Additional Information

Mack Energy
Manitoba SWD-2610

Induced Seismicity Assessment

ALL CONSULTING
GOVERNMENT RELATIONS · ENERGY · PLANNING · TECHNOLOGY
ENGINEERING · ENVIRONMENTAL

September 25, 2024

PN 1904.SEIS.00

Mr. Phillip Goetze, P.G.
NM EMNRD – Oil Conservation Division
1220 South St. Francis Drive
Santa Fe, NM 87505

Subject: **Mack Energy Corporation**
Manitoba SWD #1 - Seismic Potential Letter

Dear Mr. Goetze,

At the request of Mack Energy Corporation (Mack Energy), ALL Consulting, LLC (ALL) has assessed the potential injection-induced seismicity risks in the vicinity of Mack Energy's Manitoba SWD #1 (Subject SWD), a proposed saltwater disposal (SWD) facility in Eddy County, New Mexico, and summarized the findings in this letter. This assessment used publicly available data to identify the proximity and characteristics of seismic events and known faults to evaluate the potential for the operation of the Manitoba SWD #1 to contribute to seismic activity in the area.

Geologic Evaluation

The Subject SWD is requesting a permit to inject into the Devonian Formation at a depth of 10,985-11,525 feet below ground surface (bgs). The Devonian Formation consists of cherty limestone and dolomites and is overlain by approximately 80 feet of low porosity and permeability Woodford Shale, which would prevent the upward migration of injection fluid and serve as the upper confining layer (see **Attachment 1**). Additionally, the Devonian Formation is underlain by various low porosity and permeability zones within the Middle Silurian, Fusselman, and Montoya Group, which consist of limestones, dolomites, and interbedded shale zones. No geophysical logs penetrating the Middle Silurian, Fusselman, and Montoya Group were available within 10 miles of the Subject SWD. A stratigraphic chart depicting the geologic setting is included as **Figure 1**.[1]

Seismic Events and Fault Data

A review of United States Geological Survey (USGS) and New Mexico Tech Seismological Observatory (NMTSO) earthquake catalogues determined that one (1) seismic event has been recorded within a 100 square mile area [9.08-kilometer (km) radius] around the Subject SWD.

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[1] Yang, K.-M., & Dorobek, S. L. (1995). The Permian Basin of west Texas and New Mexico: Tectonic history of a "composite" Foreland Basin and its effects on stratigraphic development. *Stratigraphic Evolution of Foreland Basins*, 149–174. https://doi.org/10.2110/pec.95.52.0149

The closest recorded seismic event was a M0.68 that occurred on April 12, 2018, and was located approximately 5.63 miles east of the Subject SWD (see **Attachment 2**). **Per the USGS earthquake catalog, no seismic events M2.5 or greater have been recorded within 10 miles of the proposed SWD.**

Fault data from United States Geological Survey (USGS) and the Texas Bureau of Economic Geology (BEG)[2] indicates that the closest known fault is located approximately 3.62 miles east of the Subject Well (see **Attachment 2**). This identified fault is within the Precambrian basement, which is approximately 2,475 feet below the proposed injection interval.[3] **No Precambrian basement faults were identified within two miles of the subject well, or within the 100 square mile area of review centered on the subject well**. A map of the seismic events and faults within 9.08 km of the Subject SWD is included as **Attachment 2.**

Figure 1 – Delaware Basin Stratigraphic Chart (Adapted from Yang and Dorobek 1995)

SYSTEM	SERIES/ STAGE	CENTRAL BASIN PLATFORM	DELAWARE BASIN
PERMIAN	OCHOAN	DEWEY LAKE RUSTLER SALADO	DEWEY LAKE RUSTLER SALADO CASTILE
	GUADALUPIAN	TANSILL YATES SEVEN RIVERS QUEEN GRAYBURG SAN ANDRES GLORIETA	DELAWARE MT GROUP BELL CANYON CHERRY CANYON BRUSHY CANYON
	LEONARDIAN	CLEAR FORK WICHITA	BONE SPRING
	WOLFCAMPIAN	WOLFCAMP	WOLFCAMP
PENNSYLVANIAN	VIRGILIAN	CISCO	CISCO
	MISSOURIAN	CANYON	CANYON
	DESMOINESIAN	STRAWN	STRAWN
	ATOKAN	ATOKA BEND	ATOKA BEND
	MORROWAN	(ABSENT)	MORROW
MISSISSIPPIAN	CHESTERIAN MERAMECIAN OSAGEAN KINDERHOOKIAN	CHESTER MERAMEC OSAGE "BARNETT"	CHESTER MERAMEC OSAGE "BARNETT"
		KINDERHOOK	KINDERHOOK
DEVONIAN		WOODFORD DEVONIAN	WOODFORD DEVONIAN
SILURIAN		SILURIAN SHALE FUSSELMAN	MIDDLE SILURIAN FUSSELMAN
ORDOVICIAN	UPPER	MONTOYA	SYLVAN MONTOYA
	MIDDLE	SIMPSON	SIMPSON
	LOWER	ELLENBURGER	ELLENBURGER
CAMBRIAN	UPPER	CAMBRIAN	CAMBRIAN
PRECAMBRIAN			

Seismic Potential Evaluation

Experience in evaluating induced seismic events indicates that most injection-induced seismicity throughout the U.S. (e.g., Oklahoma, Ohio, Texas, New Mexico, and Colorado) occurs as a result of injection into Precambrian basement rock, into overlying formations that are in hydraulic communication with the Precambrian basement rock, or as a result of injection near critically stressed and optimally oriented faults. Seismicity at basement depths occurs because critically stressed faults generally originate in crystalline basement rock and may also extend into overlying sedimentary formations. [4]

Injection into either the Precambrian basement rock or its overlying formations that are hydraulically connected to the basement rock through faulting or fracture networks can increase the pore pressure and may lead to the fault slipping, resulting in a seismic event.[4] As such, the vertical distance between the injection formation and Precambrian basement rock and the

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[2] Horne E. A. Hennings P. H., and Zahm C. K. 2021. Basement structure of the Delaware Basin, in The Geologic Basement of Texas: A Volume in Honor of Peter Flawn, Callahan O. A., and Eichubl P., The University of Texas at Austin, Bureau of Economic Geology.

[3] G. Randy Keller, J. M. Hills &; Rabah Djeddi, A regional geological and geophysical study of the Delaware Basin, New Mexico and West Texas, Trans Pecos Region (West Texas) (1980).

[4] Ground Water Protection Council and Interstate Oil and Gas Compact Commission. *Potential Injection-Induced Seismicity Associated with Oil & Gas Development: A Primer on Technical and Regulatory Considerations Informing Risk Management and Mitigation.* 2015. 141 pages.

presence or lack of faulting within the injection interval are major considerations when determining the risk of injection-induced seismicity.

Geophysical data from nearby well records, aeromagnetic surveys, and gravity surveys indicates the top of the Precambrian basement to be approximately 14,000 feet bgs at the Subject SWD, or approximately 2,475 feet below the proposed injection interval.[3] In addition, publicly available fault data does not indicate any transmissive faulting is present above the Precambrian basement around the Subject SWD. **There are insufficient Precambrian basement penetrations and/or well data regarding Precambrian basement depth to generate an accurate structural contour map of the Precambrian basement in the vicinity of the proposed SWD.**

Class II SWDs in New Mexico are administratively permitted with a maximum pressure gradient of 0.2 psi/ft. Review of New Mexico Oil Conservation Division (OCD) Order IP-537 from the Mack Energy Round Tank SWD #1, which is located approximately 4.24 miles west of the Subject SWD, determined the fracture gradient of the Devonian Formation in the region is 0.41 psi/ft from an approved step-rate test. Typical SWD permitting standards in New Mexico would indicate that formation parting pressure would not be exceeded by the Subject SWD.

Fault Slip Potential Modeling

Due to the presence of mapped Precambrian basement faults within the 100 square mile area of review for the Subject SWD, a Fault Slip Potential (FSP) model was prepared to indicate the likelihood that operation of the Subject SWD would result in a seismic event based on the proximity and characteristics of known injection rates, faults, and subsurface conditions. A map of the FSP area, model parameters, nearby deep SWD parameters, and model run results are included as **Attachment 3**.

The FSP modeling results through 25 years, with injection rates that are likely overestimated, resulted in FSP values of 0.00 on all mapped faults within 100 square miles of the Subject SWD indicating the area presents little to no risk for injection induced seismicity.

Conclusion

As an expert on the issue of induced seismicity, seismic monitoring, and mitigation, it is my opinion that the potential for the Subject SWD to cause injection-induced seismicity is expected to be minimal, at best. This conclusion assumes the Subject SWD will be operated below formation parting pressure and is based on (1) the presence of numerous confining layers above and below the injection interval, (2) the significant vertical and lateral distance between the injection zone and Precambrian basement rock in which the nearest fault has been identified, and (3) Fault Slip Potential modeling results which indicate no potential slip on mapped faults near the Subject SWD.

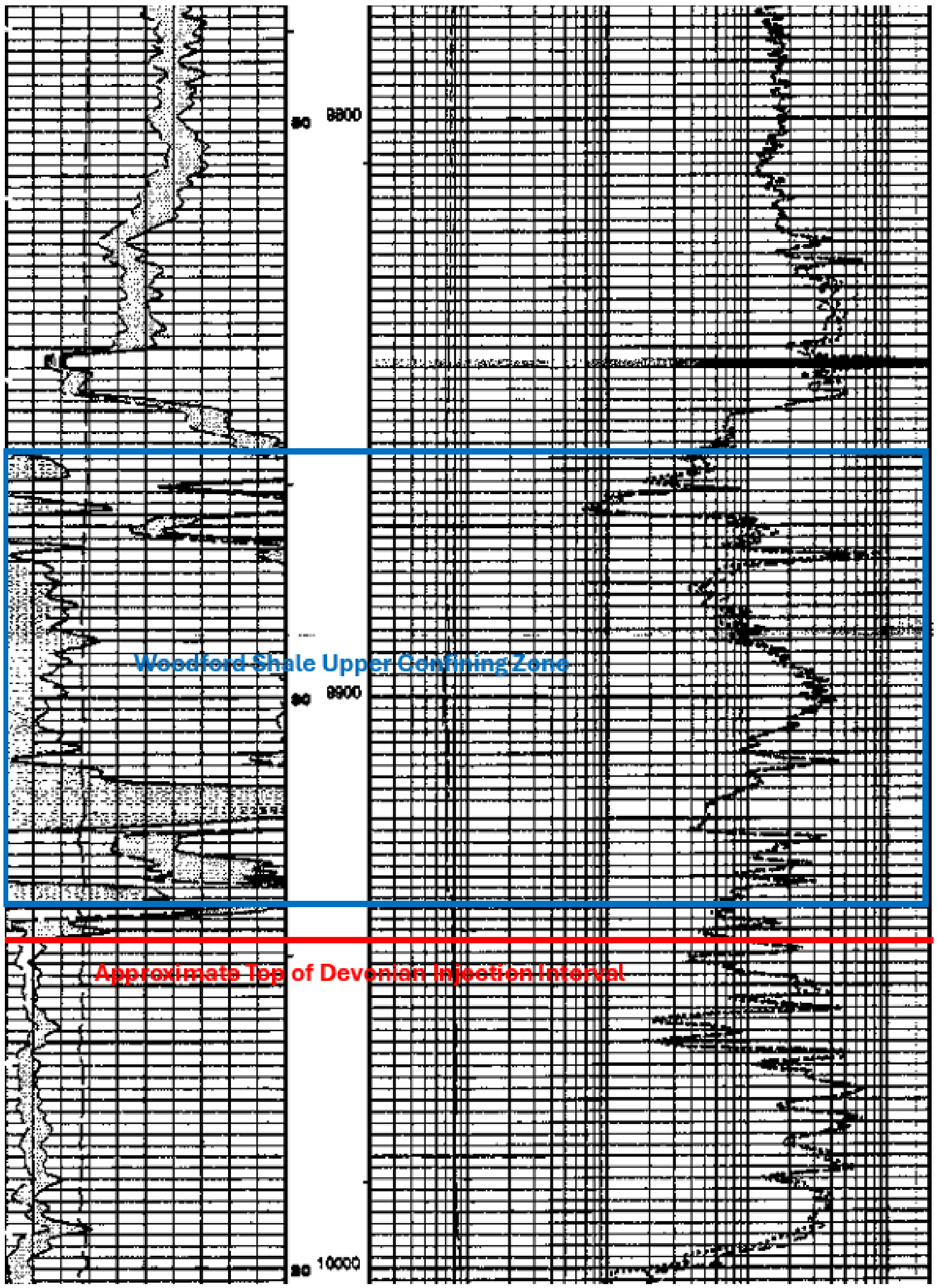
Sincerely,
ALL Consulting

Reed Davis
Geophysicist

Attachment 1
Woodford Shale Upper Confining Zone

Mack Energy Corporation
Manitoba SWD #1 Seismic Information
September 25, 2024

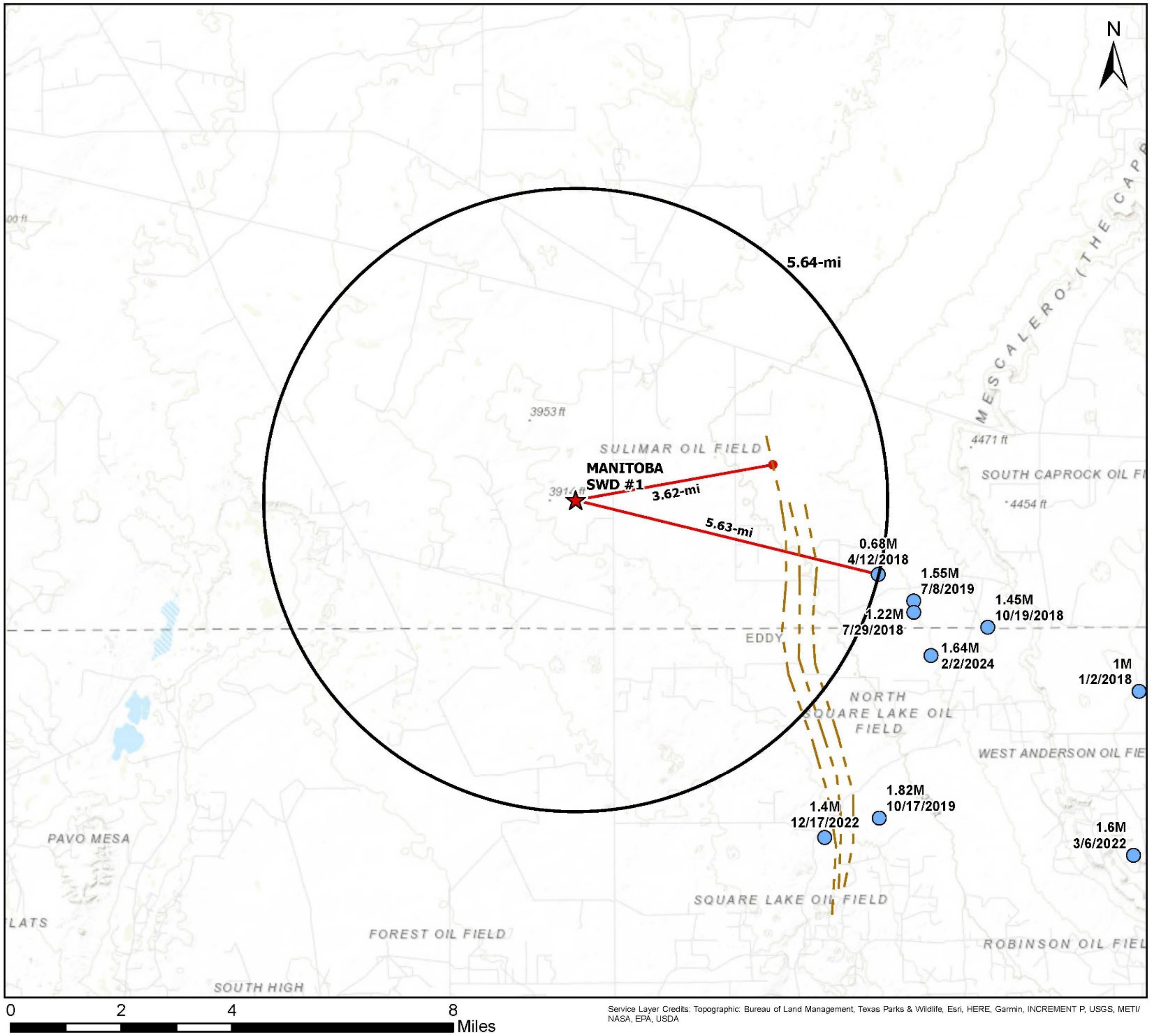
Woodford Shale Upper Confining Zone from API No. 015-32444



Attachment 2
Seismic Event Map

Mack Energy Corporation
Manitoba SWD #1 Seismic Information
September 25, 2024

Manitoba SWD #1 Nearby Seismic Events and Faults

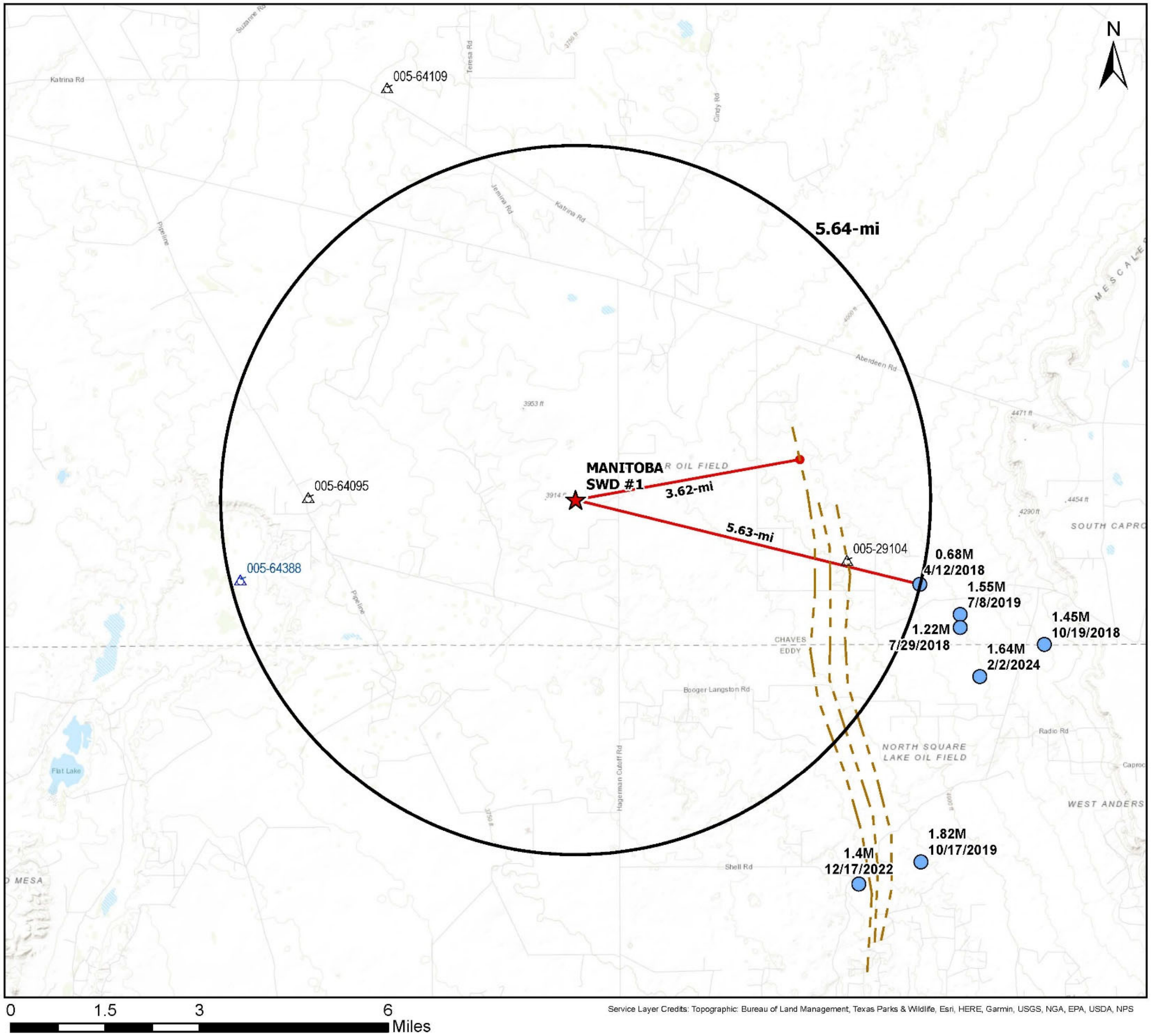


Seismic Analysis Map		
MANITOBA SWD #1 CHAVES COUNTY, NEW MEXICO		
Proj Mgr: Oliver Seekins	February 19, 2024	Mapped by: Ben Bockelmann
Prepared for: MACK Energy Corporation		Prepared by: ALL CONSULTING

Attachment 3
FSP Area Map, Parameters, and Results

Mack Energy Corporation
Manitoba SWD #1 Seismic Information
September 25, 2024

Manitoba SWD #1 FSP Area Map



FSP Area Map		
MANITOBA SWD #1 CHAVES COUNTY, NEW MEXICO		
Proj Mgr: Oliver Seekins	March 13, 2024	Mapped by: Ben Bockelmann
Prepared for: MACK Energy Corporation		Prepared by: ALL CONSULTING

Manitoba SWD #1 FSP Parameters

Parameter	Value	Source
Vertical Stress Gradient (psi/ft)	1.05	ALL Research / Standard Value (2024)
Horizontal Stress Direction (degrees azimuth)	35	Lund Snee (2020)[5]
Reference Depth (ft)	10,985	Mack Energy (2024)
Initial Reservoir Pressure Gradient (psi/ft)	0.43	ALL Research / Standard Value (2024)
A-Phi Parameter	0.52	Lund Snee (2020)
Friction Coefficient	0.6	Lund Snee (2020)
Injection Interval Thickness (ft)	540	Mack Energy (2024)
Porosity (%)	5	Nearby Geophysical Logs (2024)
Permeability (mD)	35	Nearby Geophysical Logs (2024)
Fault Strike (degrees)	Varies	BEG Fault Data (2024)
Fault Dip	60	BEG Fault Data (2024)
Fluid Density (kg/m^3)	1040	ALL Research and Reynolds (2019)[6]
Dynamic Viscosity (Pa*s)	0.0003	ALL Research and Reynolds (2019)
Fluid Compressibility (Pa^-1)	4.70E-10	ALL Research and Reynolds (2019)
Rock Compressibility (Pa^-1)	8.70E-10	ALL Research and Reynolds (2019)

[5] Lund Snee, Jens-Erik, 2020, State of Stress in North America: Seismicity, Tectonics, and Unconventional Energy Development [Ph.D. thesis]: Stanford University, 254p.
[6] Renolds, Todd. 2019. “FSP Analysis (Fault Slip Potential) Exhibits.” New Mexico Oil Conservation Division Case No. 20313, Case No, 20314, and Case No. 20472.

Manitoba SWD #1 Deep SWD Parameters

SWD Name (API)	SWD Status	Injection Rate (BWPD)	Modeled Time Period
Manitoba SWD #1	Pending	15,000	2024 - 2049
Sam Federal SWD #3 (05-29104)	Active	1,267	2024 – 2049
Fraser SWD #1H (05-64388)	Pending	15,000*	2024 – 2049
Round Tank SWD #1 (05-64095)	Active	7,900	2024 - 2049

Notes:

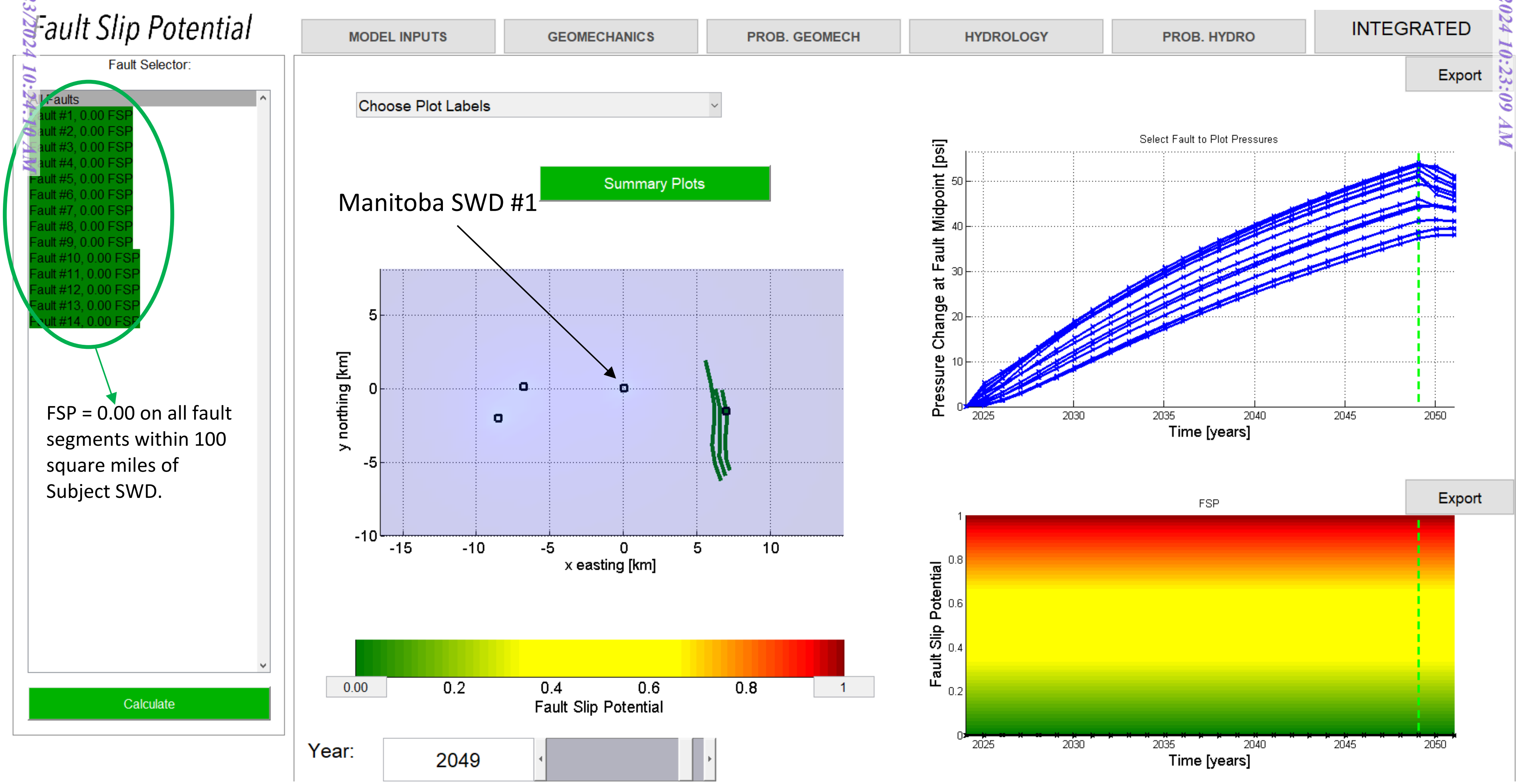
Pending SWDs modeled at maximum permitted or requested injection rate when available.

Active SWDs modeled at permitted injection rate when available, or maximum monthly reported volume when permitted rate unavailable.

*Permitted / requested rate unavailable. Modeled at 15,000 BWPD based on Subject SWD.

Mack Energy Corporation
Manitoba SWD #1 Seismic Information
September 25, 2024

Manitoba SWD #1 FSP Results



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State of New Mexico
Energy, Minerals and Natural Resources
Oil Conservation Division
1220 S. St Francis Dr.
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CONDITIONS

Action 395053

CONDITIONS

Operator:	
MACK ENERGY CORP P.O. Box 960 Artesia, NM 882110960	OGRID: 13837
	Action Number: 395053
	Action Type: [IM-SD] Admin Order Support Doc (ENG) (IM-AAO)

CONDITIONS

Created By	Condition	Condition Date
anthony.harris	None	10/23/2024