Attachment 1: Class VI Permit Application Narrative
40 CFR 146.82(A)
Vervain Project, McLean County, Illinois
24 March 2023

Navigator CO_2

Project Information

Project Name:	Vervain
Project Operator:	Heartland Greenway Carbon Storage, LLC
Project Contact:	Tyler Durham, SVP and Chief Development Officer 13333 California St., Suite 202, Omaha, NE 68154 Phone: 402-520-7089 Email: tdurham@navco2.com
Project Location:	McLean, McLean County, IL

Confidential Business Information

Several figures contained within this document (Narrative without CBI) contain Confidential Business Information (CBI) that is privileged and is exempt from public disclosure.

These attachments and images will be delivered to the EPA in a separate document (Narrative with CBI). The below listed attachment, figures, and table contain Confidential Business Information that are redacted from the public disclosure version of this document:

CBI Attachments, Tables, and Figures

CBI: Attachment 03: Financial Assurance, 2023
Table 5: CBI: Summary of average Young's Modulus, Poisson's Ratio, and Bulk Compressibility values calculated from ADM CCS1 well logs.
Figure 21: CBI: West – East 2D seismic line 303**.**
Figure 22: CBI: North – South 2D seismic line 304
Figure 28: CBI: Effective porosity and permeability cross plots.
Figure 29: CBI: Effective porosity histograms of the key petrophysical wells.
Figure 30: CBI: Permeability histograms of the key petrophysical wells.
Figure 31: CBI: ADM CCS1 geophysical logs and petrophysical results.
Figure 32: CBI: T.R. McMillen #2 geophysical logs and core analyses.

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List of Acronyms

2D	two-dimensional
3D	three-dimensional
ACZ	Above Confining Zone
ADM	Archer Daniels Midland Company
AoR	Area of Review
BHFP	bottomhole flowing pressure
CARB	California Air Resources Board
CCS	Carbon Capture and Sequestration
CO_2	carbon dioxide
CWA	Clean Water Act
DENS	density
DNR	Department of Natural Resources
DOW	Division of Water
DPHI	Density Porosity Log
DST	Drill Stem Test
EPA	Environmental Protection Agency
ERRP	Emergency and Remedial Response Plan
FEMA	Federal Emergency Management Agency
fbsl	feet below sea level
GSDT	Geologic Sequestration Data Tool
GR	Gamma Ray
h	thickness
HGCS	Heartland Greenway Carbon Storage, LLC
IBDP	Illinois Basin–Decatur Project
IDNR	Illinois Division of Natural Resources
IEMA	Illinois Emergency Management Agency
IL-ICCS	Illinois Industrial Carbon Capture and Storage Project
ILD	Induction Log Deep
ILM	Induction Log Medium
ISGS	Illinois State Geological Survey
JV	Joint Venture
k	permeability
kt	metric kilotons
LAS	Log Ascii Standard
lbs	pounds
LCZ	Lost Circulation Zone
Ma	mega annum
mD	millidarcy
MICP	mercury injection capillary pressure
MMscf	million standard cubic feet
MNSM	Mt. Simon Sandstone Formation
MSL	Mean Sea Level
Mtpa	million tonnes per annum
NA	not applicable
NCV	Navigator CO_2 Ventures

NESHAPS	National Emission Standards for Hazardous Pollutants
NPHI	Neutron Porosity Log
NV_ACZ1	Vervain Above Confining Zone Monitoring Well #1
NV_ACZ2	Vervain Above Confining Zone Monitoring Well #2
NV_INJ1	Vervain Injection Well #1
NV_INJ2	Vervain Injection Well #2
NV_MA1	Mahomet Aquifer Monitoring Well #1
NV_MA2	Mahomet Aquifer Monitoring Well #2
NV_OBS1	Vervain Deep Observation Well
O&G	oil and gas
PE	photoelectric log
PISC	Post Injection Site Care
PPMV	parts per million by volume
PSD	Prevention of Significant Deterioration
RA	risk assessment
RCRA	Resource Conservation and Recovery Act
RESD	deep resistivity
RESM	medium resistivity
RMP	Risk Management Plan
SDWA	Safe Drinking Water Act
TBD	to be determined
TCS	Total Closure Stress
TD	total depth
TDS	total dissolved solids
UIC	Underground Injection Control
US	United States
USGS	United States Geological Survey
USDW	Underground Source of Drinking Water

Change Log

Item Changed	Date	Version	Description
Pg 94 Sec 7.2	3/24/2023	V1.1	Added a description of the sources of the CO2 stream

1. Project Background and Contact Information [40 CFR 146.82(a)(1)]

1.1 Project Contact Information

Project Name: Vervain

Project Operator: Heartland Greenway Carbon Storage, LLC

Project Contact: Tyler Durham, SVP and Chief Development Officer
13333 California St., Suite 202, Omaha, NE 68154
Phone: 402-520-7089
Email: tdurham@navco2.com

Project Location: McLean, McLean County, IL

1.2 Project Background

The Vervain Project is part of the Heartland Greenway proposed carbon capture, utilization, and sequestration (CCUS) system. The system is planned to connect industrial customers in Illinois, Iowa, Minnesota, Nebraska, and South Dakota through a 1,300-mile pipeline network and permanently sequester up to 15 million tonnes per annum (Mtpa) of carbon dioxide (CO_2) into sequestration sites in central Illinois. The Heartland Greenway system is proposed by Navigator CO_2 Ventures (NCV) and will be operated by Heartland Greenway Carbon Storage, LLC (HGCS), a subsidiary of NCV. Operations will be phased with an expected start date in early 2025.

The Vervain Project is one of several sites in Central Illinois that is being developed by NCV for long-term sequestration into the Mt. Simon Sandstone. The project seeks to transport 2.5 Mtpa to a location in the southwest corner of McLean County, Illinois. Well construction is expected to commence in Q1 2024. Injection will commence following completion and approval of all UIC Class VI permit requirements.

HGCS will be the owner, operator, and permit holder for the two injection wells, NV_INJ1 and NV_INJ2.

Neither an injection depth waiver nor aquifer exemption expansion is being requested for this project.

Within the Area of Review (AoR) there are no major surface water bodies, deep stratigraphic boreholes, State or EPA approved subsurface clean-up sites, mines, quarries, nor federally recognized Native American tribal lands or territories.

Figures 1 and 2 display the project location and the location of the two CO_2 injection wells, one deep observation well, two above zone monitoring wells, and two shallow groundwater monitoring wells. Table 1 provides the coordinates and depth for the primary wells associated with the Vervain Project.

Information on Oil and Gas (O&G) wells and water wells within the AoR can be found in Section 4.1 of the AoR and Corrective Action Plan (Attachment 2: AoR and Corrective Action Plan, 2023).

This document is one of the fourteen (14) attachments that are being submitted to the United States (US) Environmental Protection Agency (EPA) for approval for a Class VI well for the Project. Note that Attachment 03: Financial Insurance contains Confidential Business Information (CBI) that is privileged and is exempt from public disclosure. This Financial Assurance attachment will be delivered to the EPA separately from the other thirteen (13) attachments.

Full list of attachments:
(Attachment 01:Project Narrative, 2023)
(Attachment 02: AoR and Corrective Action Plan, 2023)
CBI: (Attachment 03: Financial Assurance, 2023)
(Attachment 04A: NV_INJ1 Well Construction Plan, 2023)
(Attachment 04B: NV_INJ2 Well Construction Plan, 2023)
(Attachment 05: Pre-Op Testing Program, 2023)
(Attachment 06A: NV_INJ1 Well Operations Plan, 2023)
(Attachment 06B: NV_INJ2 Well Operations Plan, 2023)
(Attachment 07: Testing And Monitoring Plan, 2023)
(Attachment 08A: NV_INJ1 Well Plugging Plan, 2023)
(Attachment 08B: NV_INJ2 Well Plugging Plan, 2023)
(Attachment 09: PISC and SC, 2023)
(Attachment 10: ERRP, 2023)
(Attachment 11: QASP, 2023)
-End-

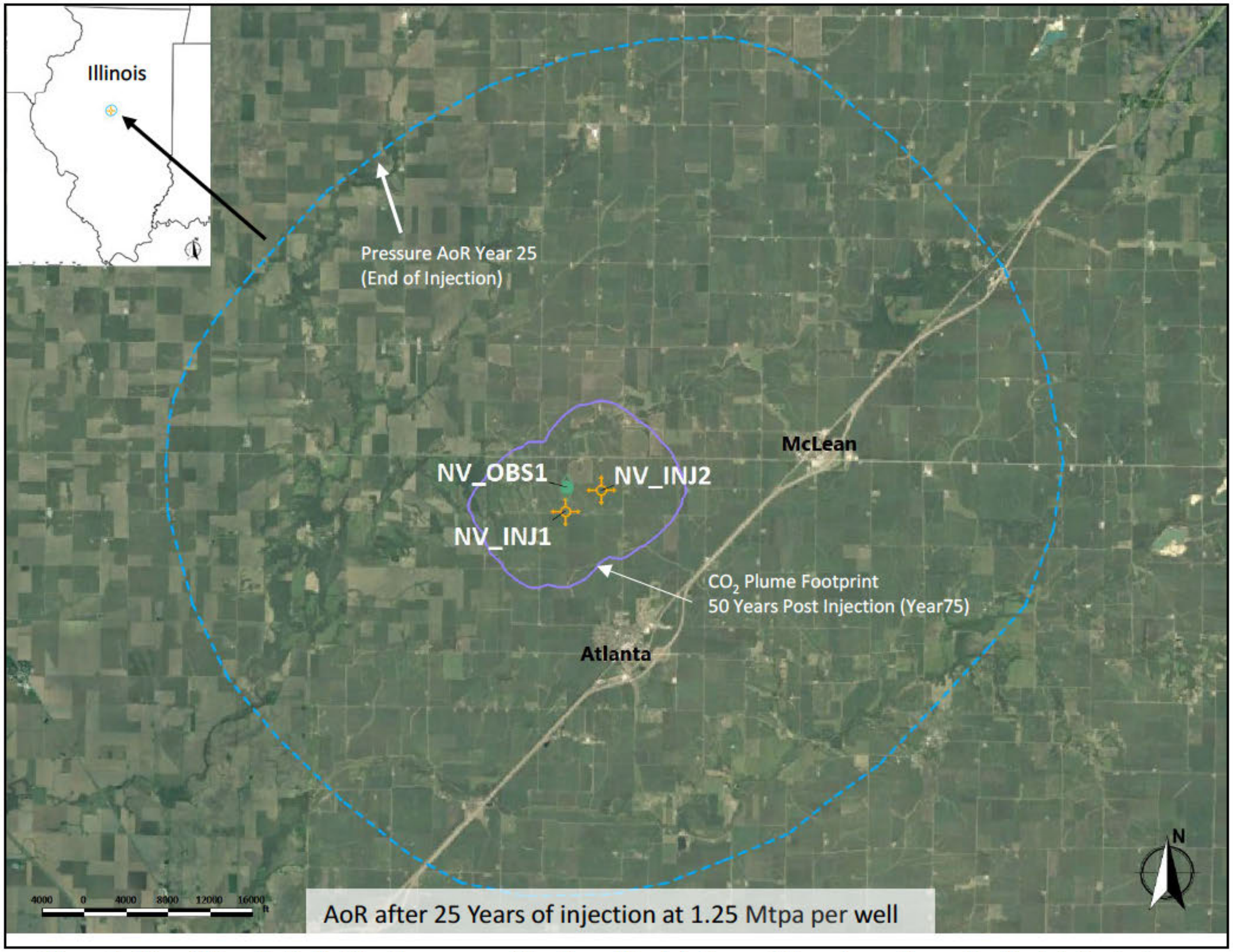

Figure 1: Map of Vervain Project location, proposed location of the injection and deep observation wells, simulated extent of the CO_2 plume 50 years post injection, and the pressure based AoR.

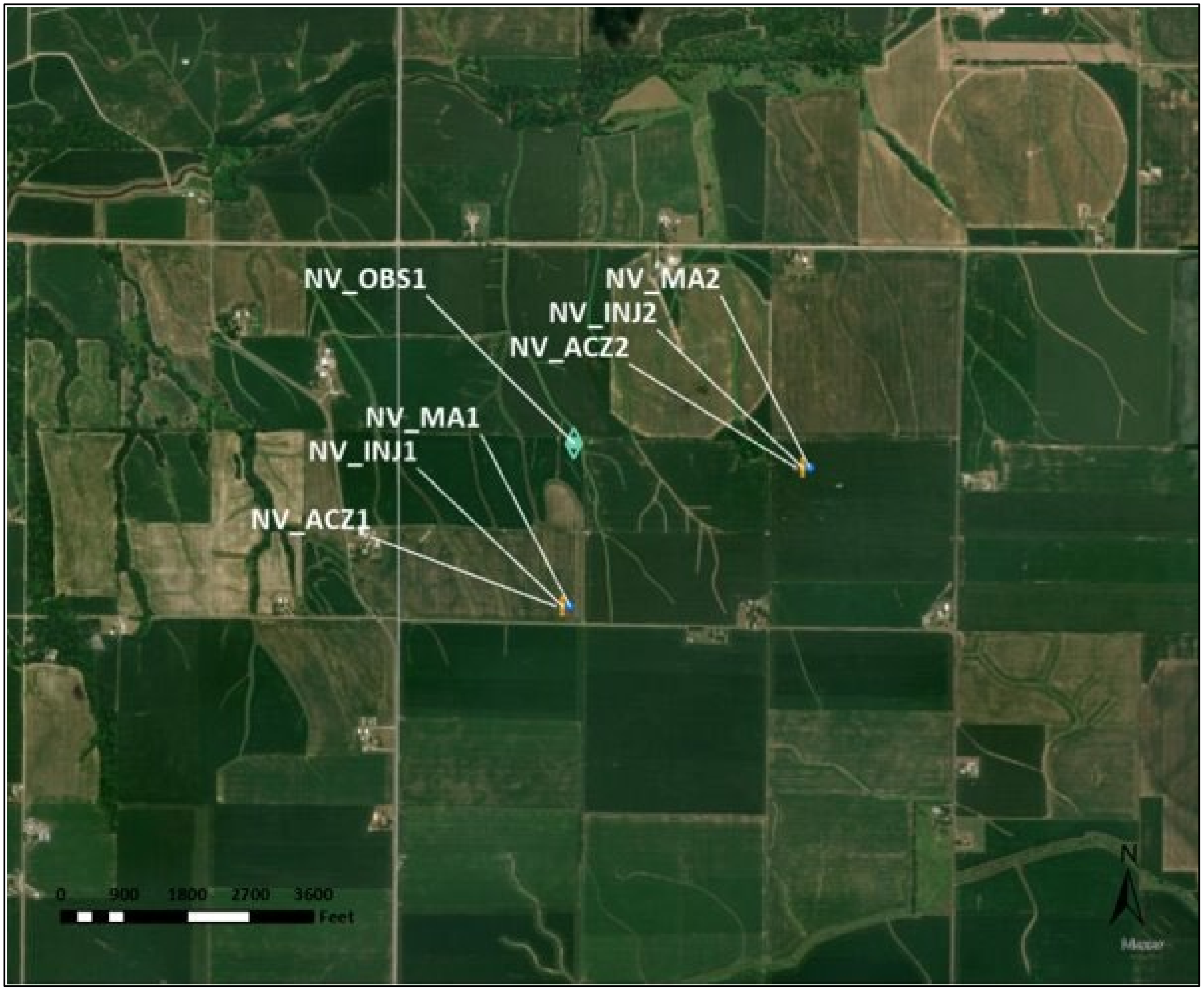

Figure 2: Proposed locations of injector (NV_INJ1, NV_INJ2), deep observation (NV_OBS1), above confining zone monitoring (NV_ACZ1, NV_ACZ2), and Mahomet Aquifer monitoring (NV_MA1, NV_MA2) wells.

Table 1: Proposed Vervain Project wells

Well Long Name	Well Name	Sensitive, Confidential, or Privileged Information [redacted]	Purpose
Injection Well 1	NV_INJ1	[redacted]	CO_2 Injector
Injection Well 2	NV_INJ2	[redacted]	CO_2 Injector
Deep Observation Well 1	NV_OBS1	[redacted]	Injection Zone Observation Between the Injector Wells
Above Confining Zone Monitoring Well 1	NV_ACZ1	[redacted]	Above Confining Zone Monitor Near NV_INJ1
Above Confining Zone Monitoring Well 2	NV_ACZ2	[redacted]	Above Confining Zone Monitor Near NV_INJ2
Mahomet Aquifer Monitoring Well 1	NV_MA1	[redacted]	Mahomet Aquifer Monitor near NV_INJ1
Mahomet Aquifer Monitoring Well 2	NV_MA2	[redacted]	Mahomet Aquifer Monitor near NV_INJ2

1.3 Local, State, and Federal Emergency Contacts [40 CFR 146.82(a)(20)]

Table 2: Local, State, and Federal Emergency Contacts

Agency	Phone Number
McLean County Sheriff's Office	(309) 888-5034
Mt. Hope-Funks Grove FPD, McLean, IL (Fire & EMS)	(309) 874-2532
McLean Police Department, McLean, IL	(309)-874-2731
Illinois State Police District 6	(815) 844-1500
McLean County Emergency Management Agency (EMA)	(309) 888-5020
Illinois Emergency Management Agency (IEMA)	(217) 782-2700 (217) 782-7860 (24-hour Response)
Federal Emergency Management Agency (FEMA)	(800) 621-3362 (FEMA Helpline) (312) 408-5500 (FEMA Region 5 General)
Environmental Services Contractors : EnviroServe GFL Environmental UMO Peoria	(800) 488-0910 (EnviroServe 24/7 Emergency Response) (309) 637-6243 (GFL)
US Environmental Protection Agency (EPA) Region 5 Underground Injection Control (UIC), UIC Supervisor Class VI Wells/Carbon Sequestration/Climate Change	(312) 353-7648 (UIC Supervisor) (312) 353-3944 (Class VI Wells/Carbon Sequestration)
EPA National Response Center (24 hours)	(800)- 424-8802
Illinois Department of Natural Resources (DNR) Oil & Gas Resource Management	(217) 782-6302

1.4 Summary of Other Permits Required

Table 3 provides a summary of permits required for the Vervain Project.

Table 3: Permits Required for the Vervain Project

Agency	Program	Permit(s) Required	Regulation Reference	Note
U.S. Environmental Protection Agency (US EPA), Resource Conservation and Recovery Act (RCRA)	Hazardous Waste Management program under RCRA	Not Required	40 CFR 144.31 (e)(1) 40 CFR 144.31 (e)(6)(i)	NA, non-hazardous waste.
U.S. Environmental Protection Agency (US EPA), Safe Drinking Water Act (SDWA)	UIC program under SDWA	Class VI Underground Injection Permit	40 CFR 144.31 (c) 40 CFR 144.31 (e)(1) 40 CFR 144.31 (e)(6)(II)	Applied for. No injection depth waiver or aquifer exemption expansion needed for project.
National Pollutant Discharge Elimination System (NPDES)	NPDES program under CWA	Stormwater Pollution Prevention Plan (SWPPP) or Stormwater Management Plan (SWMP)	40 CFR 144.31 (e)(1) 40 CFR 144.31 (e)(6)(iii)	Will apply for prior to construction.
Prevention of Significant Deterioration (PSD) Clean Air Act (CAA)	PSD program under CAA	Not Required	40 CFR 144.31 (e)(1) 40 CFR 144.31 (e)(6)(iv)	NA, not a major source.
U.S. Environmental Protection Agency (US EPA) Clean Air Act (CAA)	Nonattainment program under CAA	Not Required	40 CFR 144.31 (e)(6)(v)	NA, McLean County, IL is in attainment for all criteria pollutants.
National Emission Standards for Hazardous Air Pollutants (NESHAPS) Clean Air Act (CAA)	NESHAPS preconstruction approval under the CAA	Not Required	40 CFR 144.31 (e)(6)(vi)	NA, non-hazardous.
Marine Protection Research and Sanctuaries Act	Ocean dumping permits under Marine Protection Research and Sanctuaries Act	Not Required	40 CFR 144.31 (e)(6)(vii)	NA, onshore project.
Army Corp. of Engineers	Section 404 of CWA	Not Required	40 CFR 144.31 (e)(6)(viii)	NA. No disturbance to waters of US planned nor anticipated.
State or Other	**Other relevant environmental permits, including state permits**		**40 CFR 144.31 (e)(6)(ix)**	
Illinois Division of Natural Resources (IDNR)	Oil & Gas Resource Management	Drilling Permit	Illinois Oil and Gas Act (225 ILCS 725)	Will apply for prior to drilling monitor well(s)

2. Site Characterization [49 CFR 126.82(a)(2), (3), (5) and (6)]

Unless otherwise stated, all depths are in reference to feet below ground surface.

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

The Vervain Project, located in McLean County of central Illinois, is within the intracratonic Illinois Basin that extends beneath much of Illinois, western Indiana, and western Kentucky (Figure 3). The Illinois Basin is comprised of Cambrian to Permian strata that reach a maximum thickness of nearly 23,000 feet in its southern portion (Collinson et al., 1988). The Illinois Basin has been the focus of extensive research into geological carbon sequestration for over two decades through the Midwest Regional Carbon Sequestration Partnership (MRCSP 2005, 2011; Greenberg 2021) and the US DOE sponsored CarbonSAFE program (Leetaru 2019; Whittaker and Carman 2022; Korose 2022; Whittaker 2022). In addition, the Illinois Industrial Carbon Capture and Storage Project (IL-ICCS) is an active carbon commercial sequestration project taking place at the Archer Daniels Midland ethanol facility at Decatur, IL, approximately 35 miles southeast of the proposed location for the Vervain Project (Figure 3). The IL-ICCS project storage complex uses the Cambrian Mt. Simon Sandstone as the sequestration reservoir and the overlying Eau Claire Formation as the confining zone (Gollakota and McDonald, 2014; Figure 4). The Vervain Project proposes to use the same formations for the storage complex.

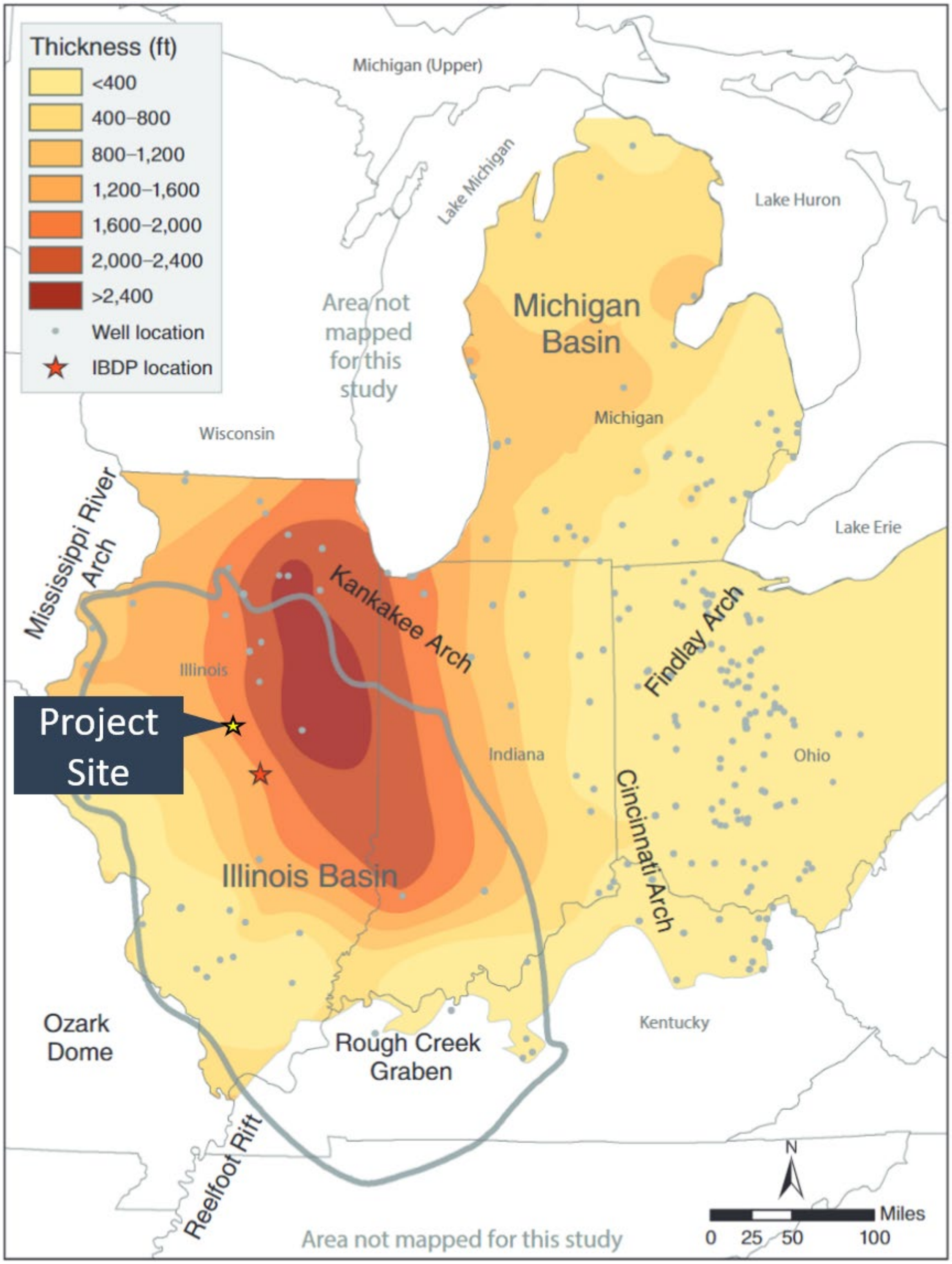

Figure 3: Mt. Simon Sandstone isopach map (feet) with the Illinois Basin extent, major structural features, and the Vervain Project Site shown by yellow star. The location of the Illinois Basin – Decatur Project and Illinois Industrial CCS project are shown by the red star. Modified from Medina and Rupp (2012).

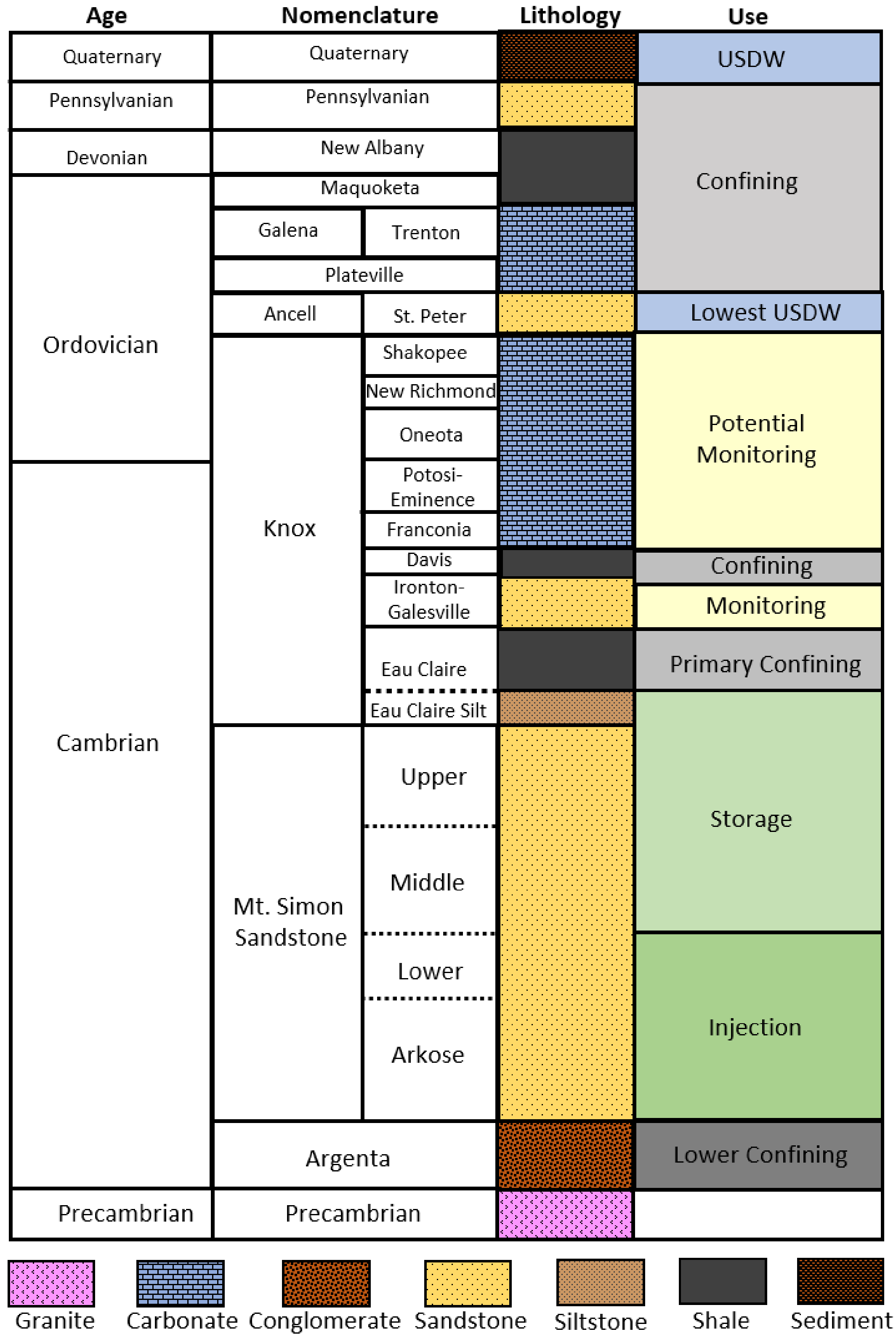

Figure 4: Site-specific Illinois Basin stratigraphic column with age, nomenclature, generalized lithology, and zone of use.

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Figure 5: West to east regional cross section A-A' through the project site (see inset map). MNSM=Mt. Simon; Prog=prognosed depths.

The Illinois Basin began to form during the late Precambrian to early Cambrian during the breakup of the supercontinent Rodinia (Braile et al., 1986; Kolata and Nelson 1991; 1997; 2010). The basin is bounded to the northwest by the Mississippi River Arch, to the north - northeast by the Kankakee Arch and to the east by the Cincinnati Arch (Figure 3). The Reelfoot Rift and Rough Creek Graben are significant features within the southern portion of the basin related to processes linked to basin subsidence, and where the thickest accumulation of sediments exist in the basin (Kolata, 2010). It is noteworthy, however, that the depocenter for Cambrian sediments was more northerly as shown by the greatest thickness of the Mt. Simon Sandstone in Figure 3. Paleozoic sedimentary strata of the basin unconformably overlie the Precambrian basement, which is broadly composed of felsic intrusives and volcanics of the Eastern Granite-Rhyolite Province (Figure 5; Bradbury and Atherton, 1965; Bickford et al., 1986; Atekwana, 1996; Lidiak, 1996; Green, 2018).

The Cambrian Mt. Simon Sandstone and Eau Claire Formation are among the oldest and deepest strata in the basin (Figure 4 and Figure 5) and will serve as the injection/sequestration and confining zones, respectively, for the Vervain Project. The clastic sediments of the Mt. Simon Sandstone are interpreted to have been deposited in the failed rift basin that ultimately provided up to 2,600 feet of accommodation space for Mt. Simon sediments to accumulate (Figure 3). The Mt. Simon Sandstone is underlain by the Argenta Formation that is variably present in the basin and that was, until recently, considered part of the Mt. Simon Sandstone. An erosional unconformity exists between the Argenta Formation / Mt. Simon Sandstone and the underlying Precambrian basement.

By late Cambrian, the tectonic regime evolved from a rift to a broad embayment, and the Illinois Basin was a slowly subsiding cratonic basin for the remainder of the Paleozoic (McBride and Kolata, 1999). Eustatic sea level fluctuations coupled with tectonics allowed for the accumulation of both marine and terrestrial sediments in the basin. Uplift during the Pennsylvanian to Late Cretaceous isolated the basin and created the present geometry (Figure 3; Kolata and Nelson 1991, 1997; McBride and Kolata 1999).

Much of the Illinois Basin was covered by a sea during by the early Ordovician; this was followed by a marine regression that exposed newly deposited marine sediments to erosion and created the Middle Ordovician Knox Group unconformity. A series of transgressions and regressions and periods of both uplift and subsidence dominated the remainder of Ordovician time (Freeman, 1953).

By early to mid-Silurian time, central Illinois was close to wave-base and the surrounding sedimentary basins to the west, north, and east received large quantities of sediment (Janssens, 1968). Sea-level regressed and uplift occurred during the Devonian, causing extensive erosion. A sea level transgression during the Devonian-Mississippian deposited marine shales across the region including the regionally extensive New Albany Shale (Mikulic et al., 2010) that forms a barrier to vertical fluid movement.

Subsidence and uplift continued to the end of the Paleozoic Era, and erosion and/or nondeposition prevailed throughout the Mesozoic and Cenozoic. During the Pleistocene Epoch, the region was covered by continental ice sheets that deposited hundreds of feet of glacial sediment in the region, some of which now serve as shallow groundwater aquifers.

2.2 Regional Stratigraphy

The stratigraphic chart shown in Figure 4 is specific for the central Illinois Basin and will be referred to throughout this narrative. The regional continuity of the Paleozoic strata in the vicinity of the project site [40 CFR 146.82(a)(3)(i)] is demonstrated through cross-sections of the site model (Figure 5) and geophysical logs of regional wells (Figure 7). Quaternary glacial sediments overlie the bedrock (Figure 4) and are discussed in *Section 2.7 Hydrologic and Hydrogeologic Information*.

To develop a comprehensive understanding of the site-specific geology for this project, a database of publicly available geophysical well logs from Illinois, Indiana, Kentucky and Ohio was compiled. The well logs were interpreted and used to develop a static geomodel for the project site. Within 50 miles of the Vervain Project Site, seven wells penetrate the Precambrian Basement and over 100 wells penetrate the Upper Mt. Simon Sandstone, all of which were used to assess the site-specific geology. Additional wells penetrate the Mt. Simon Sandstone outside of the 50-mile radius (Figure 6). The closest wells that penetrate into the Mt. Simon Sandstone and have well log data are located within the Hudson gas storage field, approximately 22 miles northeast of the project site (Figure 6). This field, along with the Lake Bloomington, Lexington, and Manlove gas storage fields, utilize the Upper Mt. Simon Sandstone as a gas storage reservoir. Most wells do not penetrate to the Lower Mt. Simon Sandstone. Most of the wells in these fields were drilled in the 1970s and remain active. The closest well that penetrates through the entire Mt. Simon Sandstone into the Precambrian basement is 35 miles southeast of the project site at the Archer Daniels Midland (ADM) site in Decatur, IL.

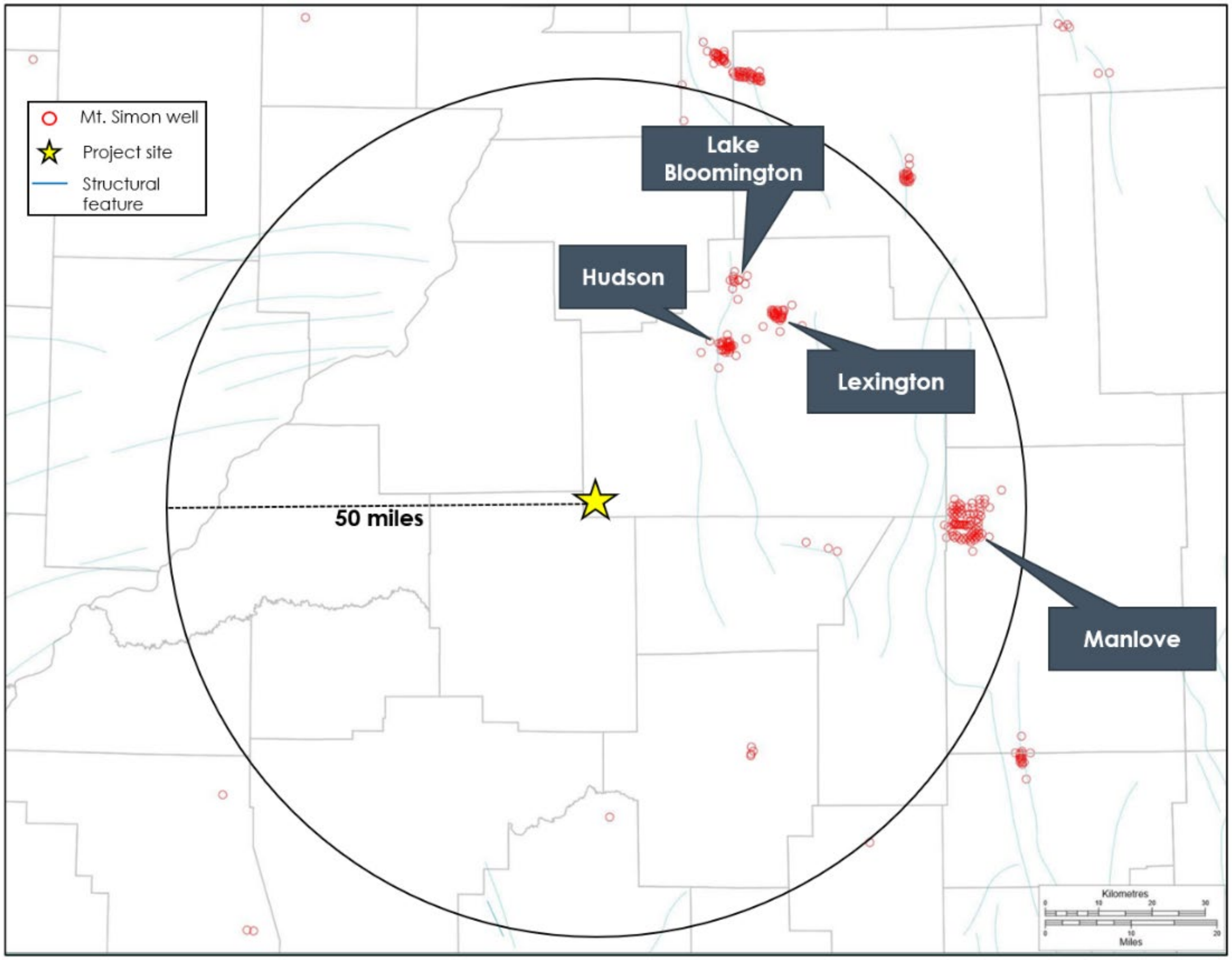

Figure 6: Map depicting Mt. Simon Sandstone wells (red circles) within a 50-mile radius (black circle) of the project site (yellow star). The Hudson, Lake Bloomington, Lexington, and Manlove gas storage fields are also highlighted.

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Figure 7: Regional cross section B-B' demonstrates the regional continuity of the Eau Claire Formation, Mt. Simon Sandstone, Mt. Simon Arkose, and Argenta Formation. Gamma Ray Logs (GR_norm) are color-filled, deep resistivity (RESD) is red, medium resistivity (RESM) is black, and density (DENS) is orange. Well locations are shown on the inset map. Project location shown as well as yellow star. The cross section is flattened on the Eau Claire Formation top.

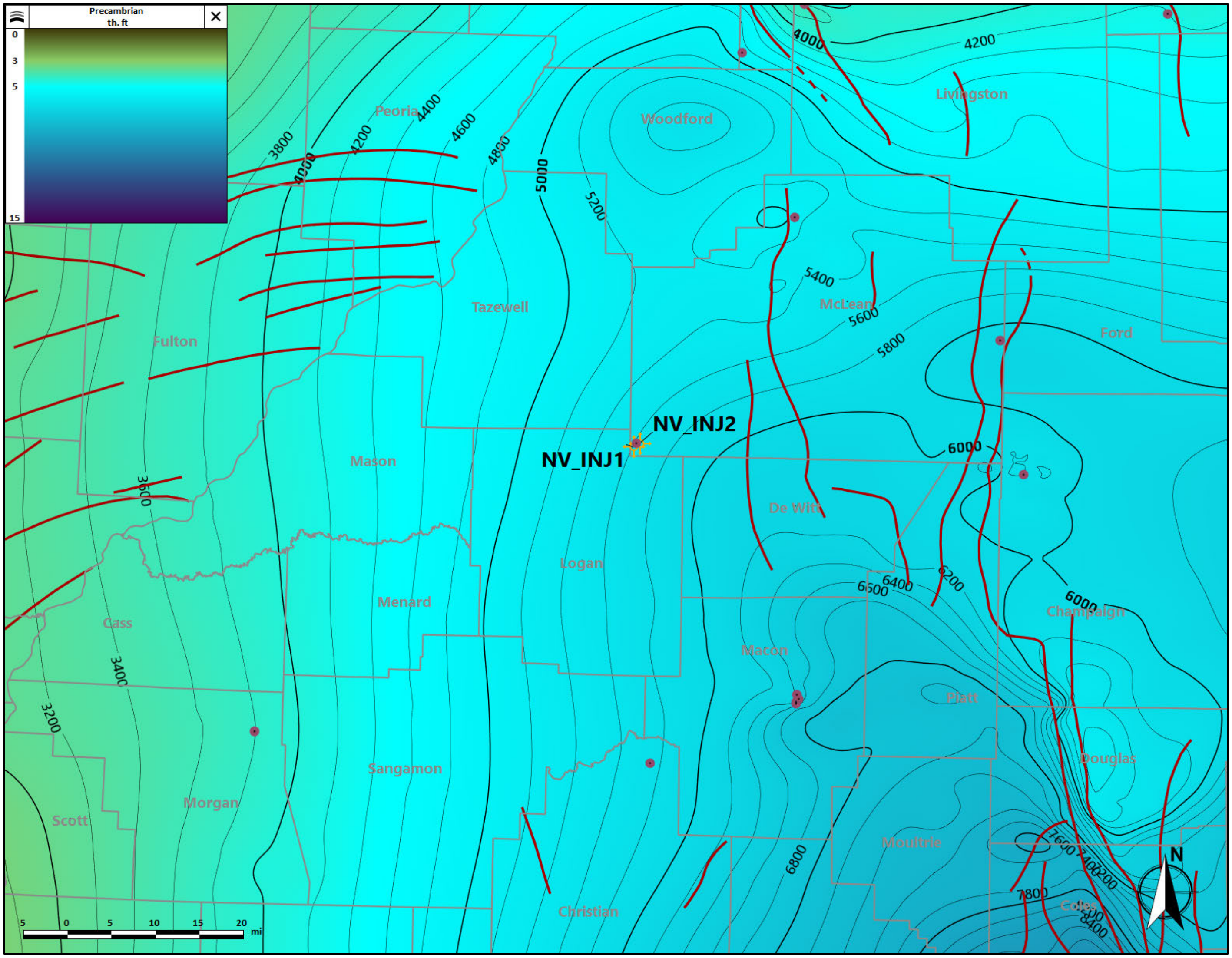

Figure 8: Elevation map in feet below sea level (fbsl) of the Precambrian Basement with structural features shown in red (Nelson, 1995). Red dots indicate wells that penetrate the Precambrian Basement top. The injector wells (NV_INJ1 and NV_INJ2) are shown.

2.2.1 Precambrian Basement Complex

The project site overlies granite, rhyolite, trachyte, and quartzite of the Eastern Granite-Rhyolite Province of the Precambrian basement (Denison et al., 1984). These basement rocks are of extensional tectonic origin and contribute to the source of Early Cambrian siliciclastic strata in the Illinois Basin (Bickford et al., 1986). Figure 8 shows the Precambrian Basement deepens from approximately 3,200 feet below sea level (fbsl) in the west and northwest of the map area to more than 7,200 fbsl in the southeast where basin structure becomes more complex.

2.3 Argenta Formation/Lower Confining Zone (Cambrian)

The Precambrian surface represents a 900-million-year depositional hiatus before Cambrian sediments of the Argenta Formation were deposited forming an unconformable contact. The Argenta strata are of variable thickness (e.g., Figure 7), in part due to Precambrian topography, and locally the Argenta Formation onlaps against the Precambrian Basement as observed in Figure 5. The Argenta Formation is also in unconformable contact with the overlying Mt. Simon Sandstone (Leetaru, 2015). Until recently, the Argenta was considered to be part of the Lower Mt. Simon Sandstone but work by the Illinois State Geological Survey (Freiburg, 2015) suggests it is a pre-Mt. Simon sedimentary unit. The Argenta Formation is composed of shallow-marine, shoreface to fan-delta sandstone and conglomerate with some interbedded mudstone. Conglomerates are dominantly clast supported and exhibit inverse and normal graded bedding, as well as planar and cross-beds. Bioturbation is abundant in some sandstone intervals, suggesting a Lower to Middle Cambrian age for this formation, and it was likely deposited during a marine transgression associated with thermal subsidence (Freiburg, 2015).

The elevation map of the Argenta is shown in Figure 9 and the thickness map in Figure 10. The Argenta Formation is generally not present due to non-deposition in the western part of the mapped area beyond the limits of the Vervain Project.

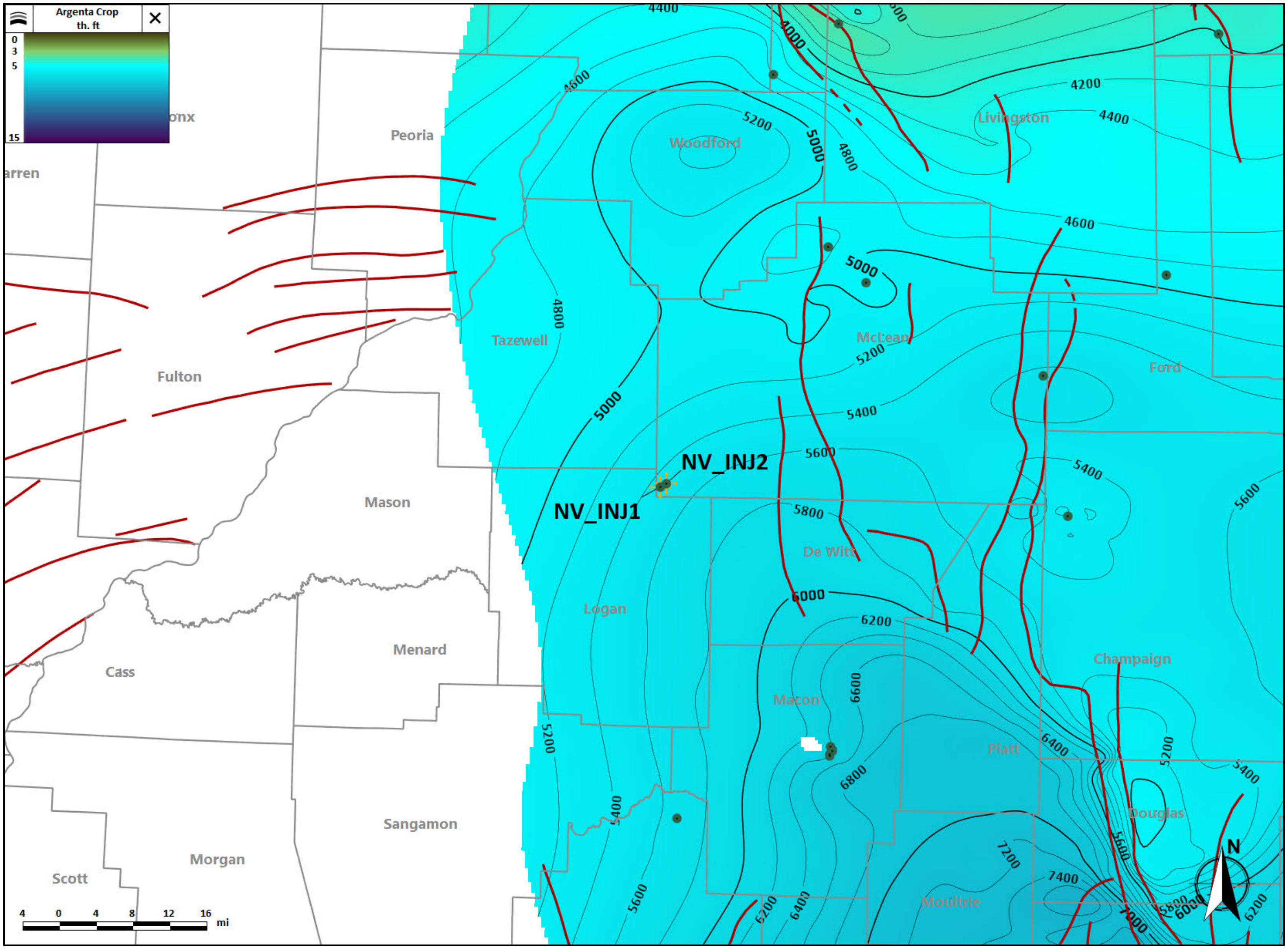

Figure 9: Elevation map (fbsl) of the Argenta Formation. Structural features are in red (Nelson, 1995). Black circles are wells that penetrate the Argenta Formation top.

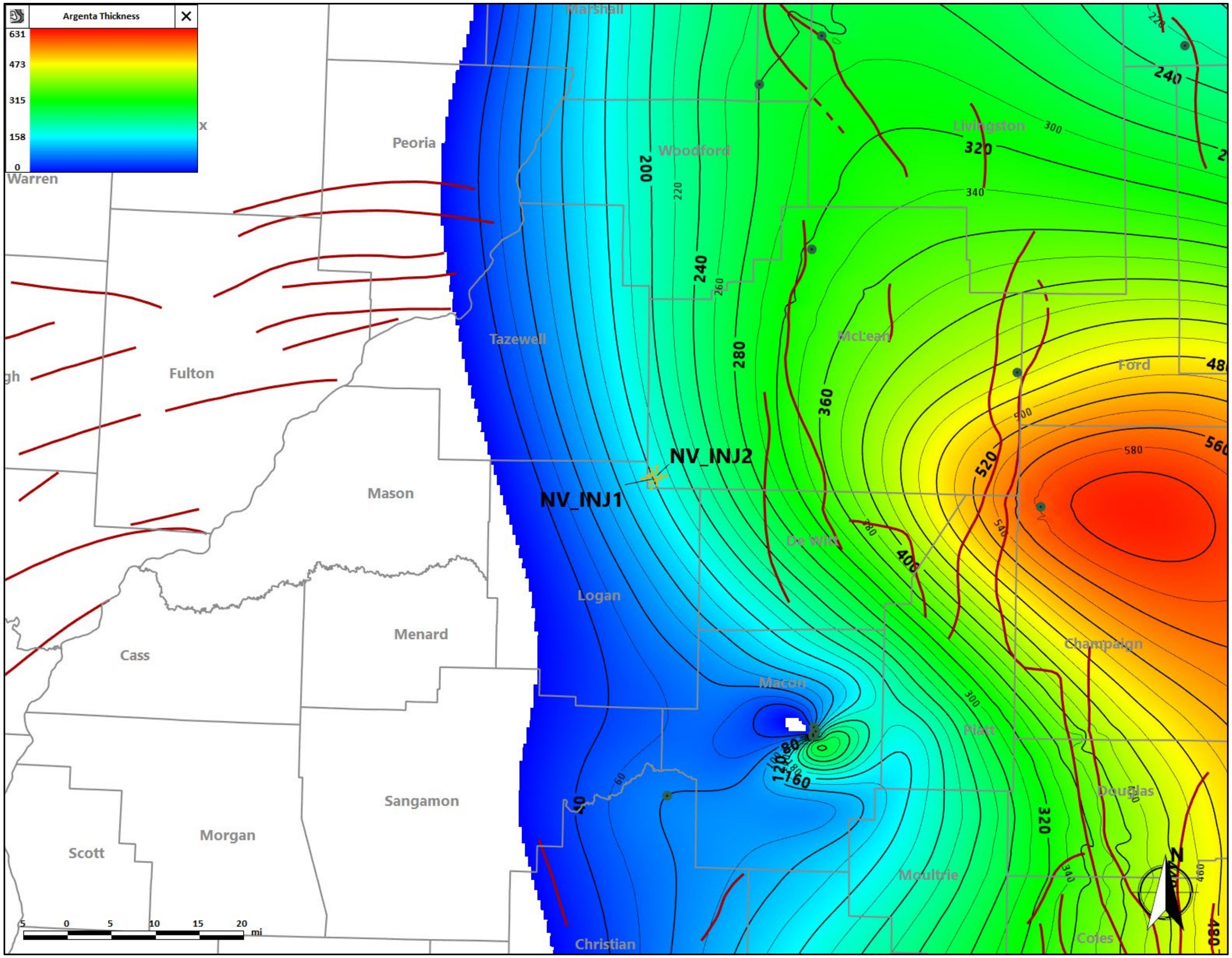

Figure 10: Thickness map of the Argenta Formation in feet with structural features in red (Nelson, 1995). Black circles are wells that penetrate the Argenta Formation top.

2.4 Mt. Simon Sandstone/Injection and Sequestration Zone (Cambrian)

The Cambro-Ordovician Sauk sequence unconformably overlies the Argenta Formation and includes the Mt. Simon Sandstone, the Eau Claire Formation, and the Knox Group (Figure 4, Figure 5, and Figure 7). Specific to this project, the Mt. Simon Sandstone is being considered for the injection and sequestration zone, and the Eau Claire Formation as the confining zone.

The Mt. Simon Sandstone is a transgressive terrestrial to shallow marine sequence that is a laterally extensive deposit in the Illinois Basin and throughout the Midwest (Kolata and Nelson, 1990). It is thickest in northeastern and east-central Illinois (Figure 3; Leetaru and McBride 2009). Mt. Simon sedimentology was impacted by a wide range of depositional environments including shallow marine, deltaic, fluvial, eolian, and coastal (Janssens, 1973; Saeed, 2002; Baranoski, 2007, Freiberg et al., 2016). Fine to coarse-grained, poorly sorted, arkosic and quartz sandstone primarily compose the Mt. Simon Sandstone. Typically, the Mt. Simon Sandstone is subdivided into Lower, Middle, and Upper intervals, with the Lower Mt. Simon Sandstone containing a basal arkosic zone. In this report, the arkosic zone will be referred to as the Mt. Simon Arkose and will be differentiated from the overlying Lower Mt. Simon Sandstone (Figure 4).

The Mt. Simon Sandstone has been the focus of considerable research into carbon sequestration in the Illinois Basin through a number of US DOE funded projects including the Regional Carbon Sequestration Partnerships (e.g., Greenberg 2021) and the CarbonSAFE program (e.g., Leetaru, 2019; Korose, 2022; Whittaker and Carman, 2022). It has also been demonstrated as an effective sequestration formation through an active carbon sequestration project (IL-ICCS) at the Archer Daniels Midland facility in Decatur, IL (UIC Class VI Permit IL-115-6A-0001).

The Lower Mt. Simon Sandstone and Mt. Simon Arkose together are the target injection zone for the Vervain Project. These beds are dominantly medium- to fine-grained cross-bedded to ripple-laminated subarkose arenite (Freiberg et al., 2014). They also contain planar-bedded sandstone and conglomerate composed of subarkosic to arkosic arenite, arkosic wacke and mudstone. Grading upwards the Mt. Simon Sandstone contains mixed eolian and fluvial deposits to marine tidal deposits in its upper portions. Porosity in the Mt. Simon Arkose and to a lesser degree in the Lower Mt. Simon is largely a result of diagenesis including dissolution of feldspars and clay (illite) coating of grains that restrict formation of porosity occluding cements. The dominant diagenetic cement is quartz, and the presence of authigenic quartz is less in the Arkose and Lower Mt. Simon units than in the Middle and Upper intervals (Freiberg et al., 2016). The Upper Mt. Simon Sandstone also exhibits good reservoir characteristics and is used for natural gas storage in several locations in the Illinois Basin including the sites shown in Figure 6.

The elevation map of the Lower Mt. Simon Sandstone, which represents the top of the planned injection zone, is shown in Figure 11 and shows the continuity of the unit across a wide region and its deepening southward toward the basin center. The thickness of the injection zone comprising both the Lower Mt. Simon unit and the Mt. Simon Arkose is shown in Figure 12. The elevation map of the top of the Mt. Simon Sandstone is presented in Figure 13.

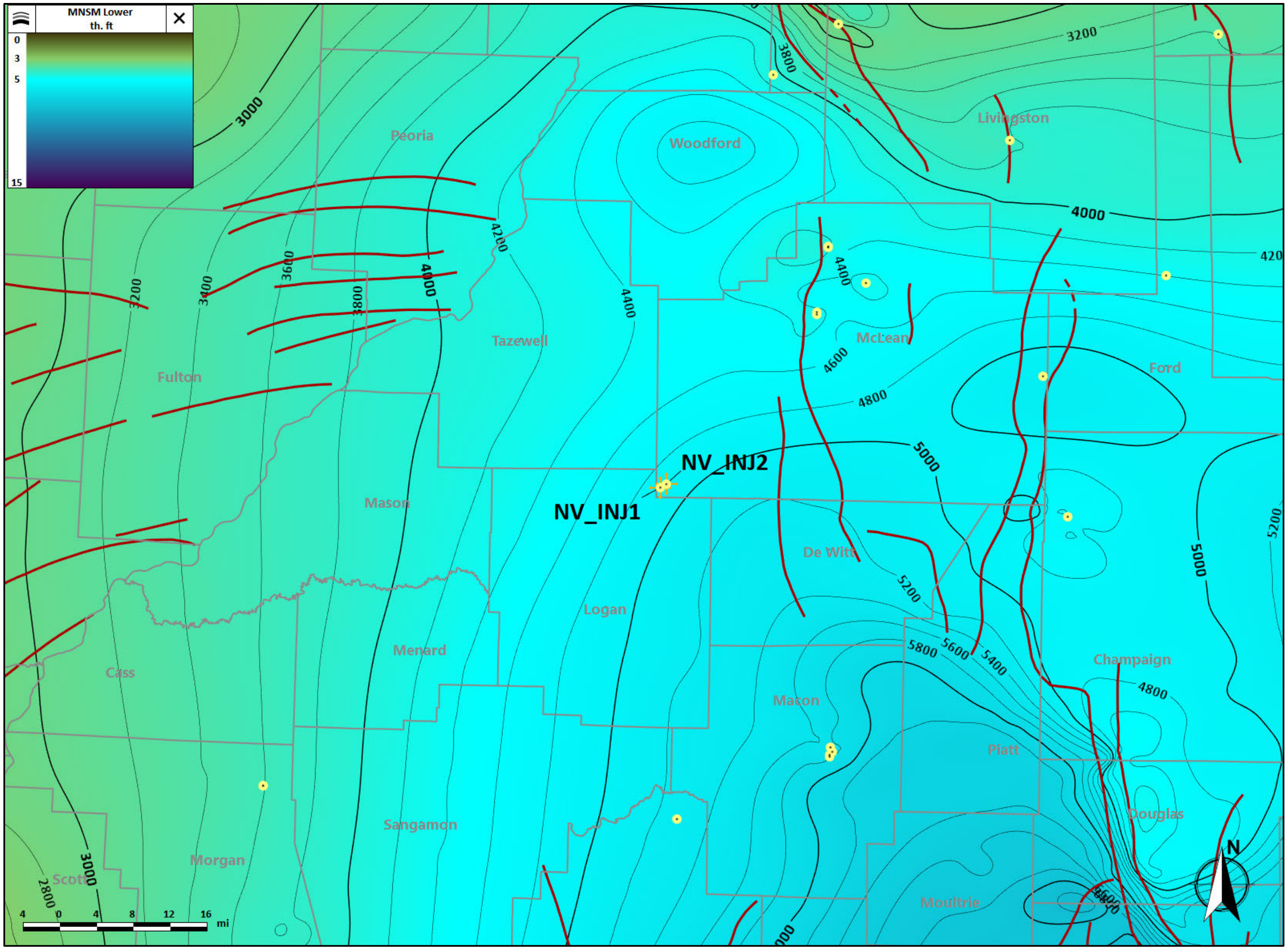

Figure 11: Elevation map (fbsl) of the Lower Mt. Simon Sandstone. Structural features annotated in red (Nelson, 1995). Yellow dots indicate wells that penetrate the Lower Mt. Simon Sandstone top.

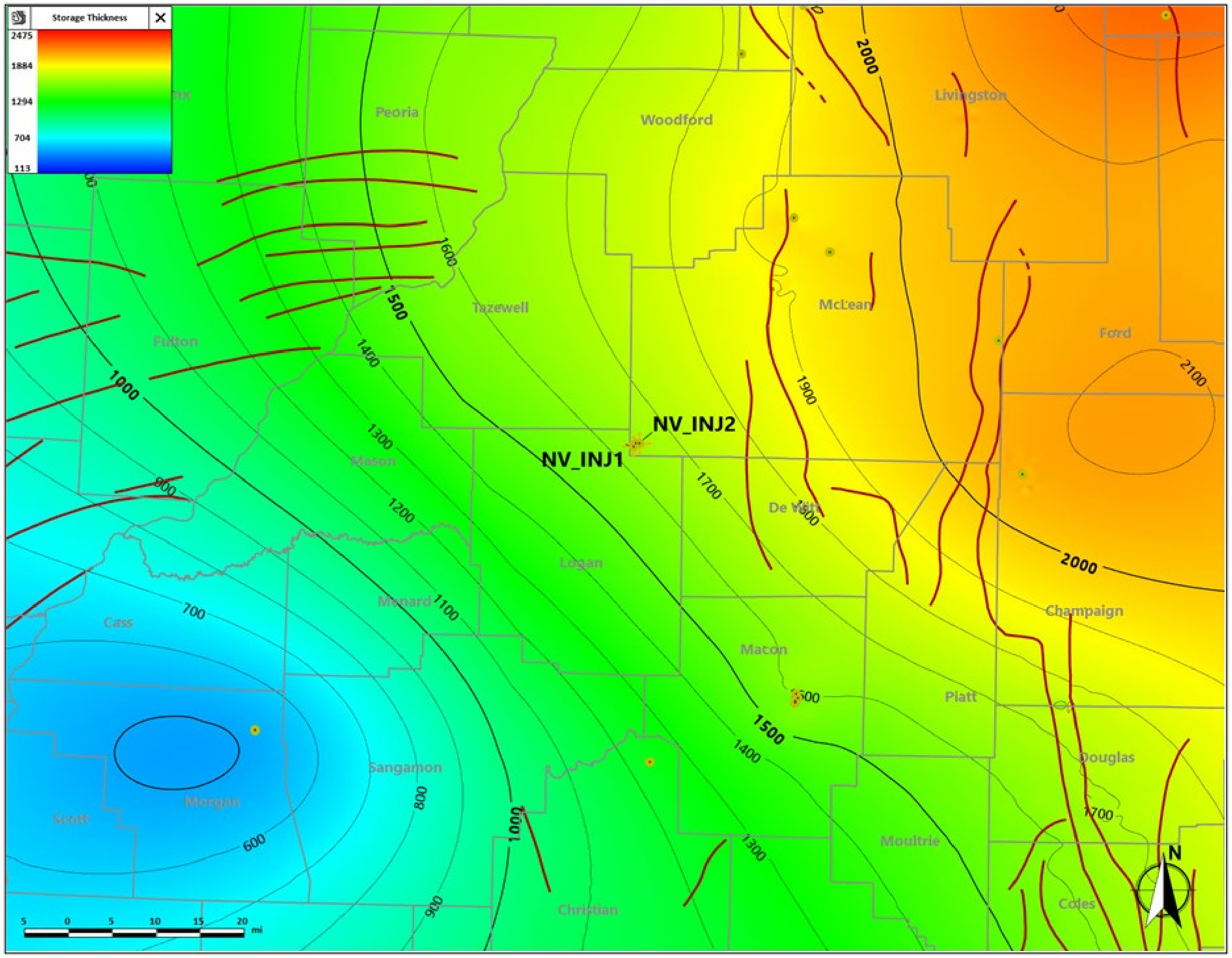

Figure 12: Thickness map (in feet) of the injection zone comprised of the Lower Mt. Simon and Mt. Simon Arkose with structural features annotated in red (Nelson, 1995). Yellow and grey dots indicate wells that penetrate the Lower Mt. Simon Sandstone top.

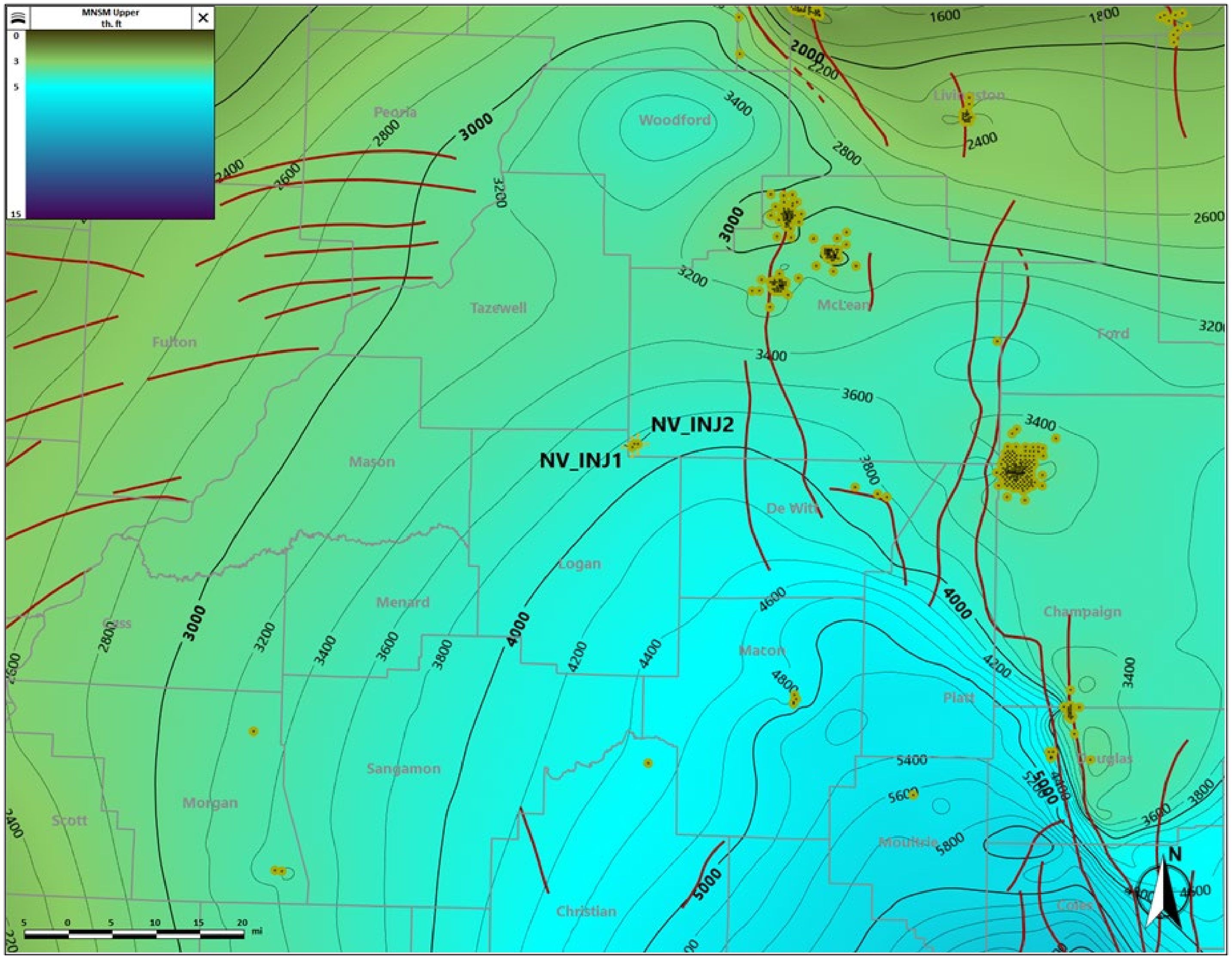

Figure 13: Elevation map (fbsl) of the Upper Mt. Simon Sandstone. Structural features in red (Nelson, 1995). Yellow dots indicate wells that penetrate the Upper Mt. Simon Sandstone top. The clusters of wells northeast and east of the project site are natural gas storage fields in the Upper Mt. Simon Sandstone.

2.5 Eau Claire Formation/Primary Confining Zone (Cambrian)

The Eau Claire Formation is the primary confining unit at the Vervain Project Site (Figure 4, Figure 5, and Figure 7). The Eau Claire Formation directly overlies the Mt. Simon Sandstone and is the basal unit of the Knox Group (Kolata, 2010). Regionally, the Eau Claire Formation is a thick succession of fine-grained strata that is present across much of the Illinois Basin (Figure 14). The regional thickness of the Eau Claire Formation is shown in Figure 15. The Eau Claire Formation exhibits a range of mineralogical and textural features across the Illinois Basin, and Neufelder et al., (2012) report five lithofacies in seven Illinois Basin cores: 1) sandstone, 2) clean siltstone, 3) muddy siltstone, 4) silty mudstone, and 5) shale. Lahann et al., (2014) additionally evaluated the sealing properties of the Eau Claire Formation and determined the finer-grained facies, such as mudstones and shale would restrict vertical entry of CO_2 into the rocks. Figure 16 shows Eau Claire Formation core and well log porosity and permeability data from four Illinois Basin wells, and these data were divided into the five lithofacies listed above. In general, the coarser grained lithofacies have higher porosities and associated permeabilities, and the finer grained, clay-rich lithofacies have lower values, though there is considerable scatter in this data. The base of the Eau Claire Formation can be siltstone to very fine-grained sandstone that forms a gradational contact with the underlying Mt. Simon Sandstone and is sometimes referred to as the Elmhurst Member (Willman et al., 1975). However, in this document it is called the Eau Claire Silt and is considered part of the sequestration zone.

At ADM CCS1 drilled as part of the Illinois Basin–Decatur Project (IBDP) (Greenberg, 2021) approximately 35 miles southeast of the Vervain Project Site (Figure 3), the Eau Claire Formation is about 500 feet thick and grades from highly laminated shale to silty shale in the bottom portion to clayey limestone in the top half of the formation. The shale and muddy siltstone layers isolate the clayey limestone from the injection zone (Leetaru and Freiberg, 2014). The characteristics of the Eau Claire Formation around the Vervain Project Site are described in more detail in *Section 2.4 Injection and Confining Zone Details*.

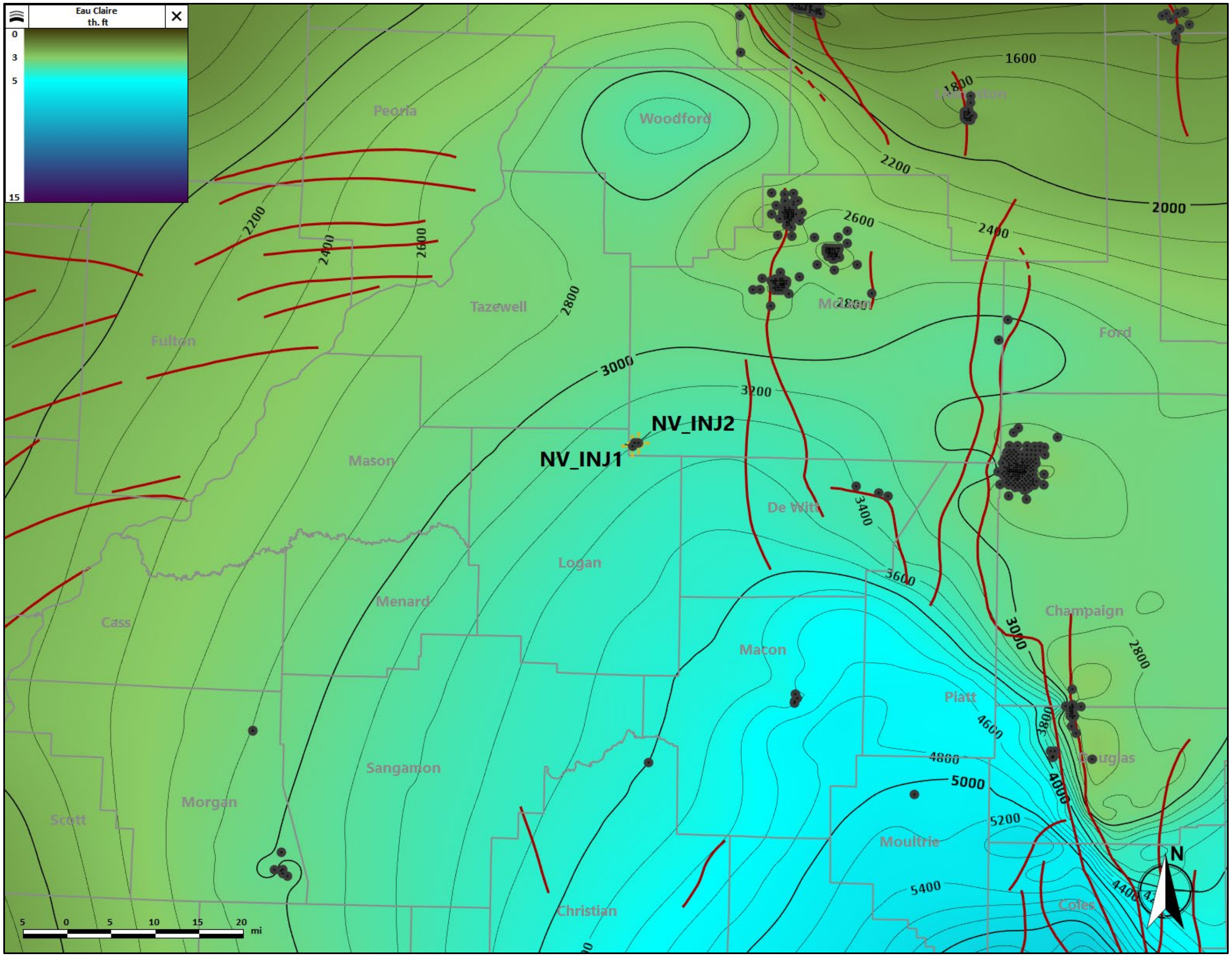

Figure 14: Elevation map (fbsl) of the Eau Claire Formation. Structural features annotated in red (Nelson, 1995). Black dots indicate wells that penetrate the Eau Claire Formation top.

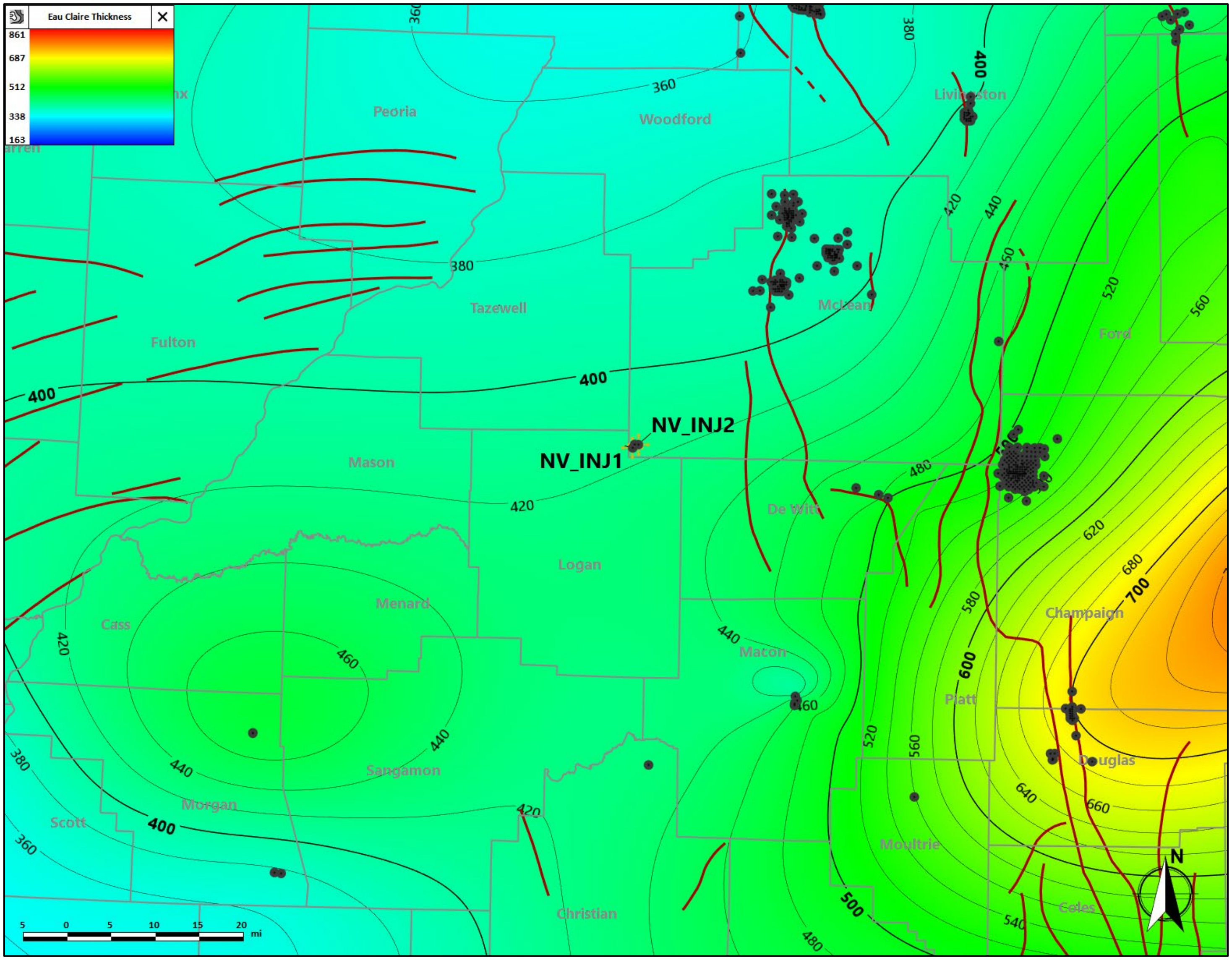

Figure 15: Thickness map (feet) of the Eau Claire Formation with structural features annotated in red (Nelson, 1995). Black dots indicate wells that penetrate the Eau Claire Formation top.

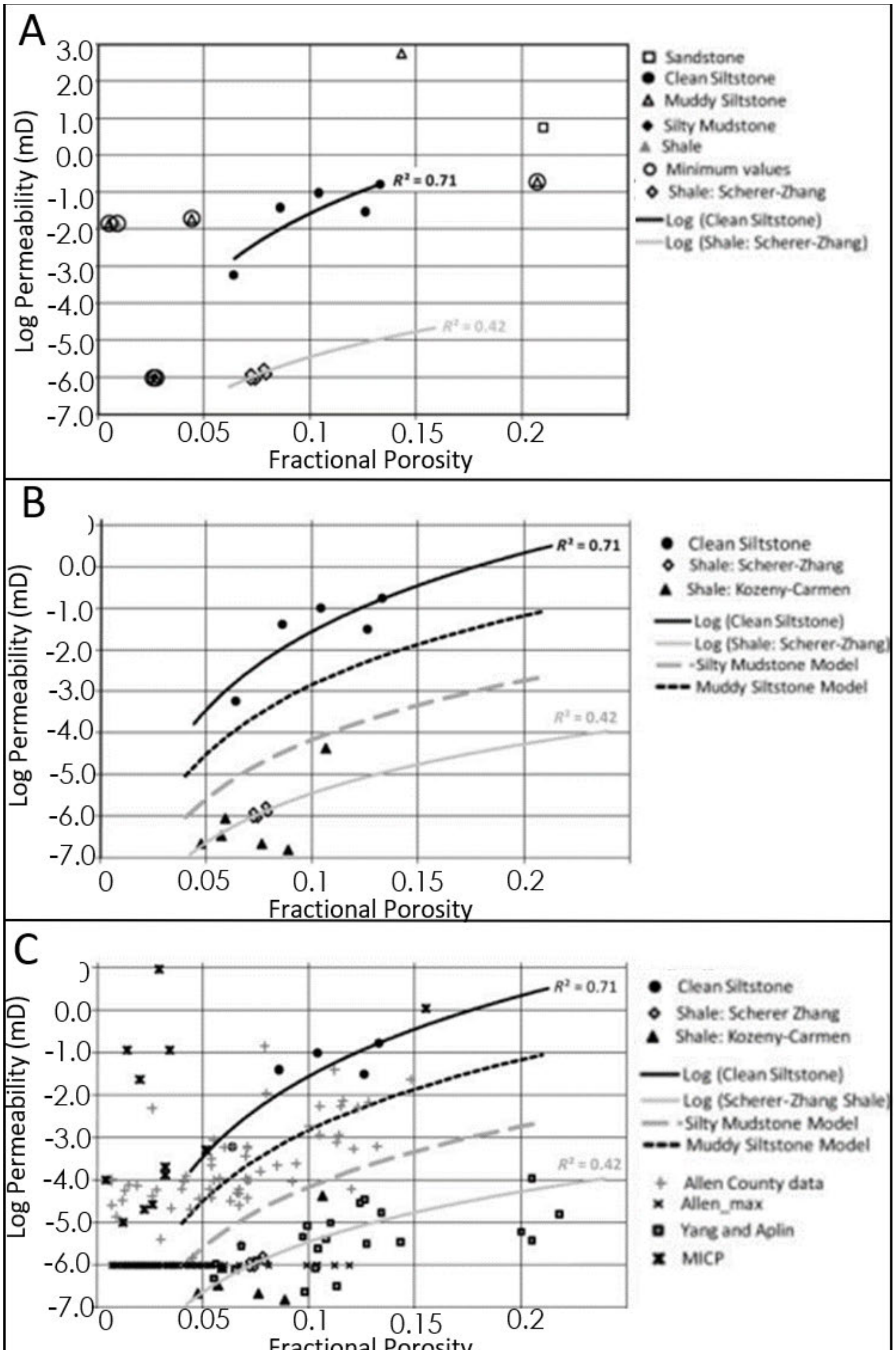

Figure 16: Porosity-permeability models for the Eau Claire Formation lithofacies modified from Neufelder et al., 2012. (A) Cross plot of conventionally derived core porosity and permeability with regression lines for the clean silt lithofacies. (B) Cross plot of traditional core porosity and Kozeny-Carmen calculated permeability with regression lines for the clean silt, muddy siltstone, and silty mudstone lithofacies. (C) Cross plot of traditional core porosity and Kozeny-Carmen calculated permeability for clean silt, muddy silt, and shale lithofacies.

2.6 Ironton-Galesville Formations (Cambrian)

The Eau Claire Formation is overlain by the Ironton-Galesville Formations, which are also part of the Knox Group and will serve as the Above Confining Zone (ACZ) monitoring interval for the Vervain Project (Figure 4). These sandstones were derived from pre-existing sedimentary rocks, sourced from the northern Michigan Highlands (Emrich, 1966). The sediments were deposited on a broad, shallow shelf with clastic deposition in the north and carbonate deposition in the south. The Ironton Formation is a fine to coarse grained, poorly sorted silty sandstone. The underlying Galesville Formation is fine to medium grained, well sorted sandstone and, in the lower part, fossiliferous (Emrich, 1966). Due to the gradational nature of the Ironton and Galesville Formations, it is difficult to distinguish between these formations in well data and they are typically considered together.

2.7 Davis Member/Secondary Confining Zone (Cambrian)

The Davis Member of the Knox Group overlies the Ironton-Galesville Formations and is composed of a number of carbonate and clastic lithologies, including: 1) brownish gray, silty, glauconitic dolomite with oolites, 2) yellowish gray, feldspathic siltstone with dolomite and glauconite, 3) dark gray, calcareous shale, and 4) gray limestone with interbedded shale, siltstone, and sandstone (Figure 4). They are interpreted to have been deposited in a shallow marine environment (Willman et al., 1975).

2.8 Franconia Formation (Derby-Doerun Dolomite) /Secondary Confining Zone (Cambrian)

The Davis Formation is conformably overlain by the Franconia Formation (Figure 4), which consists of glauconitic, argillaceous sandstone and dolomite that underlies the relatively clean Potosi Dolomite. In extreme northern Illinois, the Franconia Formation primarily consists of gray to pink, fossiliferous, glauconitic, silty, argillaceous, fine-grained, dolomitic sandstone with some interbedded red and green shale (Willman and Templeton, 1951). It becomes increasingly shaly to the south, and the uppermost part grades to silty and sandy dolomite. In north-central Illinois, these two units are separated by a wedge of fine-grained, glauconitic, dolomitic sandstone, which is absent in central and southern Illinois where the silty, shaly sandstone of the Davis is directly overlain by relatively pure dolomite. Because of its diminishing amounts of sand, shale, and glauconite, the upper part of the Franconia Formation is difficult to differentiate from the overlying Potosi Dolomite (Willman et al., 1975). For this project, the Potosi and Franconia Formations will not be differentiated.

2.9 Potosi and Eminence Formations/Secondary Confining Zone (Cambrian)

The Potosi Formation overlies the Franconia Formation and consists of crystalline, clean to slightly argillaceous, brown to pinkish-gray dolomite (Figure 4). It is sandy at the base and glauconite content increases upward. Drusy quartz sometimes covers the surfaces of small to large cavities within the rock, which is a defining characteristic in both outcrops and well samples, and portions of this formation have relatively high permeability (Willman et al., 1975). Intervals within the Potosi Formation exhibit karst dissolution features (e.g., large vugs) and can be zones of lost circulation during drilling throughout the Illinois Basin.

2.10 Oneota Formation/Secondary Confining Zone (Ordovician)

The Oneota Formation consists of crystalline, light gray to brownish gray, cherty dolomite with minor amounts of sand and thin shaly beds at the base (Figure 4). The rock is generally white to pinkish gray with some sandy and oolite layers. The chert occurs in layers, lenses, isolated nodules, and irregularly shaped bodies that have a distinctive branching habit (Willman et al., 1975).

2.11 New Richmond Sandstone (Ordovician)

The New Richmond Sandstone overlies the Oneota Dolomite and is locally unconformable. The New Richmond Sandstone grades upwards and laterally into the Shakopee Formation (Willman et al., 1975). The sandstone is gray, fine to medium grained, subrounded to rounded, friable, moderately-well sorted, with cross beds, ripple marks, and interbedded sandy dolomite with oolitic chert. The characteristics of the sandy dolomite intervals are similar to those of the overlying Shakopee Formation (Willman and Payne, 1943).

2.12 Shakopee Formation/Secondary Confining Zone (Ordovician)

The Shakopee Formation consists of argillaceous to pure, crystalline dolomite with some thin beds of medium-grained, cross-bedded sandstone, medium-grained dolomite, green to light gray shale, and buff siltstone. It contains oolitic, partly sandy chert in discontinuous bands and isolated nodules, conglomerate beds, ripple marks, and mud cracks (Willman et al., 1975). Bentonite layers are present in a quarry in northern Illinois (Willman and Templeton, 1951; Figure 4).

2.13 St. Peter Sandstone/Lowermost USDW (Ordovician)

The Knox Group is overlain by the St. Peter Sandstone (Figure 4), which consists of fine to medium, well sorted, rounded, frosted quartz sand grains that are friable or weakly cemented. The St. Peter Sandstone is an exceptionally pure quartz sandstone and was deposited in a near-shore environment (Lamar, 1928a; Willman and Payne, 1942; Buschbach, 1964). Bedding is primarily horizontal with some low-angle cross bed. It has three members:1) the Kress Member at the base (chert, sand, clay, and shale), 2) the Tonti Sandstone Member, and 3) the Starved Rock Sandstone Member (Willman et al., 1975). The St. Peter Sandstone is one of the major aquifers in Illinois and is the lowermost USDW zone in the project area.

2.14 Joachim Dolomite/Glenwood (Ordovician)

The St. Peter Sandstone is overlain by the Joachim Dolomite (Figure 4), which can be differentiated into six members regionally within the basin. This rock is generally light gray, argillaceous, silty or sandy dolomite, and also contains beds of relatively pure dolomite, sandstone, limestone, shale, and chert. Dolomitic algal domes are also found within the Joachim Dolomite. Layers of anhydrite exist in the subsurface but are dissolved where the Joachim Dolomite crops out. The general absence of marine fossils and existence of algal domes suggests that the Joachim was deposited in a shallow, closed basin, and mud cracks and ripples occur in some beds. The Joachim contains more clastic material than the overlying Platteville Group (Willman et al., 1975).

2.15 Platteville Group (Ordovician)

The blue-gray, mottled limestone of the laterally continuous Platteville Group overlies the Joachim Dolomite. A diastem divides the Platteville Group into the lower Pecatonica Formation, which is a persistent dolomite, and the overlying Plattin Subgroup limestone (Buschbach, 1964; Willman et al., 1975).

2.16 Galena Group/Trenton Limestone (Ordovician)

Overlying the Platteville Group is the Trenton Limestone of the Galena Group (Figure 4). The Galena Group has three major facies:1) fine-grained limestone in northwestern Illinois, 2) dolomite, and 3) a calcarenite in southern Illinois. In most of northern Illinois, the group is entirely dolomite and the lower part grades into a limestone to the south. Still farther south, the limestone interval is truncated so that the group is entirely calcarenite and calcarenitic limestone (Willman et al., 1975).

2.17 Maquoketa Group/Potential Confining Zone (Ordovician)

The shale and carbonate of the Maquoketa Group exists in most of Illinois, unconformably overlies the Galena Group, and truncates the portions of the upper half of the Galena Group in southern Illinois (Figure 4). Silurian strata locally truncate the upper half of the Maquoketa. Throughout most of Illinois, the Maquoketa Group consists of a lower shale unit (Scales Shale), a middle limestone (Fort Atkinson Limestone), and an upper shale (Brainard Shale) (DuBois, 1945; Gutstadt, 1958b; Templeton and Willman, 1963; Buschbach, 1964). The Maquoketa Group will serve as a significant confining zone for this project.

2.18 Silurian System

The Silurian System unconformably overlies the Maquoketa Group. During this period, a shallow sea transgressed across the Illinois Basin and deposited carbonate sediments. This, in conjunction with the subsidence of the Illinois and surrounding basins, allowed prominent shelf-edge carbonate banks to develop. At the end of the Silurian, eustatic fluctuations, cratonic uplift, and local tectonic events caused sea level to regress. This ended sedimentation, exposing and eroding the Silurian strata for millions of years (Mikulic et al., 2011).

2.19 New Albany Shale Group/Potential Confining Zone (Devonian)

The New Albany Shale of Middle to Upper Devonian age unconformably overlies Silurian strata and is widely distributed across the Illinois Basin. Its cumulative thickness of the organic-rich black shales is greatest near the center of the basin and thins toward the basin edge. Organic-poor, greenish-gray shales predominate in the basin center and are thickest in western and west-central Illinois. A broad transitional zone, where these organic-rich and organic-poor facies interfinger and grade laterally into one another, trends northeast-southwest across central Illinois (Cluff and Dickerson, 1982).

Sea level regressed during the Mississippian, and the Illinois Basin contained a river system that flowed southwestward across a swampy lowland, carrying mud and sand from the highlands located to the northeast. This river system formed thin, widespread deltas that prograded into the shallow sea that covered much of present-day Illinois. Because the lowland stood only slightly above sea level, slight changes in relative sea level caused great shifts in the position of the shoreline (Siever, 1951). The Mississippian strata (i.e., St. Genevieve, St. Louis, Keokuk) are more than 3,000 feet thick in some parts of Illinois (Willman et al., 1975) but are expected to be thin to absent at the project site.

2.20 Pennsylvanian System

The Illinois Basin continued to subside throughout the Pennsylvanian, leading to accumulation and preservation of about 3,000 feet of sediments in the basin. The previously described Mississippian river system persisted to flow across a swampy lowland, carrying mud and sand from bordering highlands. These rivers formed thin but widespread deltas that coalesced into a vast coastal plain, and sediments continued to prograde into a shallow sea (Siever, 1951). During the late Pennsylvanian, a eustatic sea level regression coupled with the Alleghenian Orogeny tectonics, resulted in erosion of much Pennsylvanian and pre-Pennsylvanian strata.

2.21 Regional Structure

The Illinois Basin (Figure 3) has been affected by three major tectonic episodes during the Phanerozoic Eon, including Rodinia-related rifting; widespread compressional (reverse) faulting during the assembly of the supercontinent Pangea in the late Paleozoic; and extensional (normal) faulting during the Mesozoic related to Pangea's breakup (Denny et al., 2020).

The most prominent structural feature in the central basin area is the La Salle Anticlinorium (Nelson, 1995), which is a large upward fold belt comprised of smaller domes, anticlines, monoclines (step-like folds), and intervening synclines; it trends N-S to NE-SW and is about 200 miles (320 km) long by 80 miles (130 km) wide. Major uplift of the La Salle Anticlinorium began during the Late Mississippian and lasted throughout most of Pennsylvanian time (Kolata and Nelson, 1990).

The closest mapped structural feature to the Vervain Project Site is the Clinton Syncline, which is more than 13 miles to the east (Figure 17). The western flank of this fold is relatively gentle compared to the eastern flank, which merges with the western limb of the Downs Anticline (Figure 17). The asymmetrical, south-plunging Downs Anticline is a component of the larger, north-south trending La Salle Anticlinorium and has a significantly steeper western flank. Several domes occur along the Downs Anticline, and borehole data shows that this fold is likely a basement structure. A series of east-plunging, asymmetrical individual folds (Bryant, Canton, Fairview, and Elmwood) compose the larger Peoria Fold Complex and are locate more than 30 miles northwest of the project site (Nelson, 1995).

High density 2D seismic data acquired specifically for the Vervain Project indicate there are no significant structural features identified within the project's AoR. The 2D seismic is discussed in detail in the *Faults and Fracture* section. The structural features listed above are significantly removed from the project area and are not considered impactful to carbon sequestration operations.

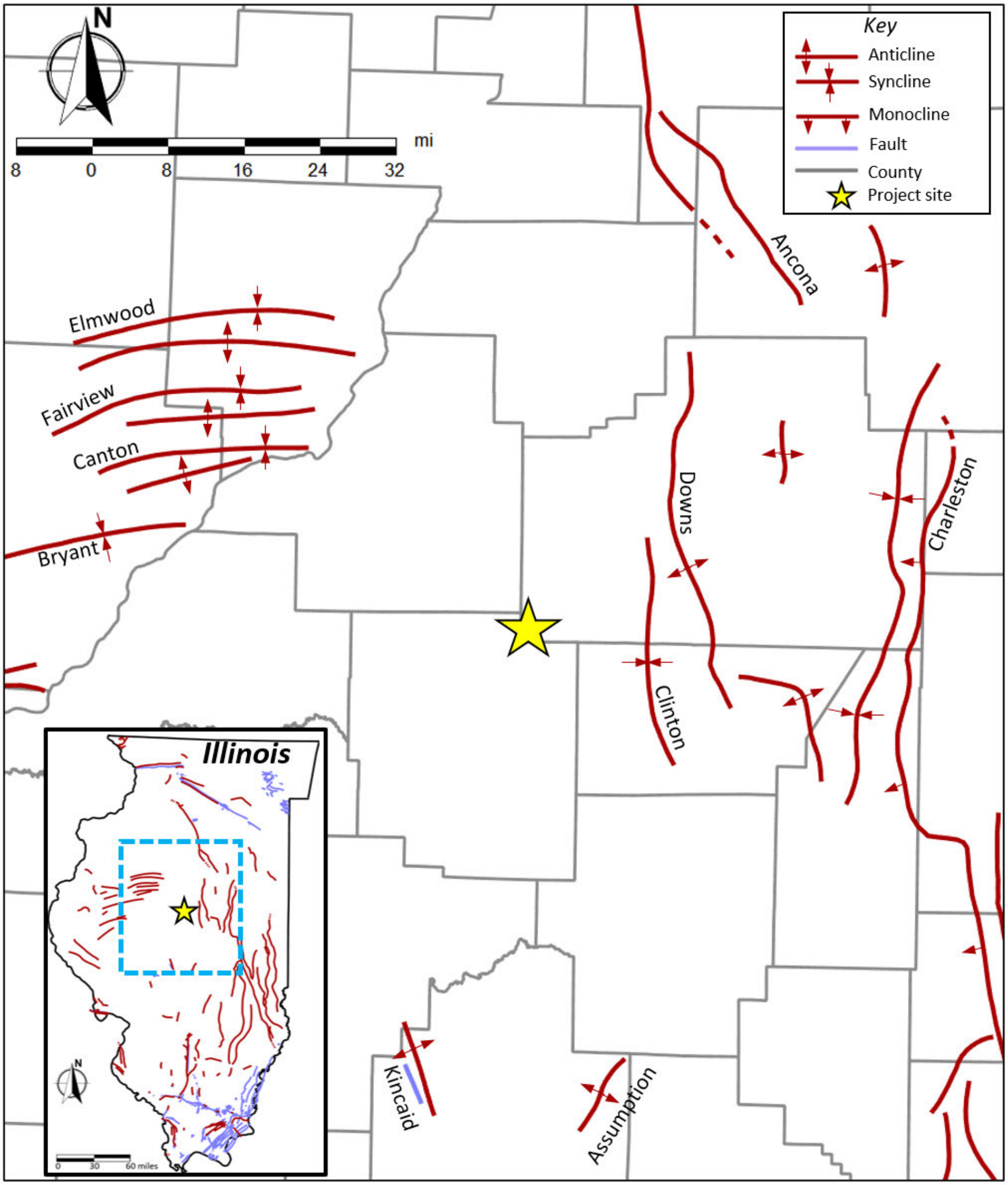

Figure 17: Regional structural features in the central Illinois Basin. Inset map highlights the detailed mapped area. Folds and faults are depicted as red and purple lines, respectively. Yellow star indicates location of the project site. Modified from Nelson (1995)

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

Figure 18 shows the AoR for the Vervain Project, based on differential pressure front after 25 years of injection, and all the existing wells within the area. This is the maximum extent of AoR in the project timeframe. The method for delineation of the AoR is described in the AoR and Corrective Action Plan (Attachment 02: AoR and Corrective Action Plan, 2023).

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Figure 18: All oil/gas wells (26) and water wells (481) within the Vervain AoR. Injector wells are also shown.

The Mt. Simon Arkose and Lower Mt. Simon Sandstone comprise the injection zone, the Eau Claire is the confining zone for the Vervain Project, and all extend laterally beyond the AoR limits. This is demonstrated by the regional thickness maps (Figure 12 and Figure 15), the cross section shown in Figure 5 in *Section 2.1 Regional Geology* of this narrative, and 2D seismic data discussed below (Figure 19, Figure 20, Figure 21, and Figure 22).

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2D seismic data (Figure 21 and Figure 22) acquired specifically for the Vervain Project and discussed in *Section 2.2 Faults and Fractures* of this document also indicate the Mt. Simon Sandstone and Eau Claire strata are laterally continuous and exhibit no significant faults or structural features. A small basement fault with limited offset, as shown in Figure 22, may be present that terminates within the Argenta or basal Mt. Simon Arkose zone that will have no impact on containment, as it does not penetrate the Eau Claire Formation confining zone. The ductile nature of the Eau Claire Formation and lack of structural features indicate the confining zone has excellent characteristics for sequestration of CO_2 at the Vervain Project Site. No potential conduits for CO_2 to migrate out of the Mt. Simon storage zone were identified in the AoR of the Vervain Project.

The St. Peter Sandstone is the lowermost USDW present within the AoR based on regional data Sensitive, Confidential, or Privileged Information [redacted] above the top of the Eau Claire confining zone at the Vervain Project Site (*Section 2.27.3 Determination of Lowermost USDW)*. There are no structural features or faults observed to intersect the St. Peter Formation in the AoR. As described in *Section 2.1 Regional Geology* there are several secondary confining zones within the Knox Group between the Eau Claire Formation and the St. Peter Sandstone in the AoR.

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No existing well penetrates the confining strata of the Eau Claire Formation in the AoR at the Vervain Project Site.

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

A high density 2D seismic program conducted November - December 2022 acquired and processed approximately 11 miles of seismic data at the Vervain Project Site to provide information regarding subsurface structure and stratigraphy (Figure 19). The data were acquired with a vibrator truck operating on county roads with a 2-120 Hz broad band sweep of 20 second duration. Source and receiver spacing of 32 feet was used to enable high density processing to identify both shallow and deep subsurface features. Long offsets were obtained to enable additional inversion work to identify any lithological changes at target.

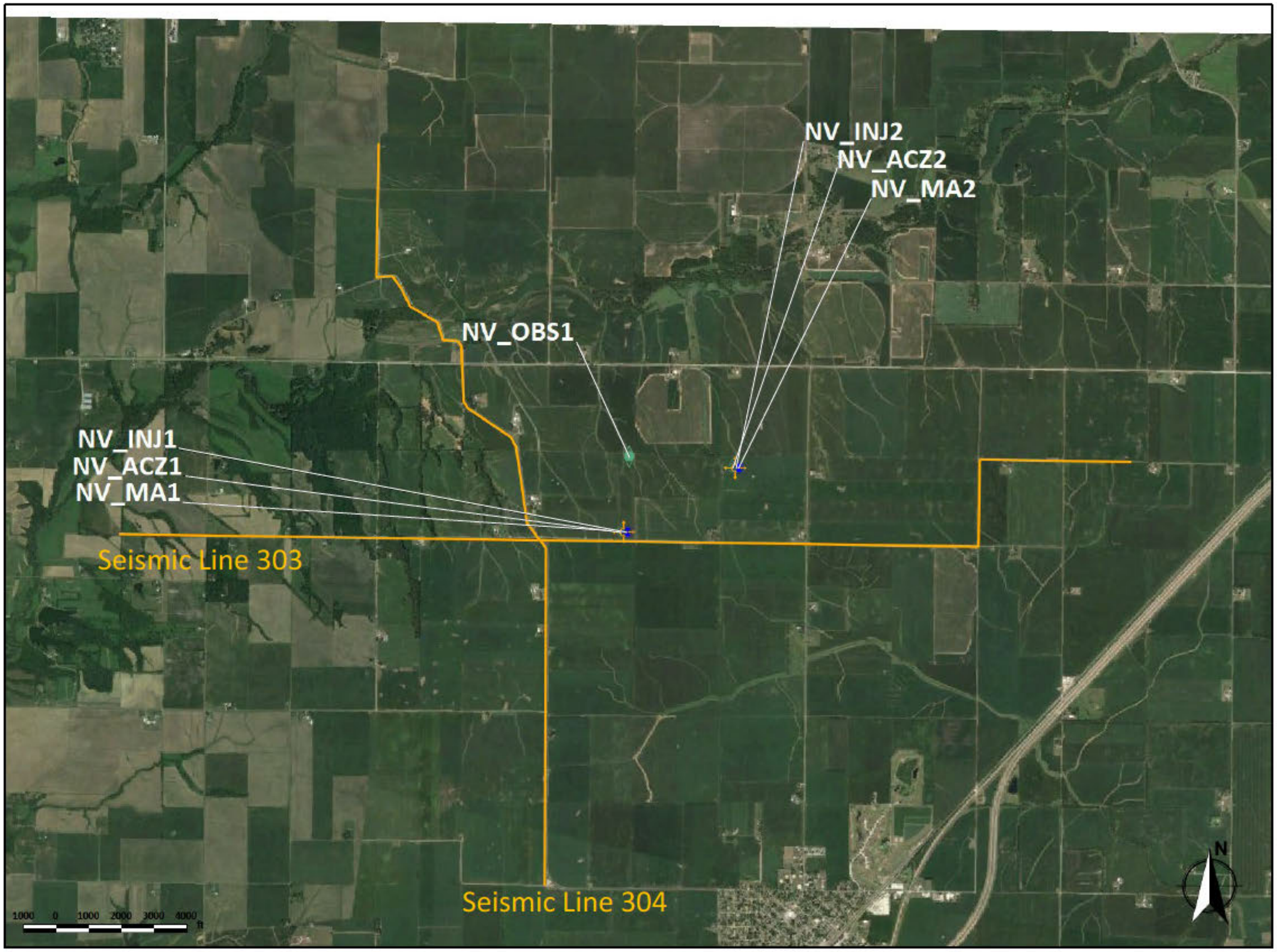

Figure 19: Map of 2D seismic lines 303 and 304 acquired for the project. Project well locations also shown.

No deep wells are in immediate proximity to the two 2D seismic lines acquired at the Vervain Project Site that allow a direct tie to the seismic surveys, so the ADM CCS1 well drilled for the IBDP about 35 miles southeast was used to correlate the stratigraphy to the seismic data. The ADM CCS1 well penetrates similar stratigraphy as is present at the Vervain Project Site. Data from ADM CCS1 was used to generate a synthetic seismogram which was then used to help correlate the stratigraphy to the seismic lines (Figure 20). Although ADM CCS1 is located some distance from the seismic lines, which leads to more uncertainty in the seismic interpretation than if a well was located close to the seismic lines, the stratigraphy and resulting seismic stratigraphy in the central part of the Illinois Basin are generally well understood. The uncertainty on the seismic interpretation is considered to be plus or minus one seismic cycle. Seismic data will be converted to depth once site wells have been drilled.

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Figure 20: Well logs and synthetic seismogram from ADM CCS1 well. The penetrated stratigraphy at the ADM CCS 1 location is similar to the Vervain Project Site and was used to tie the 2D seismic for seismic interpretation.

Seismic lines 303 (Figure 21) and 304 (Figure 22) acquired at the Vervain Project Site indicate the stratigraphy of the area to be generally flat lying, continuous and without notable structural features. In the central Illinois Basin, the Maquoketa, Trenton, St. Peter, and Knox seismic horizons are generally associated with a zone of high amplitude continuous reflectors, representing the impedance contrasts between the high impedance Trenton and Knox dolomites and the low impedance Maquoketa Shale and St. Peter Sandstone. The Eau Claire Formation confining zone and the Mt. Simon Sandstone storage zone are indicated to be of relatively consistent thickness and with no structural features that would impair storage or containment. For the Precambrian pick on lines 303 and 304, a lower amplitude, high impedance reflector was chosen based on a combination of the ADM CCS1 synthetic seismogram as well as comparing the overall time-depth relationships of other Precambrian picks from other deep wells across central Illinois.

Figure 21: CBI: West – East 2D seismic line 303 from the Vervain Project Site with annotated interpreted stratigraphy.

Figure 22: CBI: North – South 2D seismic line 304 from the Vervain Project Site with annotated interpreted stratigraphy. The diagonal green line is a possible fault that originates in the Precambrian Basement.

No faults or fractures are observable within the Eau Claire Formation confining zone. The Eau Claire Formation and Mt. Simon Sandstone are without notable structural features. On line 304 (Figure 22), one possible fault was identified that originates from the deeper Precambrian and cuts through the Arkose Zone and tips out in the Lower Mt. Simon. This fault shows both reverse and normal motion, suggesting polyphase movement. The Illinois Basin has experienced significantly variable tectonic stresses since the Precambrian and polyphase faults have been seen elsewhere in the Illinois Basin. The fault has a shallower dip than many Illinois Basin faults, which may indicate the seismic line is oriented nearly perpendicular to the strike of the fault, suggesting a fault orientation of approximately east-west. Because this fault tips out in the lower Mt. Simon Sandstone and does not reach the Eau Claire containment interval, there is no risk to containment from this fault. There are potentially other faults within the Precambrian section that are truncated below or at the Precambrian unconformity. These faults would have no impact on containment.

2.23.1 Impact on Containment

Previously collected seismic data associated with CO_2 sequestration projects in the Illinois Basin suggests that minor faults in the Precambrian and Argenta / Mt. Simon strata are not expected to act as conduits through the confining zone (e.g., Greenberg, 2021) and that they present negligible endangerment to USDWs. HGCS intends to acquire a baseline 3D surface seismic survey at the Vervain Project Site and any identified structural features or faults will be mapped and assessed to determine if there is any potential impact to storage or containment. The data gathered during the pre-operational phase of the project will be used for geomechanical modeling to evaluate whether any minor faults identified in the surface seismic data are stable or whether they are critically stressed.

2.23.2 Tectonic Stability

Faults originating in the Precambrian basement and terminating in the basal units of the Argenta and Mt. Simon Sandstone have not been active since Cambrian time. Regionally, thickness changes in the Cambrian-aged Argenta, Arkose, and Lower Mt. Simon formations may be related to interpreted syn-depositional fault movement along the basement-involved faults, but at the Vervain Project Site no changes in thickness of strata overlying the Mt. Simon Sandstone can be attributed to these faults, suggesting there has been little active faulting since early Cambrian time.

Structural features such as the Downs Anticline and Clinton Syncline to the east of the project area (Figure 17) were possibly active into late Mississippian and Pennsylvanian time (Nelson, 2010). These features are related to the LaSalle Anticlinorium, which formed in response to the Ancestral Rocky Mountains orogeny (McBride 1998, McBride and Nelson 1999).

A future 3D seismic survey will be acquired at the Vervain Project Site to evaluate injection and confining zone properties, map Precambrian basement topography, and characterize any identified basement faults. The 3D seismic survey will be designed to obtain full fold data over the predicted extent of the CO_2 plume after 25 years of injection and proposed 15-year PISC period (Attachment 07: Testing And Monitoring Plan, 2023). The Pre-Operational Testing Program details the geophysical log and core data that will be acquired to evaluate the nature of any identifiable fractures and their impact on long-term integrity of the confining zone (Attachment 05: Pre-Op Testing Program, 2023).

In Central Illinois, the area of the Vervain Project, earthquakes above M 2.5 are rare. See *Section 2.26 Seismic History.*

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

2.24.1 Injection Zone and Confining Zone Extent and Thickness

The Mt. Simon Arkose and Lower Mt. Simon Sandstone units together represent the injection zone for the Vervain Project. The entire storage interval is represented by the sedimentary succession bracketed by the base of the Mt. Simon Arkose and the top of the Eau Claire Silt (Figure 4). Within this package, the Middle Mt. Simon unit typically has relatively poor reservoir quality in the central Illinois Basin and serves as a baffle to upward fluid migration. Most of the injected CO_2, as simulated, remains in the Mt. Simon Arkose and Lower Mt. Simon Sandstone (Attachment 02: AoR and Corrective Action Plan, 2023). The Upper Mt. Simon Sandstone can also have good reservoir characteristics and is used for natural gas storage within the Illinois Basin region (Figure 6). The Eau Claire Formation above the Eau Claire Silt is the confining zone for the Vervain Project (Figure 4). Characteristics of the injection and confining zones are also described in *Section 2.1.1 Regional Stratigraphy*.

Available public data were collected and integrated to develop site-specific subsurface maps, petrophysical relationships, and a geomodel of the Vervain Project Site. Geophysical well logs were used to generate thickness maps for the Argenta Formation through Eau Claire Silt (the total storage interval; Figure 23), the combined Mt. Simon Arkose and Lower Mt. Simon Sandstone (injection zone; Figure 24), and the Eau Claire Formation (confining zone; Figure 25). Within the Vervain AoR there are only minor elevation variations and no significant thinning of either the injection zone (Lower Mt. Simon Sandstone and Mt. Simon Arkose) or confining zone

(Eau Claire Formation). Sensitive, Confidential, or Privileged Information [redacted] Site specific 2D seismic data discussed in *Section 2.3 Faults and Fractures* confirms the lateral continuity and structural integrity of these strata across the AoR.

CO_2 plume development is expected to be controlled dominantly by sedimentological heterogeneities within the injection zone, as structural features will have minimal influence on plume development at this site. The Eau Claire Formation confining zone will provide a thick, laterally extensive barrier to prevent upward migration of injection zone fluids over time.

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Figure 23: Thickness (feet) of the storage interval (Mt. Simon Arkose, Lower-Middle-Upper Mt. Simon Sandstone and Eau Claire Silt) in the AoR.

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Figure 24: Thickness (feet) of injection zone (Mt. Simon Arkose and Lower Mt. Simon Sandstone) in the AoR.

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Figure 25: Thickness (feet) of the confining zone (Eau Claire Formation) in the AoR.

2.24.2 Porosity and Permeability

Public log and core information from five wells in Illinois provide significant data to characterize the injection, storage, and confining zones at the Vervain Project Site. Available wells that penetrate the Mt. Simon Sandstone or deeper are from gas storage sites, UIC Class VI sites, and structure test wells that have well logs, core, and fluid injection data from the Mt. Simon Sandstone and Eau Claire Formation (Figure 26). The ADM CCS1 well is located 35 miles southeast of the project site and represents the closest analog for the injection and confining zones (Figure 26). Mt. Simon Sandstone average porosity and permeability values from the five offset wells in central Illinois are presented in Table 4.

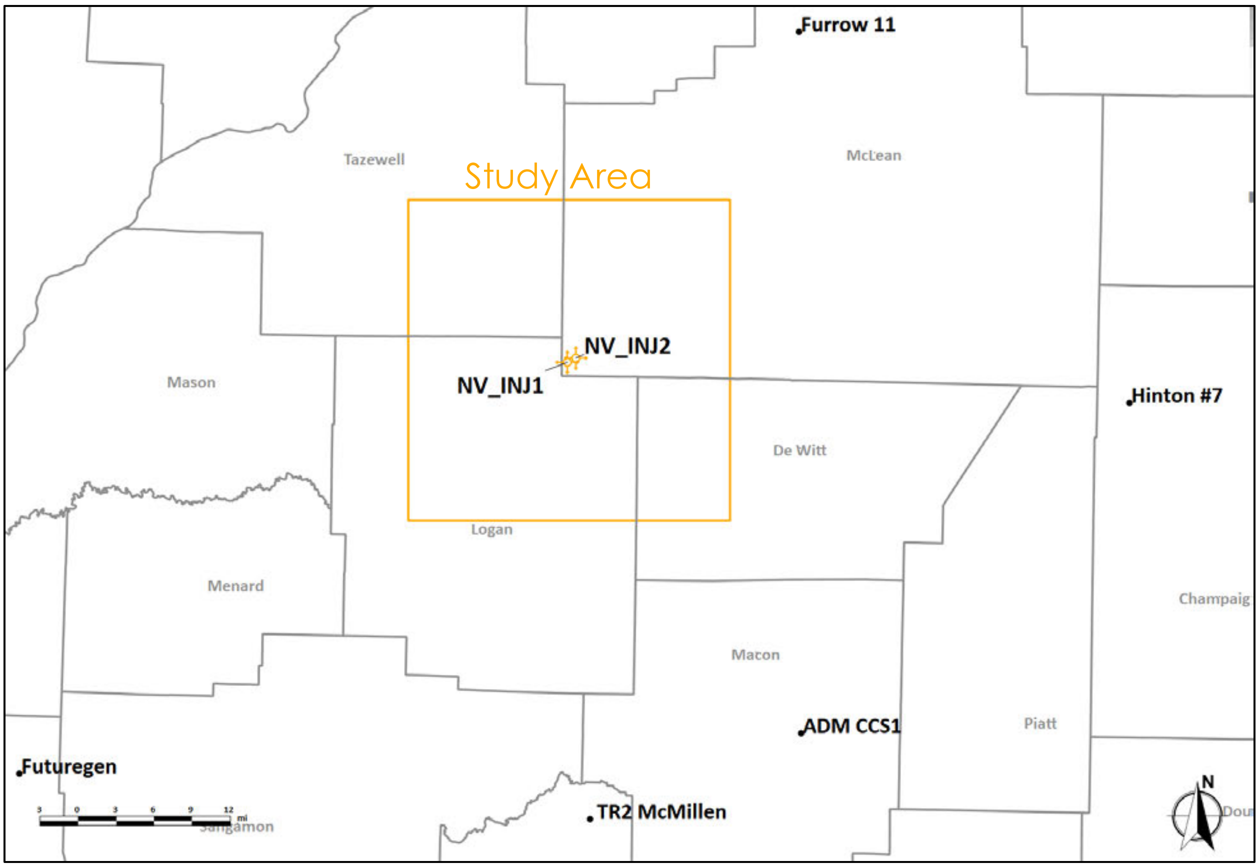

Figure 26: Wells used for petrophysical analysis of the Vervain injection and confining zones. ADM CCS1 Mt. Simon Sandstone porosity and permeability values are reported in Table 4, and geomechanical properties are reported in Table 5.

2.24.3 Mt. Simon Sandstone

As described in *Section 2.1.1 Regional Stratigraphy,* the Mt. Simon Sandstone can be divided into Lower, Middle, and Upper intervals with a basal Arkose Sandstone unit (Figure 4) that often has enhanced reservoir quality through secondary porosity development resulting from dissolution of feldspar grains (Leetaru and McBride, 2009; Medina and Rupp, 2012; Freiburg et al., 2016; Leetaru et al., 2019). As shown in the cross-section of Figure 5, the sub-units of the Mt. Simon Sandstone are present across a wide expanse within the Illinois Basin, including the Arkose zone that can be correlated regionally. For example, at the Hinton #7 well approximately 44 miles east of the project site the Arkose zone is about 215 feet thick, at the TR McMillen #2 well about 36 miles south it is about 175 feet thick (Whittaker and Carman, 2022) and at the ADM CCS1 well 35 miles southeast it is 342 feet thick (Leetaru and Freiberg, 2014). Very good reservoir quality is found in the Arkose zone at each of these wells including porosity values generally over 20% and permeability values of 100's to 1,000's of mD (Whittaker and Carman, 2022).

The Middle Mt. Simon Sandstone generally has poorer reservoir properties than either the Lower or Upper Mt. Simon units (Leetaru and Freiberg, 2014; Whittaker and Carman, 2022). At ADM CCS1 and TR McMillen #2, the Middle Mt. Simon consists of planar parallel and low-angle to trough cross-stratified, medium- to coarse-grained pure quartz sandstone, interbedded with thin intervals of feldspar sandstone. The average porosity and permeability of the Middle Mt. Simon strata at ADM CCS1 (Table 4) is 8.7% and 10.2 mD, respectively, and impairs vertical movement of CO_2 out of the injection zone.

The Upper Mt. Simon Sandstone may exhibit good reservoir characteristics particularly in thin, tidal flat channel sands such as are utilized for natural gas storage in the basin (Morse and Leetaru, 2005). The Upper Mt. Simon Sandstone is heterogeneous with interbedded shale and has regional log-derived porosity and permeability averages of 8.5% and 5.4 mD, respectively, although more porous and permeable units are present (Leetaru et.al, 2019).

At the ADM CCS1 well, the entire Lower Mt. Simon Sandstone interval (which integrates the Arkose zone) is reported to have a mean well log porosity of 16.6% and permeability values as high as 400 mD (Leetaru et al., 2019). The average effective porosities and intrinsic permeabilities for various depth intervals within the Mt. Simon Sandstone and Argenta Formation were reported by Patrick Engineering (2011; Figure 27). These data are also shown on the ADM CCS 1 well log, were calculated by integrating geophysical logs/core/well test data, and then used to divide the Eau Claire, Mt. Simon Sandstone, and Argenta Formation into seven sub-intervals based on lithologic and porosity trends (Table 4 and Figure 27). The ADM CCS1 data show that the Lower Mt. Simon Sandstone and the Mt. Simon Arkose have the best reservoir quality, with the highest reported average porosity and permeability values (21.8%, 107 mD) found within the Mt. Simon Arkose (Table 4 and Figure 27). The Upper Mt. Simon Sandstone has relatively high average values (10.8%, 19.4 mD) compared to the underlying Middle Mt. Simon Sandstone interval (8.7%, 10.2 mD; Table 4; Figure 27).

Table 4: ADM CCS1 depth interval, formation, average effective porosity, and average intrinsic permeability for seven sub-intervals in the Mt. Simon Sandstone and Argenta Formation (Patrick Engineering, 2011). These data are also shown on the ADM CCS1 well log in Figure 27.

Measured Depth Interval (feet)	Formation	Average Effective Porosity (%)	Average Intrinsic Permeability (mD)
5,545-5,900	Upper -Middle Mt. Simon Sandstone	10.8	19.4
5,900-6,150	Middle Mt. Simon Sandstone	8.7	10.2
6,150-6,430	Middle Mt. Simon Sandstone	10.1	8.4
6,430-6,650	Lower Mt. Simon Sandstone	15.2	8.2
6,650-6,820	Lower Mt. Simon Sandstone-Mt. Simon Arkose	21.8	8.6
6,820-7,050	Mt. Simon Arkose	18.7	107
7,050-7,165	Argenta	9.8	4.4

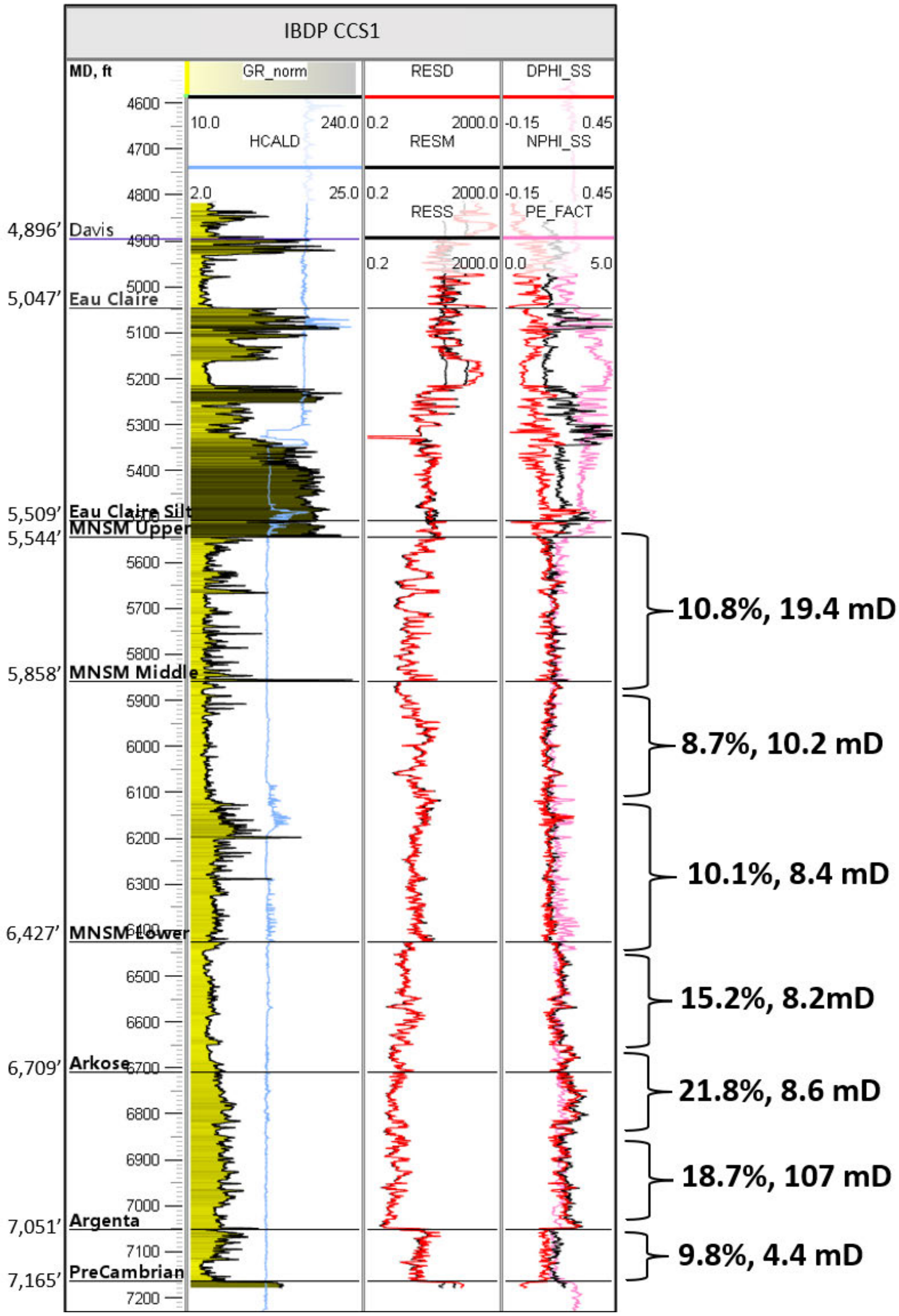

Figure 27: ADM CCS1 geophysical logs with measured depth (MD), formation tops, average effective porosity (%), and intrinsic permeability (mD) values. GR_norm=normalized gamma ray log; HCALD=caliper; RESD, RESM, and RESS = deep, medium, and shallow resistivity; DPHI_SS=density derived sandstone porosity; NPHI_SS=neutron-derived sandstone porosity; PE_FACT= photoelectic factor.

Site specific information from the injection zone will be acquired when the project wells are drilled through the pre-operational testing program and will include, but are not limited to, well logging, fluid sampling, core acquisition and analysis, and injectivity testing (Attachment 05: Pre-Op Testing Program, 2023).

The baseline 3D surface seismic data will be calibrated to the well data and used for inversion analysis. This will allow the project to characterize variations in injection zone porosity and lithology away from the project wells over the imaging area of the 3D surface seismic data volume.

2.24.4 Eau Claire Formation

The low porosity, clay-rich mudstones of the Eau Claire Formation have extremely low permeabilities and serve as an effective seal for gas storage projects in the central Illinois Basin (Patrick Engineering, 2011). At ADM CCS1, the upper portion of Eau Claire Formation is composed of dense limestone with siltstone stringers, and the lower portion primarily consists of shale (60% clay minerals and 37% quartz and potassium feldspar) with a silt interval at the base of the formation. Twelve sidewall cores were collected from the Eau Claire Formation in ADM CCS1, and the average horizontal permeability for these cores is 0.00034 mD. Average vertical permeability of the Eau Claire Formation is expected to be lower than horizontal permeability, and regional collection of Eau Claire Formation core from underground injection wells shows that the confining zone has median regional porosity and permeability values of 4.7% and 0.000026 mD, respectively (Patrick Engineering, 2011). Neufelder et al., (2012) and Lahann et al. (2014) inferred that MICP values and higher permeabilities of the coarser grained Eau Claire Formation lithofacies may have entry pressures that could allow CO_2 to enter the formation and the finer grained, whereas clay-rich lithofacies have MICP values and lower permeability that would restrict CO_2 movement (Figure 16). Experimental results and modeling by Roy et al., (2014) using samples of Eau Claire Formation from ADM CCS1 have shown that advective flow and ionic diffusion of CO_2 from the Mt. Simon Sandstone into the Eau Claire is expected to be insignificant.

Similar to the injection zone, well logs, core analyses, and seismic data collected as part of the pre-operational testing program will be used to further characterize the porosity and permeability of the confining zone (Attachment 05: Pre-Op Testing Program, 2023). The capillary pressure of the confining zone is not yet known at the Vervain Project Site; however, the permeability of the confining zone is expected to be very low and unlikely to allow vertical migration of CO_2. Capillary pressure and permeability will be measured as part of the Eau Claire Formation core analysis reported in the pre-operational testing program (Attachment 05: Pre-Op Testing Program, 2023). As the Eau Claire Formation regionally exhibits effective seal characteristics, it is expected to be a competent seal for the underlying Mt. Simon Sandstone injection zone at the Vervain Project Site.

2.24.5 Knox Group

The thick Knox Group carbonates above the Eau Claire Formation are considered a secondary confining zone and monitoring zone. These formations include the Potosi/Eminence, Oneota, and Shakopee Formations (Figure 4). The low-porosity Knox Group carbonates may function as locally effective seals for CO_2 injection (Leetaru, 2014), though the Potosi Formation may have permeable intervals (Willman et al., 1975). Below the Knox Group, porous members of the Ironton/Galesville formations will be used for above zone monitoring.

Well logs acquired as part of the pre-operational testing program will be used to further characterize the porosity and permeability of the Knox Group formations and verify that some of the formations will provide an effective secondary confining zone (Attachment 05: Pre-Op Testing Program, 2023). The baseline 3D surface seismic data will be calibrated to the well data and used for inversion analysis. This will allow the project to characterize variations in porosity and lithology away from the project wells for the Knox Group formations over the seismic imaging area.

2.24.6 Maquoketa Shale

The regional Maquoketa Shale generally exceeds 100 feet thickness within the Illinois Basin, and regionally serves as a seal for hydrocarbons in the underlying Trenton Limestone (Patrick Engineering, 2011). Young (1992) indicates the Maquoketa Shale is a low permeability groundwater-confining unit throughout the Midwest. Core from Kentucky reveals that the Maquoketa is a black, fissile shale dominated by clay minerals and has both sufficiently low permeability and high compressive strength to serve as caprock for an underlying CO_2 reservoir. In the Decatur area of the central Illinois Basin, the Maquoketa Shale contains higher fractions of quartz and carbonate minerals relative to clays and is thinly laminated with low effective porosity (<3%) and permeability (<9.86×10^{-12} cm^2 [1 mD] (Zaluski, 2014).

2.25 Geomechanical and Petrophysical Information [40 CFR 146.82 (a)(3)(iv)]

2.25.1 Geomechanics

A dual permeability, finite difference reservoir simulation model was constructed with a corresponding 3-D finite element geomechanical grid to evaluate the confining zone (Eau Claire Formation) integrity. The geomechanical model has gridblocks that range in size from 400 feet × 400 feet to 1,000 feet × 1,000 feet laterally. The geomechanical model calculates the effective minimum stress of each gridblock as CO_2 is being injected and the pore pressure increases, using specific rock properties for each formation. Young's Modulus, Poisson's Ratio, and the bulk compressibility for the Ironton-Galesville, Eau Claire, Mt. Simon Sandstone, and Argenta Formations were calculated from the well logs available from the ADM CCS1 well on a 0.5 ft interval, and the averages for each zone are shown in Table 5. The log suite consisted of modern sonic, density, neutron, PE, GR, and resistivity logs. A caliper log was also available and was used to assist in quality control of the log data.

Average total closure stress (TCS), initial pore pressure, and the change in stress needed to open fractures are listed in Table 6. TCS was calculated by multiplying the pore pressure by Biot's constant and subtracting from the overburden stress. Note that the average TCS gradient in the Lower Mt. Simon zone is 0.715 psi/ft, which is consistent with a fracture gradient obtained from a step-rate test and is used to calculate the maximum bottomhole flowing pressure (BHFP). EPA requirements state that no fractures should be created and that no existing fractures should be propagated as a result of CO_2 injection (40 CFR 146.88(a)). The maximum BHFP was calculated by multiplying the depth of the top perf by the max BHFP gradient and then multiplying that value by a safety factor of 0.8. This assures that the operating BHFP will be much lower than the anticipated fracture pressure. The TCS values for each zone were used to define the initial effective stress in the model. The Barton-Brandis fracture model was included to simulate the opening of fractures if the effective minimum stress falls below the fracture opening stress. In this way, it is possible to determine if fractures will develop or open given a particular injection rate.

Two cases were run:

- Case 1 – Max BHFP < Fracture Pressure x 0.8 (Rate = 1.25 Mtpa)
- Case 2 – Max BHFP = Fracture Pressure (Rate = 6.23 Mtpa)

Case 1 is the base case, with operating conditions as proposed in this application, i.e., maximum BHFP is 80% of the fracture pressure, and the injection rate is limited to 1.25 Mtpa; this is mainly due to THP constraints (~1,700 psi). Case 2 is a theoretical case to test fracture behavior should the BHFP equal the fracture pressure assuming no THP constraints. It should be noted that THP constraints prevent the project from reaching the rates used in Case 2.

For Case 1, the results indicate that no fractures are created in any zone when a 0.8 safety factor is used. In Case 2, where max BHFP = fracture pressure, fractures are created in the Lower Mt. Simon Sandstone, but they do not extend into the Middle Mt. Simon or Arkose intervals. In the unlikely event that fractures were to occur in the Lower Mt. Simon Sandstone, the sudden decrease in THP would be noticed and corrective actions would be taken immediately. The results from the two cases demonstrate that even with a very large injection rate, no fractures are created that will propagate into and compromise the confining zone. In addition, the Middle and Upper Mt. Simon units provide a large buffer zone between the perforated interval and the Eau Claire Formation.

Table 5: CBI: Summary of average Young's Modulus, Poisson's Ratio, and Bulk Compressibility values calculated from ADM CCS1 well logs.

Table 6: Summary of average TCS, Pore Pressure, and the reduction in stress needed to open fractures

Formation	Top, feet	Mid, feet	TCS Grad, psi/ft	TCS, psi	Pore Pressure Gradient, psi/foot	Pore Pressure, psi	Delta Fracture Opening Stress, psi
Ironton-Galesville	3,928	4,006	.820	3,285	.452	1,810	-1,475
Eau Claire	4,085	4,296	.857	3,682	.452	1,942	-1,740
Eau Claire Silt	4,507	4,523	.844	3,817	.452	2,044	-1,773
Mt. Simon Upper	4,539	4,750	.744	3,534	.452	2,147	-1,387
Mt. Simon Middle	4,993	5,262	.755	3,973	.452	2,378	-1,595
Mt. Simon Lower	5,531	5,650	.715	4,040	.452	2,553	-1,487
Arkose	5,768	5.885	.709	4,172	.452	2,660	-1,512
Argenta	6,002	6,124	.729	4,464	.452	2,768	-1,696

During the pre-operational phase of the project, a variety of site-specific data from the confining and injection zones will be acquired in the project wells to support further geomechanical modeling. Information on the core testing that will provide ductility information for the injection and confining zones are provided in of the Pre-Operational Testing Program (Attachment 5: Pre-Operational Testing Program). These data include:

- Caliper and image logs,
- Triaxial testing to establish geomechanical parameters such as rock strength, Young's Modulus, Poisson's Ratio, and fracture gradient,
- Step-rate testing.

2.25.2 Petrophysics

Petrophysical analysis of the Precambrian Basement, Mt. Simon Sandstone, and Eau Claire Formation was completed using data from five (5) wells in the general region of the Vervain Project Site (Figure 26; Table 7). Log ascii standard (LAS) files and routine core data was acquired from the Illinois State Geological Survey, Illinois Oil and Gas Resources Map (Illinois Oil and Gas Resources, 2022), and public data sources.

Table 7: Well logs used for petrophysical analysis. Log abbreviations can be found at the beginning of this document.

Well Name	Well UWI	Well Logs
FutureGen Industrial Alliance	IL121372213200	Gamma ray, medium/deep resistivity, sandstone porosity (density and neutron), limestone porosity (density and neutron), photoelectric factor, density, sonic
TR McMillen #2	IL120212565000	Caliper, gamma ray, medium/deep resistivity, sandstone porosity (density), photoelectric factor, limestone porosity (density)
ADM CCS1	IL121152341500 1	Gamma ray, medium/deep resistivity, sandstone porosity (density and neutron), limestone porosity (density and neutron), photoelectric factor, density, sonic

Well Name	Well UWI	Well Logs
Hinton 7	IL12019239960000	Spontaneous potential, gamma ray, medium/deep resistivity, sandstone porosity (density and neutron), limestone porosity (density and neutron), density
Furrow 11	IL12113229420000	Spontaneous potential, gamma ray, medium/deep resistivity, sandstone porosity (density and neutron), photoelectric factor, limestone porosity (density and neutron), density

Core and log data were calibrated to well test data that was publicly available from the Illinois Basin–Decatur Project dataset (2021), (Sandia Technologies, 2013) and the TR McMillen #2 well (Whittaker and Carman, 2022). Histograms and cross plots were made using this data which enabled better analysis of wells which did not have core data and improved the geologic model (Figure 28 and Figure 29).

Petrophysical analyses were completed to evaluate the characteristics of the confining and injection zones (Figure 28, Figure 29, and Figure 30). Geophysical well logs, core plugs and well test data were used to calibrate the petrophysical calculations to derive effective porosity and permeability (Figure 29 and Figure 30). These analyses will be re-visited once the project acquires site-specific well logs and core data in the project wells (Attachment 05: Pre-Op Testing Program, 2023).

Pre-processing work on the raw log data, including depth shifting, unit conversion, and synthetic log generation, was performed prior to the petrophysical calculations. Gamma, neutron porosity, sonic, PE, and density logs were used to derive the petrophysical properties for the eight wells, which included:

- Effective Porosity
- Permeability
- Mineralogy (where data quality was reliable)
    - Volume Shale (VSH_V)
    - Volume Quartz (Quartz_V)
    - Volume Limestone (Limestone_V)
    - Volume Dolomite (Dolomite_V)
    - Volume Sphalerite (Sphalerite_V)
    - Precambrian (Basalt_V)
    - Bound Water (BVW_V)

Table 8 and Table 9 summarize petrophysical values determined from geophysical well logs and calibrated using data from core and reservoir testing for the Mt. Simon Sandstone and Eau Claire Formation, respectively. The petrophysical values are incorporated into the static geomodel for the Vervain Project Site (Attachment 02: AoR and Corrective Action Plan, 2023). Of the wells evaluated, ADM CCS1 has the highest Mt. Simon Sandstone average porosity and permeability values (13.7% and 56.4 mD) whereas Furrow #11 has the lowest values (10.5% and 13.9 mD).

The effective porosity/permeability cross plots (Figure 28), effective porosity histograms (Figure 29), and permeability histograms (Figure 30) indicate that the Upper, Lower and Arkose Mt. Simon Sandstone intervals have the highest porosity and permeability values. The Middle Mt. Simon has slightly poorer reservoir quality. The Argenta and Eau Claire Shale have the lowest porosity and permeability values. (Attachment 02: AoR and Corrective Action Plan, 2023)

The petrophysical and core data show that the Mt. Simon Sandstone is primarily composed of quartz sandstone with some interbedded shale layers, and that the Lower and Upper Mt. Simon Sandstone intervals generally have better reservoir quality. The Eau Claire Formation primary confining zone has significantly lower effective porosity and permeability values and higher shale content compared to the underlying Mt. Simon Sandstone and the carbonate content increases upward (Figure 29 and Figure 30).

Table 8: Summary of log-derived porosity and permeability values for the Mt. Simon Sandstone from wells in the region (calculated using applied cut-offs: Phie>0.05 and Perm>=1 md, Argenta Formation properties included in values).

Well Name	API	Thickness (feet)	Porosity Avg. (%)	Permeability Avg. (mD)
Future Gen	121372213200	424.8	12.2	20.7
T.R. McMillen #2	120212565000	949.3	12.3	30.2
ADM CCS1	121152341500	1102.8	13.7	56.4
Hinton Bros. #7	120192399601	1904.0	11.3	19.6
Furrow #11	121132294201	1703.5	10.5	13.9

Table 9: Summary of porosity and permeability values for the Eau Claire Formation from wells in the region (no cut-off applied).

Well (API)	API	Thickness (feet)	Porosity Avg. (%)	Permeability Avg. (mD)
T.R. McMillen #2	120212565000	284.5	0.008	0.046
ADM CCS1	121152341500	494.0	0.006	0.002
Hinton Bros. #7	120192399601	551.0	0.010	0.009
Furrow #11	121132294201	430.0	0.008	0.026

Figure 28: CBI: Effective porosity (PHIE) and permeability cross plots with core plug values (grey squares). A) the Eau Claire Formation confining zone above Eau Claire Silt, B) the Upper Mt. Simon Sandstone and the Eau Claire Silt storage zone, C) the Middle Mt. Simon Sandstone, D) the Lower Mt. Simon Sandstone, E) the Mt. Simon Arkose, and F) the Argenta Formation.

Figure 29: CBI: Effective porosity (PHIE) histograms of the key petrophysical wells. The plots are divided into the various storage and confining intervals: A) the Eau Claire Formation confining zone above Eau Claire Silt, B) the Upper Mt. Simon Sandstone and the Eau Claire Silt, C) the Middle Mt. Simon Sandstone, D) the Lower Mt. Simon Sandstone, E) the Mt. Simon Arkose , and F) the Argenta Formation.

Figure 30: CBI: Permeability (mD) histograms of the key petrophysical wells. The plots are divided into the various storage and confining intervals: A) the Eau Claire Formation confining zone above Eau Claire Silt, B) the Upper Mt. Simon Sandstone and the Eau Claire Silt, C) the Middle Mt. Simon Sandstone, D) the Lower Mt. Simon Sandstone, E) the Mt. Simon Arkose, and F) the Argenta Formation

.

Figure 31: CBI: ADM CCS1 (IL121152341500) geophysical logs and petrophysical results. Normalized gamma-ray API (Gamma), resistivity (Res), porosity (PHI), and photoelectric (PE) logs are shown. Effective porosity (PHIE), permeability (Perm), mineralogy/rock type (Min, Limestone, Dolomite, Sphalerite, Quartz), and bound water (Water). Results from petrophysical analyses are also displayed. Core porosity and permeability data are represented by black circles.

Figure 32: CBI: T.R. McMillen #2 geophysical logs and petrophysical results. Normalized gamma-ray API (Gamma), resistivity (Res), porosity (PHI), and photoelectric (PE) logs are shown. Effective porosity (PHIE), permeability (Perm), mineralogy/rock type (Min, Limestone, Dolomite, Sphalerite, Quartz), and bound water (Water). Results from petrophysical analyses are also displayed. Core porosity and permeability data are represented by black circles.

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

Based on Federal Emergency Management Agency (FEMA) classification the Vervain Project Site has a very small probability of experiencing damaging earthquake effects. The site is more than 230 miles north of the strongest shaking Zone E associated with the New Madrid Seismic Zone (Figure 33). All earthquakes since 1800 having magnitude of 2.5 or greater within a 100-mile radius of the project site are shown in Figure 34 and listed in Table 10 (USGS, 2022). The largest earthquake within this 100-mile radius occurred in 1909 approximately forty miles west-southwest with a magnitude of 4.8 Mw. The most recent earthquake occurred on June 17, 2021, approximately 100 miles from the project site near the Indiana/Illinois border with a magnitude of 3.8. No earthquakes have been recorded that have an epicenter within the project AoR.

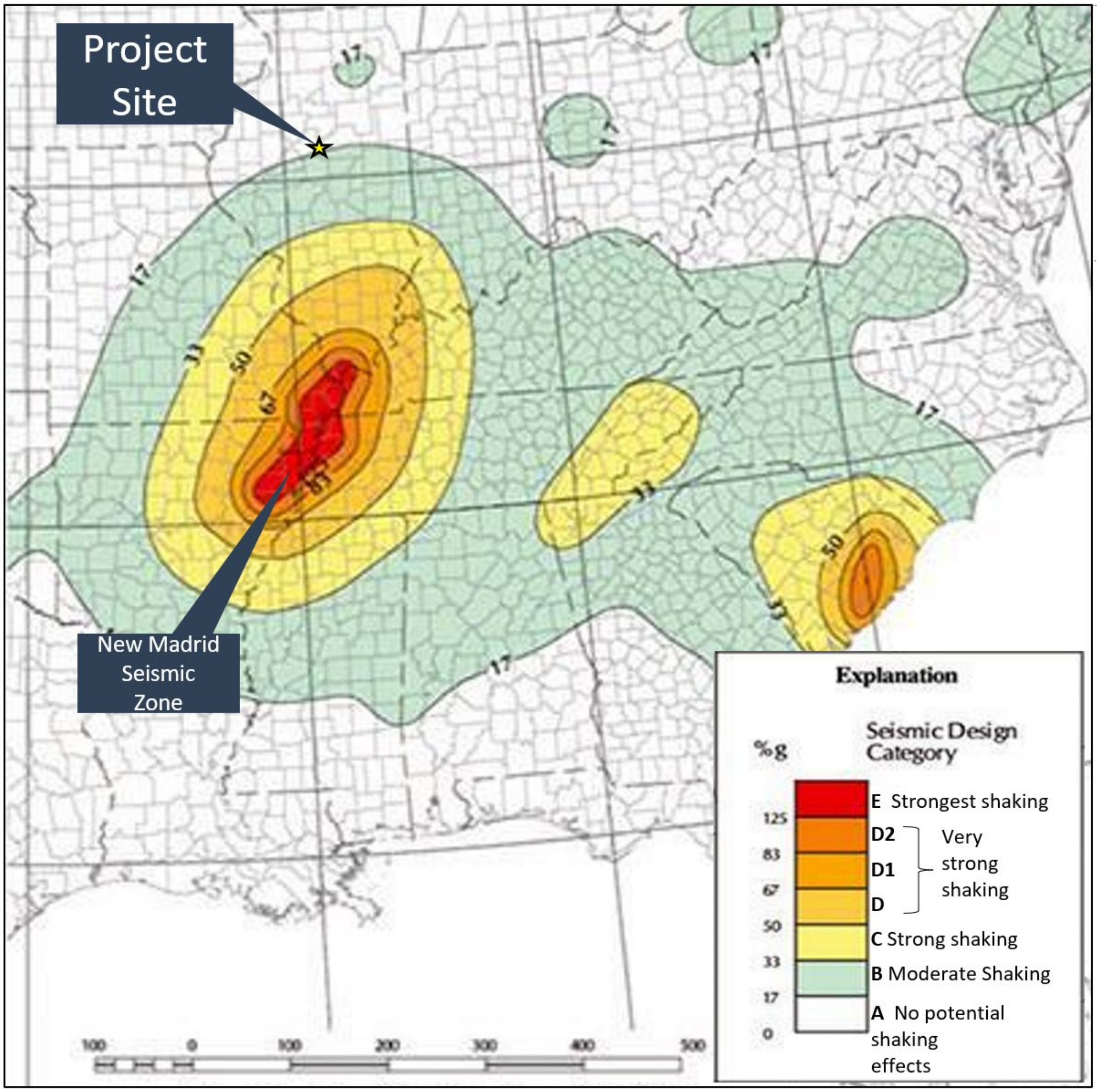

Figure 33: FEMA Earthquake Hazard Map shows that the project site (gray arrow) is located in the lowest earthquake hazard category A (FEMA, 2022).

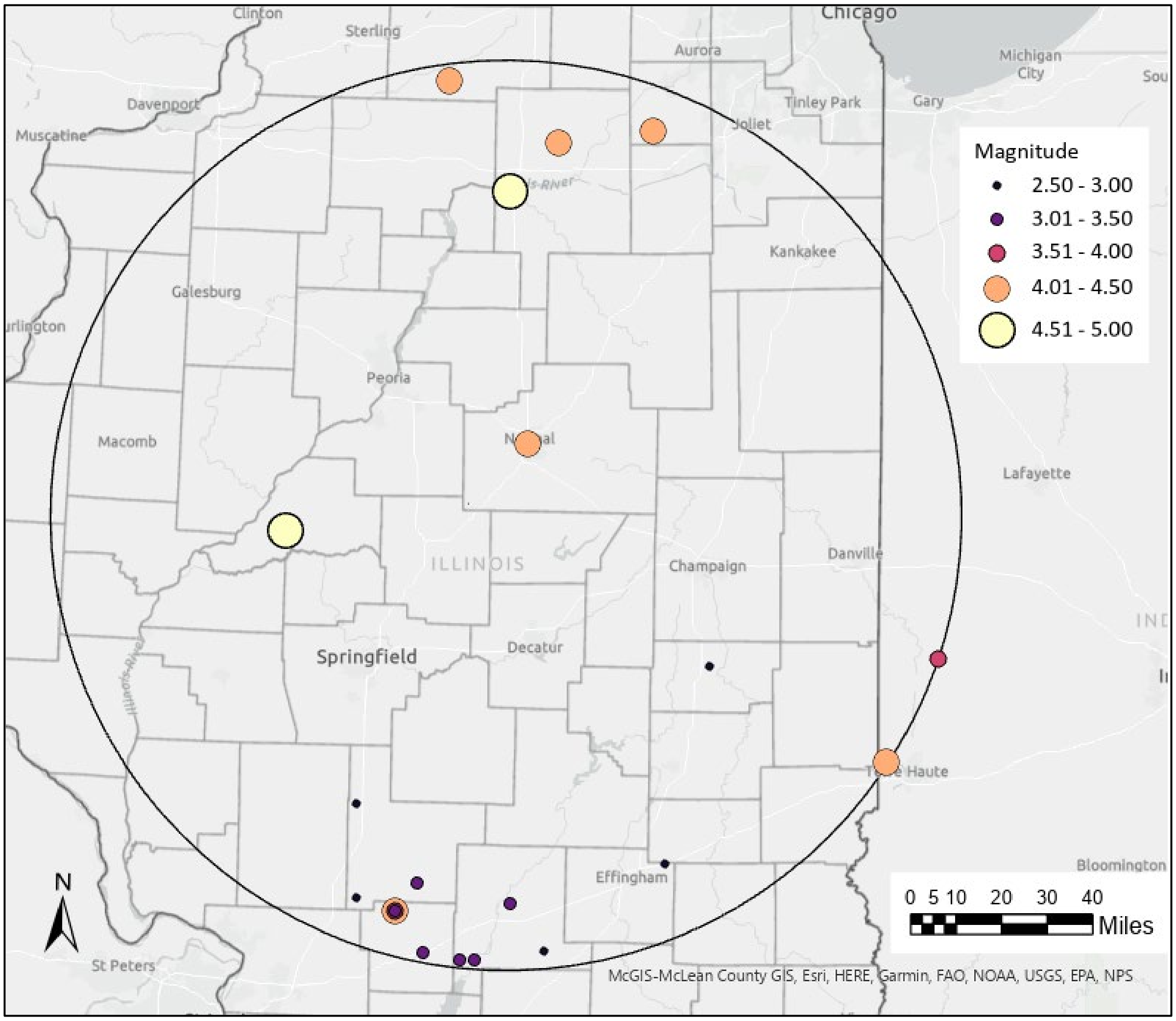

Figure 34: Map of earthquake epicenters with magnitudes of 2.5 or greater within 100 miles of the Vervain AoR. These earthquakes occurred between 1800 and October 2022. Table 10 provides further details.

Table 10: Earthquakes since 1800 with magnitude of 2.5 or greater within a 100-mile radius of the project site.

	Date	Latitude	Longitude	Depth	Magnitude	Location
1	06/17/2021	39.83	-87.29	6.3	3.8	Illinois-Indiana border region
2	07/01/2017	38.85	-89.23	16.8	3.1	9 km SSE of Mulberry Grove, Illinois
3	09/05/2004	38.89	-88.89	33.1	2.9	3 km WNW of Saint Peter, Illinois
4	06/28/2004	41.46	-88.90	10.0	4.2	12 km NW of Dayton, Illinois
5	01/29/1993	39.03	-89.03	5.0	3.2	7 km WNW of Brownstown, Illinois
6	03/02/1990	38.85	-89.17	0.1	3.4	9 km NW of Vernon, Illinois
7	03/13/1987	39.09	-89.41	1.1	3.2	1 km W of Coffeen, Illinois
8	03/28/1985	39.04	-89.66	5.0	2.5	4 km SW of Walshville, Illinois
9	07/01/1982	39.34	-89.67	5.0	2.6	4 km SSW of Waggoner, Illinois
10	04/08/1981	38.87	-89.38	1.1	3.5	3 km SE of Greenville, Illinois
11	02/16/1978	39.80	-88.23	5.0	2.7	4 km E of Tuscola, Illinois
12	02/28/1977	39.17	-88.40	5.0	2.9	1 km WNW of Montrose, Illinois
13	09/15/1972	41.65	-89.37	11.0	4.0	8 km SSW of Amboy, Illinois
14	03/14/1921	39.50	-87.50		4.4	3 km WSW of Saint Mary-of-the-Woods, Indiana
15	01/02/1912	41.50	-88.50		4.5	2 km NW of Lisbon, Illinois
16	07/19/1909	40.20	-90.00		4.8	5 km N of Kilbourne, Illinois
17	02/04/1883	40.50	-89.00		4.3	Near Bloomington, Illinois
18	10/15/1882	39.00	-89.50		4.0	Southern Illinois
19	10/15/1882	39.00	-89.50		3.4	Southern Illinois
20	10/15/1882	39.00	-89.50		4.0	Southern Illinois
21	09/27/1882	39.00	-89.50		4.4	Southern Illinois
22	05/27/1881	41.30	-89.10		4.6	Near La Salle, Illinois

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

The following sections provide information regarding available drinking water resources and delineation of the lowermost Underground Source of Drinking Water (USDW), which is the St. Peter Sandstone, around the project site. Water well, monitoring well, and dry well records were collected for the project AoR from the Illinois State Geological Survey. [redacted] The AoR and Corrective Action Plan includes a detailed discussion of the number and locations of the groundwater wells within the AoR (Attachment 02: AoR and Corrective Action Plan, 2023). A shallower USDW source, the Mahomet Aquifer (Figure 35), is located above the St. Peter Sandstone in both unconsolidated sediments and bedrock.

2.27.1 Near Surface Aquifers

The study site is located within the Sugar Creek sub-basin of the Sangamon River Basin, which is a major tributary to the Illinois River (Figure 35). These rivers primarily drain rural agricultural land between Peoria and Springfield, Illinois. The average ground elevation within the AoR is approximately 710 feet above mean sea level (MSL).

Illinois glacial deposits overlie bedrock and affect surface hydrology and aquifers in the region. During the Pleistocene Epoch, the Illinois Basin experienced several glacial intervals, and glacial processes and post-glacial streams deposited more than 500 feet of valley fill in certain areas of the state (Figure 36 and Figure 37). Specific to glacial geology, the AoR is located where the till and diamict of the Wisconsinan-aged Wedron Group (specifically the Delavan Member of the Tiskilwa Formation) were deposited (Figure 36; Ardith and Johnson, 1996). The Wedron Group is part of the larger Mahomet Aquifer system (Figure 35). Figure 37 shows that there is between 200 to 300 feet of glacial drift sediments overlying the above the Pennsylvanian Shelburn-Patoka Formation bedrock in the AoR (Figure 38).

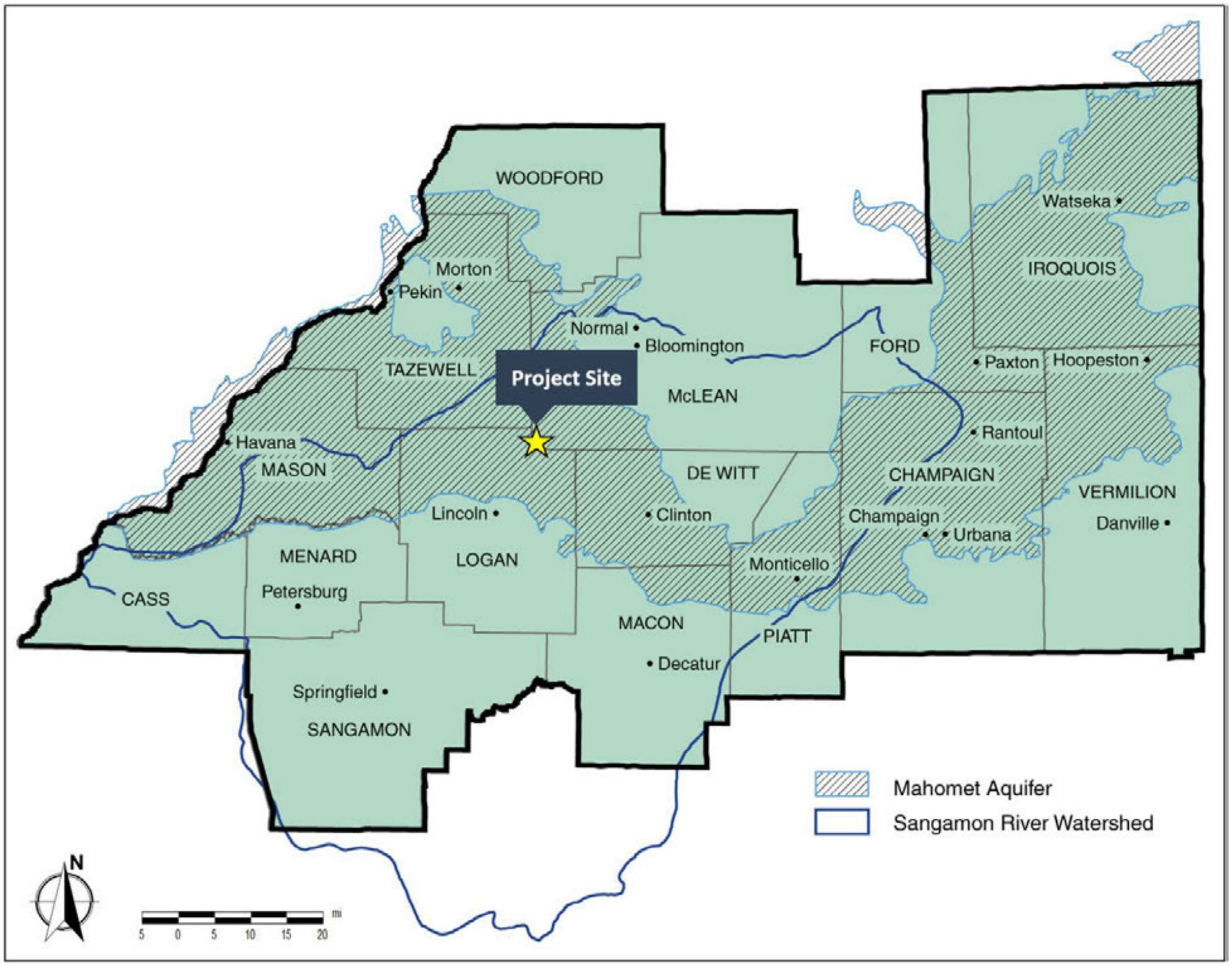

Figure 35: Map of the Mahomet Aquifer and the Sangamon River Watershed. County names and major municipalities are labeled. From Mahomet Aquifer Consortium (2022).

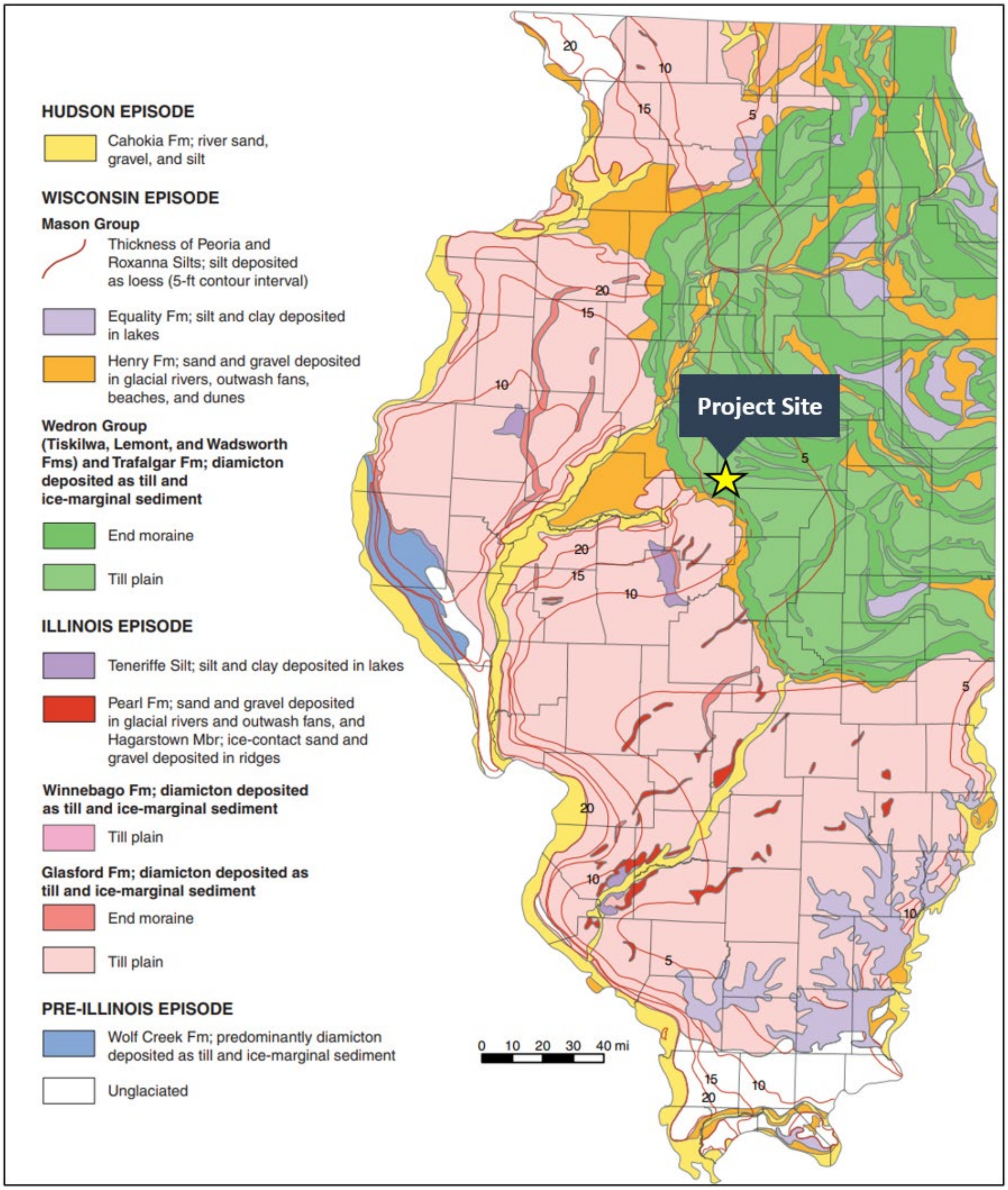

Figure 36: Quaternary deposits of Illinois map show the project site is located on the Wedron Group ice-margin, sediments and till. ISGS, 2005, Quaternary deposits: Illinois State Geological Survey, ISGS 8.5 × 11 map series

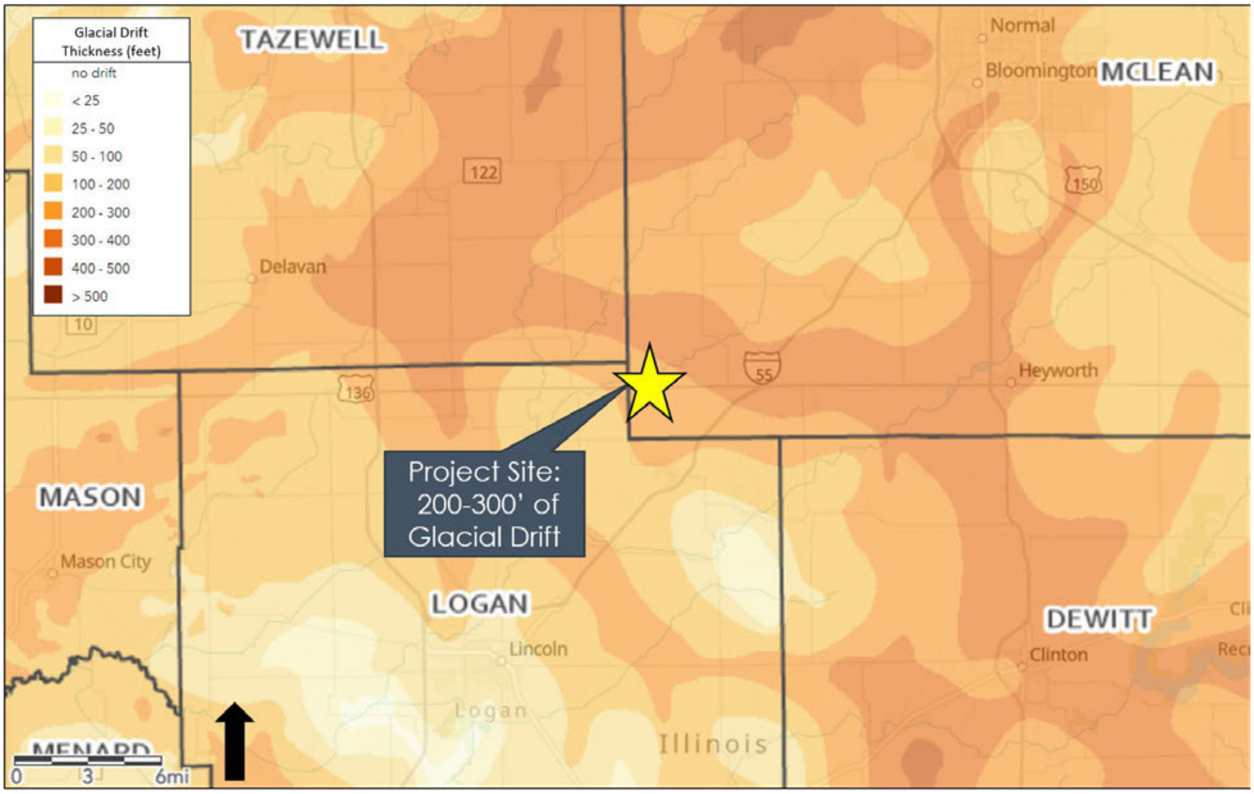

Figure 37: Map of glacial drift thickness in feet. At the project site, 200 to 300 feet of glacial drift are expected.

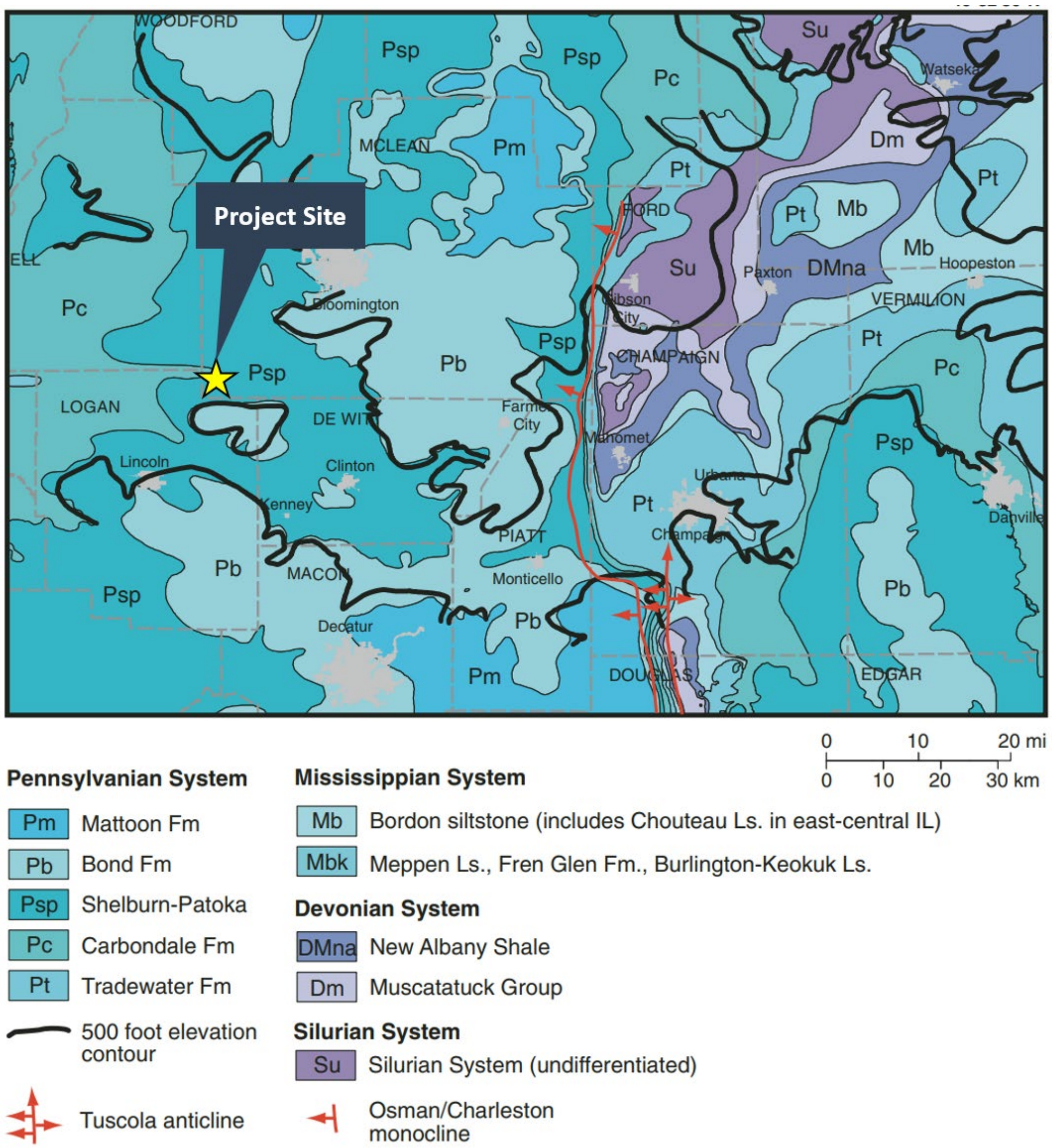

Figure 38: Bedrock geology underlying the Mahomet Aquifer. Modified from Kempton et al., 1991 & Kolata et al., 2005.

2.27.2 Mahomet Aquifer System

Unconsolidated aquifers provide much of the water supply to communities, agriculture, and industry in central Illinois, and the main source of groundwater at the project site is the unconsolidated Wedron Group of the Mahomet Aquifer System (Figure 36). The project site is underlain by 200 to 300 feet of glacial sediments that were deposited on the Pennsylvanian Shelburn-Patoka Formation (Figure 37 and Figure 38).

The Mahomet Aquifer occurs within an east–west trending buried bedrock valley in east-central Illinois, extends into western Indiana, and flows westward at the project site (Figure 39; Kempton et al., 1991; Roadcap et al., 2011). Glacially derived sand and gravel deposits compose the Mahomet Aquifer, which was subsequently buried by up to 300 feet of glacial till in some areas (Kempton et al., 1991). This aquifer is an extensive source of high-quality, fresh groundwater in central Illinois and provides an estimated 220 million gallons of water per day to communities, agriculture, industry, and rural wells (Mahomet Aquifer Protection Task Force, 2018). The aquifer is recharged by natural processes in the surficial glacial deposits (Panno et al., 1994; Roadcap et al., 2011; Panno and Kelly, 2020). Within the project AoR, there are 621 shallow water less than 300 feet depth there were primarily drilled into the shallow glacial deposits (Figure 40).

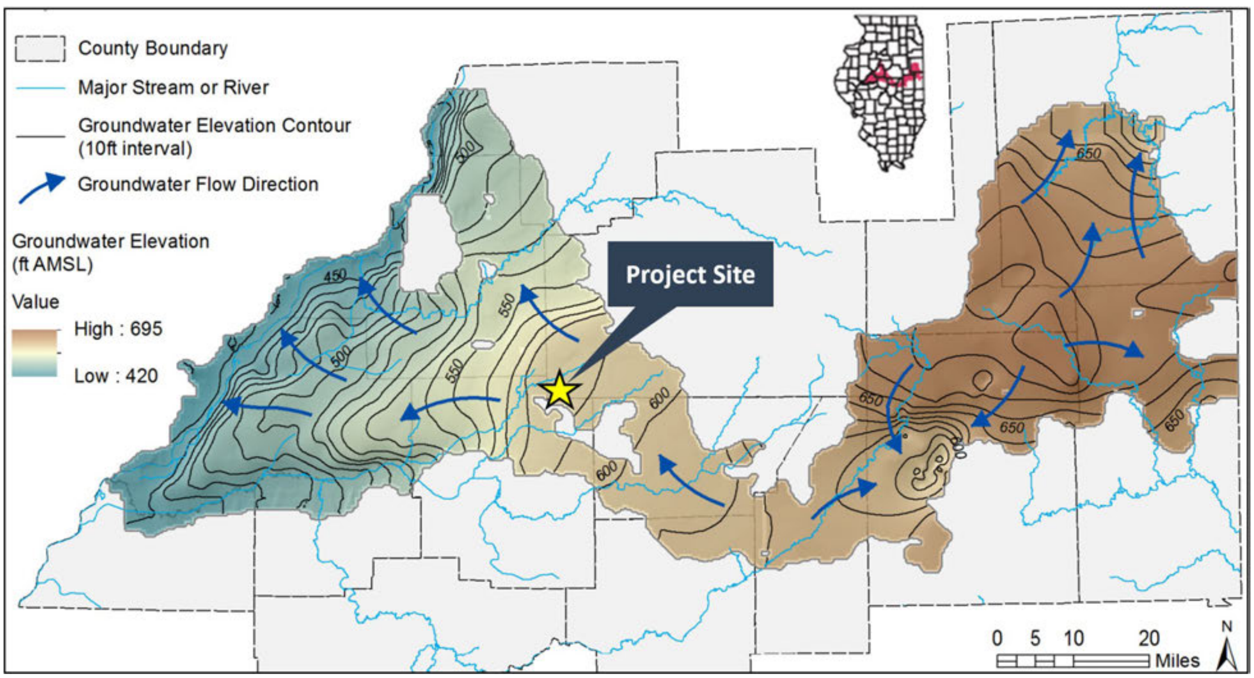

Figure 39: Map of the Mahomet aquifer with groundwater elevation in feet above mean sea level (AMSL) contours and flow direction. Modified from Roadcap et al., (2011).

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Figure 40: Map of groundwater wells within AoR.

2.27.3 Determination of Lowermost USDW

A USDW is defined by the EPA as an aquifer that (40 CFR 146.3):

- Supplies any public water system
- Contains a sufficient quantity of groundwater to supply a public water system; and
  - Currently supplies drinking water for human consumption, or
  - Contains fewer than 10,000 mg/l total dissolved solids (TDS),
- Which is not an exempted aquifer.

At the Vervain Project Site, the Ordovician St. Peter Sandstone is the lowermost USDW based on data from the IBDP and IL-ICCS sites where TDS values range from 4,500 to 5,400 mg/l (Figure 41; Gallokata and McDonald, 2014; (Attachment 02: AoR and Corrective Action Plan, 2023)). The St. Peter Sandstone is a widespread, near-shore quartz arenite (Lamar, 1928a; Willman and Payne, 1942; Buschbach, 1964) and is part of the larger St. Peter Sandstone-Prairie du Chien-Jordan regional aquifer system that is located across the Midwest United States (Young 1992).

The geophysical logs from the ADM CCS1 well shows the top of St. Peter Sandstone USDW at approximately 3,269 feet and base at 3,477 feet (Figure 41). Figure 42 displays that the St. Peter Sandstone formation water is expected to have a TDS concentration around 4,500 mg/l at the Vervain Project Site, which less than the EPA 10,000 mg/l TDS threshold (Young, 1992). The bottom of the St. Peter Sandstone is estimated to be more than 1,700 feet above the top of the Eau Claire Formation confining zone at the project site.

Based on regional data and mapping, the Mt. Simon Sandstone injection and storage zone formation water TDS is expected to be around 100,000 mg/L at the Vervain Project Site (Figure 43). The Cambrian Ironton-Galesville Formations are an aquifer in northern Illinois, but the ADM CCS1 well indicates that it contains saline water in central Illinois (Patrick Engineering, 2011). In general, the Silurian through Pennsylvanian-aged rock in central Illinois are not USDW's, as they either have poor water quality and/or limited production potential.

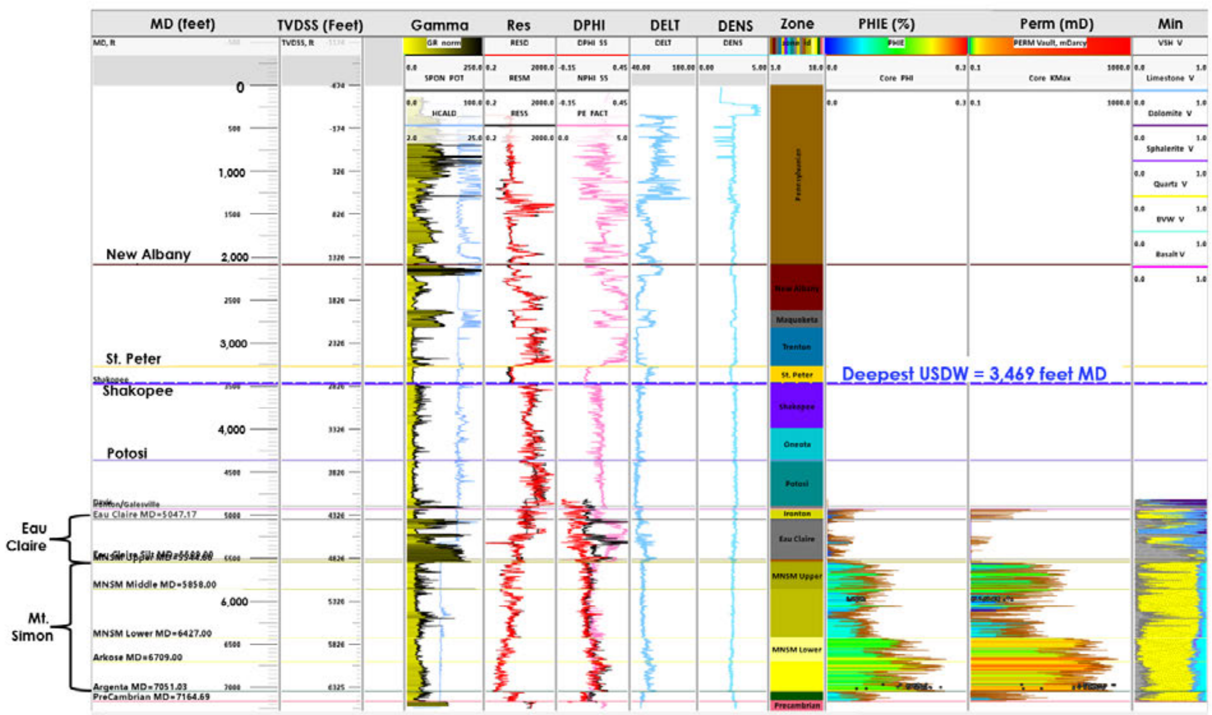

Figure 41: ADM CCS1 (IL121152341500) well logs that show that the lowermost USDW occurs in the St. Peter Sandstone at 3,469 feet measured depth. MD=measured depth in feet, TVDSS=subsea true vertical depth, Gamma=gamma ray, RES=deep resistivity, DPHI=density porosity, DELT=sonic, DENS=density, Zone=stratigraphic zone, PHIE=effective porosity (%), Perm=permeability (mD), and Min=mineralogy.

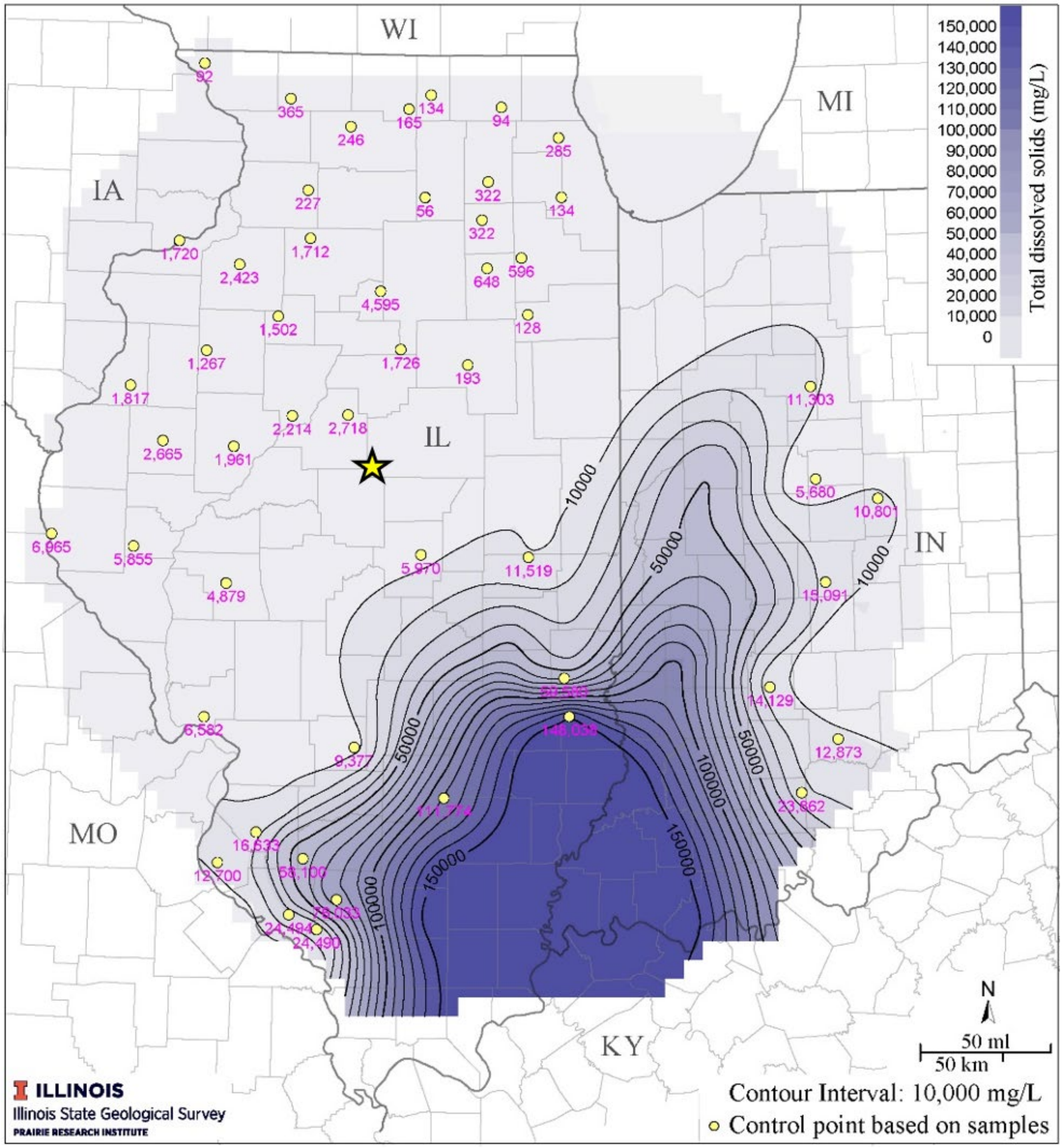

Figure 42: Map of the St. Peter Sandstone total dissolved solids. The project site is represented with a yellow star and sample locations are shown by yellow circles. This is unpublished work by the Illinois State Geological Survey (Whittaker, 2021).

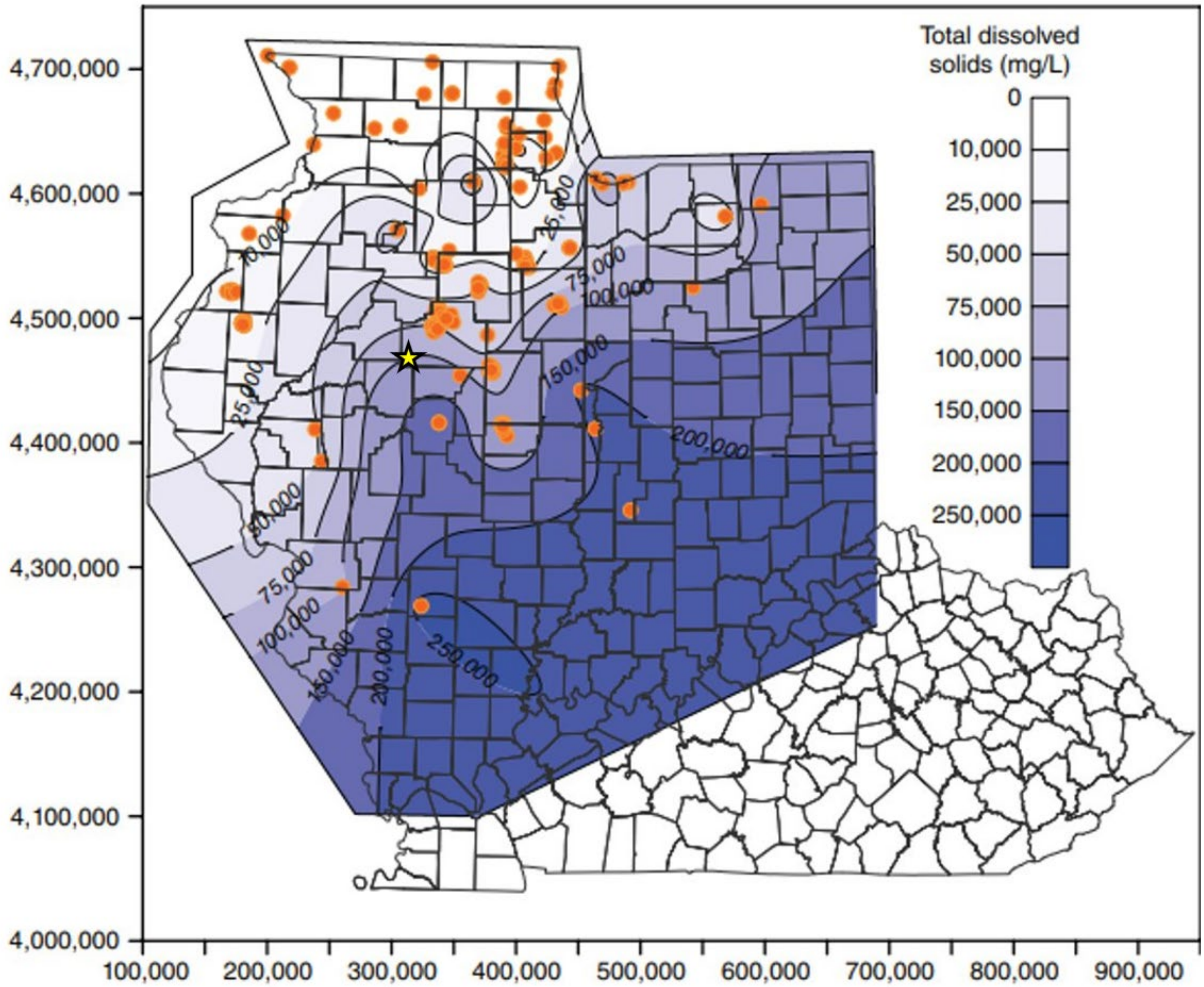

Figure 43: Map of total dissolved solids concentration contours in the Mt. Simon Sandstone formation water. The project site is represented with a yellow star and sample locations are shown by orange circles. (Modified from Mehnert and Weberling, 2014)

2.27.4 Topographic Description

The Vervain Project is located in section 5 and 6, Township 21N, Range 1W, McLean County at an elevation of approximately 710 feet above sea level. It is part of the Till Plains Physiographic Province, which is characterized by generally flat or gently sloping topography with glacial deposits overlying bedrock (Figure 36). This is an area of minimal flood hazard as established by FEMA, and a Zone A flood hazard (1% chance of annual flooding) is located more than one mile to the north of the site along the Sugar Creek flood plain (Figure 44; FEMA, 2022).

Figure 44: National Flood Hazard Layer from the FEMA website.
The two injector wells are located on this map, and there are no flood hazards located within the AoR.

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

2.28.1 Data Sources, Analyses

There has been extensive research into the regional understanding of the geochemistry of fluids and lithology of most strata within the Illinois Basin from numerous studies by the Illinois State Geological Survey as well as detailed work at CCS projects in the vicinity of the Vervain Project Site including the IBDP (Greenberg, 2022), IL-ICCS (Gallokata and McDonald, 2014), and CarbonSAFE Illinois – Macon County (Whittaker and Carman, 2022). Although local variations will exist, there is high confidence in the bulk lithology and mineralogy of rock and geochemistry of formation fluids in injection zone, confining zone, and USDW in the Vervain AoR. Formation fluids, full-diameter rock core, and side-wall core samples have been collected and analyzed by the projects identified above.

The Pre-Operational Testing Program details the data that will be acquired in Deep Observation Well (NV_OBS1) and NV_INJ1 that may be used to support future geochemical evaluation (Attachment 05: Pre-Op Testing Program, 2023). The mineralogy of the injection zone and confining zone will be determined through a combination of core analysis and well logging. Well log data will also be acquired through the lowermost USDW and ACZ monitoring zone to assist in establishing the mineralogy of these formations. Fluid samples will also be collected and analyzed from the St. Peter Sandstone (lowermost USDW), the Ironton-Galesville formations (ACZ), and the Mt. Simon Sandstone (injection zone).

The Testing and Monitoring Plan details the parameters and analytes that will be used to establish baseline conditions for these formations as well as during the injection phase of the project (Attachment 07: Testing And Monitoring Plan, 2023). The aqueous geochemistry data gathered during the pre-operational phase of the project will also be used to support future geochemical modeling work. Geochemical modeling will likely focus on reactions in the injection zone and any reactions in the confining zone that may impact long-term containment and endangerment of USDWs.

2.28.2 Fluid Geochemistry

Many fluid samples have been collected from the Mt. Simon Sandstone in the central Illinois Basin (e.g., Locke et al., 2013). To fulfil the requirements for Underground Injection Control (UIC) Class I or VI permits for the IBDP and IL-ICCS projects, the Illinois State Geological Survey has collected fluid samples since 2011 from both the Mt. Simon Sandstone and St. Peter Formation from these sites at Decatur, IL, about 35 miles southeast of the Vervain Project Site. Mt. Simon fluids are of the Na-Ca-Cl type with Cl/Br ratios typically ranging 165±15 (Panno et al., 2013). The general range of total dissolved solids measured for fluids from Mt. Simon Sandstone at the Decatur, IL, sites is from 150,000 to 200,000 mg/L and the salinity at the Vervain Project Site is expected to be slightly lower around 100,000 mg/L (Figure 43).

The St. Peter Sandstone is the lowermost USDW at the Decatur sites and fluid samples had TDS values around 4,500 to 5,400 mg/L. Panno et al., (2018) indicates the salinity of St. Peter Formation trends lower as the formation becomes shallower to the north of Decatur so salinities at Vervain are expected to be slightly less than about 4,500 mg/L.

2.28.3 *Solid-Phase Geochemistry*

The mineralogy of the Mt. Simon Sandstone has been regionally characterized by numerous studies (Carroll et al., 2013; Freiburg et al., 2014; Yoksoulian et al., 2014; Davila et al., 2020; Shao et al., 2020) that indicate that it is dominated by quartz (63-95%) with lesser amounts of feldspar (2 to 22%), authigenic clay, and detrital clay minerals (Freiburg et al., 2014). The clay-sized fraction of minerals usually present in the Mt. Simon Sandstone are a very small percentage (1 to 3% by volume). The comparison of the clay mineral components of the Mt. Simon Sandstone in central Illinois is consistent among wells and are predominantly illite, montmorillonite, fine mica, and minor kaolinite.

2.28.4 *Geochemical Reactions and Modeling*

Laboratory batch studies have been conducted using rock samples collected from Mt. Simon Sandstone and Eau Claire Formation at IBDP wells to investigate the geochemical interaction of rock, brine, and CO_2 (Carroll et al., 2013; Yoksoulian et al., 2014; Shao et al., 2020). The experiments were conducted under relevant reservoir conditions to identify the reaction mechanisms, kinetics, and solid-phase products that are likely to occur when rock and brine are exposed to injected CO_2. The results of batch studies were also used to constrain the conceptual geochemical model, calibrate mean parameter values, and quantify parameter uncertainty in reactive-transport simulations.

The batch reactor experiments with Mt. Simon Sandstone generally indicated that limited dissolution of rock minerals occurs (Carroll et al., 2013; Yoksoulian et al., 2014; Shao et al., 2020). A decrease of pH occurs quickly in these experiments after CO_2 is introduced because of its dissolution into the brine and dissociation of carbonic acid. Reaction of the Mt. Simon Sandstone can be characterized by an increase in dissolved Si and Al after reaction, suggesting the dissolution of aluminosilicate minerals, such as feldspar and clay minerals. The amount of mineral dissolution is limited, however, as the mass of Al that dissolved from the solid phase into aqueous phase accounted for less than 0.3% of total Al in the rock samples. The liquid to solid ratios in batch experiments were much higher than aquifer conditions suggesting that under aquifer conditions less than 0.002% of Al would be mobilized. Results from XRD analyses indicated the bulk mineral composition remained unchanged for all sandstone samples after reaction (1 to 4 months), indicating that the influence of rock-brine-CO_2 interaction on bulk rock composition was negligible.

Batch experiments introducing CO_2 to crushed Eau Claire shale indicated mineral dissolution from Eau Claire samples were more significant than Mt. Simon sandstone samples (Carroll et al., 2013; Shao et al., 2020). This is likely, in part, due to the processing of rock samples to small fragments that increased the reactive surface area, thus accelerating mineral dissolution of Eau Claire rock. The Eau Claire Formation, however, is a highly laminated, fissile shale to silty shale with the shaliest section near the base (above the Eau Claire Silt) and advective flow from the Mt. Simon Sandstone into the Eau Claire is expected to be insignificant (Roy et al., 2014). Modeling of ionic diffusion into the Eau Claire has also shown this to be insignificant (Roy et al., 2014).

Numerical simulations with PHREEQC 2.17.0 geochemical code (Carroll et al., 2013) suggested that the geochemical alteration of the Mt. Simon Sandstone and Eau Claire Shale can be modeled by incongruent dissolution of annite, illite, K-feldspar, and formation of montmorillonite, amorphous silica, and kaolinite. However, the formation of these secondary minerals were not confirmed with available characterization techniques.

2.28.5 *Mineral trapping*

Computational modeling for the Vervain Project Site investigated the effect of mineralization on long-term trapping of CO_2 based on the potential reactions between brine-CO_2-rock matrix as part of the PISC Alternative Timeframe using the information currently available (Attachment 09: PISC and SC, 2023). This modeling confirmed that mineralization is not expected to play a significant role in trapping for thousands of years.

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

The Pre-Operational Testing Program presents the data that will be collected in order to determine and verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the injection zone, confining zone, and other relevant geologic formations via petrophysical logging and analysis, and core acquisition and testing (Attachment 05: Pre-Op Testing Program, 2023). In addition, baseline 3D surface seismic data will be acquired during the pre-construction phase of the project to assist in characterizing injection zone and confining zone rock properties away from NV_INJ1, NV_INJ2, and NV_OBS1.

At this time, the project does not plan to acquire baseline atmospheric or soil gas data, nor are there plans to pursue atmospheric or soil gas monitoring during the injection phase of the project.

2.30 Site Suitability [40 CFR 146.83]

2.30.1 *Summary*

The Mt. Simon Sandstone at the Vervain Project Site meets all requirements necessary to serve as a competent storage formation and can sequester an estimated 62.5 million tonnes of CO_2 over 25 years as evident through geologic evaluation, static modeling, and computational modeling results (Attachment 02: AoR and Corrective Action Plan, 2023). The Eau Claire Formation at the project site has sufficient thickness, continuity, and low porosity and permeability that support it to be an effective primary confining zone. The successful demonstration of CCS by the IBDP and ongoing commercial IL-ICCS project near Decatur, IL, have each provided significant data that supports the Mt. Simon – Eau Claire storage complex as being highly suitable for long-term carbon sequestration.

Specifically, the injection zone comprised of the Lower Mt. Simon Sandstone and Arkose intervals, as well as the Argenta Formation lower confining zone, have the following properties at the proposed project site:

- Depth to the top of the Lower Mt. Simon Sandstone/Arkose primary injection zone: 4,865 fbsl
- Thickness of the Lower Mt. Simon Sandstone/Arkose primary injection zone: 879 feet

- Thickness of the entire Eau Claire Silt/Mt. Simon Sandstone storage zone: 1,631 feet
- Lateral continuity of the Mt. Simon Sandstone over the region
- Estimated average porosity of the Lower Mt. Simon Sandstone/Mt. Simon Arkose injection zone: 11%
- Estimated average permeability of the Lower Mt. Simon Sandstone/Mt. Simon Arkose injection zone: 47 mD
- Thickness of the Argenta Formation lower confining zone: 158 feet

CO_2 plume development will likely be controlled by heterogeneities within the injection zone, and these heterogeneities will be characterized using a combination of well log, core, and 3D surface seismic data (Attachment 05: Pre-Op Testing Program, 2023). The AoR and Corrective Action Plan includes discussion of the capacity estimates for the injection zone (Attachment 02: AoR and Corrective Action Plan, 2023).

No deep wells penetrate the confining zone within the AoR. The closest well (API # 121130082300) penetrating the Eau Claire Formation is +/-25 miles to the northeast, which is a significant distance outside of the AoR.

FEMA classifies the project site to have a very small probability of experiencing damaging earthquake effects and a low probability of experiencing annual flooding.

2.30.2 *Primary Seal*

The Eau Claire Formation above the Eau Claire Silt will be a competent confining zone. It is estimated to be 416 feet thick at the project site and is laterally continuous across the basin. Its dominant clay content indicates that it is ductile and not prone to brittle fracturing. Based on the petrophysical analysis of wells in the region, it is expected to have low porosity and permeability of 1% and less than 1 mD, respectively, at the proposed site (Attachment 02: AoR and Corrective Action Plan, 2023). Data gathered during the pre-operational phase of the project will be used to verify the Eau Claire Shale as a highly competent confining zone (Attachment 05: Pre-Op Testing Program, 2023).

2.30.3 *Lowermost USDW*

The St. Peter Sandstone is the lowermost USDW at the project site and is expected to be more than 1,700 feet above the top of the Eau Claire Formation confining zone.

2.30.4 *Secondary Confinement Strata*

There are multiple secondary confining beds within the Knox Group to prevent fluids from reaching the lowermost USDW (St. Peter Sandstone) should they migrate past the primary confining zone. The Argenta Formation will act as a lower confining zone with an average permeability of 2.8 mD estimated for the project site.

2.30.5 *Structural Integrity*

2D seismic data acquired for the project indicate there are no faults or fractures, or other natural conduits, that can be identified that would allow injection zone fluid migration beyond the confining zone.

2.30.6 *Capacity and Storage*

The AoR and Corrective Action Plan shows that the Mt. Simon Sandstone at the Vervain Project Site storage location has the capacity and hydrogeologic characteristics necessary to store an estimated 62.5 million tonnes of CO_2. Computational modeling was used to simulate multiphase (brine and CO_2) flow in the subsurface and considered the reservoir geologic and hydrogeologic characteristics. The simulation includes two injection wells within the sequestration site and resulting AoR. Major CO_2 trapping mechanisms modeled include structural/stratigraphic trapping, residual trapping, solubility trapping, and mineral trapping. The model shows that in the post-injection phase and beyond, the pressure front dissipates rapidly, and the CO_2 plume is stable and confined to the injection reservoir.

2.30.7 *Reservoir and Compatibility with the Injectate*

Studies using laboratory experiments and reactive modeling of the Mt. Simon Sandstone from the Illinois Basin suggest that there is minimal reactivity of the rock with brine and CO_2 (Carroll et al., 2013; Yoksoulian et al., 2014; Shao et al., 2020). Experiments using Mt. Simon Sandstone core samples suggest minor dissolution of aluminosilicate minerals, such as feldspar and clay minerals may occur, but the bulk of the mineralogy (i.e., quartz) is effectively inert. Results from XRD analyses indicated the bulk mineral composition remained unchanged for all sandstone samples after reaction, indicating that the influence of rock-brine-CO_2 interaction on bulk rock composition was negligible. Computational modeling indicate that some carbonate minerals may precipitate as a result of feldspar dissolution, but it would take hundreds of years to see any impact of mineral trapping. These reactions will be monitored using fluid samples that will be taken from the injection zone in NV_OBS1 during the first three to five years of the injection phase of the project (Attachment 07: Testing And Monitoring Plan, 2023).

The well casing, tubing, and cement used through the confining zone and injection zone will be CO_2 resistant (Attachment 04A: NV_INJ1 Well Construction Plan, 2023), (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

3. AoR and Corrective Action

Computational modeling of the expected AoR for the Vervain Project shown in Figure 45. The AoR and Corrective Action module provides a detailed summary of the modeling parameters (Attachment 02: AoR and Corrective Action Plan, 2023). After a thorough review of all identified wells in the region, it has been determined that there are no wells within the AoR that penetrate the confining zone, and there is no requirement for corrective action.

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)]***

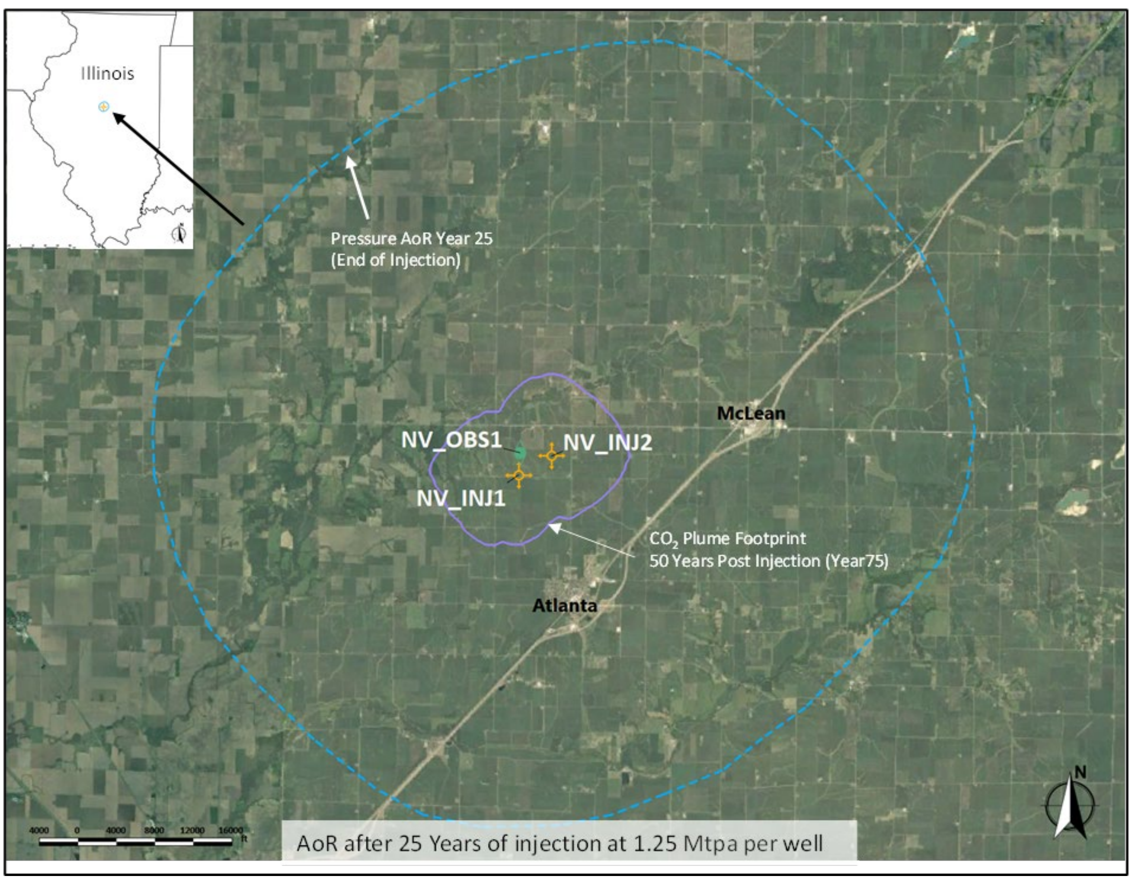

Figure 45: Map of Vervain Project location, proposed location of the injection and deep observation wells, simulated extent of the CO_2 plume 50 years post injection, and the pressure based AoR.

4. Financial Responsibility

The financial assurance estimation for the project was divided into four components: 1) Corrective Action, 2) Injection Well Plugging and Abandonment, 3) Post Injection Site Care and Closure, and 4) the Emergency and Remedial Response Plan (ERRP). Components 1-3 will be covered by a segregated Escrow Account and the ERRP component will be covered by Insurance.

Costs for the first three components were based on independent, third-party engineering data. All appropriate quotes that were obtained from vendors are provided with the submittal documentation. The cost estimate for the ERRP was developed in tandem with DNV. Their full report is provided with the submittal documentation.

Further detail is provided in Section 03: Financial Assurance section of this permit application, which is considered CBI and will be submitted separately to EPA. (Attachment 03: Financial Assurance, 2023).

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]***

5. Injection Well Construction

HGCS intends to use construction materials (casing, cement, etc.) that are verified by independent third-party sources as suitable for the worst-case corrosive load expected to occur during the life of the project. Verification of the suitability is provided as part of the supporting documents for (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

The Vervain Injection wells are planned to have three (3) hole sections [redacted] The surface and intermediate casing cement systems will provide isolation of the deepest USDW.

Both injection wells along with the deep observation well (NV_OBS1) are planned to penetrate the top of the Precambrian Granite Basement (basement). Depending upon the drilling order one of these wells will be used to collect basement characterization data. Once the basement characterization data has been collected, whether in NV_INJ1, NV_INJ2 or NV_OBS1, the open basement section will be plugged back to the injection zone such that the CO2 will not be directly injected into the basement. This will be done prior to running and cementing the long string casing in place.

Should a substantial lost circulation zone (LCZ) be encountered during the drilling of the long string section, well control and loss prevention measures will be implemented. The potential anticipated LCZ is the Knox Group.

Wellheads will be used with appropriately sized components and construction materials based on the build of the wellbore. Following installation of the long string casing and cement, perforations will be made into the casing to access the Lower Mt. Simon Sandstone and Arkose Sandstone for injection.

Schematics for the wellbore and wellhead are provided in the well construction plan attachments (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023) of the permit application.

Downhole pressure and temperature gauges will be installed just above the packer at [redacted]. The downhole pressure gauge will be used to help ensure that the maximum allowable bottomhole pressure (BHP) does not exceed 90% of the fracture pressure. The downhole temperature gauge will be used to calculate the bottomhole density and volume of the injected fluid. The BHP gauges will be programed to take data at the intervals outlined in the testing and monitoring program section of this application (Attachment 07: Testing And Monitoring Plan, 2023). The data collected from these measurement systems will be collected continuously and sent to a surface SCADA system. More information about these sensors is provided in the Well Operations and Testing and Monitoring Plans (Attachment 06A: NV_INJ1 Well Operations Plan, 2023), (Attachment 06B: NV_INJ2 Well Operations Plan, 2023), (Attachment 07: Testing And Monitoring Plan, 2023).

Further details on the proposed stimulation program, construction plans, and materials of construction are provided in this section and in the well construction attachments (Attachment 04A: NV_INJ1 Well Construction Plan, 2023), (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

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

Based on current analysis, it is unlikely that well stimulation will be necessary on either of the injection wells after initial completion, other than to clean out the perforations made in the long-string casing.

HGCS reserves the right to perform intermediate stimulation on the proposed injector wells, should the need arise. A list of some of the common remediation techniques that may be deployed in the future is listed below. Note that this is not an exhaustive list and additional technologies or treatments may be used. Further detail on methods, materials, and chemicals to be used during treatments is provided in (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

- Matrix acid stimulation,
- Coil tubing chemical stimulation,
- Coil tubing mechanical stimulation,
- Perforations.

Stimulations will occur as necessitated by well conditions. These will be identified by evaluating well performance over time. The necessary notification will be provided to the Agency prior to any field mobilization. Within this notification, detail on the proposed procedure, equipment, and chemicals to be used will be provided.

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

The injection wells will be drilled as new wells. Multiple strings of carbon steel and 13-Chrome casing will be installed and cemented in place to protect the USDWs and other strata overlying the injection formation. Fluids will be injected into the Lower Mt. Simon Sandstone and Arkose Sandstone using internally coated carbon steel tubing landed in a nickel coated packer. The Lower Mt. Simon Sandstone and Arkose Sandstone will be accessed through perforations in the long string casing.

A high-level construction procedure is provided below, and a more detailed schedule and procedure is provided in (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

1. Conductor casing will be driven into the ground.
2. Surface hole section will be drilled below the base of the Mahomet Aquifer.
3. Open hole logs will be run.
4. Casing will then be run and cemented in place.
5. After allowing sufficient time for the cement to harden, cased hole logs will be run, and the casing will be pressure tested.
6. Intermediate string hole section will be drilled to within the Davis Formation.
7. Open hole logs will be run.
8. Casing will then be run and cemented in place.
9. After allowing sufficient time for the cement to harden, cased hole logs will be run, and the casing will be pressure tested.
10. Long string hole section will be drilled into basement.
11. Fluid samples will be collected in the Mt. Simon Sandstone for analysis. Or if not run at this time, fluid samples will be collected during well completion operations.
12. Open hole logs will be run.
13. Casing will then be run and cemented in place.
14. After allowing sufficient time for the cement to harden, cased hole logs will be run, and the casing will be pressure tested.
15. Perforations will be made in the long string casing into the Lower Mt. Simon Sandstone and Arkose Sandstone.
16. The packer, tubing, and wellhead will then be installed.

Specifications on the casing, tubing, and cement are provided in more detail in (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023). All materials of construction are designed to API standards.

5.2.1 Casing and Cementing

Table 11 and Table 12 display the safety factors and safety factor loads based on the proposed well design. It is noted that an 80% derating factor is applied prior to any analyses. This implies an additional 1.20 safety factor on top of those displayed in the table. Additionally, material and specification derating based on tensile loading is also considered. Finally, worst-case analyses (i.e., evacuated casing while pumping cement while also pulling up at the max tensile rating) were considered in casing evaluation. Anticipated loads are displayed first, followed by worst case loads. In addition to these analyses, cyclic and temperature loading analysis was performed. The results of this analysis are presented in (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

Table 13 displays the setting depths and specifications of the casing to be used for the injection wells. All casing conforms with API specifications. Table 14 shows the design parameters of the casing, tubing, and packer to be used for the injection wells.

Details on the cement program are provided in (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023). All cement used conforms with API standards. Corrosion resistant cement will be used from the bottom of the well to above the top of the Eau Claire Formation.

Mechanical integrity will be demonstrated as part of the initial completion, and routinely as discussed in (Attachment 05: Pre-Op Testing Program, 2023) and (Attachment 07: Testing And Monitoring Plan, 2023), respectively.

All materials of construction are suitable for the anticipated loading and are not anticipated to decrease in suitability over time.

Table 11: Casing Safety Factors for Design.

Burst	Collapse	Tensile	Von Mises
1.2	1.2	1.5	1.5

Table 12: Casing Safety Factor Loads for Design.

String	Burst	Collapse	Tensile*	Von Mises*
Surface	10.54	2.43	45.2	7.19
Intermediate	1.82	2.53	2.39	2.83
Long String	2.87	2.12	2.91	2.86
Injection Tubing	3.55	4.93	3.57	2.23

Table 13: Injection Wells Casing and Tubing details.

Sensitive, Confidential, or Privileged Information

[redacted]

Table 14: Injection Wells Casing and Tubing Design Parameters.

Sensitive, Confidential, or Privileged Information

[redacted]

5.2.2 Tubing and Packer

The tubing will be internally coated [redacted] and is anticipated to withstand the corrosive loading experienced during normal operations. The internal coating has been field-proven to be suitable for more extreme cases of Enhanced Oil Recovery (EOR) projects. Further detail on the suitability is provided in (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

The packer to be used for the project is Baker Hughes Signature F Injection style packer. This packer will be externally coated with chrome and nickel to resist any corrosion. This packer and coated mechanism are typical for disposal purposes and designed to prevent corrosion or leakage. Further details on the packer are provided in (Attachment 04A: NV_INJ1 Well Construction Plan, 2023) and (Attachment 04B: NV_INJ2 Well Construction Plan, 2023).

6. Pre-Operational Logging and Testing

Details on the pre-operation testing plan are provided in the relevant section of this permit application (Attachment 05: Pre-Op Testing Program, 2023).

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]***

7. Well Operation

The following provides a brief overview of the well operation conditions. Further details on the well operation program are provided in (Attachment 06A: NV_INJ1 Well Operations Plan, 2023) and (Attachment 06B: NV_INJ2 Well Operations Plan, 2023).

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

Table 15 displays the operational parameters that will be used during injection operations. Details on the methods of calculations and inputs for these values are provided in (Attachment 06A: NV_INJ1 Well Operations Plan, 2023) and (Attachment 06B: NV_INJ2 Well Operations Plan, 2023). Values provided in this table are designed to stay below the critical fracture pressure, while also managing the pressure loading experienced during operations to protect equipment. It is not anticipated that significant deviation from these values will occur during the life of the project.

Table 15: Injection Wells Proposed operational procedures.

Parameters/Conditions	NV_INJ1 Limit or Permitted Value	NV_INJ2 Limit or Permitted Value	Unit
Maximum Injection Pressure			
Surface*	2,012	2,016	psi
Downhole	3,180	3,187	psi
Average Injection Pressure**			
Surface	1,645	1,640	psi
Downhole	3,065	3,076	psi
Maximum Injection Mass			
Annual	1.25	1.25	Mtpa
Daily	3.425	3.425	kT
25-year Project	31.25	31.25	Mt
Average Injection Rate*			
Mass Injection Rate	2,378	2,378	kg/min
Volumetric Injection Rate	1,123	1,179	gal/min
	38,514	40,424	barrels/day
Annulus Pressure			
Maximum	1,500	1,500	psi
Minimum	-5	-5	psi
Operational	100	100	psi

* Calculations made based on annual maximum injection volume, assuming the density provided in Attachment 6A and Attachment 6B (Section 4).
**Based on the projected computational modeling results after stable injection operations have occurred

7.2 Proposed CO_2 Stream [40 CFR 146.82(a)(7)(iii) and (iv)]

The CO_2 injection stream will be sourced from biofuel and fertilizer plants located in Illinois, Iowa, Minnesota, Nebraska, and South Dakota and is anticipated to have the fluid composition as shown in Table 16. Once injection begins, HGCS will analyze the CO_2 stream during the injection phase of the project to provide data representative of its chemical characteristics and to meet the requirements of 40 CFR 146.90 (a). Details on the testing and monitoring of the CO_2 stream are provided in the testing and monitoring section of this permit (Attachment 07: Testing And Monitoring Plan, 2023). Additional details on technical standards, QA/QC policy, sample collection and storage policies, and analytical methods are provided in the QASP (Attachment 11: QASP, 2023).

It is currently anticipated that quarterly sampling of the CO_2 injection stream will be sufficient to accurately track the composition of the stream. The regular samples will be taken on quarterly intervals, at the end of each quarter (March, June, September, and December).

Table 16: Anticipated CO_2 Injection Stream Composition.

Component	Specification	Unit
Minimum CO_2	98	mole %, dry basis
Water Content	< / = 20	lb/MMscf
Impurities (dry basis):		
Total Hydrocarbons	< / = 2	mol% dry basis
Inerts (N_2, Ar)	< / = 2	mol% dry basis
Hydrogen	< / = 1	mol% dry basis
Alcohols, aldehydes, esters	< / = 500	ppmv
Hydrogen Sulfide	< / = 100	ppmv
Total Sulfur	< / = 100	ppmv
Oxygen	< / = 800	ppmv
Carbon monoxide	< / = 100	ppmv
Glycol	< / = 1	ppmv

8. Testing and Monitoring

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]

Details on the well operation program are provided in (Attachment 07: Testing And Monitoring Plan, 2023) that address 40 CFR 146.82(a)(15) and 146.90.

9. Injection Well Plugging

Following the conclusion of injection operations, the injection wells will be permanently plugged and abandoned. Details on the methods of these operations are provided in (Attachment 08A: NV_INJ1 Well Plugging Plan, 2023) and (Attachment 08B: NV_INJ2 Well Plugging Plan, 2023). The methods and procedures presented in the attachments are consistent with industry standards and the requirements detailed in 40 CFR 146.92. All materials to be used for the plugging and abandonment are suitable for the anticipated corrosive loading below the top of the Eau Claire Formation. Above the top of the Eau Claire Formation, the materials are standard construction materials, conforming to the API specifications.

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)]

10. Post-Injection Site Care and Closure

The requested documents listed below have been included in the file submission (Attachment 09: PISC and SC, 2023). These documents address the rule requirements for the above EPA citations. HGCS is requesting a 15-year alternative PISC timeframe for the Vervain Project.

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)]***

11. Emergency and Remedial Response

The requested documents listed below have been included in the file submission (Attachment 10: ERRP, 2023). These documents address the rule requirements for the above EPA citations.

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)]*

12. Injection Depth Waiver and Aquifer Exemption Expansion

HGCS does not intend to apply for a Depth Waiver or Aquifer Exemption for the Vervain Project. As such, no supplemental documents have been filed.

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)]***

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(2023). *Attachment 03: Financial Assurance.* Class VI Permit Application Financial Responsibility; Vervain.

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(2023). *Attachment 04B: NV_INJ2 Well Construction Plan.* Class VI Permit Application Injection Well #2 Construction Plan; Vervain.

(2023). *Attachment 05: Pre-Op Testing Program.* Class VI Permit Application Pre-Operational Formation Testing Program; Vervain.

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(2023). *Attachment 06B: NV_INJ2 Well Operations Plan.* Class VI Permit Application Injection Well #2 Operations Plan; Vervain.

(2023). *Attachment 07: Testing And Monitoring Plan.* Class VI Permit Application Testing And Monitoring Plan; Vervain.

(2023). *Attachment 08A: NV_INJ1 Well Plugging Plan.* Class VI Permit Application Injection Well #1 Plugging Plan; Vervain.

(2023). *Attachment 08B: NV_INJ2 Well Plugging Plan.* Class VI Permit Application Injection Well #2 Plugging Plan; Vervain.

(2023). *Attachment 09: PISC and SC.* Class VI Permit Application Post-Injection Site Care And Site Closure Plan; Vervain.

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