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Review of groundwater monitoring and opportunities for optimal network design for the Narrabri Gas Project area

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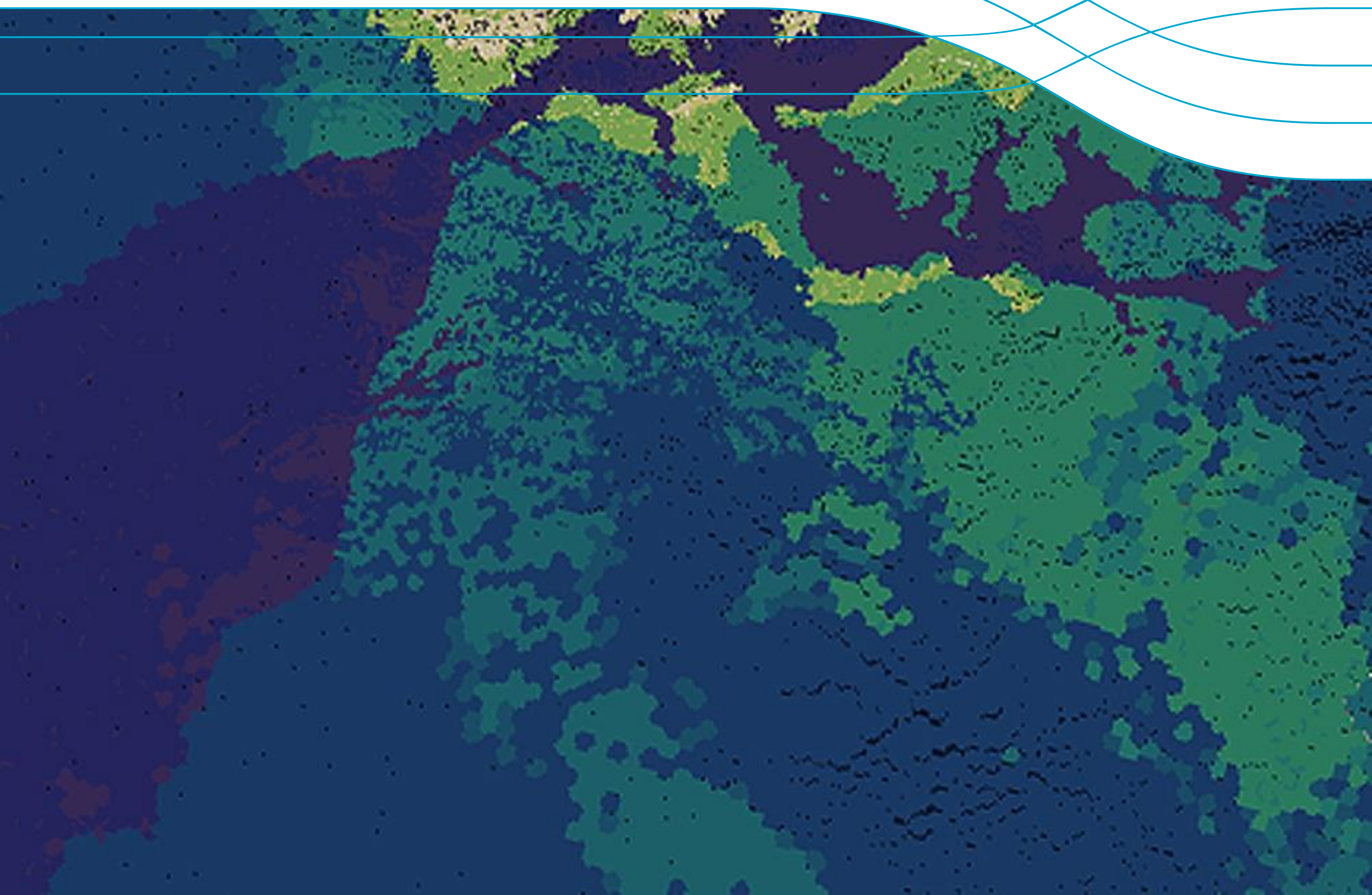

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The Gas Industry Social and Environmental Research Alliance (GISERA) undertakes publicly-reported research that addresses the socio-economic and environmental impacts of Australia's natural gas industries.
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Contents

SUMMARY

The proposed Coal Seam Gas (CSG) development in north-western NSW by the Narrabri Gas Project has raised a number of concerns about potential impacts to groundwater resources Permits and licenses for CSG exploration and development in NSW require companies to implement groundwater monitoring plans that include two years of baseline monitoring. Santos Energy have been collecting baseline water quantity and quality data and have developed a Water Monitoring Plan for monitoring potential impacts. NSW Government's Department of Primary Industries (DPI) Water is also monitoring groundwater in this area. Both Santos Energy and the NSW Government DPI Water have also proposed an enhanced monitoring scheme, which includes the installation of new monitoring bores across coal basins in NSW. The value of monitoring bores in terms of informing potential changes to water quantity and quality is maximised when they are strategically located relative to water dependent assets and the area of potential hydrological impact.

Strategies for monitoring CSG groundwater impacts that are designed and implemented in Queensland, and monitoring plans proposed for the Narrabri Gas Project area by Santos and NSW Government both provide useful insights into potential objectives of groundwater monitoring aimed at assessing CSG impacts. Review of the existing monitoring bores in the region indicates a non-uniform distribution of bores within and around the Narrabri Gas Project area, which monitor groundwater head and quality across multiple formations within the Gunnedah-Oxley Basin and the GAB. Recent research outputs from the Bioregional Assessments Programme also provides a register of water dependent assets and receptors in the region. Ongoing research undertaken through Bioregional Assessments and GISERA will provide a probabilistic assessment of the potential impacts of CSG development on groundwater resource and ecological and economic receptors in the region.

In light of the knowledge provided by these studies, the GISERA project on 'data-worth analysis and spatial design of monitoring networks' aims to develop and apply methods for optimising groundwater monitoring network. The objectives of monitoring network design is focused on maximising the probability of identifying CSG induced drawdown changes particularly at the locations in the vicinity of important water dependent ecological and economic assets. The design also focuses on improving the prediction of potential impacts at these locations by minimising model prediction uncertainty.

This report provides a brief overview of groundwater monitoring requirements in CSG development areas and existing groundwater monitoring in the Narrabri Gas Project area. The report also evaluates the opportunity for data-worth analysis and optimal design of monitoring network as underpinned by the modelling and uncertainty analysis of potential groundwater impacts undertaken through the Bioregional Assessments Programme and through GISERA research studies.

1 Introduction

One of the biggest concerns of the community in the Namoi region with respect to Coal Seam Gas (CSG) development is the risk of potential impacts to groundwater pressure and water quality occurring in beneficial aquifers that are extensively used by farmers. Quantifying the probability of pressure changes and groundwater travel times between coal seams and farmers' bores (and other assets) can inform the risk assessment of potential impacts. This can also help in delineating zones within the region where water pressure and quality should be monitored for early detection of any potential changes to the groundwater system. Such an exercise will help identify optimal locations for monitoring bores and identify monitoring strategies that will enhance the precision of models and minimize the uncertainty surrounding predictions of future changes to the groundwater system.

Gas Industry Social and Environmental Research Alliance (GISERA) is currently undertaking research on data-worth analysis and spatial design of groundwater monitoring networks for the Narrabri Gas Project area. The project aims to apply numerical modelling and statistical techniques to evaluate the relative worth of different data sets and use it for optimizing current and future monitoring. This report provides a brief overview of groundwater monitoring requirements in CSG development areas and existing groundwater monitoring in the Narrabri Gas Project area. The report also evaluates the opportunity for data-worth analysis and optimal design of monitoring network as underpinned by the modelling and uncertainty analysis of potential groundwater impacts undertaken through the Bioregional Assessments Programme and through GISERA research studies.

1.1 Potential water quantity and quality impacts of CSG development

CSG comprises mostly of methane and is found adsorbed to the surface of coal particles where it is held by the pressure of surrounding water. In order to produce gas it is required to reduce the pressure by extracting water. When water is extracted from a CSG well, groundwater pressure is reduced in the area surrounding the well. When there are several gas wells, the impacts of water extraction on the groundwater pressure can overlap. The pressure changes induced by CSG extraction can propagate to aquifers that overlie the coal formations and potentially affect groundwater resources allocated for other purposes in these aquifers. The change in pressure can be realised as a lower water level in the groundwater bores that source water from these aquifers.

National Groundwater Quality Protection Guidelines (NWQMS, 2013) identify that the key groundwater issues that arise from CSG development are depletion and contamination of groundwater resources. Potential hazards to groundwater quality include contamination of shallow and deep aquifers as a result of drilling and hydraulic fracturing activities (e.g. contaminants entering aquifers), bore failure, changes to groundwater chemistry, mobilization of naturally occurring chemicals, structural damage to confining layers, disposal of brine, gas migration and leakage and aquifer injection of co-produced water (NWQMS, 2013).

2 Groundwater monitoring for CSG development areas

Permits and licenses for CSG exploration and development in NSW require companies to implement groundwater monitoring plans that include two years of baseline monitoring. A recent report from the New South Wales Chief Scientist to the government recommends that companies seeking to mine/extract CSG should, in concert with the appropriate regulator, identify the baseline conditions and install appropriate monitoring infrastructure to detect risks (NSW Government 2014). The NSW Government is also currently investing in monitoring water impacts of extractive industries including the installation of 50 to 90 new monitoring wells across multiple coal basins in NSW (NSW Government 2015).

The National Groundwater Quality Protection Guidelines (NWQMS, 2013) specifies that a monitoring program is an integral part of any groundwater protection plan and identifies three distinct purposes of monitoring as quoted in the following:

a) **Baseline monitoring**, used to establish natural (pre-development) variations in groundwater quality

b) **Validation monitoring**, used to demonstrate effectiveness of control or remediation measures. For point sources this may occur at the discharge location. For diffuse sources this may occur at 'hot spots' in the aquifer to assess compliance with controls on contaminant release. This also provides data for model calibration to test assumptions and predict the fate of contaminants in an aquifer.

c) **Verification monitoring**, used on the perimeter of the groundwater attenuation zone to verify that all specified water quality objectives are met in the aquifer and that trends in concentrations of contaminants do not trigger implementation of further management actions.

Hydrologic monitoring locations are often selected based on addressing observation gaps in an existing network or other practical issues such as site access. However, modelling tools can be used for informing the type and location of data that provides most value for informing a specified prediction (USGS, 2011).

2.1 CSG groundwater monitoring in Queensland

The major CSG operators in the Surat and Bowen basins in Queensland have been producing gas and water in recent years. The Underground Water Impact Report (OGIA, 2016) produced for the Surat Cumulative Management Area (CMA) by the Office of Groundwater Impact Assessments specified a Water Monitoring Strategy (WMS) for the Surat CMA. The WMS and design of monitoring network for the Surat CMA of Queensland provides valuable insights and background for the development of research methods for monitoring network design for CSG development areas. The implementation of the Water Monitoring Strategy in Queensland has been progressively building knowledge about how the groundwater system is responding to water extraction by the petroleum tenure holders. The strategy was designed to complement existing monitoring strategy to achieve specific monitoring objectives. The following objectives were considered for the water monitoring strategy (OGIA, 2016):

- Establish background trends in groundwater pressure caused by climate variability and extraction of groundwater for other uses
- Identify changes within and near petroleum development for assessing the impacts of CSG water extraction at an early stage
- Identify changes near specific locations of interest where groundwater use is concentrated or of critical importance for town supply or agricultural use and to quantify risk to springs
- Improve future groundwater flow modelling by using water pressure and quality data to improve understanding of how the groundwater flow system works

In Queensland, the Water Monitoring Strategy has a key focus on cumulative impacts from multiple CSG operations that are spread across the CMA. As of 2016, there are 5127 wells producing petroleum across the Surat and Bowen basins. The WMS Underground Water Impact Report (OGIA, 2016) recommended a network of 618 pressure monitoring points spread across the CMA to be installed progressively to monitor cumulative impacts from these wells.

The Water Monitoring Strategy in Queensland considered the modelled extents of Long-term Affected Areas (LAA) to inform the design of monitoring network. The design provided a monitoring density within the LAAs of ~0.3 monitoring points per 100 km^2. This has been reported to be comparable to that achieved in other similar basin-scale aquifer monitoring networks. The monitoring requirements related mostly to background monitoring for areas beyond the footprint of planned CSG development considering the relatively minor impacts predicted for these areas. The network design primarily aimed to achieve desired coverage but was also adjusted to achieve the objective of monitoring in locations of specific interest. The overarching principles considered for the design of monitoring network for the Surat CMA is comprehensively described in the UWIR (OGIA, 2016).

2.2 Baseline groundwater monitoring around the NGP

Santos has been monitoring hydrological conditions around the Narrabri Gas Project area since 2011 (CDM Smith, 2015a, 2015b). The NSW Department of Primary Industries (DPI) Water also maintains an extensive network of groundwater monitoring bores and surface water monitoring sites in this region. The baseline studies undertaken for Santos compiled groundwater datasets from the hydrological data collected by Santos and DPI Water. The hydraulic head data was compiled from observations in 50 groundwater monitoring bores. This comprised 2 bores in the Gunnedah-Oxley Basin, 21 bores in the Great Artesian Basin, 13 bores in the Namoi alluvium and 5 bores in the Bohena Creek alluvium. In addition to hydraulic head, a suite of groundwater quality parameters is also collected at a number of monitoring bores. The baseline water quality was compiled from water quality observations in 41 groundwater monitoring bores, including 2 in the Gunnedah-Oxley Basin, 21 bores in the Great Artesian Basin, 13 bores in the Namoi alluvium and 5 bores in the Bohena Creek alluvium. Analyses of these baseline datasets have been reported by CDM Smith (2015a) as part of the Santos EIS reports.

Figure 1 shows the spatial distribution of groundwater monitoring bores in the deeper groundwater system including formations in the GAB and Gunnedah Oxley basins that have been monitored as part of Santos' baseline monitoring program. It is noteworthy that different sets of these bores monitor water resource in multiple formations that are vertically separated from each other. These include bores owned by Santos, NSW Government and some of the private bores in this region. Additional monitoring bores have been planned by Santos and NSW Government and other private and Government bores may also be present in this region. Santos' EIS report on hydrological baseline study identifies groundwater bores that are attributed to monitoring in the formations of Gunnedah-Oxley, GAB and alluvial formations.

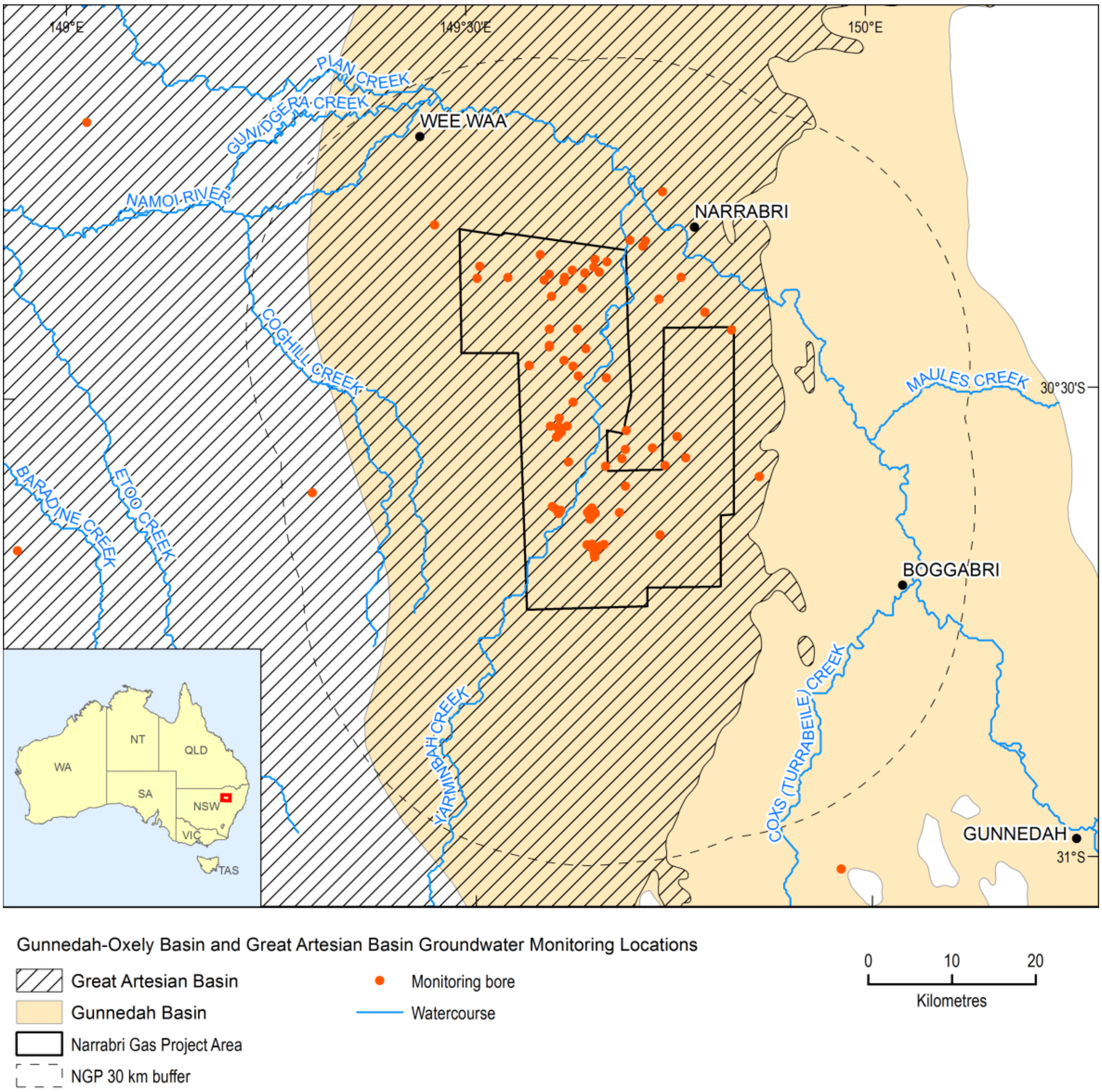

Figure 1 Monitoring bores in the deeper formations of the GAB and Gunnedah-Oxley Basin

Figure 2 shows several monitoring bores in the alluvial formations in the region including those from which baseline water quality data was collected. In addition to groundwater, the baseline study compiled monitoring datasets for stream flow data (collected by DPI Water) and surface water quality data (collected by Santos). These maps illustrate that there are several bores non-uniformly distributed in the region that may potentially be used in addition to the baseline monitoring, for monitoring water quantity and quality changes induced by CSG development. In addition to these bores that are used for baseline monitoring there are many agricultural bores in the region. Depending on the aquifers/formations these bores monitor, the relative worth of the monitoring data for informing water quantity and quality changes at target risk receptors will be different. This will also depend on the proximity of the risk receptors to these bores both horizontally and vertically.

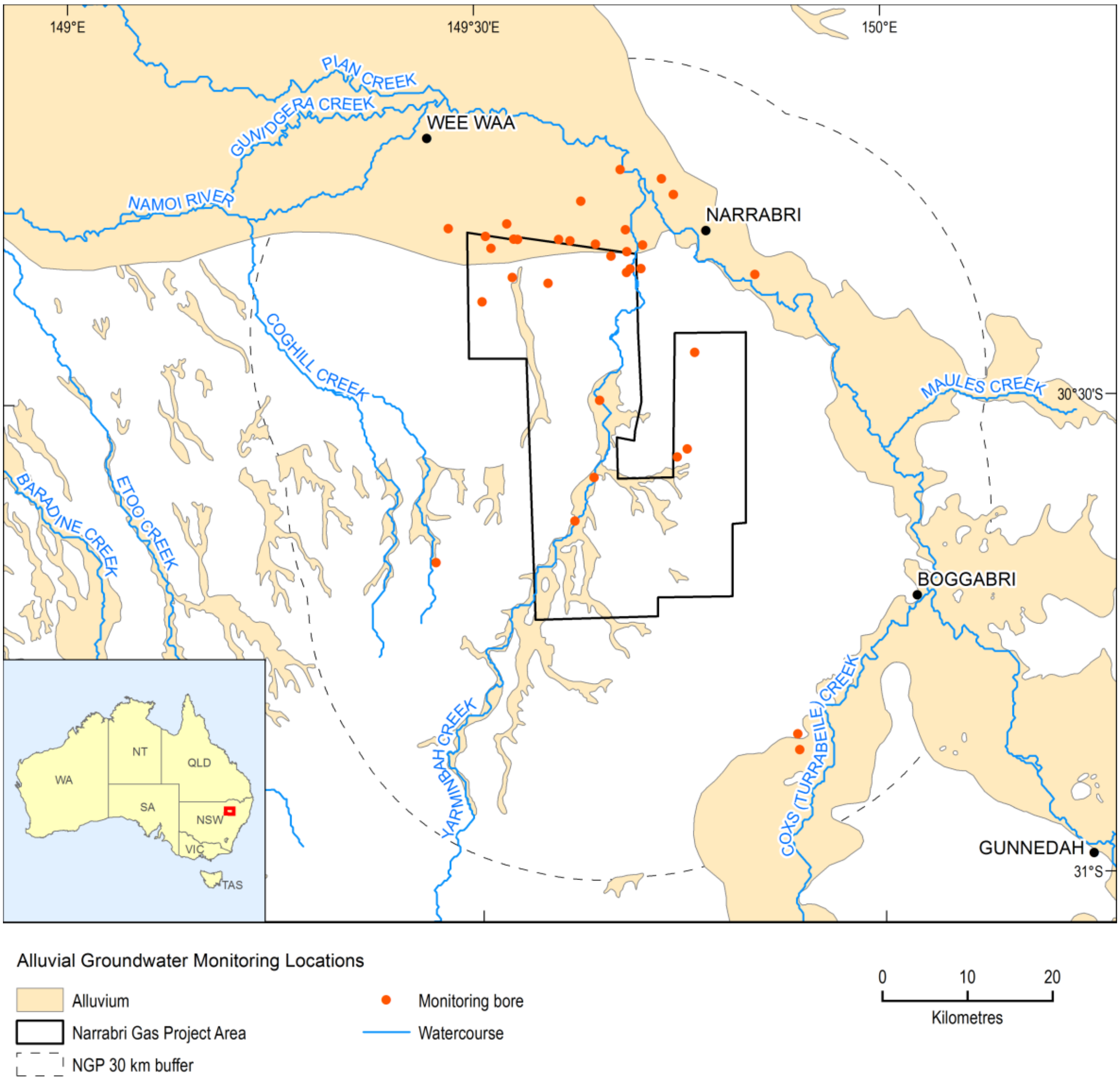

Figure 2 Monitoring bores in the alluvial groundwater sources

2.3 Santos' Water Monitoring Plan

Santos has developed a Water Monitoring Plan for the Narrabri Gas Project reported in CDM Smith (2015b). Santos' Water Monitoring Plan is scoped to meet relevant legislation and compliance requirements. Accordingly, Santos' water monitoring activities has been proposed to focus on water assets and receptors that are likely to be most sensitive to changes in water quantity and quality. The WMP proposed high frequency monitoring at 'primary' monitoring locations for the duration of the NGP, and low frequency monitoring at secondary monitoring locations. The monitoring plan is designed to inform an understanding of NGP contribution to any observed changes in water quantity or quality within water assets (particularly alluvial and GAB aquifers). Also, where possible Santos' monitoring will be used to provide early warning of potential changes to water resource condition arising from the NGP by using sentinel monitoring locations.

2.4 NSW Government program for water monitoring network expansion

DPI Water developed the water monitoring strategy for coal basins in NSW as a response to recommendations made in the NSW Chief Scientist and Engineer's Independent Review of Coal and Coal Seam Gas activities in NSW. In the short-term, the NSW Government is expanding groundwater monitoring network in the coal basins in NSW, including the drilling of 50–90 monitoring bores between 2017 and 2020. This includes the establishment of new monitoring bores in the Namoi region that focus on coal seam gas activities. The new monitoring bores will be built on Crown Land in locations where existing studies and spatial data show that new monitoring would be of most technical value. The criteria that DPI Water considers in prioritising the locations include improving the knowledge of the groundwater system, filling network gap where current information is deficient, and allowing potential impacts to be measured near sensitive environments where current/potential growth in water impacting activities. A detailed methodology for the design and prioritization of monitoring bores across multiple coal basins is currently being developed by the DPI Water.

2.5 Emerging knowledge from the Bioregional Assessment Programme and GISERA research

Recent research undertaken through the Bioregional Assessment (BA) Programme, GISERA and other recently completed research studies provide improved understanding of potential drawdown and flow changes that could be induced by CSG development in the Narrabri Gas Project area. Economic and ecological assets and potential risk receptors in coal resource development regions have been comprehensively identified through the BA programme. Hydrological modelling in the BA provides a probabilistic quantification of potential maximum drawdown impacts at these spatially explicit receptors locations. GISERA research has provided a probabilistic quantification of potential flux losses from the Great Artesian Basin. The results from these studies provide an understanding of the spatial and temporal trends in potential hydrological changes caused by coal seam gas development. These results provide valuable information for optimising future monitoring of the groundwater system.

3 Objectives of the GISERA project on data-worth analysis and monitoring network design

Currently, improved understanding of groundwater connectivity and potential impacts of CSG development is emerging from multiple research studies including Santos EIS, Bioregional Assessment Programme and GISERA research that focused on assessing potential impacts of CSG development in the Narrabri Gas Project. Given the improved knowledge of the groundwater system and potential impacts provided by these studies there is opportunity to use it to design targeted groundwater monitoring for the region.

As found in the Queensland Water Monitoring Strategy, the proposed Santos EIS Water Monitoring Plan and the NSW Government regulations, it is important to comprehensively monitor potential changes in the groundwater pressure within the footprint of predicted CSG-induced drawdown impacts. Additionally, monitoring strategies should also focus on early identification of potential water quantity and quality impacts to important ecological and economic risk receptors such as springs and agricultural bores.

The GISERA project on data-worth analysis and design of monitoring network for the Narrabri Gas Project area is scoped to develop and extend the methods from the Bioregional Assessments and GISERA GAB flux project to identify monitoring strategies that will maximise the likelihood of early detection of groundwater pressure and quality changes in the Namoi region and progressively minimize uncertainty in the prediction of groundwater changes caused by the Narrabri Gas Project. The groundwater modelling studies in the Bioregional Assessment Programme and GISERA water research for the Namoi region provides probabilistic quantification of potential impacts at spatially explicit risk receptor locations.

3.1 Data-worth analysis and optimal monitoring network design

Hydrological monitoring locations are often selected by evaluating observation gaps in existing network or by practical considerations like site access. There exists a variety of modelling and uncertainty analysis tools that can inform the choice of locations and type of data which provide the most ‘bang of the buck’ to address specified monitoring objectives (USGS, 2014). One of the advantages of such an approach is the maximization of monitoring benefits for the limited resources/budget available for monitoring. Recent studies have demonstrated the utility of data-worth analysis and modelling-based approaches for optimal monitoring network design (USGS, 2014; Sreekanth et al., 2015; Sreekanth and Datta, 2014; Nowak et al., 2012).

The worth of new data collection can be calculated by quantifying the reduction in prediction uncertainty at a target receptor location achieved by adding a monitoring location. This type of data-worth analysis can be applied for multiple number of potential monitoring locations and types of observations. Evaluation of data-worth does not require that the observed values at the proposed locations are known. The data-worth analysis largely relies on the sensitivity of the proposed observation to model parameters. The data-worth calculated for different data types and locations can be ranked for their effectiveness in reducing uncertainty around a specified prediction. Given that there are multiple predictions and risk receptors of interest in a region that may be of interest within the scope of monitoring network design, the data-worth analysis could be repeated for each prediction of interest. The design of optimal monitoring network can then take the spatial trends in the data-worth of multiple observations into consideration for the optimal design of monitoring networks. The objective of identifying sentinel monitoring locations can also be included in the design considering the probabilistic prediction of pressure changes and travel times obtained from groundwater modelling. An overview of the workflow of the proposed method is given in figure 3.

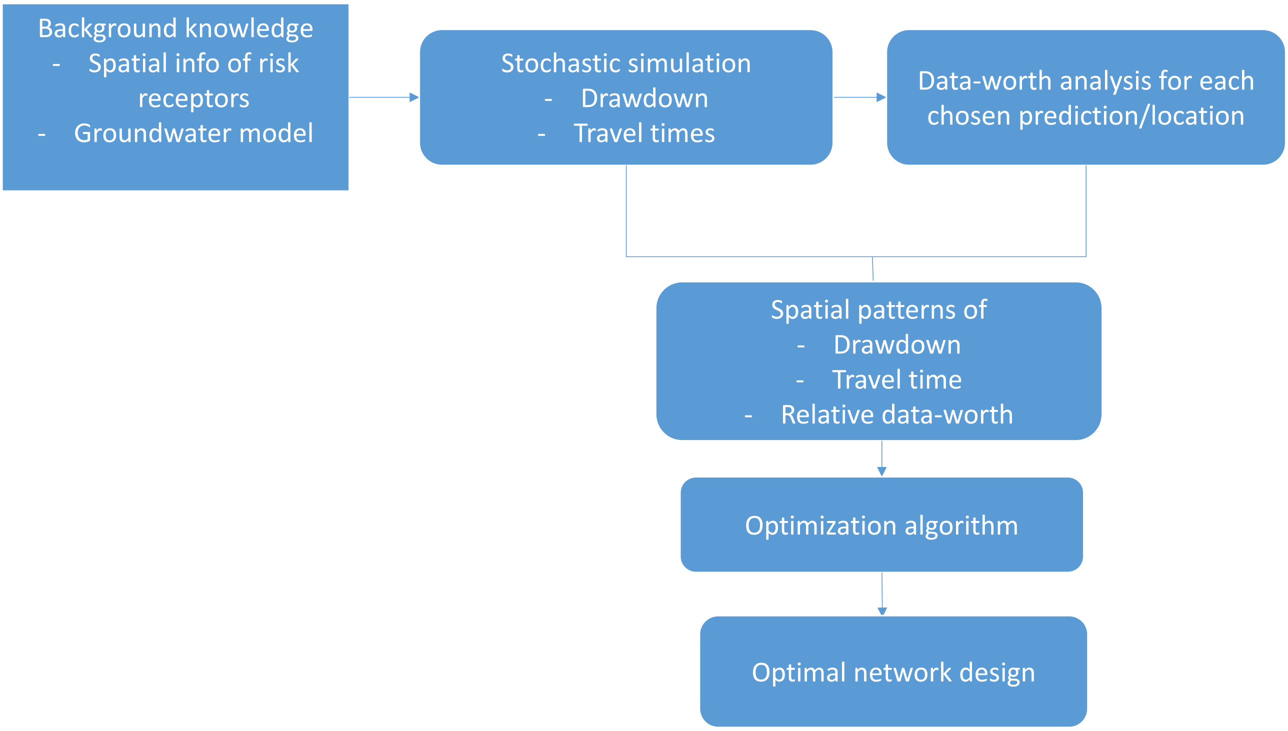

Figure 3: Workflow of proposed monitoring network design

3.2 Objectives of monitoring network design

The review of Water Monitoring Strategy for the Surat Cumulative Management Area indicates that the main objectives of groundwater monitoring in the coal seam gas development regions included identification of potential changes to groundwater quantity, identification of changes around specified locations and receptors of interest and improving the predictions of future groundwater modelling efforts. Similarly, Santos' Water Monitoring Plan for the Narrabri Gas Project also states that the key focus is on water assets and receptors that are likely to be most sensitive to changes in water quantity and quality. Also, the NSW Government's plan to improve monitoring in coal basins is also interested in monitoring near sensitive environments where current/potential growth in water impacting activities. Considering these overarching goals of groundwater monitoring in CSG development area, the GISERA water research on data-worth analysis and monitoring network design will focus on the following objectives:

- Maximising the probability of identification of CSG induced drawdown changes in and around the CSG project area. The monitoring design will focus on identifying potential changes in the aquifers of the Great Artesian Basin and Namoi alluvium. The design will also focus on sentinel monitoring to protect spatially explicit ecological and economic risk receptors that draw water from these aquifers.

- Improving the understanding of the groundwater system to minimise uncertainties in the prediction of impacts to important water dependent assets and receptors around the Narrabri Gas Project area.

4 Conclusions

Coal Seam Gas (CSG) development through the Narrabri Gas Project in north-western NSW has raised a number of concerns about potential impacts to groundwater resources. Permits and licenses for CSG exploration and development in NSW require companies to implement groundwater monitoring plans that include two years of baseline monitoring. Santos have been collecting baseline water quantity and quality data and have developed a Water Monitoring Plan for monitoring potential impacts. NSW Government's DPI Water is also enhancing groundwater monitoring in this area by installing new monitoring bores.

Review of monitoring strategies that have been implemented in the Surat CMA and plans proposed for the Narrabri Gas Project area by Santos provides useful insights into important objectives of monitoring. Bioregional Assessments also provides the register of water dependent assets in the region. Ongoing research undertaken through Bioregional Assessments and GISERA will provide a probabilistic assessment of potential impacts of CSG development to the ecological and economic risk receptors in the region. In light of the knowledge provided by these studies, the GISERA project on 'data-worth analysis and spatial design of monitoring networks' aims to develop and apply methods for quantifying the data-worth and optimising groundwater monitoring network. The objectives of monitoring network design will focus on maximising the probability of identification of CSG induced drawdown changes particularly where important water dependent, ecological and economic assets are located. The design will also focus on improving the prediction of potential impacts at these locations by minimising model prediction uncertainty.

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