Independent Review of Coal Seam Gas Activities in NSW

Information paper: Abandoned wells

September 2014

EXECUTIVE SUMMARY

As part of the independent review of coal seam gas (CSG) activities in NSW this information paper addresses the issue of abandoned wells from two perspectives: current approaches to abandoning petroleum wells in Australia and internationally, and management of the legacy issue.

In compiling this paper, information from a number of relevant parties was sought in relation to well abandonment. These included technical experts in the fields of emissions, groundwater and petroleum engineering; government agencies responsible for regulating the extractive industries in NSW; and industry, including titleholders and major contractors. In developing the information paper the Review also utilised international and national information on well abandonment best practice that was collected during the CSG Review process.

A range of national and international codes and standards exist for petroleum (including CSG) well integrity, of which well abandonment is a component. International industry experience and literature suggests that if the current methods prescribed in such codes are adopted, the risk of a petroleum well failing is considered to be low. However, often the studies that this statement is based on consider petroleum well integrity over a period of decades, with little research conducted on the potential longer-term impacts of petroleum wells. Although comparable studies exist for similar wells, that suggest sound integrity over a 1,000+ year period, there is scope for additional research that assesses the impact of abandoned CSG wells over extended timeframes.

Good well abandonment is particularly reliant on appropriate well design and construction, the choice of cement used, and the procedure for its injection.

The NSW Code of Practice for Coal Seam Gas Well Integrity ("the NSW Code"), which is currently under review, was introduced in 2012. In relation to well abandonment, it is comparable with international practice. A formalised review process is beneficial as it allows for the updating of codes to include technological advances or to reflect any changes in international practice. However, good codes and standards are only effective if adhered to. As the NSW Code is applied as a condition of title at approval or renewal, there are a number of petroleum titles for which compliance with the code is not a formal requirement, which is particularly pertinent for production titles that can remain current for up to 21 years before renewal. Similarly, there are few regulatory requirements which impose competencies on the CSG industry employees in NSW and the completion of the NSW code of practice in relation to training and certification of personnel working in the CSG industry would help to bring NSW in line with other jurisdictions.

A substantial proportion of petroleum wells in NSW are either suspended or abandoned. Current codes and standards may be adequate regarding abandonment of existing exploration or production wells, but were not in effect for historic petroleum wells (legacy wells). NSW Trade and Investment Division of Resources and Energy (DRE) is conducting a project, the Derelict Well Program, which takes a risk-based approach to address legacy petroleum wells that are no longer attached to a title, and that may need further attention in relation to their abandonment. However, as the project's primary focus is on orphaned wells, with no responsible operator to be held accountable, consideration may need to be given to the adequacy of the abandonment for legacy wells that are still attached to titles. This project is similar to existing international schemes, but as the NSW project is currently funded from the Derelict Mines Program and not guaranteed, provisions could be made for any necessary further funding.

The use of wells is not exclusive to the petroleum industry; they also have applications for mining and irrigation purposes. Like petroleum wells, mining or irrigation wells also have the potential to connect aquifers and emit fugitive emissions, including following abandonment, if their integrity is compromised. Whilst numbers of petroleum wells are comparably modest in NSW, there are many abandoned coal and water wells. The NSW Derelict Well Program could be used as pilot scheme for this broader issue, to attempt first to quantify the scale of the potential problem in NSW, and then to highlight wells for remediation.

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1 INTRODUCTION

This information paper is undertaken as part of the independent review of coal seam gas activities in NSW (the Review) by the NSW Chief Scientist & Engineer. Term of Reference Six for the Review included a request to "*produce a series of information papers on specific elements of CSG operation and impact, to inform policy development and to assist with public understanding*" (CSE, 2013). This paper provides information on CSG wells and bores and in particular the process for their abandonment.

During the course of the Review the topic of well abandonment was voiced as a concern by community members and independent experts.

Well abandonment refers to the decommissioning of a well. While the process for abandonment has changed over the years, in modern practice this generally means a well ceases production, equipment is removed from the well, the well is plugged with cement, cut and capped below the surface level, surface equipment is removed, and the land is rehabilitated and reclaimed.

The Council of Australian Governments' (COAG) Standing Council on Energy and Resources (SCER) National Harmonised Framework (2013) requires that "*Decommissioning and well abandonment must ensure the environmentally sound and safe isolation of the well for the long term. It must ensure the protection of groundwater resources, isolation of the productive formations from other formations, and the proper removal of surface equipment".*

There are approximately 900 petroleum wells in NSW, of which 567 were drilled for CSG purposes. Data provided to OCSE by DRE indicates that approximately 475 of these CSG wells are suspended or abandoned.

This paper covers two distinct themes within the topic of well abandonment:

- current international and national petroleum practice, including a comparison with NSW
- management of the legacy issue.

1.1 Well type and status definitions

There are various types of wells utilised for a CSG project. The various well types and statuses are described in greater detail in a background paper commissioned by the CSG review (Cook, 2013). Tables 1.1 and 1.2 provide a summary of the well terms most relevant to this information paper, although it should be noted that the terms and their definitions vary slightly across jurisdictions.

Table 1.1: **Types of wells used in a CSG project**

Well Type	Description
Exploration (Core and boreholes)	Typically used in the exploration phase to collect samples and to allow for assessment of the subsurface
Pilot	Typically used in the assessment phase to estimate the possible resource reserves
Production	Used at the production phase to extract the resource
Monitoring	Used to monitor subsurface conditions

Table 1.2: Well status in relation to decommissioning (SPE, 2013)

Well Status Terminology	Description
Shut in	A well that has had its valves closed to stop it from flowing
Suspended or Temporarily abandoned	A well that has temporarily discontinued operations
Abandoned or Plugged and abandoned	A well that is filled with cement and decommissioned, after cessation of function
Decommissioned	A well that is removed from service
Orphaned or Derelict	A historical well for which an operator cannot be located
Legacy	A historical well, potentially constructed or abandoned under less stringent conditions

In this information paper 'orphaned' refers to wells for which an operator cannot be located. Legacy refers to historical wells, potentially constructed or abandoned under less stringent conditions. Orphaned wells may be, but are not necessarily, legacy wells and *vice versa*.

Abandoned wells form the primary focus of this information paper. The topics of suspended, legacy, and orphaned wells are also discussed.

1.2 Approach

The Review used a range of sources to compile this paper. A selection of experts in the fields of emissions, groundwater and petroleum engineering were approached for information, as were a selection of CSG titleholders and major contractors.

Formal information requests were also sent to the government agencies that are responsible for regulating the extractive industries in NSW.

The Review also utilised international and national research on best practice in relation to well abandonment.

1.3 How this paper is structured

The remainder of this information paper is organised as follows:

- Chapter 2 outlines current best practice for well abandonment, compared with NSW
- Chapter 3 discusses legacy wells
- Chapter 4 provides the conclusions.

2 CURRENT BEST PRACTICE FOR WELL ABANDONMENT

Proper well design and construction throughout the well life-cycle, including after the well has been abandoned, are essential for well integrity and for ongoing safety and environmental protection. Active or suspended wells are typically subject to monitoring programs, which are designed to ensure the well is operated and maintained in a safe manner and that any failures are detected and promptly remediated. However, once a well is abandoned, monitoring generally ceases and the well must then stand the test of time.

International codes and standards exist for petroleum (which includes CSG) well integrity, of which well abandonment is a component. In NSW, the current standards are the NSW Code of Practice for Coal Seam Gas Well Integrity ("the NSW Code"). The NSW Code references internationally accepted and well-recognised standards, such as those maintained by Standards Australia and the American Petroleum Institute (API), for technical details. Worldwide industry experience in both conventional and unconventional petroleum resources suggests that when applying industry best practice well integrity failures are low for both active and abandoned wells (Davies, 2014).

A 2012 report prepared for the Commonwealth, *Leading practice framework for coal seam gas development in Australia,* states that risks associated with well integrity can be addressed and mitigated by the legislation and standards within Australia, which are considered to be leading practice (SKM, 2012, as cited in Commonwealth of Australia, 2014).

In addition, a recent Royal Society (UK) investigation of contamination from shale gas production stated, "*Ensuring well integrity must remain the highest priority to prevent contamination. The probability of well failure is low for a single well if it is designed, constructed and abandoned according to best practice*" (Royal Society & Royal Academy of Engineering, 2012).

This point was also made in a 2009 University of New South Wales Water Research Laboratory paper on quantifying the impact of leaky boreholes:

> *Thousands of bores have been drilled through sediments into underlying rock in NSW. Provided that sealing procedures in the Australian Standard and NSW DPI standards are adopted…, drilling for water, testing or mineral resources is a negligible risk to groundwater quality. However, improperly constructed bores and failed aging bores may have impacted on groundwater quality in some locations (Timms & Acworth, 2009).*

2.1 CONSEQUENCES OF COMPROMISED WELL INTEGRITY

In a background review paper on bore integrity prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development and the Commonwealth Department of the Environment in 2014, the consequences of well failure were highlighted:

> *Hundreds of thousands of bores have been drilled and constructed across Australia and many of these are located in key groundwater resources. Where bore integrity is not maintained, or bores are not decommissioned properly, there is the potential to impact on groundwater resources, which can affect existing and future groundwater users as well as the environment. Bore integrity failure can cause adverse and unintended changes in groundwater levels, flow rates and flow directions and can also lead to changes in groundwater quality. A further impact often associated with bore integrity failure is the contamination of aquifers by leakage of gas or water of a different quality, either through the bore casing, the bore annulus or open (i.e. uncased) bores (Commonwealth of Australia, 2014).*

The internationally accepted Norwegian standard for well integrity NORSOK D-010 defines well integrity to be "*application of technical, operational and organizational solutions to reduce the risk of uncontrolled release of formation fluids throughout the life cycle of a well*" (NORSOK, 2004).

Thus, to ensure ongoing safety compliance, adequate and effective standards must be ensured from the initial design and construction phases through to the final abandonment work. In light of its significance, it is no surprise that numerous international and national standards exist for various aspects of well design, material and construction.

2.2 FACTORS IN ESTABLISHING WELL INTEGRITY FOR OPERATING AND ABANDONED WELLS

2.2.1 Well design

The aim of well design is to ensure environmentally sound, safe production from the well, enabling the protection of groundwater resources, and isolating the productive formations from other formations (API, 2009). Poorly completed wells with compromised integrity or where the bond to the surrounding geology is weak, can cause movement of water and gas along the well annulus.

Modern well designs include contingency planning where multiple barriers, both physical and operational, are designed into the system to mitigate and eliminate the risk of failure due to unplanned events, for the protection of people and the environment (API, 2009). There are a range of different well log tests that can be used to confirm integrity and cement bonding and thickness. In the event that one barrier should fail, additional barriers are in place to prevent total well integrity failure and leaks to the environment.

In addition to this, the introduction of improvements in well tubing and pipes, cementing design and practices, couplings, pressure controls, and plugging design and practices have all worked to sustain the integrity of a well during its active life and after abandonment (Banchu & Valencia, 2014).

2.2.2 Well cementing

Cement is a critical component of well construction and thus cementing is a fully designed and engineered process. Cement is used in casing at the time of well construction, in addition to plugging at the time of well abandonment, and less commonly to address production or perforation issues. Cement used for plugging has the purpose of providing zonal isolation, preventing fluid from flowing within the well. Cementing a well casing has two main purposes: to provide zonal isolation between formations and to provide structural support to the well. According to the API, "*cement is fundamental in maintaining integrity throughout the life of the well*" (2009).

Cementing practice and design has decades of research to underpin it. Special formulations and additives are available to customise cement to individual well conditions, including increased resistance to gas migration, naturally occurring chemical ions, low pH environments, carbon dioxide (CO_2), high temperatures, sulphate, and mineral acids (King, 2012). Designs may call for using different cements for casing than for plugging a well.

Poor cement jobs, which may result in well integrity failure and potential leaks, are influenced by three main problems: failure to bring the cement top high enough, failure to surround the casing completely with cement, and gas migration in the cement during cement setting. All of these problems can be mitigated through proper cement design and competent execution. "*Cement is a strong, durable, very long-lasting barrier as long as it is mixed and placed properly*" (King, 2012).

As a high quality cement seal is critical to well integrity, various methods are available to test this. First, cements are pressure tested to ensure zonal isolation. Secondary confirmation steps include cement bond logs and other tools designed to test the bond strength between the cement, the pipe and the formation wall. *"A single cement inspection tool is not appropriate for every cemented string, but the tools are a broadly applied technique for assessing cement seal in a manner beyond that of a pressure test after cementing"* (King, 2012). Numerous tools and technologies exist for cement evaluation, with improvements being developed regularly (GE, 2013; Halliburton, 2014; Schlumberger, 2014).

Given its importance to well integrity, numerous standards exist around cementing, which are frequently referenced in petroleum regulations and rules.

2.2.3 Competencies and compliance

Significant expertise goes into the design of wells to ensure long lasting safety and integrity. To maintain well integrity, this expertise relies on proper execution of these designs. The NSW Code acknowledges this by stating, *"Worker training and certification is central to good practice and the mitigation of safety and environmental risks. Workers must have the knowledge and skills necessary to perform their work safely and to the highest possible standard"* (2012b).

Also key to ensuring well integrity is maintaining stringent compliance and enforcement programs. These not only ensure the protection of the environment and other resources but simultaneously work towards gaining public acceptance and support (Groat & Grimshaw, 2012).

2.3 LONG-TERM DURABILITY OF ABANDONED WELLS

Despite the abundance of information and research on petroleum well integrity (including design and cements), very little data exists about the long-term (100 -1000 years) durability of abandoned petroleum wells.

Although no long-term studies could be found dealing specifically with deterioration of CSG wells, other studies have been undertaken into the degradation of comparable wells. Yamaguchi, Shimoda, Kato, Stenhouse, Zhou, Papafotiou, Yamashita, Miyashiro & Saito (2013) have investigated the long-term corrosion behaviour of cement in abandoned wells under CO_2 geological storage conditions by simulating the geochemical reactions between the cement seals over a simulated period of 1,000 years. While alteration of the cement seals was found after a period of time, the alteration length after 1,000 years was approximately one meter, leading to the conclusion that cement would be able to isolate CO_2 and upper aquifers over the long-term.

Cement plug integrity in CO_2 subsurface storage was also looked at by Van der Kuip, Benefictus, Wildgust & Aiken (2011). Using estimates for degradation after 10,000 years they likewise came to similar conclusions stating that "*mechanical integrity of cement plugs and the quality of its placement probably is of more significance than chemical degradation of properly placed abandonment plugs"*.

It is important to note in the foregoing, that the literature on corrosion and cement degradation considers CO_2 stored at high pressure to be more aggressive than methane (Popoola, Grema, Latinwo, Gutti, & Balogun, 2013). Therefore, a conclusion can be drawn that if wells are properly designed, installed and maintained, the risk of long-term leakage from CSG wells from both the casing and cement can be considered to be minimal, although there is scope for additional research specifically to assess the impact of abandoned CSG wells over extended timeframes.

2.4 REGULATORY APPROACH TO ABANDONMENT IN VARIOUS JURISDICTIONS

Different jurisdictions regulate well abandonment in different ways. Some jurisdictions, including Western Australia and England, require companies to submit abandonment plans to the regulator for each project. These plans are then reviewed and approved in light of industry standards and field development plans (DMP, 2013; HSE, 2008).

Other jurisdictions, such as NSW, Queensland and Alberta, have set up Codes of Practice, Rules or Directives governing well integrity and abandonment that must be adhered to by all companies. These documents outline guiding principles and desired outcomes, specifying the minimum requirements for achieving these outcomes. Across jurisdictions abandonment regulations tend to cover three main areas: subsurface isolation, surface reclamation, and data collection (AER, 2010; DNRM, 2013a; DTIRIS, 2012b).

2.4.1 Subsurface isolation

A well provides a potential conduit through which previously unconnected geological formations may communicate. This has the potential to result in flow from and between aquifers, hydrocarbon zones and the surface, potentially causing contamination of both surface and groundwater resources.

Across jurisdictions, regulations governing abandonment mandate isolation between geological formations. Colorado states this simply in Rule 319 "[wells]…*must be plugged in such a manner that oil, gas, water, or other substance shall be confined to the reservoir in which it originally occurred*" (COGCC, 2013). Other jurisdictions such as Queensland and NSW specify isolation between hydrocarbon zones, groundwater aquifers, and zones of different pressure, while Alberta specifies non-saline water and porous zones. While the wording varies, the intent is the same.

Isolation is achieved through proper well completion design and cement plugs. The NSW Code, similar to other regions, stipulates minimum cementing design and procedure requirements, refers to industry standards, and specifies minimum cement testing that must be done to ensure proper isolation before surface equipment can be removed and the well cut and capped.

Unlike most other jurisdictions which allow for the use of multiple cement plugs covering various zones, NSW regulation requires the vertical section of petroleum wells be filled entirely, depth to surface, with cement.

2.4.2 Surface abandonment and reclamation

All jurisdictions include a requirement to abandon the surface site of the well. Surface abandonment includes cutting and capping the borehole and removing all surface equipment.

Typically jurisdictions require that wells be cut and capped one to two metres below the surface, although some jurisdictions provide additional guidance depending on future land use requirements. NSW mandates wells be cut 1.5m below the surface with a wellhead marker plate installed. These marker plates contain identification details and aid in locating the well in the future.

After a well has been cut, capped and the surface equipment removed, regulations typically mandate the land be reclaimed to a state comparable to its original use. Reclamation guidelines and requirements are often governed through environmental regulations, separate to well abandonment codes of practice.

2.4.3 Information and data collection

Proper records must be kept of abandonment procedures, including accurate surface location data and in light of the emerging problem of orphaned wells, an accurate database is needed with this information. This is highlighted in the NSW Code where *"complete and accurate records of the entire abandonment procedure must be kept, with these records submitted as part of the legislative reporting requirements for the abandonment of CSG wells"* (2012b).

It is important that planning regulations look to abandoned well data to ensure abandoned wells are not compromised by future developments of any nature (residential, urban, infrastructure, etc.). Alberta recently updated its *Subdivision and Development Regulation* to mandate a check for abandoned wells, including mandatory testing, to ensure continued well integrity prior to any new development. A corresponding *Directive* for the petroleum industry was added, placing the onus on the well licensee to provide any requested data and perform the required testing (AER, 2012).

2.5 ESTABLISHMENT OF THE NSW CODE

The NSW Code was developed and introduced in 2012 to provide a practical guide for CSG titleholders on *"how to comply with a condition of title for CSG exploration, extraction or production under the* Petroleum (Onshore) Act 1991 *(PO Act) and the* Petroleum (Onshore) Regulation 2007 *to ensure that well operations are carried out safely, without risk to health and without detriment to the environment*" (DTIRIS, 2012b).

Contained within the Code are sections relating to the suspension and abandonment of wells. The NSW Office of Coal Seam Gas (OCSG) is responsible for enforcing compliance with the NSW Code, which includes reviewing and consenting to any proposed suspension or abandonment program by a titleholder.

The NSW Code covers topics from preliminary approvals and risk management planning, through reporting and notification, to well design, testing, monitoring and abandonment. The Code lists desired outcomes and principles for each topic, outlines minimum requirements and points to relevant API and Australian standards for further technical details.

The NSW Code is intended to apply to all CSG wells drilled in NSW. However, this is not currently the case as the Code is only formally applied to a title at the time of licence issue or renewal, or at an activity approval on a Petroleum Exploration Licence (PEL). There is currently no clear method for applying the Code to some active titles that have not been renewed since 2012, which is of particular pertinence to production titles as they can remain current for up to 21 years. Although despite not being formally required to do so, many titleholders appear to have adopted the standards within the Code.

The Code is currently under review, which is important as this provides a mechanism to amend for any technological advances or to reflect any changes in international practice. However, no formalised review process for the NSW Code exists in legislation, with the only requirement for review written in the Code itself.

Additionally, the well integrity code refers to another NSW code of practice that is being developed in relation to training and certification of personnel working in the CSG industry. There are currently few requirements in petroleum legislation regarding competencies, and the introduction of the code would help to bring NSW in line with other jurisdictions. This is a matter the Review has emphasised in its formal recommendations.

2.5.1 Well suspension in NSW

The NSW Code contains a section relating to well suspension. Mandatory requirements include “a well must not be left in an unsafe condition” and “a program should be in place for regular inspections to check for gas leaks and other health and safety matters” (2012b). The code refers to ‘relevant standards’, rather than specific technical details.

NSW legislation requires a petroleum titleholder to gain approval to suspend a well. It is standard practice that titleholders request a period of up to two years for the suspension, although this time limit is not mandated under petroleum legislation. A limited period of suspension is important as without it there may not be sufficient incentive to abandon the well properly. The jurisdiction of Alberta has seen problems in this area, with over 60,000 inactive wells, more than 10,000 of them inactive for more than 10 years (Robinson, 2010).

3 LEGACY WELLS

Petroleum wells have been constructed in NSW over several decades using different approaches under different conditions and with variable links to existing corporate or individual titleholders. A legacy well refers to a historic (old) well, which owing to its age, could have potentially been constructed or abandoned to less stringent standards. This chapter looks at issues relating to wells drilled in the past and their current management.

As detailed in Section 2.1, wells that have not been adequately constructed and abandoned to appropriate standards have an increased potential to connect groundwater systems, and permit fugitive emissions. Assigning responsibility to legacy wells may not be straightforward largely due to poor historical records or a lack of legal accountability if the titleholder was to exist.

3.1 LEGACY PETROLEUM WELLS IN NSW

To address the issue of legacy wells in NSW, DRE (with OCSG) has developed a project that aims to provide an assessment and management plan for orphaned petroleum wells in NSW. The project will assess the abandoned petroleum wells in the State to determine which of these wells are orphaned, i.e. can no longer be attached to an operator/titleholder. This occurs either because the titleholder has ceased operating or has relinquished the title where the well is located. The orphaned wells will be assessed to indicate the highest priority wells that may require remediation. The priority ranking of the wells will be based on factors such as environmental risk, community concern, and adequacy of historical technical records (DRE personal communications, August 2014).

One of the problems that the project is trying to address is the potential inaccuracy of the information on the status of historic wells, due to changes in the definition of terms or mislabelling. For example, the definitions of well status data may have changed since they were entered into the Department's system, e.g. "plugged and abandoned" could have been defined differently in the 1980s when compared to now. As part of the process the project will provide a more accurate account of the status of the orphaned wells.

The project itself is funded from the Derelict Mines Program (DMP), which was established under the *Mining Act* to rehabilitate abandoned mine sites in NSW, in circumstances where accountability cannot be established. In 2013-14 the program was expanded to incorporate orphaned petroleum wells. However, as the DMP allocates funds according to a prioritised list of works, it is under no obligation to fund petroleum well rehabilitation (DTIRIS, n.d.).

Further, as the project's primary focus is on orphaned wells, consideration may need to be given to the adequacy of the abandonment process for legacy wells that are still attached to titles. Currently, a legacy well would only be assessed when the titleholder status changes, with the title's relinquishment.

3.2 LEGACY PETROLEUM WELLS IN OTHER JURISDICTIONS

While NSW has approximately 900 petroleum wells dating back several decades, other jurisdictions around the world, such as Pennsylvania with more than 350,000 petroleum wells dating back as early as 1859, have significantly larger industries and have significant experience dealing with legacy and orphan well issues (DEP, n.d.-b).

3.2.1 Legacy and orphaned well programs

Most North American jurisdictions with a history of oil and gas production have set up funds, programs or associations to manage orphan or legacy wells and well sites. While the details of how these programs are managed and how sites are prioritised varies from jurisdiction to jurisdiction, they all work to identify, properly abandon, remediate and reclaim orphaned wells and sites.

Various funding models have been used to fund orphaned well programs across different jurisdictions:

- Alberta – sets a yearly budget ($15 million in 2014), which the regulator then collects from all licence holders as a levy on the annual licence fee (AER, 2014)
- Ohio – collects a portion of taxes on oil and gas production, as well as any forfeited bond money (ODNR, 2014)
- Pennsylvania – applies a surcharge of up to $200 on well licence applications (DEP, n.d.-a).

The United States Interstate Oil and Gas Compact Commission issued a report in 2008 that outlines plugging programs across 32 states including information on funding models used, which include fees, industry specific taxes, revenue from forfeited bonds and general public funds (IOGCC, 2008).

3.2.2 Adopt a well

As part of its Orphan Well Program, the State of California runs an “Adopt a well” program. This program maintains a list of orphan wells that are available for adoption; these wells have potential value and may be of interest to other operators. Interested parties can enter into an agreement which gives them 90 days to test the well without incurring any liability for its abandonment. If the testing is successful the company may choose to adopt the well becoming its permanent operator. If they choose not to adopt the well, the company bears no liability (DOC, 2013; IOGCC, 2008).

3.3 NON-PETROLEUM LEGACY WELLS

Wells are not exclusive to the petroleum industry; they are also a feature of mining and irrigation activities and, like petroleum wells, they have the potential to connect aquifers and emit fugitive emissions if their integrity is compromised, or if they are not abandoned appropriately. It is likely that the number of abandoned wells in NSW resulting from the irrigation and mining industries dwarfs those from petroleum (with a total of approximately 900 petroleum wells). By comparison there are around 10,000 coal exploration and mining wells and around 135,000 water supply and monitoring bores (DTIRIS, 2014; NOW, 2014). The exact number of these wells that have been abandoned is currently unknown; however it is likely to be high. Similarly, how many of these abandoned wells leak gas or affect groundwater movement is also unknown.

Standards exist in NSW for the decommissioning/abandonment of petroleum, coal and water wells, that require the sealing of wells during the abandonment process (*NSW Code of Practice for Coal Seam Gas Well Integrity* (2012b)*, Borehole Sealing Requirements on Land: Coal Exploration* (2012a)*,* and *Minimum Construction Requirements for Water Bores in Australia* (2012)). However, it is not certain that prior to the existence of these current standards, requirements were adequate to maintain well integrity after abandonment, as some of these wells/bores in NSW were drilled more than a hundred years ago. This is an internationally recognised concern, but little scientific literature currently exists on the topic.

A collaborative study, which is still in preparation, between UNSW Australia, Royal Holloway (University of London), and CSIRO measured and compared methane emissions from various sources including wetlands, rivers, cattle, CSG projects, urban leaks, and open cut coal mines in NSW and Queensland. At least one abandoned well, understood to be from coal exploration, was found to be emitting methane at concentrations beyond the maximum range of the detection system, at ignitable levels (UNSW, 2014).

There may also be concerns around safety related to the emission of methane from abandoned wells. A 2012 bushfire in Queensland ignited a legacy (coal exploration) borehole emitting methane gas before being extinguished and the borehole capped. This incident led to the development of guidelines for the management of uncontrolled gas emissions from legacy boreholes, outlining the assignment of responsibility in an emergency situation (DNRM, 2013b).

A cumulative desktop study aimed at developing an inventory of orphaned/abandoned wells (petroleum, mining and water) in the State could be a useful first step in quantifying the potential problem. Unlike petroleum wells in NSW, the locations of legacy wells used for mining and irrigation purposes will be largely unknown, meaning the remote sensing technologies, like those utilised by UNSW, Royal Holloway and CSIRO, would have to be adopted to detect where these wells are located.

4 CONCLUSION

A large number of wells are drilled for a variety of purposes across several different industries in NSW each year. The majority of these will ultimately be correctly abandoned and are unlikely to pose an environmental or health hazard. However, if the integrity of these wells is compromised at any stage during construction, operation or after abandonment, they have the potential to affect the environment adversely, mainly in the form of either contamination of subsurface water systems or via fugitive methane emissions.

If designed, constructed and abandoned to best practice, wells that are decommissioned to current standards have a low likelihood of environmental damage (Royal Society & Royal Academy of Engineering, 2012). To ensure this, various regulatory bodies have written codes of practice and licence conditions encompassing these requirements. In NSW, these requirements are covered for CSG wells in the 2012 Codes of Practice. The NSW Code is considered to be in line with international best practice (Commonwealth of Australia, 2014). However, as there is no legislative requirement for the Code's review, its ongoing relevance and currency is not guaranteed.

Good codes are only effective if universally applied and complied with. Ideally, all wells drilled since the introduction of the NSW Code would be required to adhere to the conditions within the Code, however currently the Code is not a formal requirement for a proportion of petroleum titles, as it is only formally applied to a title at the time of licence issue or renewal, or at an activity approval on a Petroleum Exploration Licence (PEL). If a legislative review were to occur, then thought should be given to the Code's inclusion in all active titles. Similarly, the licensing and competence of all personnel involved in the drilling and abandonment of any wells in NSW should be mandated to ensure adequate standards are maintained. There are currently few requirements in petroleum legislation regarding competencies, and the completion of the code of practice relating to training and certification for the CSG industry would help to bring NSW in line with other jurisdictions.

If an area of uncertainty were to exist in relation to the integrity of petroleum wells, it would be in relation to the potential long-term impacts. Studies exist for CO_2 subsurface storage wells, which suggest that cement would be able to isolate CO_2 and upper aquifers over the long-term (1,000+ years). Although comparisons can be made linking long-term CSG well integrity to that of the CO_2 storage wells, with a potentially more aggressive environment, there is scope for additional research to assess specifically the impact of abandoned CSG wells over extended timeframes.

Legacy wells that have been abandoned may have been constructed or abandoned to inferior standards, increasing the likelihood of well integrity failure and consequences to the environment. In NSW the issue of legacy petroleum wells is currently being addressed by DRE via their derelict well project, which adopts a risk-based approach to highlight priority orphaned wells that require further remediation. However, as the project's primary focus is on orphaned wells, with no responsible operator to be held accountable, consideration may need to be given to the adequacy of the abandonment for legacy wells that are still attached to titles.

The project seems a logical, partial solution to the problem of orphaned wells in the State, however as the project is funded from the DMP, and is not guaranteed to continue in the longer term, funding schemes for petroleum wells, as observed in Alberta and Ohio, could be adopted. In this regard, the NSW Chief Scientist & Engineer's report, *Environmental risk & responsibility and insurance arrangements for the NSW CSG industry,* recommends that Government give consideration to a robust and comprehensive policy of appropriate insurance and environmental risk coverage for the CSG industry. This consideration should examine the potential adoption of a three-layered policy of security deposits, enhanced insurance coverage and an environmental rehabilitation fund administered by Government. The latter would have the benefit of addressing any potential long-term environment impacts associated with CSG activity, including management and rehabilitation of abandoned wells (CSE, 2014).

The potential concerns outside petroleum wells in NSW, in relation to abandonment issues around legacy mining and irrigation wells, could begin to be addressed by some initial desktop studies to quantify the scale of the problem. However, any desktop study will be limited by the historical data for these wells, which in some cases dates back over a century, with substantial amounts of data having never been recorded. Unlike the petroleum wells in NSW, the locations of legacy wells used for mining and irrigation purposes will be largely unknown, meaning that, for example, remote sensing or other technologies may have to be used for the locations of these wells to be detected. The risk-based approach adopted in the derelict well project by DRE could then be utilised to focus attention on any priority wells that require remediation.

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Acronyms

CSE	NSW Chief Scientist & Engineer
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSG	Coal seam gas
DMP	Derelict Mines Program
DP&E	NSW Department of Planning and Environment
DRE	NSW Trade & Investment – Division of Resources and Energy
OCSE	Office of the NSW Chief Scientist & Engineer
OCSG	Office of Coal Seam Gas
SOPEPSR	Schedule on Onshore Petroleum Exploration and Production Safety Requirements