Chapter

Cumulative Groundwater Impact Assessment and Management – An Example in Practice

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Abstract

Production of coal seam gas (CSG), or coal bed methane, requires large-scale depressurisation of a target formation by extracting groundwater, which, in turn, has the potential to affect overlying and underlying aquifers. This leads to wide-ranging stakeholder concerns around the impacts on groundwater assets such as water supply bores, groundwater-dependent ecosystems and connected watercourses. Around 2010, the CSG industry in Queensland, Australia grew rapidly with the expansion of operations in the Surat and Bowen basins by multiple operators. This particularly raised concerns about the cumulative effects, because the target coal seams are part of the Great Artesian Basin – one of the world's largest aquifers. To respond to this challenge, an innovative framework was developed to provide for an independent cumulative impact assessment and to set up arrangements for managing those impacts. This chapter describes the main thrust of that framework.

Keywords: coal seam gas, cumulative impact assessment, groundwater management, Great Artesian Basin, groundwater, Queensland, regulatory framework, Surat Basin

1. Introduction

In the Surat Basin of Queensland, Australia, production of coal seam gas (CSG), or coal bed methane as it is known in the Americas, requires extraction of groundwater to depressurise the Walloon Coal Measures (the target formation). CSG has grown to become the dominant source of natural gas in Queensland, Australia, comprising more than 95% of the gas produced and more than 99% of the remaining proved and probable gas reserves [1]. The CSG produced from the Surat and Bowen basins is the feed stock for the liquefied natural gas export industry based in Gladstone. By 2009 to 2011, an unprecedented scale of CSG development was proposed in environmental impact statements (EIS) by four major proponents – Santos Limited, Australia Pacific LNG Pty Limited., QGC Pty Limited and Arrow Energy Pty Ltd – whereby a maximum of about 34,000 CSG wells were proposed in an area of about 37,000 km^2 [2].

The target formation for CSG production in the Surat Basin is part of the Great Artesian basin (GAB) – one of the largest groundwater systems in the world. This geology raised issues surrounding impacts of this development on groundwater assets such as water supply bores, groundwater-dependent ecosystems (GDE) and connected watercourses. There are an estimated 22,000 water supply bores in and around the CSG development area, along with a number of ecologically significant springs.

Exploration for CSG commenced in Queensland in the 1980s. Commercial production from the late Permian coal seams of the Bowen Basin commenced around 1995. By the early 2000s, the focus for development had shifted to the overlying Surat Basin, a part of the GAB (**Figure 1**), targeting the Jurassic age Walloon Coal Measures. However, over time, the development plans were revised downward in response to emerging market conditions and resource availability. Based on current

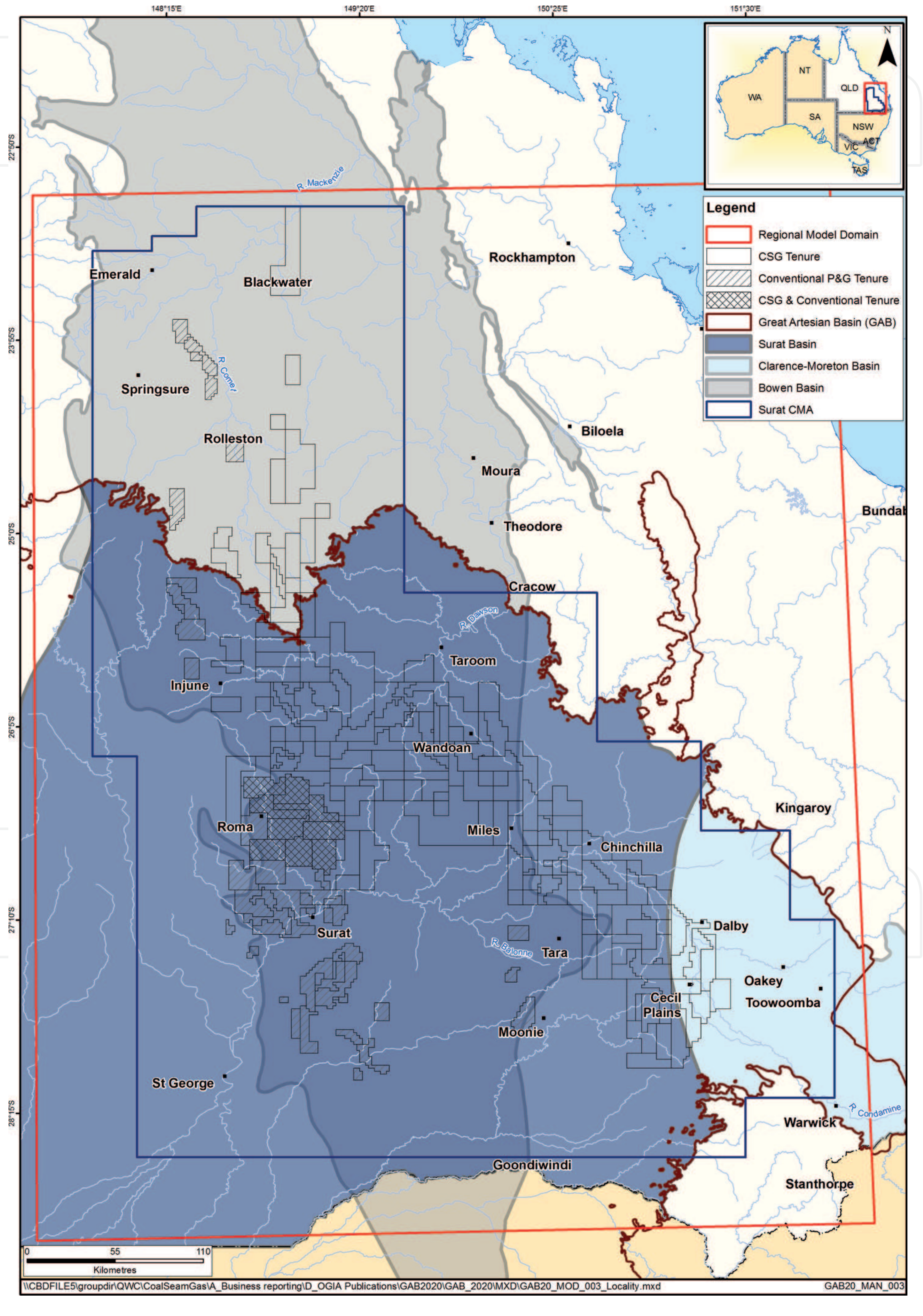

Figure 1.
A map showing the Surat Cumulative Management Area boundary in relation to the Surat Basin and the CSG tenures.

development plans, an estimated 21,000 CSG wells will have been constructed by the end of the life of the industry, of which about 7,000 are already in operation [3], extracting some 60,000 ML/year of groundwater from the CSG target formations in the Surat and southern Bowen basins.

This chapter provides some contextual background on the concept of cumulative impacts and related issues, followed by a description of how a framework was developed and implemented for managing those issues. The framework is a good example of proactive and adaptive groundwater management covering a cycle – from identifying issues to assessment and modelling, reporting, implementation and monitoring.

2. Context

2.1 The concept of cumulative impacts

The concept of cumulative impacts in water and environmental management is not new, but the context in which it is used varies widely. The term is sometimes used in relation to impacts of a single project on multiple social, environmental and economic factors [4]. In other instances, it is used to refer to impacts from the interaction of multiple activities, and/or the collective impact of many similar activities over time and space [5]. In this chapter, the term 'cumulative impacts' refers to groundwater pressure impacts from multiple CSG projects.

Regional or strategic assessments are often seen as mechanisms to assess cumulative impacts. Many authors have argued that cumulative effects are best assessed in a more regional and strategic context, at the level of strategic environmental assessment (for example, [6–9]). The Government of Alberta, Canada has developed a regulatory framework to better manage cumulative environmental effects from development through a regional planning instrument [10].

Although the term 'cumulative impacts' is not always used explicitly, the combined effects of all consumptive water use have always been considered, typically in catchment-scale and/or aquifer-scale planning for the allocation and management of water resources in Australia, following the 1994 Council of Australian Governments water reform agenda.

2.2 The Surat Basin

The Surat Basin underlies 180,000 km^2 of southeast Queensland. It is connected to the Eromanga Basin to the west, the Clarence-Moreton Basin to the east and the Mulgildie Basin to the northeast. It is a Jurassic to Cretaceous age sequence of alternating sandstones, siltstones and mudstones, with coal seams of economic significance in some areas (**Figure 2**, Video 2) [3]. The Surat Basin overlies the Permo-Triassic Bowen Basin sediments and is overlain by inliers of Quaternary alluvium and Tertiary basalts, particularly in the east. The total thickness of the Surat Basin sequence is about 3,000 m, with sediments deposited on an older erosional surface of the Bowen Basin.

The outcrop is the recharge area, with groundwater flowing generally along the formation dip for the deeper aquifers in confined areas, although there is a significant proportion of flow in outcrop areas northward along the topographic elevations [11, 12]. For the most part, groundwater in the Surat Basin occurs under sub-artesian conditions. Artesian aquifer conditions are only encountered in the southwest corner.

There are some 22,400 private water supply bores within the GAB footprint of the Surat Basin, the equivalent Clarence-Moreton Basin and adjoining parts of the southern Bowen Basin [3]. A majority of these bores access groundwater from the shallower unconsolidated alluvium or tertiary formations. The underlying GAB formations are primarily accessed for agriculture, town water supply and stock and domestic use, totalling 41,000 ML/year.

GDEs, which are associated with springs and baseflow-fed streams and include deep-rooted terrestrial vegetation, occur within the area. Springs are known to source water from some of the GAB formations. Natural groundwater discharge along the outcrop areas also feeds into watercourses and supports flow in dry periods.

2.3 Groundwater management challenges

Groundwater in the Surat Basin has long been accessed primarily for consumptive use. Long-standing arrangements for managing groundwater had been designed for consumptive use. The rapid emergence of the CSG industry, which extracts large amount of incidental groundwater (non-consumptive use) to depressurise coal seams, challenged those arrangements. For context, average CSG-related extraction over the life of the industry is expected to be about 51,000 ML/year [3], although these estimates have been declining over the years.

There are significant regional aquifers above and below the Walloon Coal Measures (**Figure 2**, Video 2) and therefore depressurisation for CSG production could potentially impact water supply bores and GDEs that rely on those aquifers (Video 3).

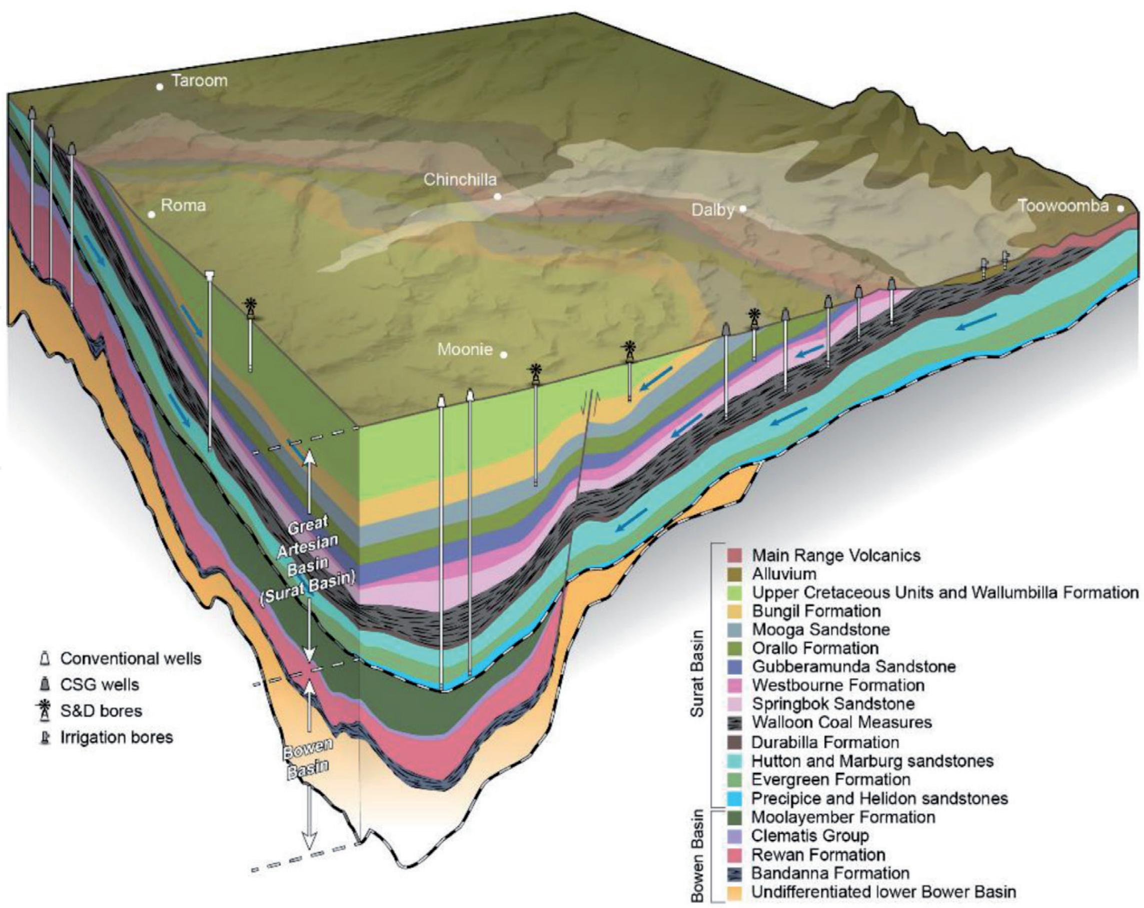

Figure 2.
A 3-D schematic of the Surat Basin sediments showing the CSG target formation and its relationship with surrounding formations [3].

Although the primary groundwater management concern was the management of the impacts of CSG water extraction on groundwater supplies and GDEs, there were also other concerns about non-pressure-related impacts on groundwater resources, such as: the potential for groundwater pollution from drilling activity; the beneficial use of the formation water extracted during development; and social impacts associated with the large workforce operating in the area [13]. These other concerns are beyond the scope of this chapter.

There was significant resistance to proposed CSG development from landholders and the community in the early stages [14]. Landholders with water supply bores in and around the CSG development areas were seeking better understanding of impacts and appropriate compensation, including provisions for alternative supply in advance of impacts occurring. There were also concerns about long-term impacts, monitoring and questions about the independence of scientific assessments presented in EISs by the CSG industry. At the same time, the industry was also seeking clarity on responsibilities where impacts may overlap.

3. Development of a groundwater management framework

To respond to the challenges outlined earlier, the existing regulatory arrangements were reformed to provide for a framework for independent assessment and management of cumulative impacts from petroleum and gas (P&G) development, including CSG. This was done in the context that, in Queensland, P&G tenure holders have a right to take groundwater that is unavoidably taken during the production of P&G. This right was made subject to certain obligations on managing impacts.

Development of the framework followed some key principles, such as: the cumulative assessment must be by an independent entity on a full-cost-recovery basis; the assessment and management arrangements must be periodic to adapt to evolution of knowledge of groundwater systems and changes to development; tenure holders must take the responsibility for making good the impacts on water supply bores; the management actions must be proactive; and there should be regular monitoring and reporting.

Two core elements of the framework that was established were: the establishment of an independent entity – the Office of Groundwater Impact Assessment (OGIA) – to displace proponents' responsibilities for preparing Underground Water Impact Reports (UWIR) in a declared Cumulative Management Area (CMA); and an ongoing three-yearly cycle of proponents preparing UWIRs containing impact assessment and management strategies, including the monitoring arrangements.

The entire intensive CSG development area, covering about 450 × 550 km, was declared a CMA (the Surat CMA) (**Figure 1**, Video 1). OGIA is tasked with assessing the cumulative groundwater impacts from P&G development in the Surat CMA. The costs associated with OGIA performing its functions are recovered through an annual levy payable by the tenure holders.

The technical assessment and arrangements for managing cumulative impacts are required to be reported by OGIA every three years in a UWIR. It is required that the report: includes an assessment and prediction of cumulative impacts in all affected aquifers; identifies the impact area for each aquifer; provides a list of affected water supply bores and GDEs; and outlines management arrangements such as the monitoring, make good of water supply bores, mitigation of impact on GDEs and assignment of responsibilities to tenure holders.

4. Implementation of the framework

The Surat CMA was declared in 2011. This was followed by the preparation and release of three iterations of assessments through UWIR 2012, UWIR 2016 and UWIR 2019.

The first cycle of assessment was completed within 12 months of the establishment of the CMA, primarily using the existing knowledge and secondary data sources to build a regional groundwater flow model and design management strategies. This was followed by a research program for the following three-year cycle, providing the foundation for the subsequent assessments in 2016 [2] and 2019 [3].

4.1 Hydrogeological assessment

A range of hydrogeological assessments were undertaken relating to the geology of the Surat Basin and aquifer interconnectivity. These investigations, in combination with complementary assessments by others, were then used to build a regional hydrogeological conceptualisation that underpinned the construction of a regional groundwater flow model and management strategies.

In the latest iteration, the geological model has 22 layers covering all major formations of the Surat and southern Bowen basins [15]. The geological model was based on the primary lithostratigraphic interpretation of geophysical logging from some 7,000 P&G wells. Primary interpretation ensures consistency in stratigraphic interpretation across the whole basin.

Most of the water use in the Surat Basin is for stock and domestic purposes, which is unmetered. Indirect estimates of water use were therefore made by developing a methodology utilising demand-based estimates per bore, while taking into account the availability of alternative water supply sources and seasonal variations [3]. The new methodology resulted in an estimate of groundwater use for stock and domestic purposes in the Surat Basin of 41,000 ML/year.

A major study was also undertaken to assess the connectivity of the overlying alluvial aquifer – the Condamine Alluvium [16]. The study involved multiple lines of investigation including drilling, coring, long-duration pump testing and monitoring. It concluded that there is a low level of connectivity.

A range of other complementary assessments was also undertaken including recharge estimation, fault characterisation and inter-aquifer connectivity. These studies provided the basis of a new regional conceptualisation [17].

4.2 Impact modelling

The most recent model developed by OGIA for the cumulative impact assessment in 2019 [15] represents the third iteration of conceptualisation, construction and calibration, based on information and data collected from monitoring and strategies developed in previous iterations. Each iteration of the model is informed by a revised understanding of key hydrogeological processes or concepts operating within the Surat CMA at the time.

The domain of the current model covers an area of around 460 × 650 km, encompassing the entire Surat CMA. The model domain is discretised into cells of 1.5 × 1.5 km areal extent, with 34 layers. The model is designed to simulate groundwater flow within the Surat Basin sequence and overlying alluvial formations in the Surat CMA, and within the CSG-producing Bandanna and Cattle Creek formations of the Bowen Basin.

The model was developed using the MODFLOW-USG simulator with a range of modifications to accommodate specific and unique processes associated with CSG extraction: the approximation of coal desaturation and dual-phase flow effects using a modified Richards equation formulation; use of a "descending drain" methodology to extract water from coal measures; recognition of the gas-filled status of CSG production wells and the consequential steep vertical gradient of water head in the vicinity of these wells; representation of 16 major fault systems in the groundwater model structure; and a new approach to parameterisation which maximised the use of the extensive lithological and other data from CSG well drilling activities.

Regional hydraulic properties were derived using numerical permeameters. The model was calibrated against a number of additional observation types including: monthly actual CSG extraction; vertical head differences between stratigraphic units; observed drawdowns; expected vertical head gradients; and saturations within the target formation.

The regional groundwater flow model was used to predict the impact of the cumulative industry development profile on groundwater pressures in aquifers. The profile was prepared based on information available at the time about historic and planned development of the individual CSG projects.

The current assessment [3] revealed that by the end of 2021, a total of 222 bores would be affected by a groundwater pressure reduction of more than five metres; these are referred to as Immediately Affected Area (IAA) bores. In the long term, a total of 571 water bores are predicted to be affected; these are referred to as Long-term Affected Area (LAA) bores.

4.3 Impact management

For all 222 water supply bores that are predicted to be impacted in the short term, i.e. IAA bores, follow-up actions are assigned to individual tenure holders – the responsible tenure holders (RTH) – based on certain rules. Each bore initially requires a bore assessment by the RTH to assess if the predicted impacts are likely to affect the intended purpose of the bore. If it is found that a bore water supply is likely to be impaired, then the RTH will have to reach a proactive 'make good' agreement with the bore owner.

The arrangement also involves the design and implementation of a monitoring network. Initially, in the first iteration, the UWIR 2012 specified the progressive installation of a network of 498 monitoring points across the Surat CMA. In recent iterations, the planned network has now been enhanced to 622 groundwater-level monitoring points and 103 water-quality monitoring points, of which about 500 are currently installed. The network is an extensive undertaking by tenure holders, considering the formations monitored are typically 200 to 1,000 m below ground. The UWIR assigned responsibilities to individual CSG companies for implementing individual parts of the regional monitoring network and reporting monitoring data.

The strategy for managing GDEs is primarily imbedded in a spring impact management strategy. Source aquifers for springs were established through investigations to predict impacts. Where the source aquifer for an identified spring was not known with confidence, the predicted pressure impact at the location of the spring was taken to be the maximum predicted pressure impact in any aquifer below the location of the spring.

4.4 Stakeholder consultation

OGIA undertakes formal and informal engagement activities to assist communities to understand the assessments that have been made, and to hear community views on groundwater impact issues. After the publication of a consultation draft UWIR, written submissions are invited and public meetings are held at community centres around the basin to hear questions and provide explanations, before finalising the UWIR. Current views on issues relating to groundwater impacts from CSG development can best be gauged by the submissions received on the consultation draft of the current UWIR 2019 [18].

Landholder and community groups have raised a range of issues relating to: the effect of both CSG and non-CSG groundwater take on the sustainability of the GAB, particularly in the Hutton Sandstone; the effect of climate change; the impact of migrating gas in water bores; delays in finalising 'make good' arrangements; the indirect impact of 'make good' bores in the Hutton Sandstone; overall impacts of CSG development; construction of CSG wells; the effect of the modelling scale on predicting impacts in water supply bores; and the inherent limitation associated with the modelling of impacts. There was a general expectation that, although many of the issues are outside the scope of the UWIR, broadening of scope should be considered in the future.

Issues raised during engagements are considered both in finalising the UWIR and in designing and implementing the subsequent research. For example, in 2012, the community raised specific concerns about connectivity between the target coal formation and the Condamine Alluvium. As a result, OGIA launched a research project on improving understanding of the connectivity through an extensive field program for data gathering and analysis. Ongoing community engagement on interim findings and field testing to build community understanding and confidence was an integral component of this program. Similar other engagements have continued, in collaboration with public and private sector organisations.

5. Conclusion

Extractive resource industries have a potential to impact groundwater resources. Particularly where the development is large-scale and involving multiple operators, the impacts can magnify due to their cumulative effects. In such situations, there are often a number of difficulties in managing impacts due to: different approaches to impact assessment by individual operators; lack of clarity on management responsibilities where impacts may overlap; constantly changing plans for development and evolving knowledge; and lack of community trust in assessments by industry.

These generic issues were well manifested in Queensland, Australia, where large-scale CSG development in 2010 brought them to the surface. In response, an innovative cumulative assessment and management framework applying adaptive groundwater management principles was developed and has been applied since then.

The framework involves an iterative cycle of independent impact assessment using progressively updated data and information, supported through secure funding arrangements. The cyclic assessment underpins progressive revision of strategies for managing impacts and enables identification of knowledge gaps to drive subsequent investigation.

The framework and its implementation are broadly regarded as effective in providing stakeholders with information and a mechanism to address issues relating to groundwater pressure impacts from CSG water extraction. As an independently funded and scientifically focused body, OGIA links assessment with regulatory management arrangements, and in doing so, has been able to build stakeholder confidence. For CSG companies, the framework provides clarity about statutory obligations. The involvement of OGIA reduces concerns about conflicts of interest, benefitting both CSG companies and bore owners.

Acknowledgements

TBD.

Videos

- Video 1: Introductory overview of the Surat CMA (https://www.business.qld.gov.au/industries/mining-energy-water/resources/environment-water/coal-seam-gas/surat-cma/location-geology).
- Video 2: The basins and geological formations, the complexity of the geological layers, effects of these layers, and movement of groundwater in the Surat CMA (https://www.business.qld.gov.au/industries/mining-energy-water/resources/environment-water/coal-seam-gas/surat-cma/location-geology).
- Video 3: How groundwater impacts may occur in aquifers surrounding the CSG formations in the Surat Basin. (https://www.business.qld.gov.au/industries/mining-energy-water/resources/environment-water/coal-seam-gas/surat-cma/location-geology).

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