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Strategic Qualitative Risk Assessment of Thousands of Legacy Wells within the Area of Review (AoR) of a Potential CO_2 Storage Site

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Abstract: The subsurface confinement of anthropogenic carbon dioxide (CO_2) demands robust risk assessment methodologies to identify potential leakage pathways. Legacy wells within the Area of Review (AoR) represent one potential leakage pathway. Robust methodologies require enormous amounts of data, which are not available for many old legacy wells. This study strategically categorizes 4386 legacy wells within the AoR of a potential CO_2 storage site in the Illinois basin and identifies the high-risk wells by leveraging publicly available data—reports and well logs submitted to state regulatory agencies. Wells were categorized based on their proximity to the injection well location, depth, the mechanical integrity of well barriers, and the accessibility to these wells throughout the project lifecycle. Wells posing immediate risks were identified, guiding prioritized corrective actions and monitoring plans. Out of 4386 wells, 54 have high priority for corrective action, 10 have medium priority, and the remainder are of low priority. Case study results from the Illinois basin demonstrate the effectiveness and applicability of this approach, to assess the risk associated with legacy wells within the AoR of potential CO_2 storage site, strategically categorizing over 4000 such wells despite data limitations.

Keywords: carbon capture and storage (CCS); well integrity; risk assessment; legacy wells; CO_2 leakage; Class VI Permit application

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1. Introduction

The escalating levels of greenhouse gases, primarily carbon dioxide (CO_2), in the atmosphere are attributed to global climate changes. To mitigate this, Geological Carbon Sequestration (GCS) or Carbon Capture and Storage (CCS) methods have emerged, enabling the capture and permanent storage of CO_2 underground [1]. Pilot CCS projects worldwide have capitalized on learnings from CO_2-enhanced oil recovery initiatives, as highlighted in research [2]. The core aim of CCS projects is to securely store CO_2 underground, preventing its escape to underground sources of drinking water (USDW) or surface leakage, which could contaminate water sources and alter their chemical composition [3,4]. Essential to safeguarding groundwater quality is a robust testing and monitoring regimen encompassing various parameters such as mechanical integrity, injection pressure, corrosion, and groundwater assessments [5,6]. Understanding CO_2 leakage pathways, classified as artificial penetrations (wellbores) and geological features (faults and fractures), is critical for effective monitoring [7].

Legacy wellbores, or improperly plugged and abandoned oil and gas wells, act as a threat to the success of the CCS projects if they remain unidentified and/or if remedial actions are not taken. The standards for cement compositions and well-plugging procedures were set up in 1952 by the American Petroleum Institute (API); prior to that, mainly wood (logs), mud, animal carcasses, etc. were used as plugging materials. With the standardized plugging procedures and regulations set by the API, cement and mud became the most widely used plugging materials [8]. After the discovery of oil in 1859, several thousands of wells were drilled and left unplugged until the oil and gas divisions for each state were set up [4,9]. As of April 2022, there were 123,318 documented orphaned oil and gas wells (a sub-category of unplugged abandoned oil and gas wells) in the US that represent ~3% of the abandoned wells. This count does not take into account the undocumented orphaned wells or potential orphaned wells based on experts' opinions [10]. Cahill and Samano [11] assessed the long-term integrity of onshore decommissioned oil and gas wells in the UK and differentiated them into groups based on their potential of integrity failure. There are several reasons for the improper plugging of wells which could be divided into two broad categories, regulations and operations. The regulations regarding the plugging and abandonment of oil and gas wells vary from country to country, as well as the year when these regulations were implemented [12]. The operational difficulties include the effects of mud–spacer–cement interactions and the reduction in the effective length of cement plugs due to mud contamination [13–18]. The way to mitigate improperly plugged wells is to re-enter the wells and re-plug them using appropriate sealant systems, which is a very costly operation depending upon the number of wells to be re-plugged [19,20]. If a large number of wells needs to be re-plugged then the operator has another option of geosteering the CO_2 plume using active reservoir management techniques to avoid some of the risky wells within the predicted Area of Review (AoR) [21–24]. Thus, the density of improperly plugged and abandoned wells within the CCS sites is one of the components that will decide the success of the project.

The cement used to plug these abandoned wells was not CO_2-resistant cement. Much of the research in the previous two decades focuses on the interactions of supercritical CO_2, brine, and oil well cement. The reaction of supercritical CO_2 with cement is referred to as the carbonation rate of cement. It is critical to know this rate, as it can be extrapolated to determine how many years the cement can resist the leakage of CO_2, provided the experimental studies are carried out under field conditions [25–30]. Two studies in particular, Teodoriu and Bello (2020) and DePaolo and Cole (2013) [31,32], reviewed the experimental work performed by several research groups and summarized their findings related to interactions of supercritical CO_2, brine, and oil well cement. The length of cement coverage across the casings was the main concern of the operators, but several other factors showing the integrity of legacy wells were also highlighted in the survey conducted by Iyer et al. [5,6]. It is, therefore, critical to evaluate if the well barriers reported in the well documents can resist the attacks of CO_2 throughout the lifecycle of the CCS projects or whether the well barriers need to be repaired for wells within the AoR of the CCS projects.

Various qualitative and quantitative risk assessment methods exist for evaluating legacy wells, with quantitative methods offering a knowledgeable assessment of risks and solutions. The literature highlights methodologies utilizing regional well integrity testing programs, focusing on indicators such as sustained casing pressure (SCP) or casing vent flow (CVF) data [33–41]. However, SCP reports are scarce and are available for recently drilled wells where they are mandated by regulations. Other approaches include using Cement Bond Logs (CBLs) or cement coverage in the annulus as indicators of well integrity [42–44]. While some studies focus on currently producing or recently drilled wells, the highest-risk wells are those pre-dating standardized procedures and lacking SCP reports, CBL data, and cementing or casing details. In instances of missing or inconsistent data, qualitative assessments are preferred over quantitative methods. The qualitative risk assessment (QRA) methodology proposed in [45] offers a systematic approach to evaluate the risks associated with various types of legacy wells, addressing the challenges posed by limited information and diverse well types. By categorizing legacy wells based on geological penetrations, accessibility, and barrier integrity, this methodology lays the foundation for effective risk mitigation strategies and standardized comparisons across CCS projects globally.

Building upon the methodologies outlined in Arbad et al. [46] this study employs rigorous analysis techniques to evaluate over 4000 legacy wells within the AoR of a potential geological carbon sequestration site in southern Illinois. By integrating spatial analysis, geological characteristics, and well integrity assessments based on publicly available data, this study provides valuable insights into the potential risks associated with the storage site. The findings serve as a crucial foundation for future decision-making processes, offering stakeholders a comprehensive understanding of the environmental and safety implications surrounding the utilization of the site for storage purposes.

2. Materials and Methods

2.1. Categorization Methodology

The qualitative risk assessment (QRA) devised by Arbad et al. [45] centered on evaluating legacy wells within the Area of Review (AoR) using solely well construction details reported to state agencies, aiding in categorizing and pinpointing wells requiring attention. The authors delineated nine pre-defined well types based on construction (Figure 1) and five accessibility levels to these well types, contingent upon their status—Dry and Abandoned (DA), Plugged and Abandoned (PA), Injection wells (Inj), Producer (Prod.), and Observation wells (Obs.)—with detailed definitions provided in Arbad et al. [45]. Assessing the potential for CO_2/brine migration, the methodology considered well integrity barriers and geologic penetration from publicly available well reports and logs, with well types and accessibility levels correlating inversely with risk and corrective action costs. A stepwise procedure to implement this methodology is discussed in Arbad et al. [46] and this study is the application of the same methodology.

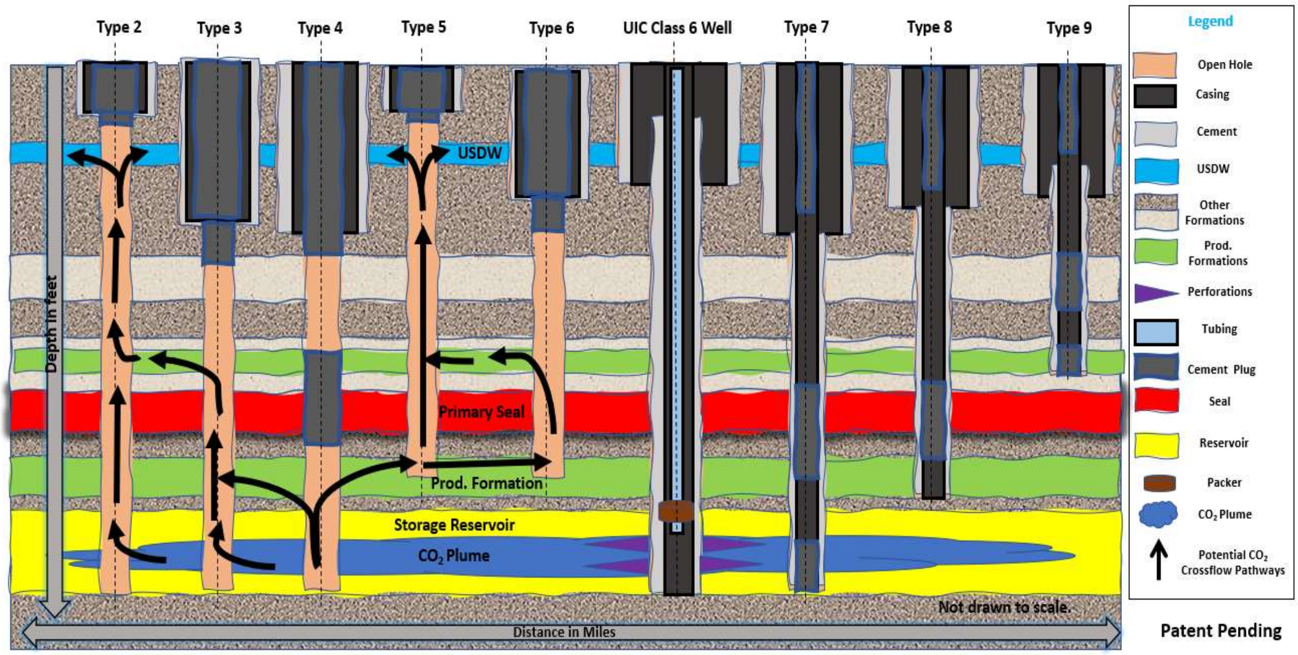

Figure 1. Nine pre-defined types of wells within AoR reprinted with permission from Elsevier [46].

2.2. Case Study Details

Southern Illinois is a historic coal mining area. The legacy of this area is that it is home to several coal-fired plants. These coal-fired plants act as point sources of CO_2. A summary of subsurface evaluations for a Southern Illinois site is presented below in Table 1, which includes the information of the reservoir targets, primary confining units (seals), USDWs, and legacy wellbore information. The reservoir quality of the St. Peter Sandstone is well known for historic potable water production across the upper Midwest and successful natural gas storage operations in Illinois. In the Illinois natural gas storage fields, the St. Peter Sandstone has excellent reservoir quality with porosity values of 5% to over 25% (average 14–16%) and permeability from 10 mD to over 1000 mD (average 150–400 mD). Maquoketa shale acts as a primary confining seal with average porosity determined using mercury injection of 0.9% and permeabilities near 1.8×10^{-4} mD, indicating its effectiveness as a barrier to vertical migration of fluids [47].

Table 1. Summary of Subsurface Evaluations—Lively Grove #1 well (LG1) Site.

Storage Reservoir	**Name**	St. Peter Sandstone
	Approx. Depth (ft)	3570
	Approx. thickness (ft)	170
Primary Confining Seal	**Name**	Ordovician Maquoketa Shale Group
	Approx. Top (ft)	2790
	Approx. thickness (ft)	150
Lowermost USDW	**Formation name**	Shallow Bedrock deposits
	Approx. Top (ft)	Within 500 ft
Legacy Wellbores	**Well penetrating lowermost storage reservoir**	300 boring records within 25 miles area penetrating through Maquoketa Shale.

2.3. Data Collection and Quality Control

Illinois State Geological Survey (ISGS) sent the existing database and the related well reports of legacy wells within a 15-mile radius of the LG1 well. The center of the 15-mile radius is the LG1 location, i.e., one of the 10-acre spots in the following quarter: SW quarter of T5W R2W Section #15 at approximately (38.353028, −89.644836) WGS84. The data package contained 6454 documents (well files in PDF format, and logs in either LAS, TIF, or pdf format). The existing database provided information on 4386 wellbores with a depth greater than 100 ft—well data mainly comprised latitude, longitude, proximity to proposed injection location, completion and plug dates, depths, target formations, formation tops, and other relative information. The quality and quantity of the data within the files varied greatly as the wells were drilled and reported during different years ranging from 1893 to 2018. The wellbores of interest for the qualitative risk assessment were shortlisted based on the following criteria:

- Formation code filtering: All the 4386 wellbores in the existing database were filtered based on the formation codes, i.e., the deepest formation penetrated by the well. All the formation codes for formations below the primary confining seal were selected and all the wells penetrating those formations were shortlisted for evaluation. Table 2 provides the list of formations that are classified as primary confining seals, formations below the primary confining seals, and the storage reservoir complex for the target site.
- Depth filtering: As the approximate top of the Maquoketa seal near the LG1 is 2790 ft and its thickness is approximately 150 ft, wells with TD greater than 2470 ft were considered for preliminary risk assessment. This eliminated thousands of wells and only 521 wells with depths greater than 2470 ft were shortlisted.
- AoR filtering: Once the AoR was predicted for a 3-year post-injection differential pressure based on a 20-year injection period using ISGS, the shapefiles of AoR were imported into Petra to identify the wells within the predicted AoR. Once the above-mentioned filters were applied, 94 wells that were penetrating the primary confining seal (i.e., Maquoketa formation) were evaluated using the qualitative risk assessment (QRA) methodology developed by Arbad et al. [45,46].

Table 2. Lively Grove 1 site formation code summary.

Southern Illinois			**Northern Illinois**		
Primary Confining Seal					
System	**Group**	**Formation**	**Formation**	**Group**	**System**
Ordovician (*209ODVC*)		Maquoketa Fm (*203MQKT*)	Brainard (*203BRRD*)	Maquoketa Fm (*203MQKT*)	Ordovician (*209ODVC*)
			Ft. Atkinson (*203FRAK*)		
		Cape Ls (*352CRPR*)	Scales Sh (*203SCLS*)		
Below Primary Confining Seal					
Ordovician (*209ODVC*)	Galena (*202GLEN*)	Kimmswick Ls (*202KMCK*)	Dubuque (*203DUBQ*)	Galena (*202GLEN*)	Ordovician (*209ODVC*)
			Wise Lake (*203WSLK*)		
		Decorah (*202DCRH*)	Dunleith (*202DNLT*)		
			Decorah (*202DCRH*)		
	Platteville (*202PLVL*)	Plattin Ls (*202PLTN*)	Quimbys Mill (*202QMBY*)	Platteville (*202PLVL*)	
			Nachusa (*202NCHS*)		
			Grand Detour (*202GRDD*)		
			Mifflin (*202MFLN*)		
		Pecatonica (*202PCNC*)	Pecatonica (*202PCNC*)		
	Ancell (*202ANCL*)	Joachim Dol (*202JCHM*)	Joachim Dol (*202JCHM*)	Ancell (*202ANCL*)	
		Dutchtown Ls			
Storage Reservoir					
Ordovician (*209ODVC*)	Ancell (*202ANCL*)	St Peter (*202SPTR*)	St Peter (*202SPTR*)	Ancell (*202ANCL*)	Middle Ordovician (*209ODVC*)
Secondary Storage Reservoir					
Cambrian (*159CMBR*)	Knox (*169KNOX*)	Potosi (*153POTS*)	Potosi (*153POTS*)	Knox (*169KNOX*)	Cambrian (*159CMBR*)

2.4. Well Record Evaluation

The well reports of 521 wells were manually evaluated to extract the necessary information for QRA, such as casing details, cementing data, well depths, plugging information, etc. The log files were uploaded to IHS Markit Petra™ software (Version 3.13.2) for geospatial mapping, well log correlation, and for estimating formation tops for wells with missing information. The structural elevation of the Maquoketa formation, mapped with the 94 wells penetrating the primary confining seal as per the ISGS database, is shown in Figure 2. The yellow circles represent the wells evaluated using the proposed risk assessment methodology. These wells may serve as a potential leakage pathway for CO_2 if their well integrity is compromised. Similarly, Figure 3 shows the structural elevation of the storage complex evaluated for this site, i.e., the St. Peter Sandstone. The red star on all the maps (Figures 2 and 3) denotes the LG1 well, and the red solid box indicates the hypothetical injection well location.

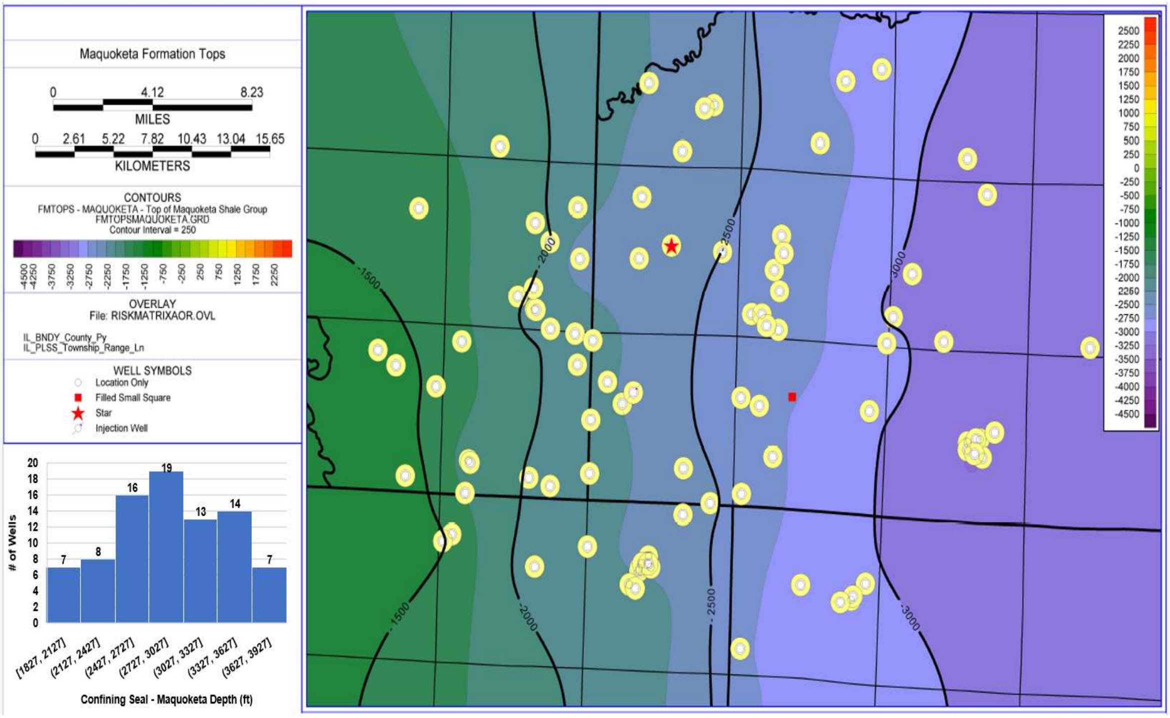

Figure 2. Structural elevation of primary confining seal—Maquoketa formation.

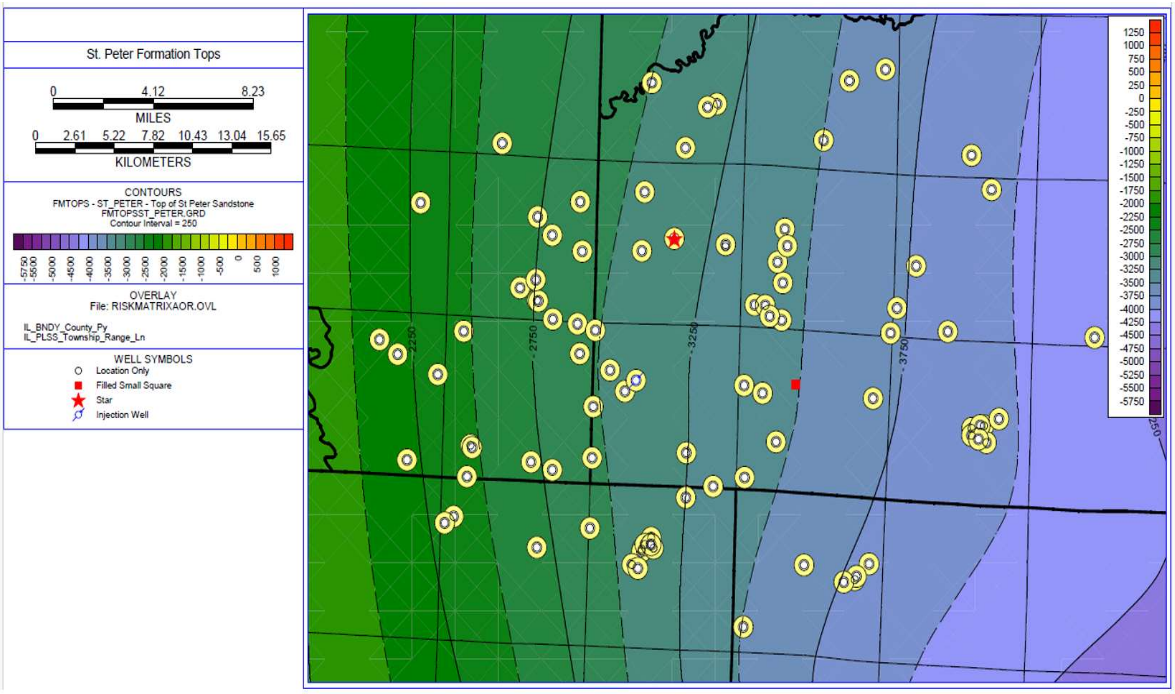

Figure 3. Structural elevation of the storage complex—St. Peter Formation.

3. Results

3.1. Summary of Wells Evaluated

Based on the depth and formation code filtering mentioned in the previous section, 521 wells were thoroughly evaluated, and a QRA was performed. Figure 4A shows the age distribution of these 521 wells, while Figure 4B shows the availability of well logs. Most of the wells were between 32 and 52 years old, with 70 wells aged between 62 and 72 years. These wells were drilled and/or plugged before the standardization of plugging practices. Approximately 266 wells had electric logs available on the ISGS website, and 203 wells did not run electric logs as mentioned in their well reports. Similarly, the logs of 15 wells were missing, and 37 wells did not mention anything about well logs. Out of the 521 wells, 8 wells had three-hole sections (surface, intermediate, and production), while the rest had just two-hole sections (surface and production). The statistics regarding the depths of hole sections and the top of cement (TOC) are presented in Figure 5. Cementing details were inconsistently reported for the wells under evaluation. The authors contacted a cementing service provider to gain additional insights into the cement slurries, such as Class A Portland cement, used to cement most wells (yield—1.18 ft^3/sack). If the top of cement (TOC) was not reported in the well reports, then it was estimated by multiplying the yield with the number of cement sacks and dividing the product by the annular capacity.

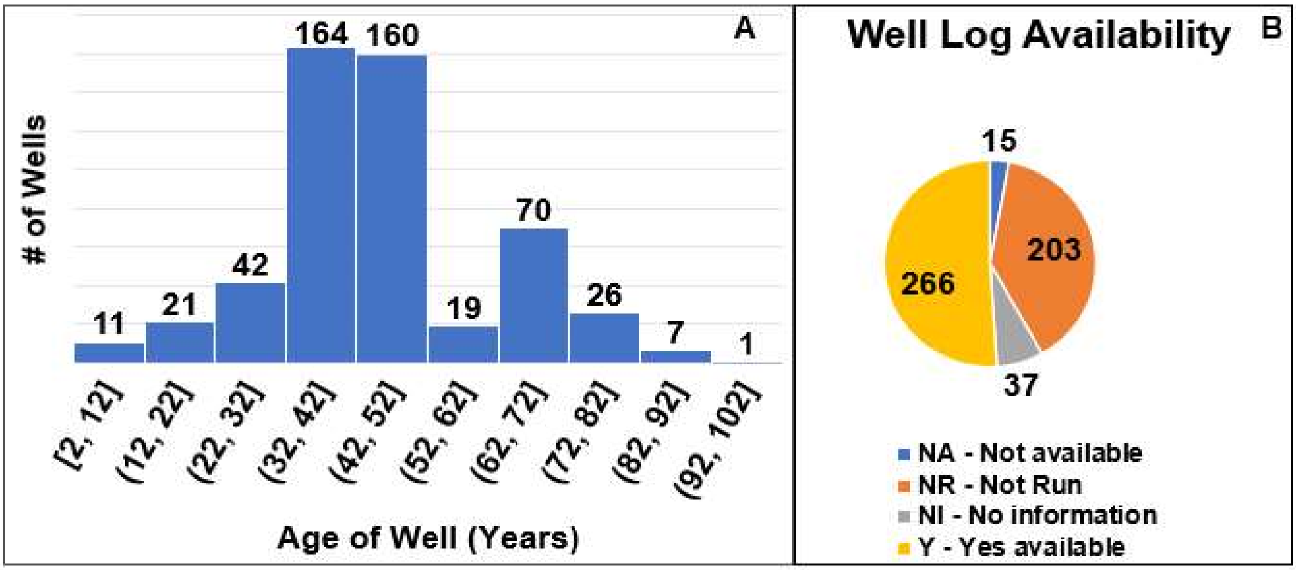

Figure 4. (**A**) Age of wells and (**B**) availability of well logs.

Out of 521 wells, 327 were plugged and abandoned status or dry and abandoned status, and plugging reports were available for 311 wells. Since some of the wells were plugged before the establishment of plugging standards, the number of plugs within each well varied, as described in Table 3. The length of individual plugs for wells with one, two, and three plugs is depicted in Figure 6.

Table 3. Number of plugs in abandoned wells.

Number of Cement Plug (s)	Number of Wells
1	135
2	115
3	56
4	3
5	1
6	1

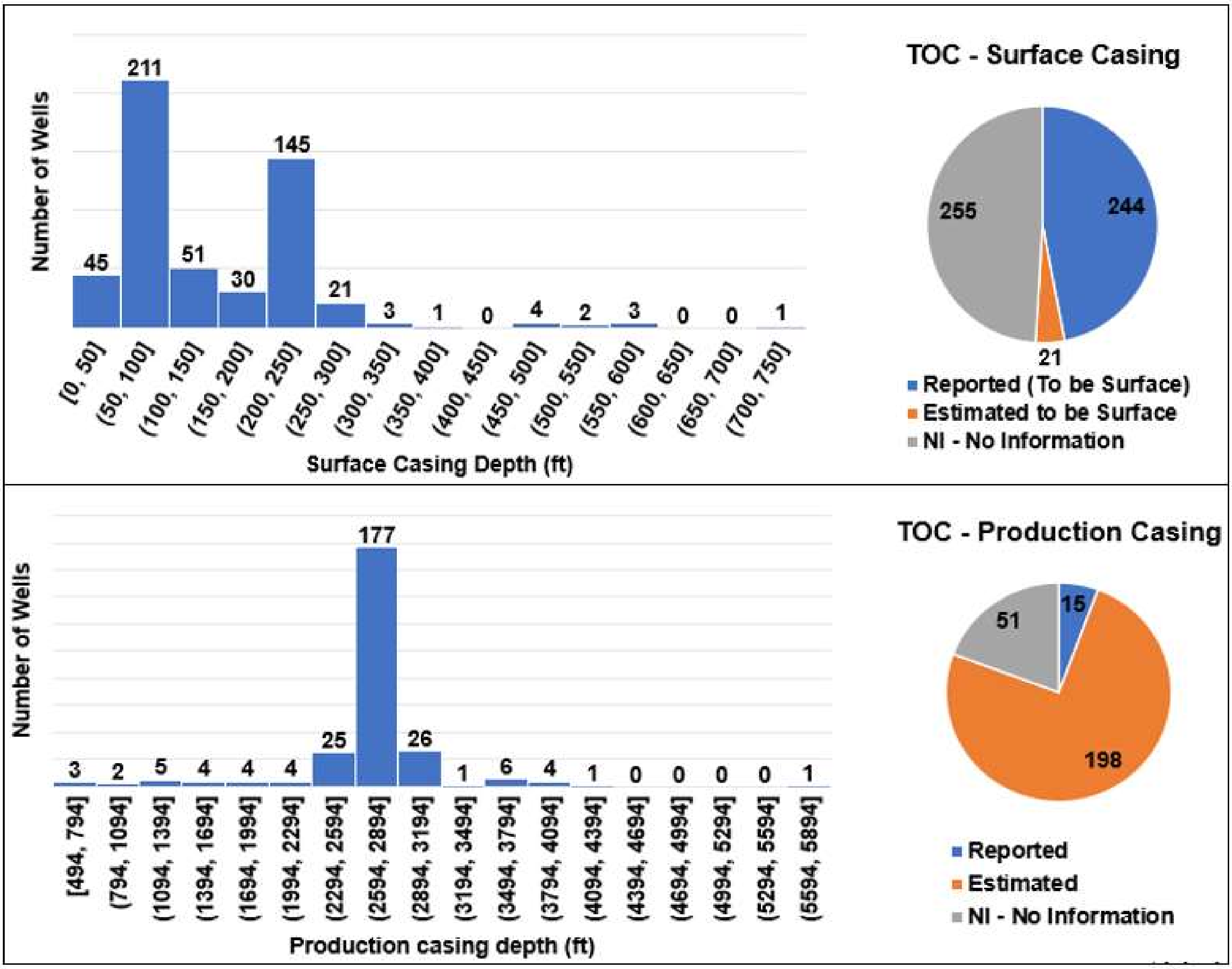

Figure 5. Hole section depths—surface and production casings.

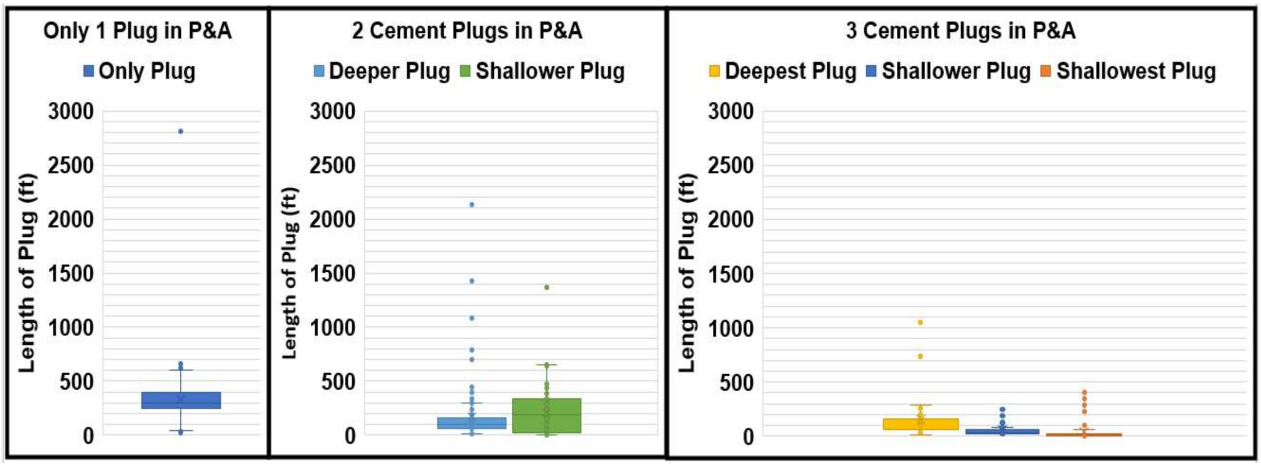

Figure 6. Length of individual plugs with 1, 2, and 3 plugs in P&A reports.

3.2. Qualitative Risk Assessment Summary

Out of 521 wells, only 94 wells within the AoR penetrated the primary confining seal, and their QRA results are presented in Figure 7. Upon detailed investigation, 85 wells penetrated the primary confining seal, and 4 wells reached the storage reservoir. There were two Type 1 wells, i.e., undocumented wells; zero Type 2 and Type 4 wells, two Type

3 wells, eight Type 5 wells, and fifty-two Type 6 wells. Fifty-four wells had a high priority for corrective action due to the lack of documentation and/or uncertainty of barriers across the primary confining seal, while ten wells had medium priority as their status was active. Twenty-nine wells had a low or the least priority for corrective action as they did not penetrate the primary confining seal. There was a total of 4312 Type 9 wells (not penetrating the primary confining seal) within the AoR, including the 10 listed in Figure 7. However, the 10 listed in Figure 7 were reported as penetrating the primary confining seal according to the ISGS database, but they were not actually penetrating the primary confining seal based on the authors' evaluation of the well logs and regional stratigraphy.

QRA Results	Accessibility Level				
Well Type	1 (DA)	2 (PA)	3 (Inj.)	4 (Prod)	5 (Obs.)
Type 1	1 (DA) and 1 Unknown Status				
Type 2	0	0	0	0	0
Type 3	0	0	0	2	0
Type 4	0	0	0	0	0
Type 5	8	0	0	0	0
Type 6	41	3	3	5	0
Type 7	1	1	0	0	0
Type 8	3	3	3	8	0
Type 9*	7	0	0	3	0

Legend - Corrective Action Priority & Approximate Cost: High (red), Medium (orange), Low (light green), Least (green)

- * = Listed here are only the wells that were penetrating confining seal according to ISGS database, but based on a QRA they are not penetrating confining seal. Therefore, there is a total of 4312 Type 9 wells not penetrating the Maquoketa within the AoR.
- DA – Dry & Abandoned well, PA – Plugged & Abandoned well, Inj. – Injection well, Prod – Producer well, Obs – Observation well.

Figure 7. LG 1 site risk assessment results.

The combined map with the risk assessment of all the wells within the AoR of the LG 1 site is displayed in Figure 8. The inner circles are color-coded according to their accessibility, and the outer circles are color-coded based on the well type. The hollow black circles represent shallow wells that did not penetrate the confining zones and were filtered out. Figure 9 illustrates the risk assessment of the 94 wells that penetrated the primary confining seal according to the ISGS database. The pink polygon in Figures 8 and 9 represents the pressure front of the St. Peter Sandstone (storage reservoir) after 20 years of CO_2 injection and a 3-year post-injection period, indicating the maximum size of the AoR. The red star denotes the LG1 well, and the red solid box indicates the hypothetical injection well location. This type of map facilitates the easy identification of high-risk wells and suggests phased corrective actions if there are numerous wells requiring remedial actions. Additional information, such as faults, surface bodies of water, springs, mines, quarries, water wells, territory boundaries, and roads, could also be displayed on the maps using their shapefiles and Geographic Information System (GIS) software. However, this information is not shown in Figures 8 and 9 to avoid confusion and to highlight the identification of risky wells with respect to the hypothetical injection location. Presently, the map component of the UIC Class VI Permit application submitted to the US EPA merely conveys the surface location of all wellbores, faults, surface bodies of water, springs, mines, quarries, water wells, territory boundaries, and roads within the AoR. The proposed categorized mapping of risky legacy wells provides much more information about the geological penetrations and protections than solely the surface locations submitted to the US EPA.

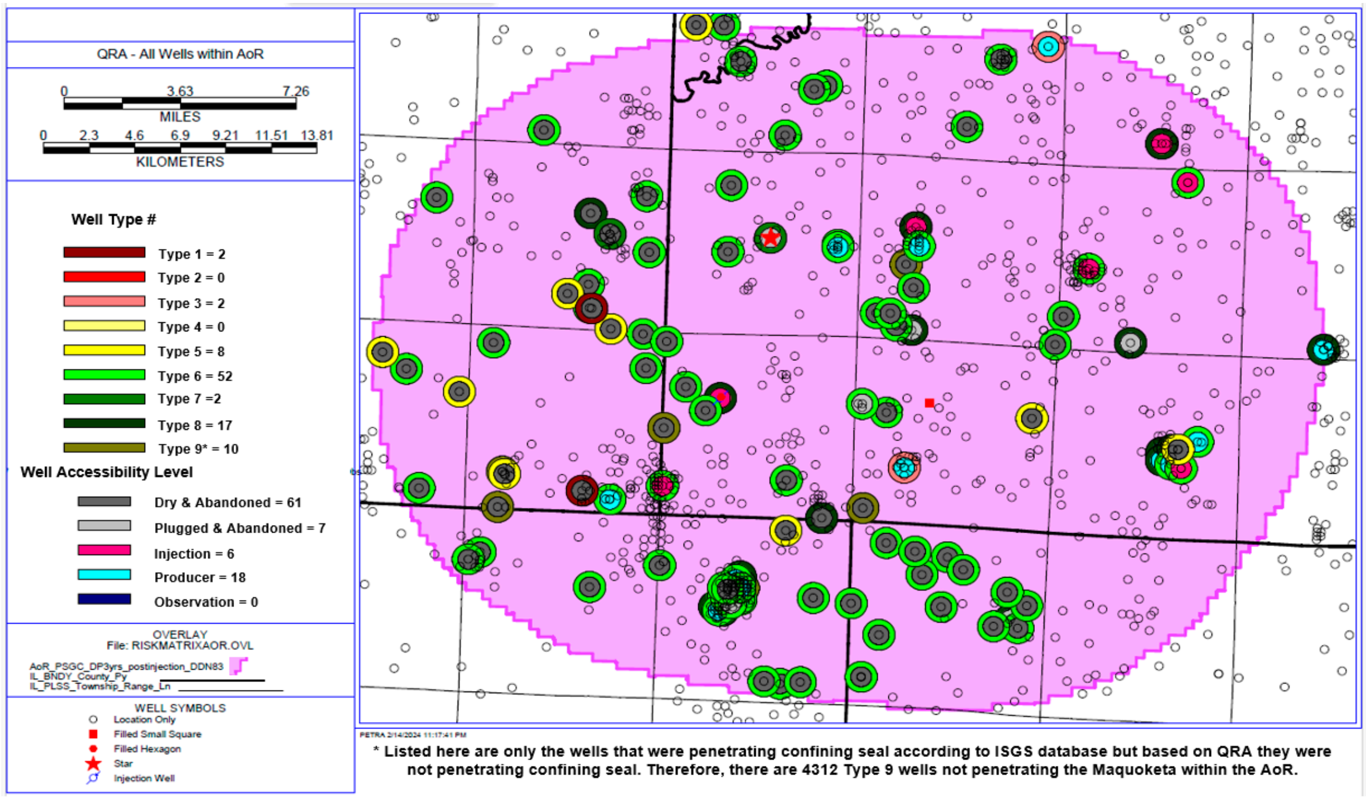

Figure 8. Risk assessment map of all wells within AoR.

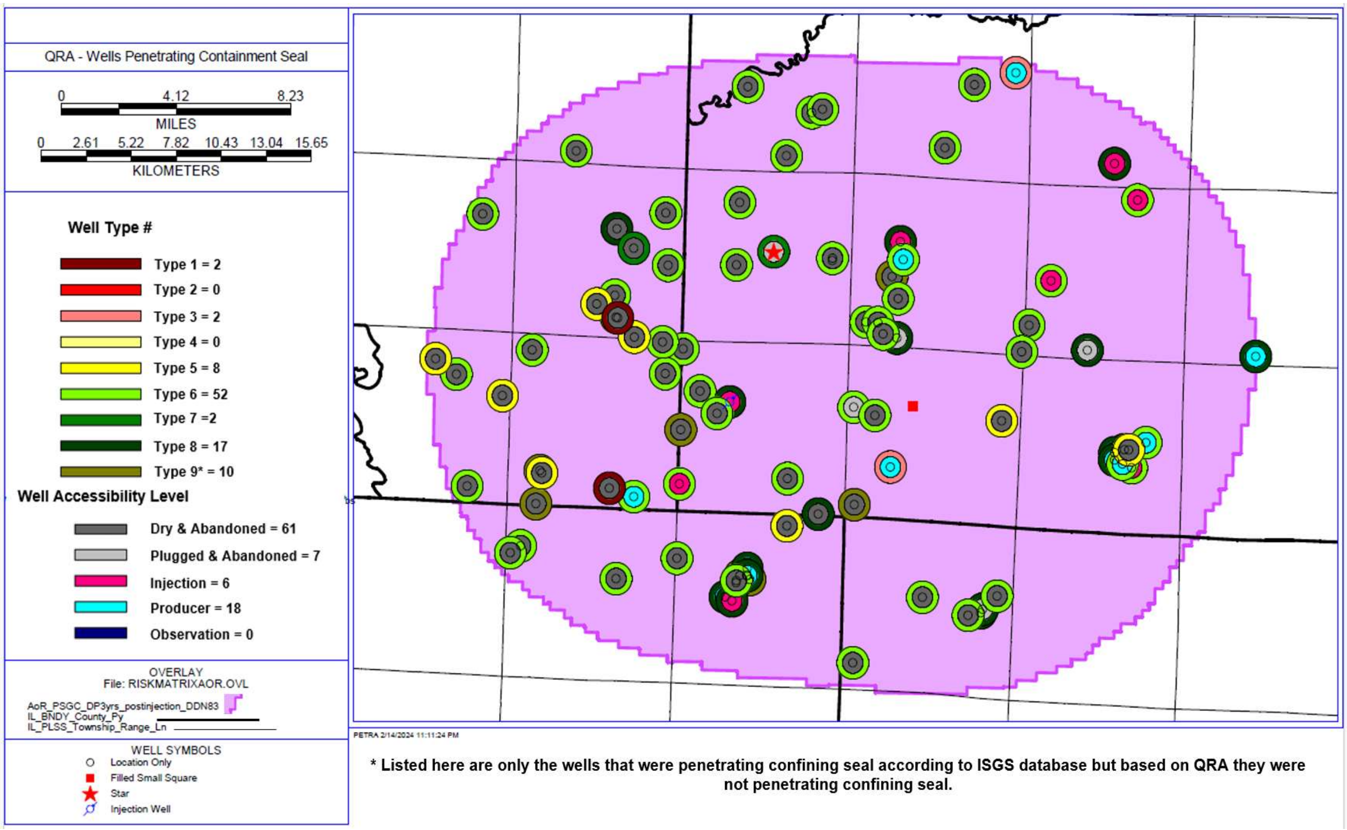

Figure 9. Qualitative risk assessment of 94 wells penetrating primary confining seal within the AoR.

4. Discussion

4.1. Salient Features of Wells within AoR

In Appendix A, one example of each well type is discussed in detail. However, the well schematics of all the wells penetrating the primary confining seal were drawn, and leakage pathways were identified. The absence of plugging reports for Type 5 wells suggests that had these reports been accessible, these wells could have either retained their Type 5 classification or potentially transitioned to less risky categories, such as Type 6 or 8, contingent upon their evaluations. Similarly, the well reports for both Type 3 wells mention that they were plugged back to the TD and produced from a shallower depth (Devonian formation), but they failed to report the plugging details. These Type 3 wells could transition to the less risky category of Type 7 contingent upon their evaluations.

4.2. Wells with Target Depth (TD) Formation Code as 203MQKT

Table 4 lists the wells that had a TD formation code as Maquoketa seal (203MQKT). An investigation was conducted to check whether these wells penetrated through the Maquoketa shale and reached the Trenton formation, or if they partially penetrated the Maquoketa seal. These wells are currently listed as penetrating through the Maquoketa seal as the authors were unsure about how much Maquoketa seal below the TD is enough for confinement. An additional caprock integrity study needs to be performed to answer this uncertainty, and it was out of the scope of this study. Once an appropriate assumption was made for this, the well type of these wells changed to Type 9. Figure 10 shows the isopach map of Maquoketa along with these wells under consideration, which helped in estimating the approximate Maquoketa thicknesses below the TD of each well, as shown in Table 4.

Table 4. Wells with Maquoketa as TD formation code.

Sr. No	Current Well Type	API10P	TD (ft)	Estimated Maquoketa Thickness (ft)	Trenton Tops Estimated (ft)	Maquoketa Below TD (ft)
1	Type 1	1216329365	2613	155	2655	42
2	Type 1	1216323789	2350	150	2435	85
3	Type 6	1216325631	2614	145	2702	88
4	Type 6	1218924586	3300	155	3327	27
5	Type 6	1218924485	3002	122	3080	78
6	Type 6	1218901772	2712	145	2780	68
7	Type 6	1218902866	3601	105	3655	54
8	Type 8	1215724984	2600	116	2716	116

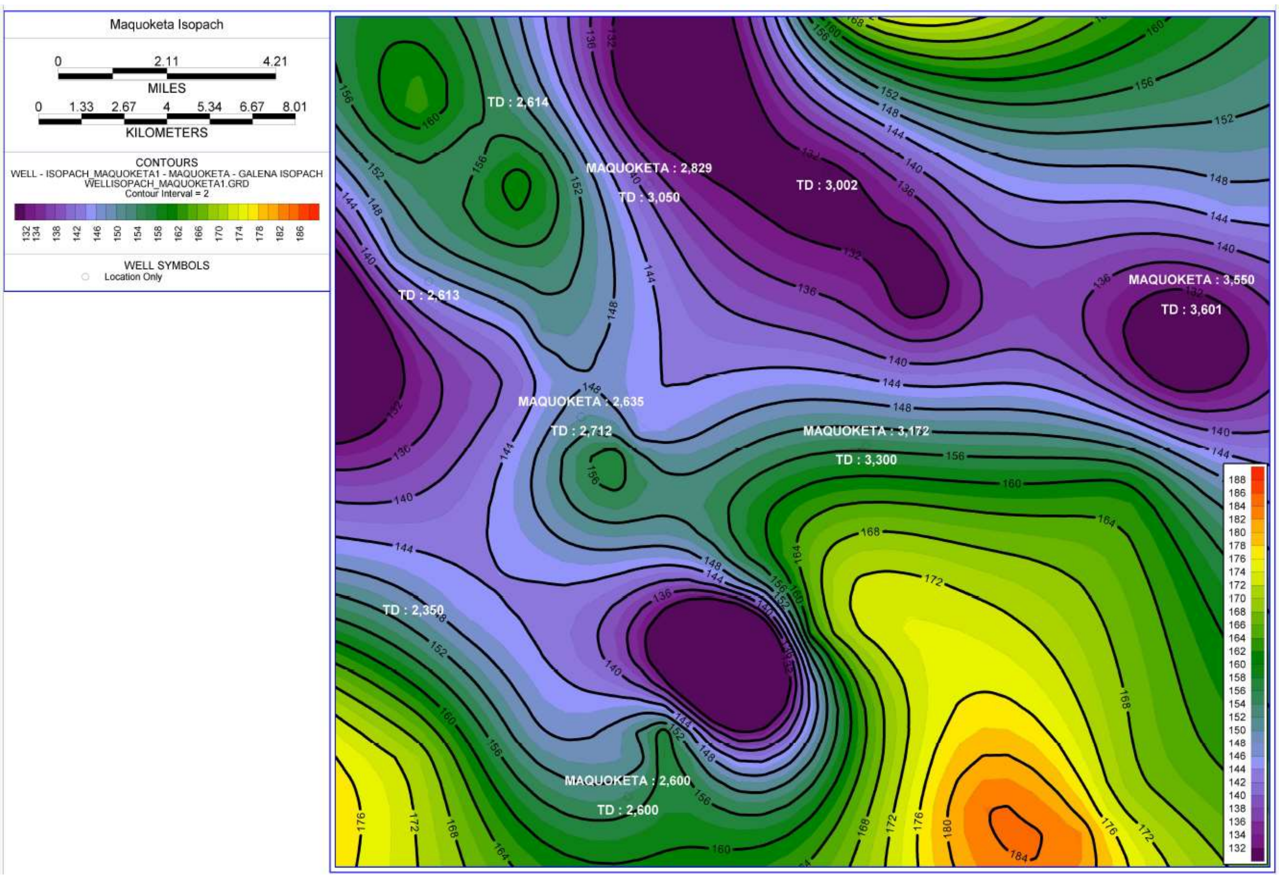

Figure 10. Maquoketa isopach along with wells of concern (partially penetrating Maquoketa).

4.3. Phased Corrective Action Plan

For the phased corrective action plan, it is recommended to overlay the CO_2 plume for intervals of 3–4 years over the mapped risky wells. This approach prioritizes wells based on their proximity to the expanding CO_2 plume over time. The AoR overlay in Figures 8 and 9 spans a total of 23 years (20 years injection and 3 years post-injection), and 54 wells that have a high priority for corrective action fall within the same period. By overlaying AoR for different time intervals onto the mapped risky wells, it becomes easier to identify which wells require prioritized corrective action before each period. For instance, if the combined CO_2 plume and pressure front radius is projected to reach a 2.5-mile radius (red circle) after 4 years of injection, as shown in Figure 11, then wells within the red circle should be prioritized. For this example, there is one Type 3 well that has producer status, two Type 6 wells each with D&A and P&A status, and one Type 8 well with P&A status. Thus, the priority for corrective action in this example would be as follows:

1. Type 6 with D&A status: This well just has surface casings and shallow plugs as barriers but no cement plugs across the confining seals.
2. Type 6 with P&A status: This well has a cast iron bridge plug set at a shallower depth within the production casing that is cut and retrieved above the TOC.
3. Type 3 with producer status: As this well is accessible due to its producer status, priority should be given to abandoned wells since locating them and re-entering would be challenging.

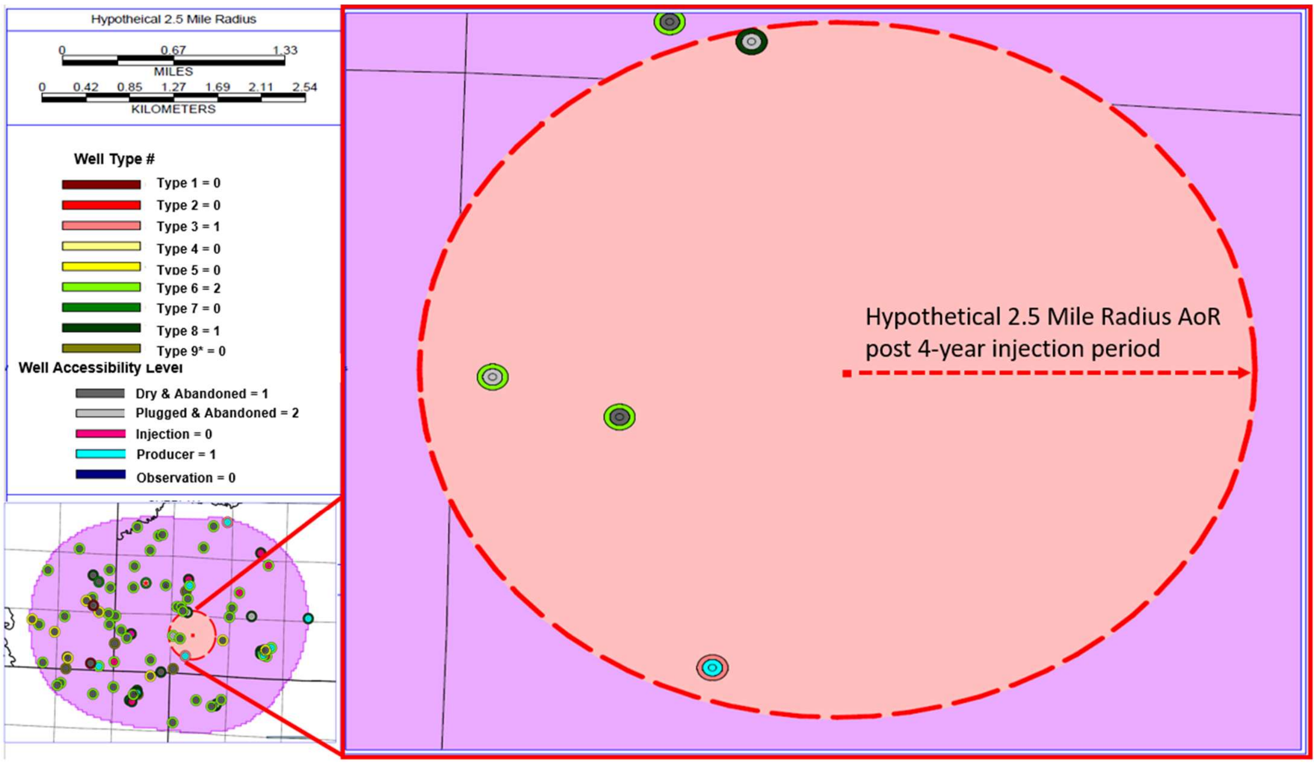

Figure 11. Hypothetical phased corrective action plan mapping.

4.4. Uncertainty Reduction and Future Work

This study was purely based on publicly available data, and inconsistencies in data reporting to the state were observed for several reasons, such as changes in regulations, advancements in technology, and poor maintenance of the data. The lease operator changed for a many wells over the decades, and data were lost in the transition. The uncertainty discussed in this section could be reduced by reaching out to the current operators of these identified risky wells to gain additional insights. Furthermore, the National Risk Assessment Partnership–Open–Integrated Assessment Models (NRAP-Open-IAM) tool could be used to estimate the leak rates through these risky wells and reduce the uncertainty [48–52]. These tools help in quantitative risk assessment. The application of active reservoir management techniques for geosteering the CO_2 plume and avoiding some of the risky wells should be evaluated [24,53]. If there were still numerous wells that required corrective action, then the deeper secondary storage reservoir (Potosi in this case study) should have been evaluated.

5. Conclusions

Robust risk assessment methodologies are essential for effectively containing anthropogenic CO_2 within the subsurface, particularly when dealing with legacy wells within the Area of Review (AoR). Due to a lack of data for many old legacy wells, this study strategically categorized 4386 such wells within the AoR of a potential CO_2 storage site. This study identified wells posing immediate risks, guiding prioritized corrective actions and monitoring plans.

- Utilizing publicly available data, including reports and well logs submitted to state regulatory agencies, potential risky wells were identified based on criteria such as the proximity to the injection well location, depth, and mechanical integrity of well barriers.
- Among the 4386 wells assessed, 54 were identified as having high priority for corrective action, while 10 had medium priority, and the remaining were of low priority.

- Case study results from the Illinois basin demonstrated the effectiveness and applicability of this approach, showcasing its potential to enhance the safety and success of carbon capture and storage (CCS) projects globally.

6. Patent

Nachiket Arbad et al. has patent #SYSTEM AND METHOD FOR CATEGORIZING AND ASSESSING WELLS (Application Number 63340034) pending to Texas Tech University System—Office of Research Commercialization.

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Appendix A

- Type 1 and Type 6 Well examples: There were no well reports available for this Type 1 well (API#1216329365), but an offset well (Type 6 well—API#1216300801) that was drilled by the same operator and abandoned in the same year was located just 300 ft away from this Type 1 well. Figure A1 shows the well schematic of the offset well. Based on a detailed evaluation of both wells, the authors estimated approximately 42 ft of Maquoketa shale was not penetrated by the Type 1 well. As seen in Figure A1, the offset well had all casing pulled out of the hole (POOH) and was plugged with only one 30-foot cement plug. It was still difficult to speculate if a similar plugging strategy was applied by the operator for the Type 1 well in discussion. It is interesting to note that all Type 6 wells have USDW protection, but there are no barriers across the primary confining seals.
- Type 3 well example: Figure A2 shows the well schematic of the Type 3 well (API#12189 24809). The plugback information was missing for this well, and all the nearby wells drilled by the same operator were completed and produced from the Devonian formation. This makes it difficult to understand the plugback strategy used by the operator and the uncertainty regarding the status of well barriers protecting the storage reservoir and primary confining seal remains for this Type 3 well.
- Type 5 well example: Figure A3 shows the well schematic of the Type 5 well (API#12163 00436). All casings were POOH for this well, and plugging information was missing. All the Type 5 wells have dry and abandoned status and do not have plugging information. The well type for these wells would change if the plugging information was available.
- Type 7, 8, and 9 well examples: Figure A4 shows the well schematic of the Type 7 well (API#1216325774), and Figure A5 shows the well schematic of the Type 8 well (API#1215724763). These wells have the least risk as they have appropriate well barriers protecting the primary confining seal and the storage reservoir. Since Type 9 wells are of least risk, their well schematics are not presented in this section.

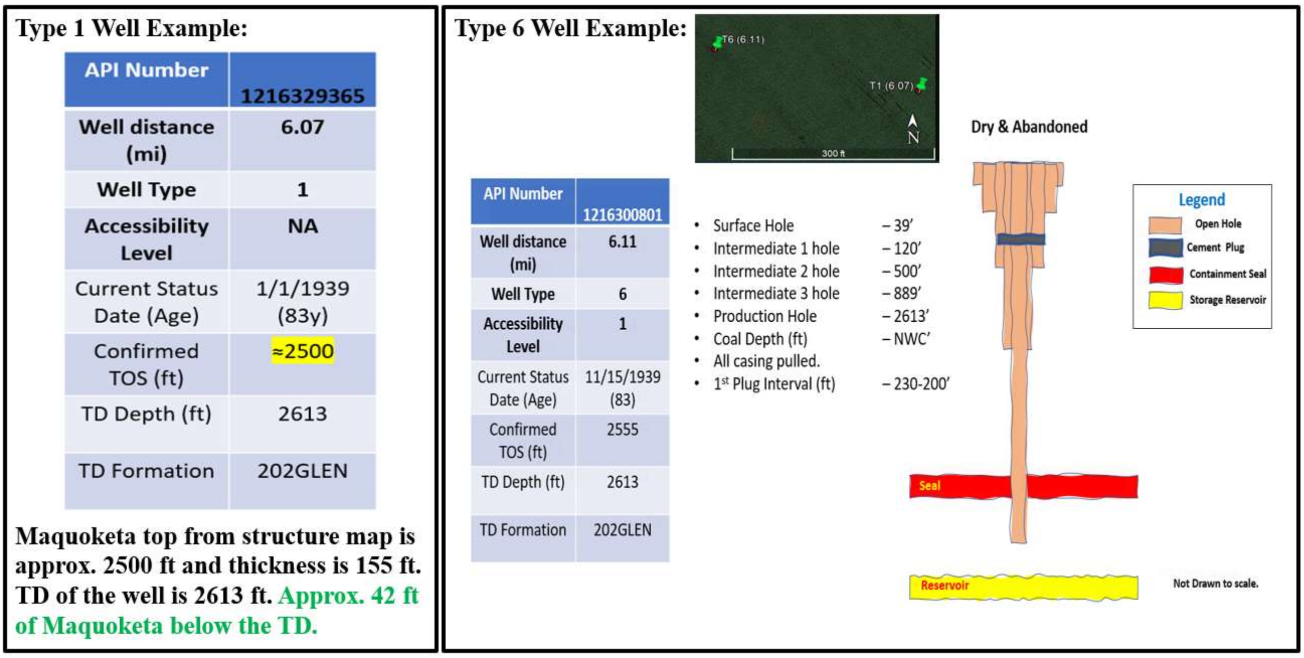

Figure A1. Example well schematic of the type 1 well (API#1216329365) and type 6 well (API#1216300801).

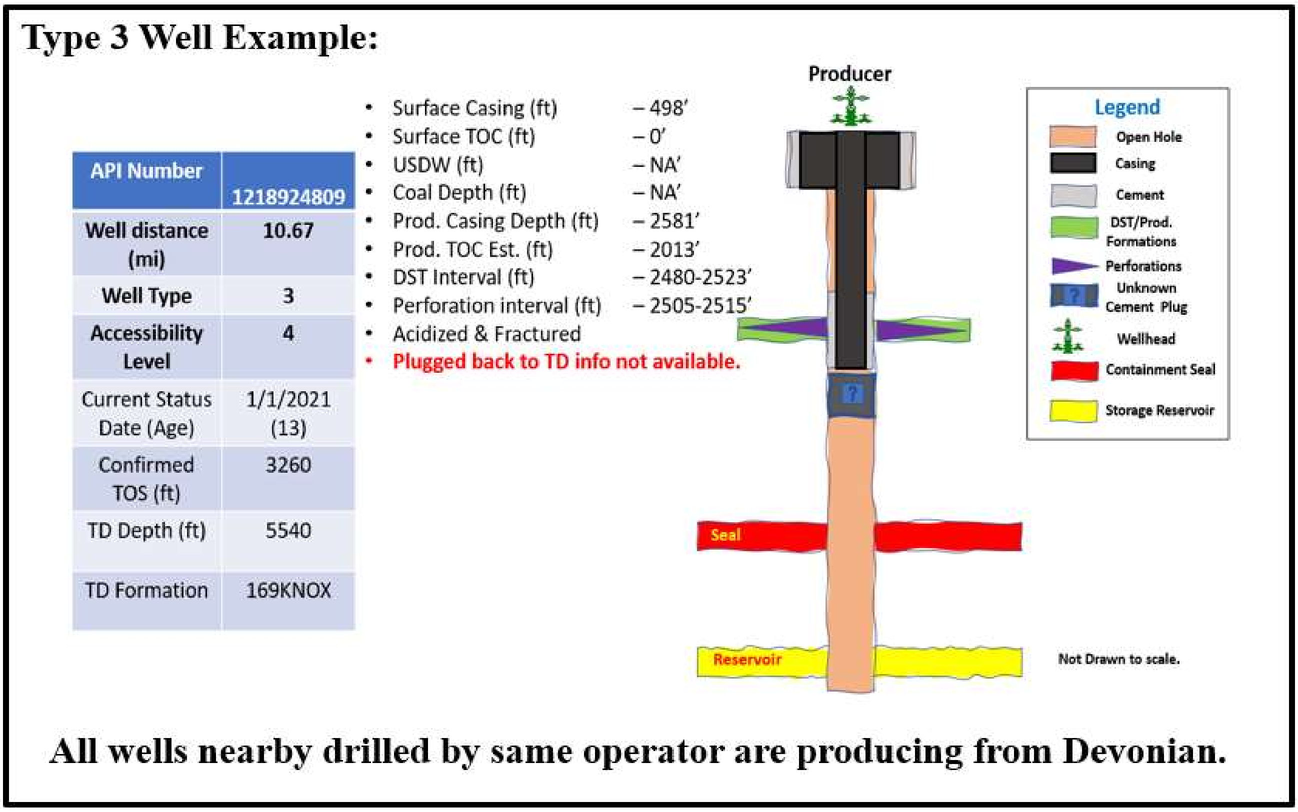

Figure A2. Example well schematic of the Type 3 well (API#1218924809).

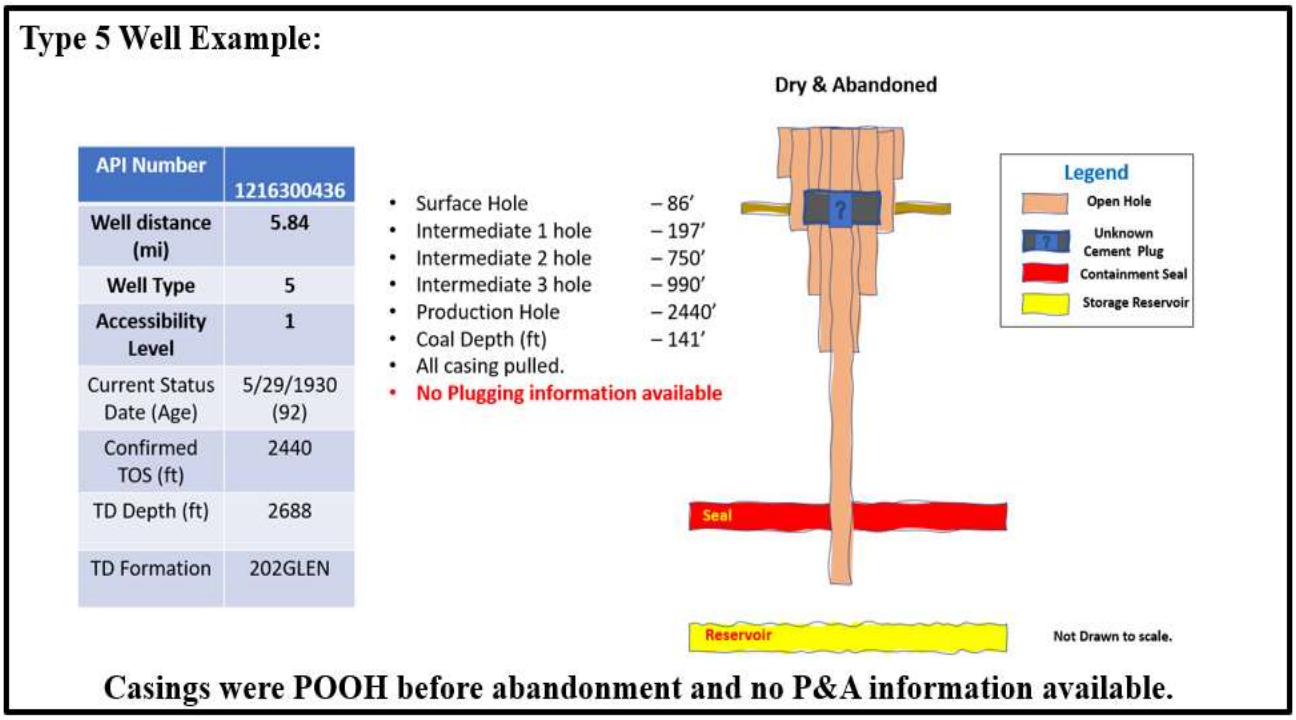

Figure A3. Example well schematic of the Type 5 well (API#1216300436).

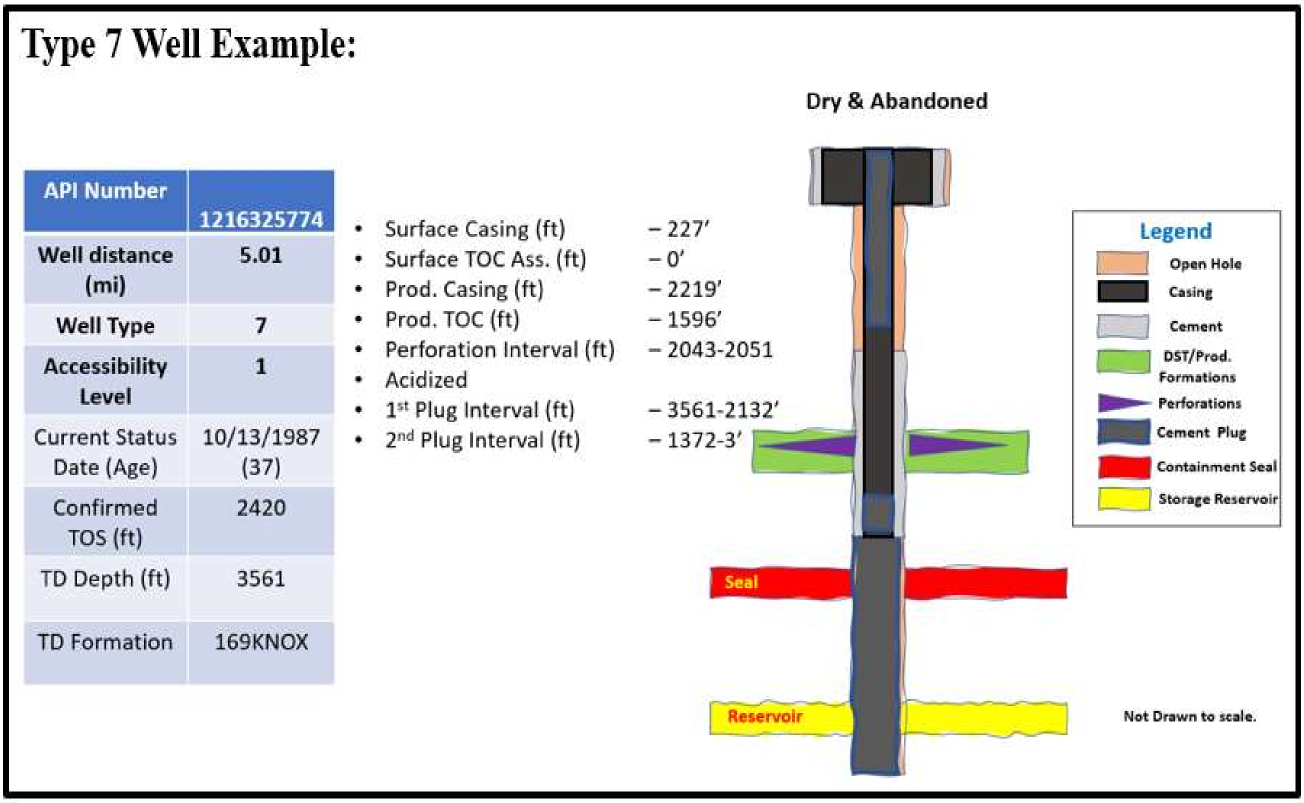

Figure A4. Example well schematic of the Type 7 well (API#1216325774).

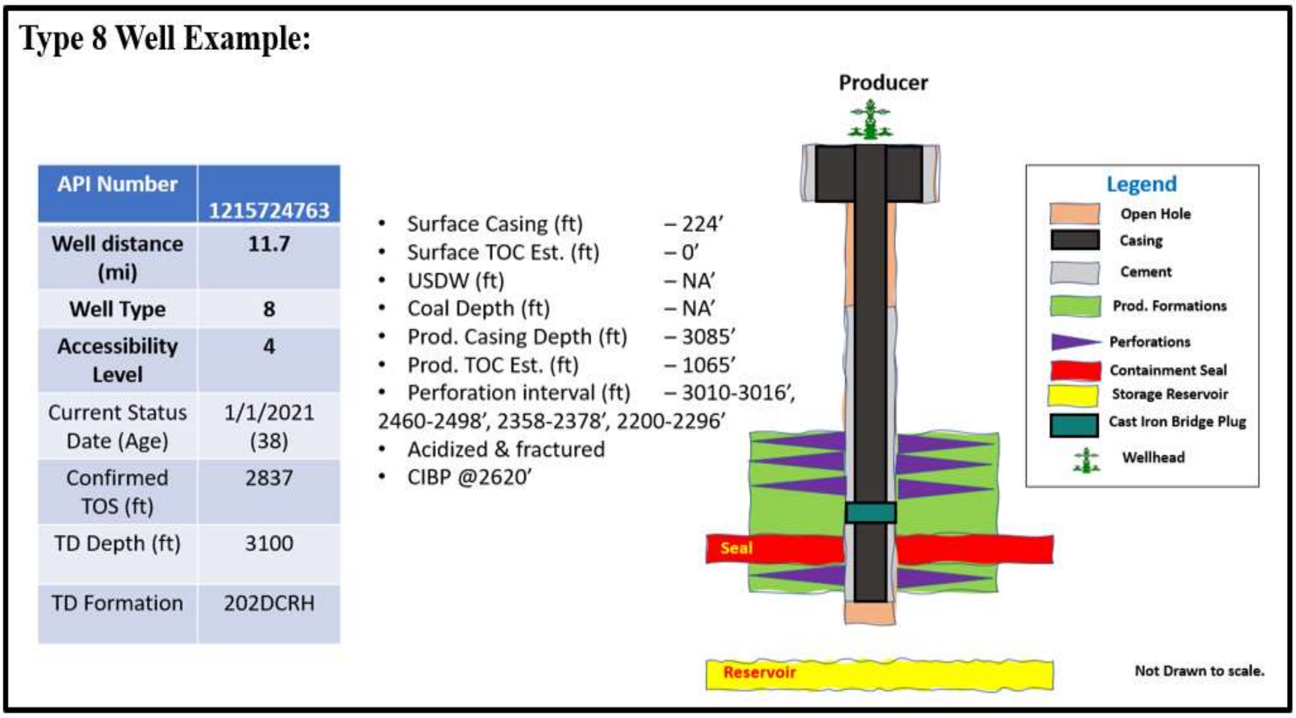

Figure A5. Example well schematic of the Type 8 well (API#1215724763).

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