OKLAHOMA GAS & ELECTRIC
McCLAIN FACILITY
UIC CLASS I PERMIT RENEWAL APPLICATION
ATTACHMENT A – AREA OF REVIEW METHODS

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ATTACHMENT A

Area of Review Methods

OG&E is applying for renewal of its permit to operate one Class I non-hazardous injection well in McClain County, Oklahoma. The well is located approximately 2.5 miles southwest of the McClain Energy Facility in Section 4, Township 9 North, Range 4 West in McClain County, Oklahoma. The site consists of a 2-acre plot of land located along 24th street, west of Newcastle, Oklahoma (Figure A-1).

Under U.S. Environmental Protection Agency (EPA) Code of Federal Regulations (CFR) Title 40 §146.6, the area of review (AOR) for a Class I injection well is defined as the area in which the owner or operator of a Class I injection well must identify all artificial penetrations into the confining and/or injection zone and determine whether they have been completed or plugged so that they do not provide conduits for fluid movement. Artificial penetrations pose a possible threat to human health or the environment because of their potential for conveying injected effluent and formation fluid out of the injection zone and/or conveying fluid (injected effluent or formation fluid) into an underground source of drinking water (USDW) (non-endangerment standard).

Under EPA regulations, the AOR for a Class I non-hazardous injection well corresponds to one of the following: the area within a fixed 2.5-mile radius of the injection well or an area that is based on the calculated "Cone of Influence" of the injection well, whichever is greater. The "Cone of Influence" is defined as the potentiometric surface area around the injection well in which increased injection zone pressures caused by injection of wastes would be sufficient to drive fluids upward into a USDW or freshwater aquifer.

The injection modeling conducted for the McClain Energy Facility proposed injection well site indicates that the Cone of Influence in the injection interval is calculated to be less than 5,500 feet based on modeling at the maximum requested injection rate of 530 gallons per minute (gpm) (see Figure 4 in Reservoir Mechanics). Plume modeling shows that the effluent plume only reaches no more than a radius of 5,360 feet at the end of the modeled period (year-end 2035). Therefore, to be very conservative the AOR used for the permit application is set at 2.0 miles (10,560 feet).

Artificial Penetration data from the ODEQ approved OG&E 2012 Permit Renewal was leveraged for this 2023 OG&E Permit Renewal application. Since the 2012 permit application, thirty-three new artificial penetrations (AP Nos 49 through 81) have been identified within the 2.0-mile radius area of review. Sixty-four artificial penetrations are identified in this updated 2.0-mile Area of Review for the OG&E Permit Renewal application. Each of these wells are evaluated for non-endangerment.

A.1 Area of Review Map

The Area of Review is determined by 2.0-miles from active OG&E injection wells or the area within the cone of influence calculated in Reservoir Mechanics, whichever is greatest. The cone of influence is determined to be within the 2.0-mile radius, and therefore, this is the established Area of Review for this permit renewal application.

A USGS topographic quadrangle base map that shows the location of the injection well and surface features is included as Figure A-1. This map shows surface bodies of water, quarries, and other pertinent surface features located in the area. A base map showing the injection well permit application identification number and locations for the OG&E injection well and the location, name, lease and well number, and depth of the artificial penetrations in the 2.0-mile Area of Review is presented as Figure A-2. This map was prepared on a 1-inch equals 1,000 feet scale Tobin basemap (P2 Tobin Data) which was obtained in June 2023. This map is scaled such that individual wells are readily defined and labeled. Figure 4 (in Reservoir Mechanics) shows the outermost perimeter of the calculated Cone of Influence based upon depth dependent contours.

A.2 Calculation of the Cone of Influence

The methodology used for calculating the Cone of Influence in this Permit Application is based on the underlying assumption that in the absence of naturally occurring, vertically transmissive conduits (faults and fractures) between the injection interval and USDW (such as at the OG&E site), the only potential pathway between the injection zone and USDW is through an artificial penetration (active or inactive oil and gas well(s)). In order to pose a potential threat to a USDW (i.e., pressure buildup from injection sufficient to drive fluids into a USDW), the pressure increase in the injection interval would have to be greater than the pressure necessary to displace the material residing within the borehole. This pressure necessary to displace the material residing within the borehole is defined as the allowable buildup pressure. Therefore, the Cone of Influence is defined as the area within which injection interval pressures are greater than this allowable buildup pressure.

A static mud column exerts pressure. For an abandoned well to be a pathway for fluid movement, the pressures acting on the static mud column must be greater than the static mud column pressure. In a static fluid column, the gel strength of the mud must also be considered.

In this case, for upward fluid movement to begin, original formation pressure (P_f) plus the pressure due to injection (P_i) must be greater than the static fluid column pressure plus the gel strength of the mud. This relationship is based on a simple balance of forces (Davis, 1986):

$$P_f + P_i > P_s + P_g$$

where:

P_f = original formation pressure (psi)

P_i = formation pressure increase due to injection (psi)

P_s = static fluid column pressure (psi)

P_g = gel strength pressure (psi)

Therefore, pressure increase due to injection must be greater than static fluid column pressure minus original formation pressure:

$P_i > P_s + P_g - P_f$

In an artificial penetration filled with drilling mud, the gel strength of the mud must also be considered. In this case, for upward fluid movement to begin, the original formation pressure (P_f) plus the pressure due to injection (P_i) must be greater than the static fluid column pressure plus the gel strength of the mud. This relationship is based on this simple balance of forces (Davis, 1986):

$P_f + P_i > P_s + P_g$

where:

P_f	=	original formation pressure (psig)
P_i	=	formation pressure increase due to injection (psi)
P_s	=	static fluid column pressure (psig)
P_g	=	gel strength pressure (psi)

Therefore, the pressure increase due to injection must be greater than static fluid column pressure plus the pressure due to gel strength minus original formation pressure, demonstrated as follows:

$P_i > P_s + P_g - P_f$

The initial step in calculating the allowable buildup pressure (cone of influence) for the Pawhuska injection reservoir at the OGE facility involved determining the maximum pressure buildup gradient. This gradient was derived by first calculating the mud column gradient from the very conservative 8.9-lb/gal mud (lightest drilling mud weight used for wells in the area) and subtracting from it the original formation pressure gradient of the injection interval sand.

In iteration, the maximum pressure buildup gradient is calculated by subtracting the original formation pressure gradient from the 8.9-lb/gal mud column gradient, as is demonstrated for the Pawhuska by the following:

0.052 x 8.9 lb./gal = 0.463 psi/ft (mud column gradient, modified from Barker, 1981)

	0.052 is a conversion factor and has units of gal/ft-in^2
-0.425 psi/ft	[average formation pressure gradient from ground level (4,566 foot depth – 18 feet) from August 2001 static survey]
0.038 psi/ft	(maximum pressure buildup gradient, based on 8.9-lb/gal mud)

Thus, 0.038 psi/ft is the maximum pressure buildup gradient allowed in the Pawhuska Sand prior to possible fluid movement. Multiplying the maximum pressure buildup gradient by the depth to the injection reservoir (4,548 feet below ground at the proposed injection well) yields the allowable pressure buildup (172.8 psi), due to the mud column pressure.

However, as an additional measure of conservatism, a 50-foot fallback of the mud column from the surface is utilized in the calculation. This 50-foot fallback in the assumed mud column reduces the allowable buildup pressure due to the mud column from the calculated 172.8 psi to a more conservative allowable buildup pressure value of 149.5 psi.

Additionally, a minimum gel pressure was determined using a conservative value of 20-lb/100 sq. ft. for the gel strength and a borehole radius of 9-inches (largest borehole, to be conservative). The pressure due to gel strength (G) in an open borehole can be calculated from the following equation:

$$P_g = \frac{0.00333 \text{ x } G \text{ x } h}{d}$$

where:

P_g = pressure due to gel strength (psi)

G = gel strength (pounds per 100 square feet [lb./100 ft.^{2}])

h = depth to the injection reservoir from the 50 foot fallback (ft.)

d = borehole diameter (in.)

0.00333 = conversion factor

For a cased hole, pressure due to gel strength (G) can be calculated from the following:

$$P_g = \frac{0.00333 \text{ x } G \text{ x } h}{d_b - d_c}$$

where:

P_g = pressure due to gel strength (psi)

G = gel strength (lb./100 ft.^{2})

h = depth to the injection reservoir from the 50-foot fallback (ft.)

d_b = borehole diameter (in.)

d_c = outside casing diameter (in.)

Multiplying the minimum gel strength by the depth to the injection reservoir (considering a conservative 50-foot fallback in the mud column) and dividing by the maximum borehole diameter yields the additive pressure buildup of 33.3 psi (measured from ground level) due to gel strength of the mud column.

The Cone of Influence allowable pressure buildup for the Pawhuska Sand at the injection well is the sum total of the incremental pressure buildup of 33.3 psi due to gel strength and the incremental pressure buildup due to the differential weight of the mud column of 149.5 psi, or 182.8 psi.

Figures 3 and 4 (in Reservoir Mechanics) presents the maximum pressure increase with distance away from the injection well at the end of the historical period, the end of one year projected injection, and the end of 12 years of projected injection at the maximum projected rate (530 gpm). Figure 4 also shows the Cone of Influence allowable pressure buildup value of 182.8 psi at year-end 2035. In both cases, the Cone of Influence remains with the 2.0-mile radius Area of Review at all times (See Table A-1).

TABLE A-1

CALCULATED RADIUS OF THE CONE OF INFLUENCE FROM THE PROPOSED INJECTION WELL

INJECTION RATE (gpm)	INJECTION INTERVAL	RADIUS OF CONE OF INFLUENCE AT YEAR 10 (YE2035) (Feet)
530	Pawhuska	<5,500

It is important to note that the current calculations of the Area of Review are very conservative and contain significant additional safety factors. The additional safety factors include the actual weight of the mud in the borehole, the actual gel strength of the drilling mud, and borehole closure, which have not been included in the conservative assessment.

A.3 Artificial Penetrations in the Area of Review

A thorough record search was conducted during the preparation of this ODEQ Permit Renewal Application by Geostock Sandia to locate and evaluate all artificial penetrations that lie within the 2.0-mile Area of Review. A total of sixty-four artificial penetrations are identified within the 2.0-mile radius of the injection well. A listing of the artificial penetrations and relevant construction and plugging information is presented on Table A-2. Locations for the artificial penetrations are shown on Figures A-2. Well records for all the wells are contained in Appendix A-1.

A.3.1 Well Identification and Data Sources

A specific and consistent methodology was used to identify all artificial penetrations within the Area of Review. Several data sources were utilized to locate pertinent information regarding each artificial penetration. A base map was secured from P2 Tobin Data in June 2023. Pre-existing information from previous OG&E permit applications was compiled with state agency files for descriptive well documentation. Enverus was used to acquire well logs as well as scout tickets for the thirty-three new wells since the 2012 permit. The Oklahoma Corporate Commission Well Data Finder was used to acquire well records for the new wells and update the records for the pre-existing wells from the 2012 permit.

A.3.2 Incomplete Records

Most of the data on the artificial penetration in the Area of Review were obtained from state records kept on file at each specific state agency. When public records were missing or inadequate, private record searches were conducted to locate additional data. Many current operators or well owners have ceased operation or have changed names making it difficult to locate records. Many of these operators did not keep records on older wells that were dry holes, making it increasingly difficult to document the present status of the well. Wells that were identified as having been drilled but missing the necessary records to document adequacy of plugging and/or construction, were considered potential problem wells and evaluated or modeled for possible vertical fluid movement utilizing the known data.

A.3.3 Confining/Injection Zone Penetration

Wells that penetrate the confining and/or injection zone may have the potential for conveying fluid from the injection zone to an overlying formation or from the injection zone to an overlying USDW. Available geophysical well logs from the artificial penetrations within the Area of Review were evaluated to determine which of the wells penetrate the confining/injection zone. Wells that do not penetrate the Injection Interval (Pawhuska) do not provide potential avenues for fluid movement and need not be evaluated further.

A.3.4 Tabulation of Artificial Penetrations in the Area of Review

A tabulation of data on all of the artificial penetrations within the 2.0-mile radius Area of Review is included in Table A-2. This data includes permit application identification number; operator information; well lease name; status; casing information; key hydrologic and geologic datums; and cement plugging depths. Well records data is contained in Appendix A-1.

A.3.5 Schematics and Records for Artificial Penetrations in the Area of Review

Schematics for all artificial penetrations are included in Appendix A-1. Records data (state forms and scout tickets) for all of the artificial penetrations within the 2.0-mile radius Area of Review are included in Appendix A-1.

A.3.6 Modeling Improperly Constructed or Plugged Wells

Each artificial penetration (active/abandoned) was evaluated as to the adequacy of construction and plugging to determine the potential of the penetration to convey fluid from an injection zone into the overlying USDWs (non-endangerment). Wells requiring further evaluation were identified and were subsequently evaluated in detail or modeled to determine the need for further action or corrective action.

The improperly constructed or plugged wells that are potentially in communication with the Injection Interval (Pawhuska) are further screened using a model evaluation. A total of fourteen wells (AP's 1, 3, 9, 10, 11, 12, 13, 17, 21, 22, 23, 31, 32, and 34) have been identified as improperly constructed or plugged. The evaluation compares the conservatively predicted pressure increases from the DuPont Multilayer Pressure Model under the maximum injection rate case modeling through year-end 2035, with the conservatively calculated allowable pressure buildup (static column pressure plus minimum gel strength) at each potential problem well, using well specific information (mud weight, borehole diameter, sand depth, etc.). The screening calculation is discussed below.

In cases where information was not available, conservative assumptions are made in the model calculations. These assumptions are summarized below:

a) For purposes of calculating the pressure due to gel, in cases where the borehole diameter (bit size) across the injection interval sands is unknown, the largest bit that would fit down the surface casing is used as the bit size. This is conservative since the actual bit diameter may be substantially less than the inner drift diameter of the surface casing string.

b) For purposes of calculating the pressure due to gel, an additional washout factor of 1-inch is added to the bit size used in the calculation.

c) For purposes of calculating the pressure due to gel, a very conservative ultimate gel strength of 20 lb/100 sq-ft is used. This is conservative as studies conducted near the BASF Beaumont Plant indicate that with time, the ultimate gel strength of mud is more than an order of magnitude higher (Pierce, 1989).

d) For purposes of calculating the static mud column pressure, in cases where the weight of the mud in contact with the injection intervals could not be found, a very conservative drilling mud weight of 9.0 lb/gal was used. The available drilling information from area well logs indicates that the mud weight was always higher than 9.0 lb/gal in the Area of Review and for wells surrounding the Area of Review.

e) In cases where shallower cement plugs are present, the additive support of these plugs over an “equivalent mud column” is discounted. This is conservative since the cement plugs would provide a significant added weight to the calculated “static column” pressure and also provide significant flow restrictions to any potential movement of the mud column.

f) A 50-foot fallback in the mud column height within the well was assumed for both calculating the pressure due to gel strength and the pressure exerted by the static mud column. This assumption is used even in cases where a surface plug was set (cement would need to be supported by the mud column immediately underneath the plug). This is conservative since there may be no or minimal mud fallback, especially in formerly productive wells that were plugged across the completion perforations, at the base of the surface casing and at the top of the surface casing, which would essentially result in a closed system with no outlet for the mud.

The calculations used in the modeling screening analysis are presented below.

A static fluid column exerts pressure. The pressures acting on the static fluid column (pressure due to injection plus original formation pressure) must be greater than the static fluid column pressure, before fluid movement will start. In this case, for upward fluid movement to begin, original formation pressure (P_f) plus the pressure due to injection (P_i) must be greater than the static fluid column pressure:

$$P_f + P_i > P_s$$

where:

P_f = original formation pressure (psig)

P_i = formation pressure increase due to injection (psi)

P_s = static fluid column pressure (psig)

In other words, pressure increase due to injection must be greater than static fluid column pressure minus original formation pressure:

$$P_i > P_s - P_f$$

Static fluid column pressure is calculated using the equation:

$$P_s = 0.052 \times h \times M$$

where:

P_s = pressure of static mud column (psi)

h = depth to the injection reservoir from the 50 foot fallback (feet)

M = fluid weight (lb/gal)

and 0.052 is the conversion factor so that P_s is in psi.

In an artificial penetration filled with a column of drilling mud, the gel strength of the mud must also be considered. In this case, for upward fluid movement to begin, original formation pressure (P_f) plus the pressure due to injection (P_i) must be greater than the static fluid column pressure plus the gel strength of the mud. This relationship is based on a simple balance of forces (Davis, 1986):

$$P_f + P_i > P_s + P_g$$

where:

P_f = original formation pressure (psig)

P_i = formation pressure increase due to injection (psi)

P_s = static fluid column pressure (psig)

P_g = gel strength pressure (psi)

Therefore, pressure increase due to injection must be greater than static fluid column pressure plus the pressure due to gel strength minus original formation pressure:

$$P_i > P_s + P_g - P_f$$

The pressure due to gel strength (G) in an open borehole can be calculated from the following equation:

$$P_g = \frac{0.00333 \text{ x } G \text{ x } h}{d}$$

where:

P_g = pressure due to gel strength (psi)

G = gel strength (lb/100 ft^2)

h = depth to the injection reservoir from the 50-foot fallback (feet)

d = borehole diameter (inches)

where 0.00333 is the conversion factor, such that P_g is in psi.

For a hypothetical open borehole, the added resistance due to gel strength for a mud with a very conservative ultimate gel strength of 20 lb/100 ft^2, in a 10-inch borehole, is approximately 6.7 psi for every 1,000 feet of depth.

For a cased hole, pressure due to gel strength (G) can be calculated from:

$$P_g = \frac{0.00333 \text{ x } G \text{ x } h}{d_b - d_c}$$

where:

P_g = pressure due to gel strength (psi)

G = gel strength (lb/100 sq.-ft.)

h = depth to the injection reservoir from the 50-foot fallback (feet)

d_b = borehole diameter (inches)

d_c = outside casing diameter (inches)

For a hypothetical cased borehole, the added resistance due to gel strength for a mud with a very conservative ultimate gel strength of 20 lb/100 ft^2, in a 10-inch borehole with 7-inch casing is approximately 22.4 psi for every 1,000 feet of depth.

An additional margin of safety is added, in reality, due to borehole rugosity (washouts), which increases the contribution in the resistance pressure due to gel strength by a factor of three to five (Collins and Kortum, 1989). As a comparative calculation, using the above formulas calculating pressure due to gel, in the two cases of an open borehole and a cased borehole, the average measured ultimate gel strength from the Nora Schulze No. 2 well (267 lb/100 sq-ft) (Pierce, 1989), and a factor of three contribution in gel strength due to borehole rugosity, the added resistance due to gel strength alone can reasonably be expected to be 266 psi per 1,000 feet of depth in an open borehole and 889 psi per 1,000 feet of depth in a cased well. These values are significantly higher than those required, based on the conservative predictions of pressure build-up at the OG&E Site.

Calculation summary data for each of the wells requiring further evaluation are listed in Table A-2. Since the calculated pressure buildup in the Pawhuska Sand Injection Interval is based on "worst-case" assumptions (maximum injection rates through the end of 2035), actual conditions are expected to fall well within the bounds of the model predictions. As discussed in Reservoir Mechanics, the modeled pressure buildup within the Pawhuska Sand Injection Interval presented in Table A-2 are anticipated to be extremes in behavior. Each of the wells requiring further evaluation pass both the maximum rate modeling evaluation case; therefore, no corrective action is required in any of these wells.

A.3.7 Corrective Action Plan for Improperly Constructed or Abandoned Artificial Penetrations

No improperly constructed or improperly plugged wells fail the conservative modeling screening evaluation. Therefore, a corrective action program is not warranted, as all of the artificial penetrations are either properly constructed, plugged or abandoned, or have a sufficient hydrostatic column as to prevent the movement of fluids into or between USDWs.

A.4 Landowner Information

The OGE injection well site is located approximately 2.0 miles southwest of the McClain Energy Facility in Section 4, Township 9 North, Range 4 West in McClain County, Oklahoma. The site consists of a 2-acre plot of land located along 24th street, west of Newcastle, Oklahoma. A copy of the deed is included as Appendix A-4. The well site is shown on the topographic map of the area (see Figure A-1).

A search for additional landowners with property interests adjacent to the property boundaries of the well site has been conducted. Figure A-3 shows landowner tracts within the AOR and contains a table of pertinent information for each of the landowners identified.

REFERENCES

Davis, K.E. *Factors Effecting the Area of Review for Hazardous Waste Disposal Wells: Proceedings of the International Symposium on Subsurface Injection of Liquid Wastes, New Orleans, National Water Well Association.* Dublin, Ohio. 1986. Pp. 148-194.

Pierce, M.S. *Long-Term Properties of Clay, Water-Based Drilling Fluids: Proceedings of the International Symposium on Class I and II Injection Well Technology, Underground Injection Practices Council Research Foundation.* Dallas, Texas. 1989. Pp. 115-132.

Earlougher, Robert C., Jr. *Advances in Well Test Analysis,* American Institute of Mining, Metallurgical and Petroleum Engineers, Dallas Texas, 1977

Moore, P. L. *Drilling Practices Manual.* PennWell Books, Tulsa, Oklahoma. 1974.

Permit Application of Disposal of Waste in Class I Injection Well submitted to State of Oklahoma, Department of Environmental Quality, Duke Energy, February 2000.

Crane Co., *Flow of Fluids Through Valves, Fittings, and Pipe*, Technical Paper No. 410, 1985