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Energy Procedia 114 (2017) 5791 – 5798

Energy Procedia

13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland

Well-based monitoring schemes for the South West Hub Project, Western Australia

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Abstract

The South West Hub CCS project (SW Hub) in Western Australia is proceeding to reduce uncertainties related to injectivity, capacity and containment through a well drilling, coring and logging program. This study provides reviews of well designs for in situ tests and well-based monitoring methods at CO_2 storage sites. Wells are expensive and complex engineering undertakings, and their design including size, geometry and materials, greatly impacts on the type of data that can be collected and techniques for monitoring that can be performed at a site. There is no 'one size-fits-all' monitoring well, but there is a tool-box or ensemble of solutions that can achieve a broad range of relevant monitoring objectives given constraints of site characteristics and budgetary limitations. For the SW Hub, a multi-well, multi-use and multi-completion monitoring scheme is proposed that combines the benefit of four different types of monitoring wells in addition to equipping the injector: 1) a well completed in the reservoir for conformance monitoring with additional completion above the storage complex, 2) a well completed above the confining layer for ensuring containment, 3) a well completed in the reservoir in the vicinity of an identified fault for monitoring potential across-fault migration and fault re-activation risks and 4) a well for fault leakage surveillance above the storage complex.

Peer-review under responsibility of the organizing committee of GHGT-13.

Keywords: CO_2 geological storage; South West Hub; Western Australia; monitoring wells; monitoring and verification

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Peer-review under responsibility of the organizing committee of GHGT-13.
doi:10.1016/j.egypro.2017.03.1717

1. Introduction

The South West Hub (SW Hub)[1] is a geosequestration project examining CO_2 storage potential within the saline aquifer of the Lesueur Sandstone at 2,000 to 3,000 m depth, 100 km south of the City of Perth, Western Australia (Figure 1). The geological storage concept for the SW Hub relies on a multi-barrier system including residual trapping and convolute migration pathway within a thick package of heterogeneous strata.[2] A key component of this investigative work involves drilling wells for data acquisition and for the wells' potential use in monitoring CO_2 distribution in the subsurface. As well-based monitoring technologies for storage sites have been evolving along the years with the implementation of new projects, this study examines available well-based monitoring methods in general and considers their suitability in the context of the SW Hub. This work will provide a framework for the future design and location of wells that may be drilled as part of the development of this potential commercial-scale storage project.

Four wells have been drilled in the SW Hub project area: Harvey 1 (2945 m) was drilled in 2011 prior to the acquisition of a large 3D seismic survey in the prospective SW Hub region during 2014, and three shallow wells (Harvey 2 - 1,350 m , Harvey 3 - 1,550 m & Harvey 4 – 1,802 m) that were completed in 2015. Planning of the shallow wells included: relative well placement scenarios considering geological uncertainty, recommendations for data acquisition including coring, core analyses, logging, well testing options to evaluate sealing potential through vertical communication, numerical simulations considering different geological scenarios to constrain well test parameters and for providing indicative well spacing, and drilling rig requirements. A number of recommendations were incorporated in the subsequent drilling campaign; however due to land use, cost and drilling issues, not all recommendations could be met, most prominently being that a vertical interference test could not performed and that the Wonnerup Member (lower member, and probable injection unit, within the Lesueur Formation) was only penetrated to132 m in Harvey 3 and 210m in Harvey 4.

It is expected that another deep well, Harvey 5, may be drilled in 2018 to characterise most of the reservoir interval of the Lesueur Formation and which will be used for production testing and possible test injection of CO_2. The design and completion of Harvey 5 must take into account these potential testing activities and also consider future use options for monitoring or injection.

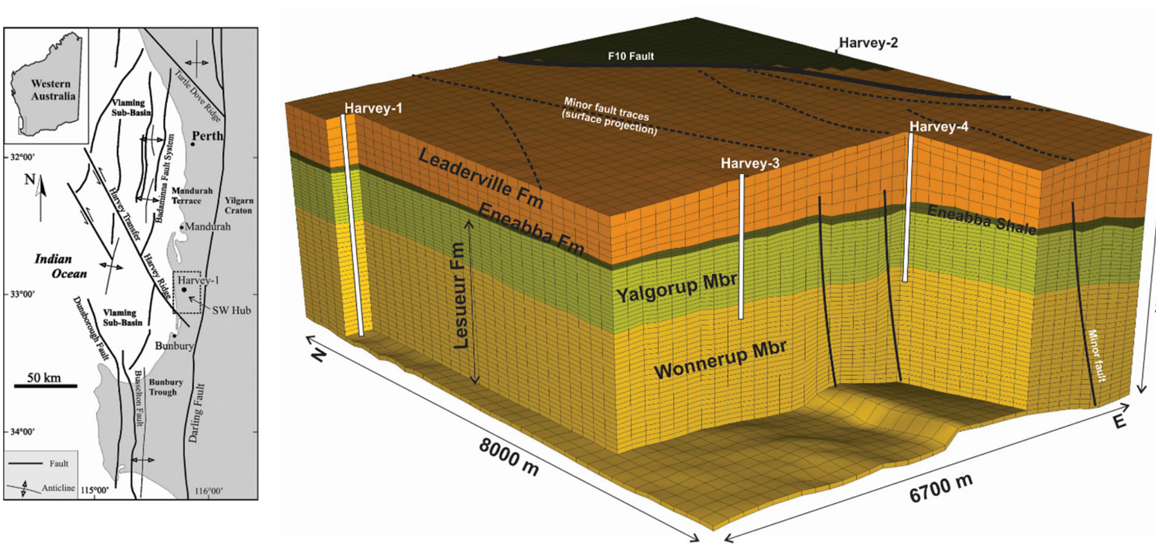

Figure 1. Location of the SW Hub project and 3D representation of existing well location within the proposed greater storage complex.

1.1. Purposes of well-based monitoring

There are two interdependent primary purposes of MMV activities: to verify storage performance (conformance) and to ensure containment and confirm volume stored of CO_2. Different well types and monitoring locations are summarized in Figure 2.

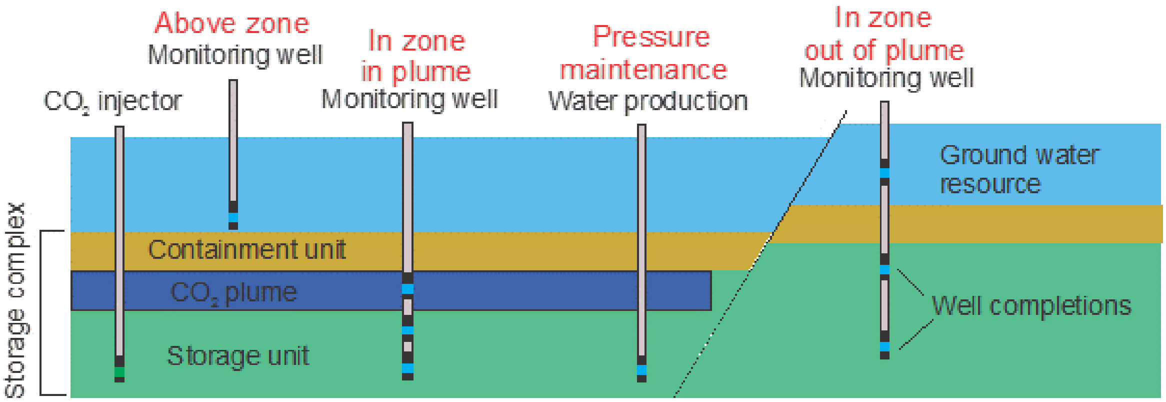

Figure 2. General schematic of possible well types and monitoring locations associated with CO_2 geological storage.

1.1.1. Conformance monitoring

The verification of storage performance implies normal operating conditions and assumes containment can be managed using well-established industry practices for well and reservoir management. The monitoring is supposed to verify that the CO_2 plume in the reservoir and reservoir pressures behave as predicted. Specific monitoring targets using wells include:

- Well integrity: Integrity of casing, tubing, cements and isolation of perforated intervals.
- Well performance: Well-head and bottom-hole pressure behave as predicted and injection rate can be maintained.
- Pressure monitoring: Monitoring of the pressure in the injection interval away from the injector for verification of reservoir models and building confidence in model predictions.
- CO_2 monitoring: Monitoring the CO_2 saturation in the injection interval away from the injector for verification of reservoir models and building confidence in model predictions. This can be achieved by either sampling of fluids or downhole geophysical methods.

1.1.2. Containment monitoring

Monitoring needs to verify no loss of containment is occurring that would affect the CO_2 inventory; and to detect early warning signs of any potential loss of containment to prompt risk mitigation measures that prevent or reduce any impacts to the environment or human health. Specific monitoring targets using wells include:

- Leak detection of fluid migrating along the outside of a well: Legacy or monitoring wells, if damaged or not cemented properly, may act as preferential flow paths through the seal for CO_2 or brine to migrate upwards.
- Leak detection of fluid migrating upwards along faults and fractures: Depending on the stress regime and geomechanical properties, faults may act as preferential flow paths through the seal for CO_2 or brine to migrate upwards.
- Leak detection of fluid migrating through the seal matrix: Contrary to the previous two potential leakage pathways which are associated with specific localised features, fluid migration out of the storage complex may occur in a more diffuse way through migration along unidentified zones of weakness in the seal.

- Fault reactivation: Detection of micro-seismic events associated with an increase in formation pressure in response to CO_2 injection.

1.2. Monitoring well completion and instrumentation

Depending on the geological environment and regulatory requirements, various degrees of well-based monitoring may be required for a CO_2 storage project. Examples of different well completion and instrumentation set ups are shown in Figure 3 and discussed below.

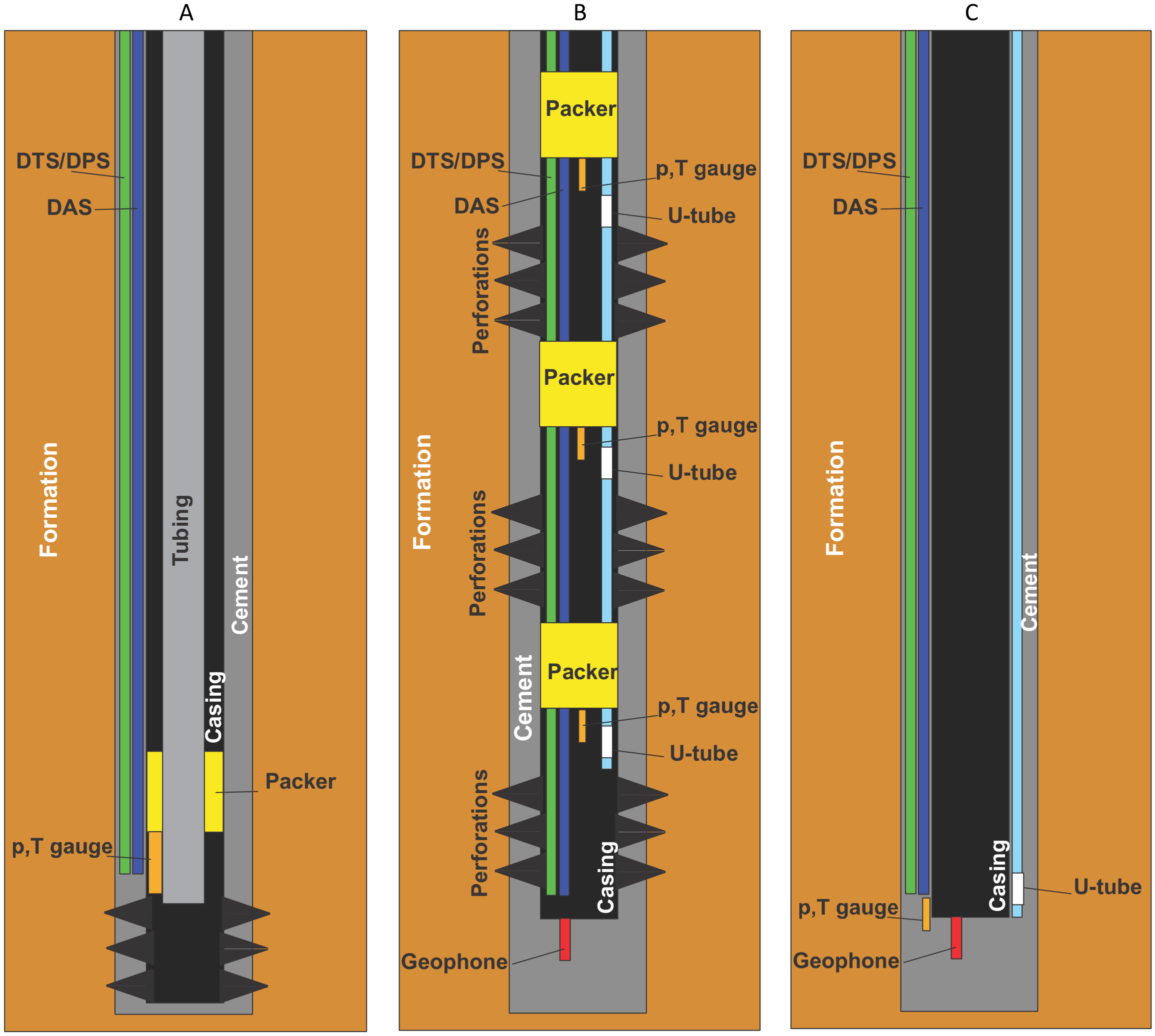

Figure 3. Suggested well instrumentation and completion for: A) CO_2 injection well, B) conformance monitoring in storage interval, and C) above-zone monitoring for containment monitoring. DTS = distributed temperature sensor, DAS = distributed acoustic sensor, DPS = distributed pressure sensor, p = pressure, T = temperature.

1.2.1. Injection well

In the most straightforward case (and as done at Sleipner[3]) no designated monitoring well is needed. The injector itself, however, can be instrumented with fibre-optic cables, pressure gauges, and geophones, primarily for monitoring well integrity and injection performance. If combined with surface monitoring, downhole measurements could also enhance pressure and CO_2 plume imaging. Some instrumentation may need to be installed outside the casing which has advantages with respect to detection limits and visualization, but may increase the complexity and risk of the cement job. Other instruments such as geophones can be deployed on tubing but may involve special mechanism so they are able to maintain contact with casing.

1.2.2. Monitoring well in storage reservoir

Completing an observation well in the storage interval has the main objective to directly detect the pressure and CO_2 plume for performance monitoring. It can have multiple monitoring completions for fluid sampling or pressure and temperature measurements, or fully cased with an open completion at the bottom. The latter case would have the advantage that fibre-optics could be installed outside the casing for better indirect imaging of the CO_2 plume, whereas the former provides multiple options for direct and repeated fluid sampling. Tubing could be installed with sliding sleeves at every perforated interval to enable independent opening/closure of each zone. The tubing enables access to the well with wireline logging tools and geophone arrays, as well as independent production and/or injection of each perforated interval.

1.2.3. Monitoring well above storage complex

The main objective of above-zone monitoring is the detection of fluid leakage from the storage complex. Depending on the location, this type of monitoring well may be used to: a) image the CO_2 plume in the underlying storage unit, b) passively detect microseismic activity associated with injection or loss of containment, c) characterise the above zone monitoring unit, d) detect changes associated with the movement of fluids out of the storage unit into the monitoring unit (pressure or fluids) and e) monitor nearby faults and determine the ongoing integrity of the monitoring well itself. The biggest advantage of this type of well is that it does not penetrate through the top seal of the storage complex and therefore does not increase the risk of leakage by providing a potential pathway for fluids. Generally, this well should be located within the radius of the CO_2 plume and, if previously identified, in close proximity to a potential point of leakage (i.e. fault, fracture zone).

1.2.4. Multiple and multi-use wells

Well-based monitoring can be enhanced by surface geophysical methods or by using multiple wells (Figure 4).

In Option 1, the design focuses on monitoring wells that are completed in the injection interval and the above-zone and thereby addresses both conformance and containment issues generally applicable in a wide range of storage scenarios. In basins with low potential for impact on other basin resources and high confidence in the sealing capacity of caprock, monitoring may be constrained to the reservoir interval largely focusing on conformance monitoring and enhanced visualization of the CO_2 plume (Option 2). In contrast, if there is a relatively high degree of uncertainty with respect to sealing capacity, monitoring could be limited to the zone above the storage complex, also limiting the additional leakage risk along wells penetrating the injection interval (Option 3). In more complex geological storage scenarios with identified faults in the vicinity of the injection location, target monitoring of the potential for fault leakage or fault reactivation may be warranted (Option 4).

1.3. Existing monitoring schemes

Previous pilot and demonstration projects focussed mainly on detecting and visualising the plume of the injected CO_2 for model calibration and improved understanding of the subsurface behaviour of injected CO_2. The first CO_2 storage project at Sleipner[3] had only the injection well with limited well-based monitoring and verification. Early CO_2 pilot projects (Frio[4], Otway[5]) used a simple injector – observation well configuration, both completed in the injection interval and mainly to investigate the nature and timing of plume migration. Other research projects (i.e. Nagaoka[6], Ketzin[7]) deployed multiple monitoring wells completed in the injection interval to better visualise and constrain the extent of CO_2 migration. Subsequent projects (i.e. Cranfield[8], new well at Ketzin, Illinois Basin – Decatur Project[9]) also monitored the interval above the injection horizon outside the storage complex. Obviously, the aforementioned different monitoring set-ups were all designed to answer specific research questions or address the local geology.

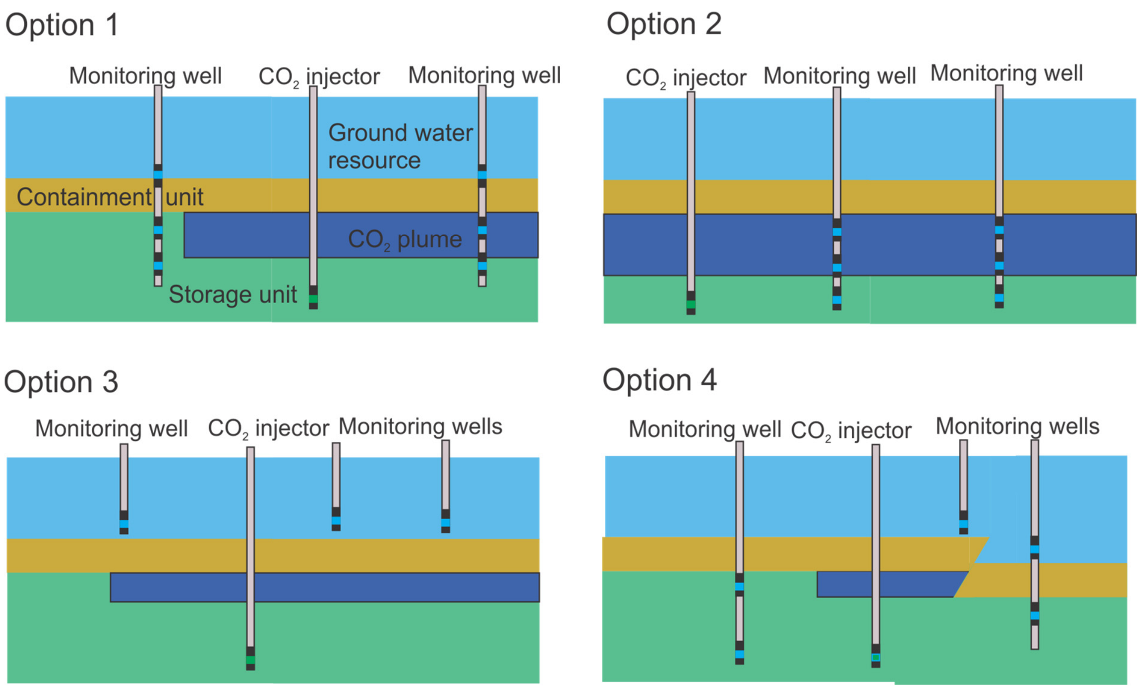

Figure 4. Schematic configuration of monitoring schemes.

2. South West Hub monitoring scheme (proposed)

Preliminary risk assessment of the South West Hub project has identified specific monitoring priorities that need to be addressed with an appropriate monitoring scheme. Therefore, suitable generic monitoring scenarios and well configurations from the previous part of the report are adapted to the specific environment of the South West Hub in this section (Figure 5). The South West Hub, being a 'greenfield' site with limited well penetration, has considerable uncertainty regarding the injection and containment characteristics of the storage complex. The target storage interval is the Wonnerup Member of the Triassic Lesueur Sandstone Formation, a >1500m thick interval of fluvial sands, overlain by the Yalgorup Member, a complex sequence of interbedded palaeosols and sandier intervals.

Because wells are needed as fundamental sources of information to characterise the site, it is prudent that some wells be designed that are suitable for conversion into monitoring wells for pilot or commercial operation. For the SW Hub the following aspects are highlighted for well-based monitoring:

- Containment: The Yalgorup Member exhibits containment characteristics, but there is limited information about the regional extent of individual palaeosols and shaly interbeds that might act as barriers and what their trapping potential might be. Thus monitoring the zone above the storage reservoir will be important to detect any vertical migration of CO_2 and confirm security of the shallow subsurface. Above-zone monitoring wells are recommended at locations that will be informed through iterative quantitative risk assessments and the updated geological models being developed.
- Capacity: The degree of compartmentalisation of the Wonnerup Member is currently uncertain, as only one well penetrates the whole of the Member within the regional study area. Compartmentalisation presents a risk of increasing pressure when injecting several million tonnes of CO_2 per year. It is recommended that at least one well is completed in the injection interval for monitoring reservoir pressure and, if necessary, to act as a pressure management well.

- Injectivity: Injection characteristics of the Wonnerup Member are influenced by permeability, diagenesis, CO_2-mineral behavior and impacts of CO_2 injection in the Wonnerup Member are the focus of current research. The number of injection wells needed to inject the required rate of CO_2 will be determined through detailed dynamic simulations. It is recommended consideration be given to redundancy for injection operations, and a multi-purpose well design for conversion from monitoring to injection or water production would be advantageous

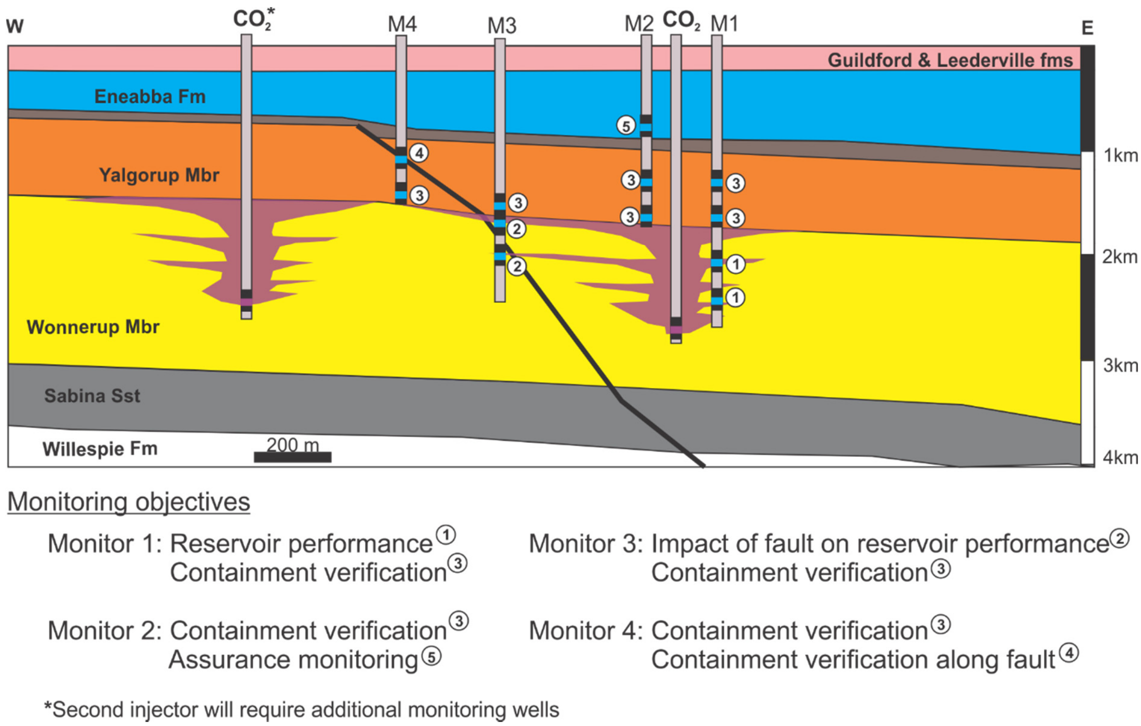

Figure 5. Generic scheme for the South West Hub CCS Project showing options for monitoring wells that are suitable for conformance and containment monitoring as part of an overall risk management strategy. It should be noted that the Yalgorup Member is part of the storage complex and migration into this unit is not considered as leakage.

3. Conclusions

Well-based monitoring schemes for storage projects have common elements to address performance and containment objectives of most projects, but the specific well requirements and designs must be based on the needs of a given individual project. This work describes generic schemes of monitoring options as potentially applied to the SW Hub project in Western Australia.

Monitoring wells can be completed within or above the storage complex, equipped with tools for direct or indirect measurements. The well design of an observation well for monitoring CO_2 geological storage depends largely on the monitoring objectives, which have to main aspects:

1. Conformance monitoring – for ensuring that the CO_2 plume is behaving as predicted in the storage interval.
2. Containment monitoring – for ensuring that the injected CO_2 is not leaving the storage complex.

The South West Hub storage project is located in a ‘greenfield’ area with very limited well coverage. Hence, there remain uncertainties regarding storage suitability (i.e., capacity, injectivity and containment) that are higher than in an area where there are multiple wells and/or a history of petroleum production. As uncertainty around these parameters is reduced by further characterisation work, the development of monitoring schemes and requirements will also become progressively more refined and risk-based around project-specific characteristics.

It is interesting to note that regulations of other subsurface injection operations (i.e., deep waste disposal, natural gas storage, acid-gas injection) rarely require monitoring wells completed in the injection interval or directly above the initial seal. In those cases, monitoring of shallow groundwater may be the only requirement for the protection of groundwater resources. Hence, while monitoring wells may be needed in the early phase of demonstrating the feasibility and safety of CO_2 geological storage, a mature CO_2 storage industry should be able to relax some of the monitoring requirements in line with regulations of other industries involved in the injection and production of subsurface fluid.

Acknowledgements

The authors wish to acknowledge financial assistance provided through Australian National Low Emissions Coal Research and Development (ANLEC R&D). ANLEC R&D is supported by Australian Coal Association Low Emissions Technology Limited and the Australian Government through the Clean Energy Initiative. The authors would like to acknowledge contributions to the South West Hub Flagship project by the Western Australian Department of Mines and Petroleum (including the Geological Survey of Western Australia) and the Commonwealth Department of Industry, Innovation and Science.

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