BELL CREEK WELLBORE INTEGRITY STUDY

Plains CO₂ Reduction (PCOR) Partnership Phase III
Task 4 – Deliverable D36

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EXECUTIVE SUMMARY

A wellbore integrity evaluation was performed by the Plains CO_2 Reduction (PCOR) Partnership to rank the relative potential for degradation of wellbore integrity as part of a larger incidental carbon dioxide (CO_2) storage study being conducted at the Bell Creek oil field. The results of such a screening-level assessment do not provide conclusive information that a well will or will not experience a degradation or failure of wellbore integrity but, rather, provide a means to prioritize detailed well evaluations, target additional data collection, identify wells requiring modifications prior to CO_2 injection, and guide monitoring efforts. The PCOR Partnership's methods were employed to demonstrate how such an assessment could be performed utilizing the legacy data sets commonly available when preparing a site for CO_2 injection. The PCOR Partnership's evaluation encompassed over 600 wells covering the entirety of the Bell Creek Field as well as adjacent updip and downdip areas.

Wellbore integrity is the ability of a well to maintain hydraulic isolation of geologic formations and prevent the vertical migration of fluids (Zhang and Bachu, 2011; Crow and others, 2010). The evaluation of wellbore integrity involved analyzing wellbore characteristics (i.e., cement types, cement additives, completion techniques, well depths, and well casing) to derive a relative leakage potential score using methods modified from Bachu and others (2012). Wells were assigned a classification based on their specific risk profile, and these scores were analyzed and ranked. Business-sensitive and confidential data sources were utilized to enhance this evaluation and, therefore, only the methodology is outlined by this report; however, the results of the study are being incorporated into the integrated adaptive management approach being employed by the PCOR Partnership as part of the Bell Creek study.

Denbury Onshore LLC (Denbury), the operator of the Bell Creek oil field, is conducting a commercial CO_2 enhanced oil recovery (EOR) flood at the site. The PCOR Partnership is studying incidental CO_2 storage associated with EOR. As the commercial operator of the field, Denbury has conducted an independent and comprehensive wellbore integrity evaluation for its commercial operations utilizing both the public and proprietary data sources utilized in the PCOR Partnership evaluation as well as new, relevant data sets such as mechanical integrity tests, casing and cement evaluation logs, production and injection profiles, and wellhead pressures. Denbury used its independent assessment to reenter and recomplete and repair or securely plug wells as necessary in perpetration of CO_2 injection and in accordance with all regulations. While Denbury's independent assessment and field preparations activities are considered business sensitive and,

therefore, not discussed within this document, the results of some Denbury activities were utilized by the PCOR Partnership study as an independent means of comparing results and to guide field monitoring and modeling efforts.

An evaluation of Bell Creek wellbore integrity was conducted for over 600 wells throughout and surrounding the Bell Creek Field. A modification of the method of Bachu and others (2012) was implemented to determine a ranking system by which to suggest wellbore integrity. The leakage potential was divided into two scores based on depth and deep and shallow leakage potential. Other factors affecting wellbore integrity were not used in this study because of the lack of data to support a correlation with decreased wellbore integrity or the ability to assign a representative ranking impact. The scores derived in this study indicate relative wellbore integrity and do not suggest whether or not a wellbore will fail or otherwise lose integrity. They only serve to identify points or areas that may require additional analysis. Ultimately, the results of this study are being used to help strategically guide monitoring activates within the field.

The overall wellbore integrity scores indicate sound wellbore integrity throughout the study area, despite the Bell Creek Field being an actively producing oil field. The study's methods provide a good screening-level assessment to rank wells that may require further investigation as part of a CCS project. Finally, the ranking of the relative integrity factors provides a mechanism to screen wells for detailed evaluation in areas being targeted for CO_2 injection.

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BELL CREEK WELLBORE INTEGRITY STUDY

INTRODUCTION

The process of carbon capture and storage (CCS) in geologic media has been identified as an important means for reducing anthropogenic greenhouse gas emissions into the atmosphere (Bradshaw and others, 2007). Several categories of geologic media for the storage of carbon dioxide (CO_2) are available, including depleted oil and gas reservoirs, deep brine-saturated formations, CO_2 flood enhanced oil recovery (EOR) operations, and enhanced coalbed methane (ECBM) recovery. The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) is pursuing a vigorous program for the demonstration of CCS technology through its Regional Carbon Sequestration Partnership (RCSP) Program, which entered its third phase (Phase III) in October 2007. Phase III is planned for a period of 10 years (October 2007 through September 2017). One of the principal elements of the DOE effort is core research and development (R&D), which includes a significant effort to identify geologic formations that can safely and efficiently store CO_2 over long periods of time.

The storage of anthropogenic CO_2 in geologic media is a technique that is immediately applicable as a result of the experience gained through oil and gas exploration and production and deep waste disposal. Studies have shown that geologic media have a large potential for CO_2 storage, with retention times of centuries to millions of years (Intergovernmental Panel on Climate Change [IPCC], 2005). Geologic storage of CO_2 is being actively investigated and pursued at multiple locations across the United States, Canada, and the world, including several sites in the Plains CO_2 Reduction (PCOR) Partnership region.

Three geologic media have been identified by the RCSPs as suitable for CO_2 storage: uneconomical coal beds, depleted oil and gas reservoirs, and deep (>800 meters) saline formations (also referred to as deep saline aquifers). Depleted hydrocarbon reservoirs have demonstrated storage and confinement properties by having previously stored oil and/or gas resources for millions of years. The long history of hydrocarbon production in the PCOR Partnership region has provided a broad base of understanding of the subsurface in oil- and gas-producing areas. A potential challenge associated with the use of active (EOR) or depleted oil and gas reservoirs for CO_2 storage is the numerous wells drilled in these areas which may impact storage security (Bachu and others, 2012).

There is growing recognition that EOR operations utilizing CO_2 as the injectant can have additional value for the public and the environment by taking advantage of the normal situation that commonly takes place in any EOR operation utilizing and outside substance to increase oil

production from a reservoir. The fluid being injected (including saltwater), when utilized in and EOR project, ultimately occupies some of the pore space vacated by the produced oil. At the time of depletion and the closure of the enhanced recovery project, the injectant remains stored in the reservoir. This project is directed at taking advantage of the opportunity to monitor and account for this incidental storage of CO_2 that occurs during normal oilfield operations.

As part of the PCOR Partnership's Phase III project demonstration efforts, Denbury Onshore LLC (Denbury) is working with the PCOR Partnership to study incidental CO_2 storage associated with EOR in an active oil field. Through this collaboration, the PCOR Partnership is able to enhance its understanding of project performance utilizing both public and proprietary data sets. This includes evaluation through a variety of geological characterization exercises, several modeling and simulation activities, a continuing risk assessment program, and an evolving monitoring, verification, and accounting (MVA) program. The data generated from these activities, coupled with the legacy data available from well files and existing monitoring points, create an excellent scenario to study wellbore integrity.

This report outlines and summarizes a wellbore integrity study performed by the PCOR Partnership at the Bell Creek oil field. The results of the study will remain internal because of the use of business-sensitive and confidential operational data. It should be noted that data provided by the internal screening assessment are not able to predict whether or not a well or wells will be compromised but, rather, provide a means to prioritize detailed well evaluations, target additional data collection, identify wells requiring modifications prior to CO_2 injection, and guide monitoring efforts. Understanding how such assessments can be performed utilizing the legacy data sets most often available when first evaluating a field for CCS will help commercial operators better make informed decisions regarding the site-specific nature of their operations.

BELL CREEK FIELD OVERVIEW

The Bell Creek oil field in southeastern Montana (operated by Denbury) is a significant hydrocarbon accumulation that lies near the northeastern corner of the Powder River Basin (PRB) (Figure 1). The field was discovered in 1967 and has undergone decades of oil and gas production through primary and secondary (waterflood and polymer flood pilot tests) recovery methods, resulting in the current implementation of a tertiary recovery process (CO_2 EOR flood). Approximately 50 million cubic feet of CO_2 a day (~1 million metric tons annually) is being delivered to the site via a 232-mile Greencore pipeline from the ConocoPhillips-operated Lost Cabin gas plant, where it is separated from the process stream during natural gas refinement. The field is being developed in a phased manner, whereby individual segments of the field are brought online for CO_2 injection sequentially, starting with Phase 1 (Figure 2).

The CO_2 is injected into a sandstone reservoir in the Lower Cretaceous Muddy (Newcastle) Formation at a depth of approximately 4500 feet (1372 meters). The Muddy Formation is dominated by high-porosity (15% to 35%) and permeability (150 to 1175 mD) sandstones deposited in a nearshore marine environment. Stratigraphically, the Muddy Formation in the Bell Creek oil field features an updip facies change from sand to shale that serves as a trap. The sand
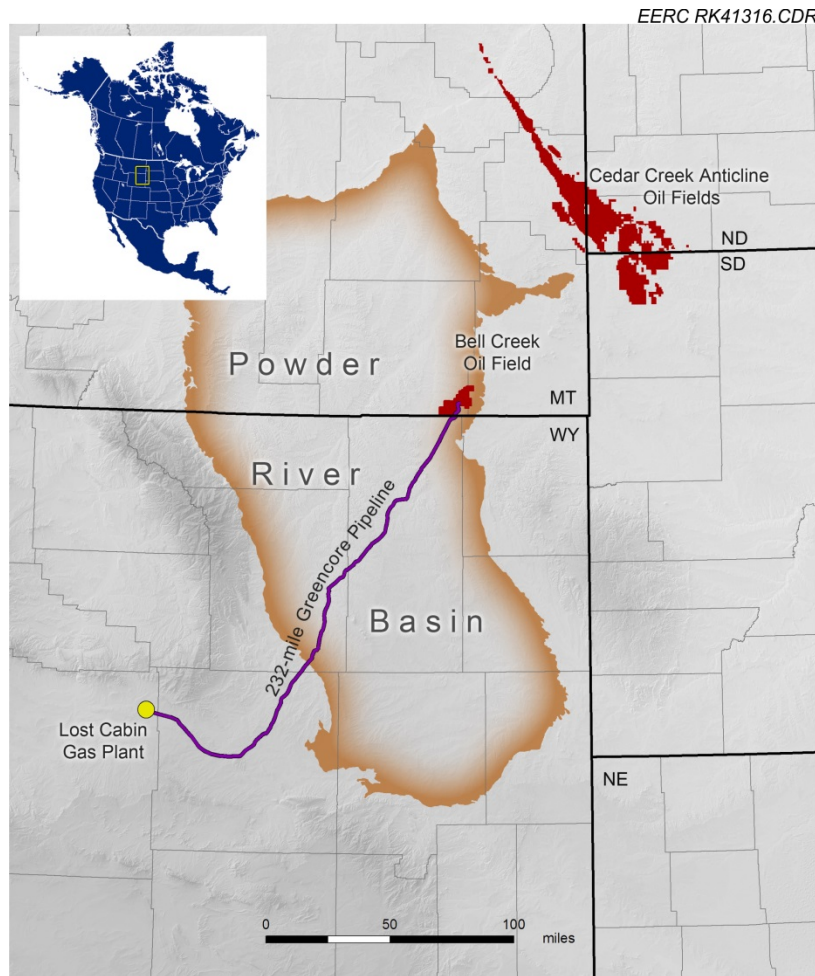
Figure 1. Map depicting the location of the Bell Creek oil field in relation to the PRB and the planned pipeline route to the site from the Lost Cabin Gas Plant.

bodies of the reservoir are partially dissected and somewhat compartmentalized by intersecting shale-filled, incisive erosional channels. The overlying Upper Cretaceous Mowry Formation shale will provide the primary seal, preventing fluid migration to overlying aquifers and to the surface. Additionally, several thousand feet of overlying shale formations provide redundant layers of protection in the unlikely event that the primary seal fails to prevent upward fluid migrations in or around the field (Figure 3).

WELLBORE INTEGRITY

For CCS to be successful, a CO_2 storage formation needs to meet three fundamental conditions: 1) capacity, 2) injectivity, and 3) confinement (Zhang and Bachu, 2011; Bachu, 2003, 2010; Intergovernmental Panel on Climate Change, 2005). The Muddy Formation in the Bell Creek Field has demonstrated the capacity and ability to securely hold materials such as oil, natural
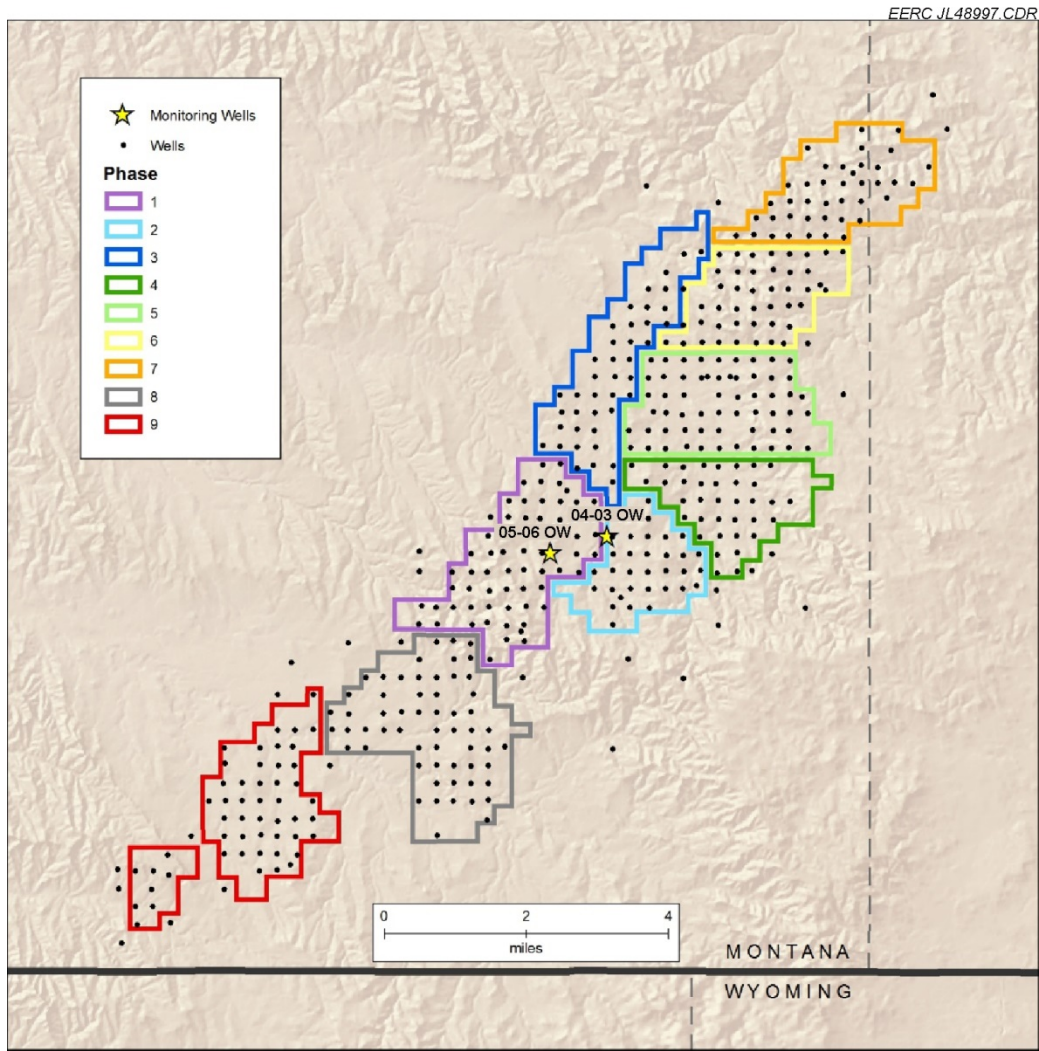
Figure 2. Map of development phases established for the Bell Creek oil field and the location of existing oil wells in and immediately adjacent to the field.

gas, and water for geologic time scales. Wellbore integrity is the ability of a well to maintain isolation of geologic formations and prevent the vertical migration of fluids (Zhang and Bachu, 2011; Crow and others, 2010). Wellbore integrity is crucial because any leakage of CO_2 poses a potential risk to surrounding groundwater, vegetation, and wildlife. In addition, it diminishes the quantity of CO_2 ultimately stored and possibly diminishes the amount of CO_2 for which storage credits could be claimed as part of either monetary agreements or regulatory compliance. For the purposes of this study, leakage will be defined as a loss of CO_2 or other fluid from its intended storage complex and not necessarily losses to the atmosphere.

For a CO_2 leak to occur, three elements must exist: 1) a leak source, 2) a driving force such as buoyancy or head differential, and 3) a leakage pathway (Watson and Bachu, 2007). When the potential for CO_2 leakage at a potential carbon storage site is evaluated, the first two elements are

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Age Units		Seals, Sinks, and USDW*	Powder River Basin
Cenozoic	Quaternary	USDW	
	Tertiary	USDW	Fort Union Fm
Mesozoic	Cretaceous	USDW	Hell Creek Fm
		USDW	Fox Hills Fm
		Upper Seal	Bearpaw Fm / Judith River Fm / Claggett Fm / Eagle Fm / Telegraph Creek Fm — Pierre Fm
		Upper Seal	Niobrara Fm
			Carlile Fm
			Greenhorn Fm
		Upper Seal	Belle Fourche Fm
		Upper Seal	Mowry Fm
		Sink	Muddy Fm
		Lower Seal	Skull Creek Fm

(Colorado Group spans Niobrara Fm through Skull Creek Fm)

*USDW = Underground Source of Drinking Water

Figure 3. Late Cretaceous to Quaternary stratigraphic column of the PRB. Sealing formations are circled in red, and the primary sink formation is circled in blue. Formations bearing USDW are also identified.

presumed to already exist. The injected CO_2 is the leak source, and the driving force is CO_2 buoyancy and, potentially, an increase in the subsurface pressure over a hydrostatic gradient caused by the CO_2 injection (Watson and Bachu, 2007). The leakage pathway is the third element required for a leak to occur.

TWO SIMULTANEOUS REVIEWS

Denbury has conducted an independent review of the oil field as part of the process necessary to bring a large-scale commercial CO_2 EOR operation online. This review included review and physical inspection of all wells within and surrounding the injection area utilizing a combination of mechanical integrity tests, casing and cement evaluation logs, wellhead pressure measurements, visual inspections of tubulars during workover, and review of the well completions history. If an issue was found, wells were either recompleted and repaired or securely plugged prior to commercial injection and in accordance with regulations. This process included collection and review of new, proprietary, and business-sensitive data to ensure that the field could and would operate safely, effectively, and efficiently.

During the same time period, the PCOR Partnership conducted an independent review of wellbore integrity within the Bell Creek Field using existing legacy data. The choice to rely on legacy data for this evaluation over acquiring additional new data was made in order to develop and demonstrate a screening-level assessment utilizing information that would be available at other potential CCS locations. However, both proprietary and public legacy data sets were utilized in order to better address site-specific gaps in the publicly available data. This decision allowed the PCOR Partnership to complete a more rigorous assessment, encompassing many risk factors. As a result of the inclusion of proprietary and business-sensitive data in the assessment, only methodologies and limited results are included in this report.

The goal of the PCOR Partnership's wellbore integrity study was to assign a relative risk score for deep and shallow well integrity factors for existing wells in the Bell Creek oil field in order to guide and optimize monitoring strategies. It is important to note that the assignment of these relative leakage potential scores is solely for purposes of comparing and contrasting the history and condition of different wellbores within this portion of the system. Stated differently, the assignment of individual wellbore integrity scores is strictly relative, meaning that a particular wellbore can be compared to the other wellbores and assigned a priority for further investigation, analysis, and monitoring in areas targeted for CO_2 injection. Additionally, the scores do not indicate the severity of a possible failure or that a wellbore will, at any point, lose integrity. They only serve to identify points or areas that may require additional analysis. Furthermore, many of the legacy wells in the Bell Creek Field have already been evaluated as part of Denbury's efforts to modernize the field.

PREVIOUS WELLBORE INTEGRITY WORK

Despite the challenges in classifying the potential for well leakage based on well files, methodologies have been developed (Watson and Bachu, 2007, 2008; Bachu and others, 2012). These papers outlined an approach that was implemented in the Canadian province of Alberta based on similar well data and, importantly, surface casing vent flow (SCVF) and gas migration (GM) data beginning in 1995. These data were used to verify the methods developed to evaluate shallow well leakage potential. SCVF is leakage of gas to the surface casing vent valve (always open) on the wellhead, and GM is a measurement of leakage of gas out of the ground around the wellhead (Bachu and others, 2012).

Watson and Bachu (2007) evaluated data for approximately 316,000 wells in Alberta in an area known to be subject to leaks to assess wellbore leakage risk based on a variety of criteria. They found that 4.5% of the wells evaluated had identified leaks, with SCVF accounting for 3.9% and GM accounting for 0.6% of the identified leaks. After identifying the wells that had indications of leakage, they evaluated the specific well file data to determine which factors could be correlated to leakage.

Watson and Bachu (2008) and Bachu and others (2012) attempted to quantitatively classify the potential for shallow and deep wellbore leakage based on risk factors identified from their previous work in Watson and Bachu (2007). Shallow leakage refers to compromised hydraulic well integrity in the upper portion of the well, where shallow gas, if present, may leak upward, along the outside of the casing/wellbore annulus to shallow freshwater aquifers or through a casing

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leak and along the inside of the production casing to the surface (Bachu and others, 2012). Deep leakage pertains to leakage along the deep part of the well from the CO_2 storage zone to adjacent permeable horizons (Bachu and others, 2012).

Bachu and others (2012) provided a numerical score for deep and shallow leakage potential. This score indicates the relative likelihood that any one well may leak based on the factors evaluated; however, the score does not reflect the volume or impact of the leak. Significant factors such as the quality of the cementing work were not included because of the lack of such data. As a result, Bachu and others (2012) identified low-risk wells that had a measured SCVF or GM leak. Likewise, wells ranked as higher-risk did not necessarily have a measured SCVF or GM leak identified. Therefore, it should be recognized that this method is useful as a screening-level evaluation for the leakage potential of a group of wells but is limited by the nature and extent of the available data.

To that end, the efforts conducted by the PCOR Partnership were limited both in size and scope relative to previous efforts of Watson and Bachu (2007, 2008) and Bachu and others (2012). While Watson and Bachu (2007 and 2008) were able to conduct statistical analysis on over 316,000 wells, the Bell Creek sample size is much smaller. In addition, these studies were able to correlate various leakage risk factors with measured SCVF or GM leakage events. This type of data is unavailable in the Bell Creek data set, meaning direct duplication of the statistical analysis presented by Bachu and other (2012) was not possible. Without this statistical base, it was sometimes difficult or impossible to know if certain leakage factors should be given more or less weight than other, better understood leakage factors. Therefore, other factors scored by Bachu and others (2012), such as cement type or surface casing size, were omitted by the PCOR Partnership analysis because of this lack of appropriate legacy data. The specific data types that were omitted from the list presented by Bachu and others (2012) are outlined in the methodologies discussion. Likewise, there are other known factors that can contribute to a leak; however, lacking a method to statistically correlate to a large data set, it is not possible to weight these factors compared with the others that were analyzed, which would preclude the rigorous ranking methodology developed in previous work. Therefore, they were not included in the PCOR Partnership's screening evaluation; however, they were accounted for in Denbury's well-by-well evaluation while preparing the field for injection.

METHODS AND RESULTS

The PCOR Partnership's screening-level wellbore integrity study consisted of a literature review of known wellbore integrity issues related to CO_2 EOR operations. Factors reviewed included issues related to engineered materials (well casing, cement, etc.); wells developed in naturally occurring, CO_2-producing reservoirs; and the knowledge gained from decades of CO_2 EOR operations by the hydrocarbon industry. Specifically, work conducted by Zhang and Bachu (2011) on wellbore integrity, Choi and others (2013) and Meyer (2013) on casing integrity, Crow and others (2010) on natural CO_2 reservoirs, and Cary and others (2007) and Duguid and others (2005) on CO_2 EOR operations was instrumental to the PCOR Partnership's study of wellbore integrity at the Bell Creek Field.

The first step in conducting the evaluation was identifying the possible integrity factors that required evaluation. In addition to evaluations of the engineering factors previously disscused, physical emplacement of these engineered materials and accurate reporting of oilfield activities (drilling, completions, workover activities, etc.) were identified as being equally important. For example, wellbore integrity could be compromised during cementing operations by a variety of factors such as poor mud displacement prior to cementing, gas migration during cement setting, stress crack and microannulus formation during well operation, inaccurate cement volume calculations, or incomplete mud removal, resulting in poor bonding to formation rock. As well records are often incomplete, a variety of information commonly available within well files, including, but not limited to, well completion reports, sundry notices, pressure test records, wellbore diagrams, cementing records, well logs, permits, well inspections, technical reports, correspondence, and operator notes, were identified as valuable sources of wellbore integrity data.

All known Bell Creek wells were identified and acquired from state regulatory offices and from operators in the Bell Creek Field. It should be noted that recent evaluation and preparation activities conducted by Denbury through its independent evaluation are not likely to be noted in the files used in this work. Using Bachu and others (2012) as a guide, information pertinent to identifying the potential for wellbore integrity failures was extracted from these well files. Specifically, the information targeted included well completion dates (drilling and/or abandonment dates), casing depths, casing diameters, casing weights, casing grades, cement types, amount of cement used, top of cement (TOC), completions plugging and abandonment procedures, fracture treatments, acid treatments, and any other relevant information about the well. The well information was entered into a database for subsequent analysis and relative risk scoring of the individual wellbores.

As previously noted, Bachu and others (2012) provided a numerical score for deep and shallow leakage potential. The score indicates the relative likelihood that any one well may leak based on the factors evaluated; however, the score does not reflect the volume or impact of the leak. Furthermore, a resulting high score for one or any combination of factors does not necessarily indicate that a well will fail or otherwise lose integrity, nor does a low score on any one or any combination of factors necessarily indicate that a well will always maintain integrity. Therefore, it should be recognized that this method is most useful as a screening-level evaluation for the leakage potential of a group of wells but is limited by the nature and extent of the available data. Areas targeted for CO_2 injection should be evaluated and/or monitored on a site-by-site basis based on the unique risk factors for the given project. The deep and shallow leakage factors that were evaluated and scored as well as those from Bachu and others (2012) that were omitted are listed below:

- Deep wellbore leakage factors:
  - History of fracture and acid treatments
  - Abandonment types
  - Completions

- Shallow wellbore leakage factors:
  - Spud date

- Well type
- Total depth
- Presence of an additional near-surface plug
- Cement to surface

- Omitted factors (as a result of lack of reliable legacy data):
  - Cement and cement additive types
  - Cementing procedures
  - Surface casing size
  - Abandonment date
  - Geographic location
  - Measured surface casing vent flow
  - Measured gas migration during drilling
  - Known instances of casing failure

Scoring matrixes were compiled based on methods modified from Bachu and others (2012). The most significant difference from Bachu and others' (2012) analysis was adding an "unknown" criterion to some of the leakage factors. For example, an additional surface plug could be "present," "absent," or "unknown" meaning no affirmative or exclusionary data are available. The scoring tables established by Bachu and others (2012) were also modified to reflect the additions of the "unknown" criterion. Tables 1–4 describe the specific scores and criterion for deep and shallow leakage factors.

Table 1. Deep Leakage Risk Factors*

Deep Leakage Factor	Criterion	Meets Criterion Value	Default Value
Fracture	Count = 1	1.5	1
Fracture	Count >1	2	1
Acid	Count = 1	1.1	1
Acid	Count = 2	1.2	1
Acid	Count >2	1.5	1
Abandonment Type	Bridge plug	3	1
Abandonment Type	Not abandoned	2	1
Abandonment Type	Unknown	2	1
Number of Completions	Count >1	2	1
Number of Completions	Count = 1	1.5	1

* Modified from Bachu and others (2012).

Table 2. Deep Leakage Potential (DLP) Score Rankings*

DLP	Score
Minimal Potential	<2
Lower Potential	2–6
Moderate Potential	6–10
Higher Potential	>10

* Based on Watson and Bachu (2008).

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Table 3. Shallow Leakage Risk Factors*

Shallow Leakage Factor	Criterion	Meets Criterion Value	Default Value
Spud Date	1974–1986*	3	1
Well Type	Drilled and cased	8	1
Well Type	Drilled and abandoned with casing	3	1
Well Total Depth	>2500 m (8202 ft)	1.5	1
Additional Plug	No	3	1
Additional Plug	Unknown	2	1
Cement to Surface	No	5	1
Cement to Surface	Unknown	3	1

* Modified from Bachu and others (2012).

Table 4. Ranking of Shallow Leakage Potential (SLP) Scores

SLP	Score
Minimal Potential	<50
Lower Potential	50–200
Moderate Potential	200–400
Higher Potential	>400

* Based on Watson and Bachu (2008).

Scores were compiled and analyzed on a relative basis to reveal patterns of potential risk that may have existed in the Bell Creek study area prior to recent injection preparation activities conducted by Denbury. As all scoring was relative, high scoring does not indicate that a specific wellbore will fail or that a specific loss of integrity exists. Rather, scores indicate that certain risk criteria have been met in order to help prioritize further inspection and analysis. The final analysis focused on the Phase 1 region of the oil field as this coincides with current injection operations and related PCOR Partnership MVA activities.

Generally, wells within the Bell Creek study site scored low for leakage potential on both deep and shallow wellbore integrity measurements, despite these wells being part of an active oil field with multiple decades of production history. The screening assessment was able to identify wellbores which may have had deployment deficiencies, higher-risk materials relative to other wells, or incomplete histories. This information could be used to prioritize more detailed evaluations, data acquisitions, and workover schedules. Additionally, the ranking of the relative integrity factors provides a mechanism to screen wells for detailed evaluation in areas being targeted for CO_2 injection. As Denbury has already inspected and retrofitted the existing infrastructure, this information will be utilized to strategically guide other PCOR Partnership activities, such as the shallow- and deep-subsurface-monitoring program.

SUMMARY

For CCS to be successful, a CO_2 storage formation needs to meet three fundamental conditions: 1) capacity, 2) injectivity, and 3) confinement (Zhang and Bachu, 2011; Bachu, 2003, 2010; Intergovernmental Panel on Climate Change, 2005). One component of confinement is evaluated based on the integrity of wellbores that penetrate the storage formation. Wellbore integrity is the ability of a well to maintain hydraulic isolation of geologic formations and prevent the vertical migration of fluids (Zhang and Bachu, 2011; Crow and others, 2010). Wellbore integrity is crucial because leakage of CO_2 may pose a potential risk to surrounding groundwater, vegetation, or wildlife and decrease the ability to accurately account for injected CO_2.

An evaluation of Bell Creek wellbore integrity was conducted for over 600 wells throughout and surrounding the Bell Creek Field. A modification of the method of Bachu and others (2012) was implemented to determine a ranking system by which to suggest wellbore integrity. The leakage potential was divided into two scores based on depth and deep and shallow leakage potential. Other factors affecting wellbore integrity were not used in this study because of the lack of data to support a correlation with decreased wellbore integrity or the ability to assign a representative ranking impact. The scores derived in this study indicate relative wellbore integrity and do not suggest whether or not a wellbore will fail or otherwise lose integrity. They only serve to identify points or areas that may require additional analysis. Ultimately, the results of this study are being used to help strategically guide monitoring activates within the field.

The overall wellbore integrity scores indicate sound wellbore integrity throughout the study area, despite the Bell Creek Field being an actively producing oil field. The study's methods provide a good screening-level assessment to rank wells that may require further investigation as part of a CCS project. Finally, the ranking of the relative integrity factors provides a mechanism to screen wells for detailed evaluation in areas being targeted for CO_2 injection.

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