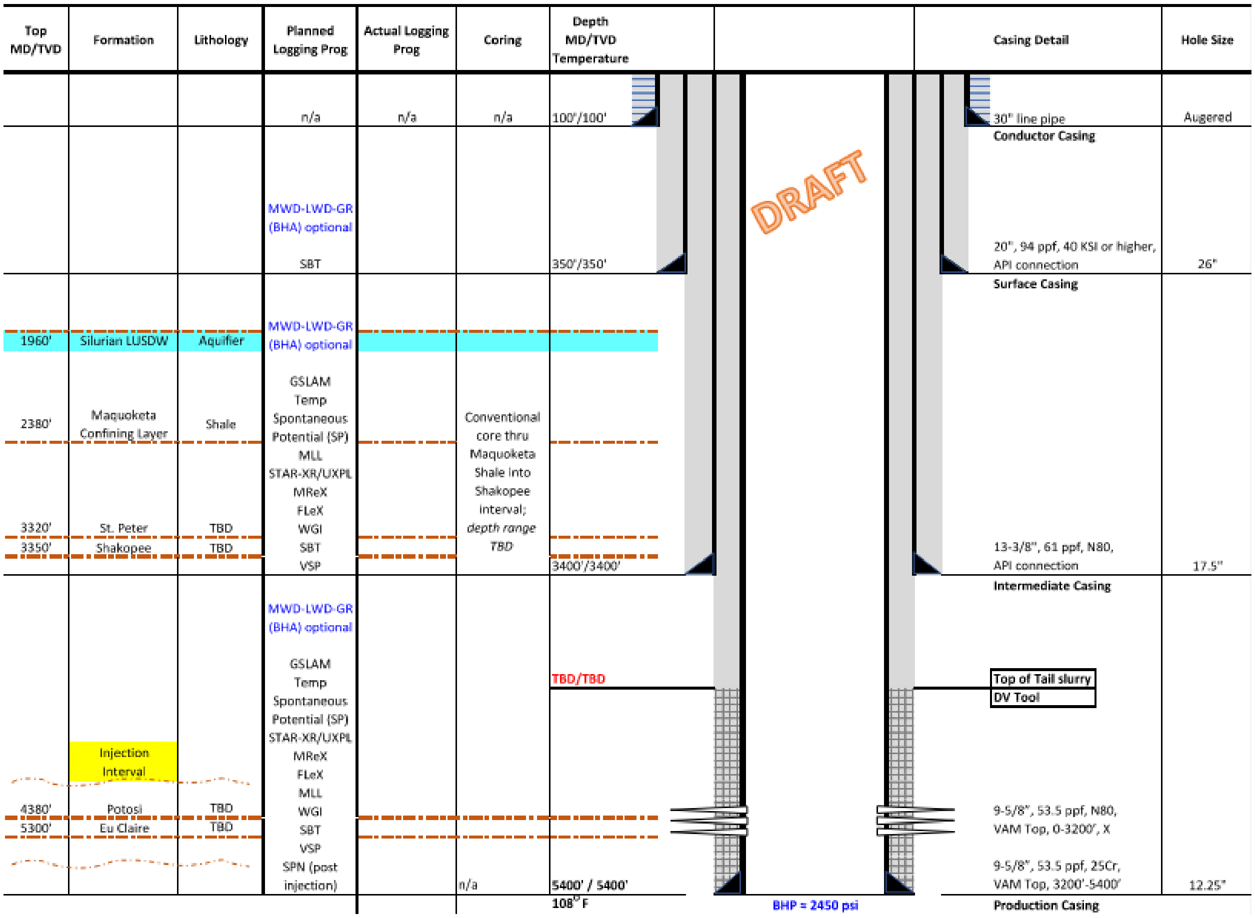

Figure 53 WVCCS #1 and #2 Casing Details

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 (25% Cr or other appropriate metallurgy) for the long string from ~3,200 Ft MD (2,650 TVDss) to ~5,400 Ft MD (4,950 TVDss) (TD). The interface from API Carbon Steel to 25 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	Augured	1.094	30	H40, Welded Coupling
Surface	0-350	26	0.438	20	94 #/ft, J55, API coupling
Intermediate	0-~3,400	17 1/2	0.430	13 3/8	61 #/ft, N80, API connection
Long String (API Carbon Steel)	0-~3,200	12 1/4	0.545	9 5/8	53.5 #/ft, N80, API connection
Long String (Chrome)	~3,200-~5,400	12 1/4	0.545	9 5/8	53.5 #/ft, L-80, 25Chrome Alloy, Special Coupling. A corrosion-resistant alloy such as 25Cr (25 % chromium) with 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	94	32,900	2110	520	1,480,000	783,000
Intermediate	61	207,400	4500	1670	1,399,000	1,169,00
Long String (Carbon)	53.5	288900	7930	6620	1,244,000	1,329,000
Long String (Chrome)	53.5		12,390	8440	1,250,000	1,943,000

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 9-5/8" 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.

- 30" casing inside augured hole cemented to surface with excess. Topped out if full returns are not obtained.
- 20" casing inside 26" hole cemented to surface. Cement top and quality to be determined by USIT (Ultrasonic Imaging Tool) or CBL (Cement Bond Log)
- 13 3/8" casing inside 17 1/2" hole to be cemented to surface. Cement top and quality to be determined by USIT or CBL
- 9 5/8" casing inside 12 1/4" hole to be cemented to surface. Cement top and quality to be determined by USIT or CBL
- 5 ½" tubing and 9 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 +	12	414	120.7	123.2	102
Long Tail	EverCRETE or similar		12.77	440	89.4	123.2	102

		antisettling (tail)					

Tubing and Packer

Table 18 Tubing and packer details.

Material	**Setting Depth**	**Tensile Strength**	**Burst Strength/Internal Yield (psi)**	**Collapse Strength (psi)**	**Material**
Tubing 5.5" 20#/ft Chrome Alloy (EUE – external upset end)	0 - ~5,322	Special	9190	8830	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, Shakopee, and Maquoketa Group formations during the construction of WVCCS1 and sidewall core used to characterize secondary zones of interest. The core collected from WVCCS1 will be compared to the core samples collected from the Wabash1 test well. The WVCCS2 will only collect rotary sidewall core over the lowermost interval as allowed by hole size as additional whole core is not warranted given its proximity to core collection sites in the adjacent well. In the intermediate whole, technical limitations due to the large borehole size prevent sidewall core collection; however, petrophysical and lithological comparisons will be made using the full suite of well logs planned for this well.

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 Feet H_2O = 1 PSIG

H_2O = 1000 Kg/M^3

Supercritical CO2 = 712 Kg/M^3

712/1000 = 0.712 percent of H_2O Density

2.3/0.712= 3.2 Feet CO_2 per PSIG

4300 ft / 3.2 Feet CO_2 per psig = 1343 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 southeast. 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 CO_2 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 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.

Testing and Monitoring GSDT Submissions
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]***

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.

Injection Well Plugging GSDT Submissions
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)]***

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 10 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)]***