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PAPER

# Challenges in sustainably managing groundwater in the Australian Great Artesian Basin: lessons from current and historic legislative regimes

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**Abstract**
In certain areas, key aquifers of the Great Artesian Basin (GAB), Australia, are experiencing continued declining water-level trends. This has been accompanied by heated conflicts between water users and a lack of trust in governance arrangements, particularly since the introduction of coal-seam gas development. These outcomes suggest current and historic unsustainable groundwater extraction within the GAB. An analysis of the current governance framework using Ostrom's (1990) design principles for common pool resources reveals several management challenges which appear to create incentives for individualistic behaviours. Historic legislative approaches provide additional insight into key factors that have influenced decision-making. This research has implications for the future management of the GAB. Acknowledging these current and historic challenges will facilitate changing attitudes and behaviours so as to elevate the communal status of the resource and progress towards sustainable management of the basin. Ostrom E (1990) Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, UK.

**Keywords** Groundwater development · Australia · Common pool resources · Design principles · Legislation

## Introduction

> "It would be difficult to exaggerate the value of the State's artesian water supply…The mistaken conception that water, like air, is free to all alike, added to the prejudices which are easily aroused against public control of water supplies, will doubtless require some educational work on the part of the Government." (Mead 1910).

Dr. Elwood Mead, the former territorial and state engineer of Wyoming, USA (MacDonnell 2014), made these comments after reviewing Queensland's water resources in 1910. Even at that time, the value of Australia's Great Artesian Basin (GAB) and the deleterious impacts of unrestricted access and uncontrolled bores were apparent (Habermehl 2019). Dr. Mead's report supported the rationale to vest control of all water, including artesian groundwater, in the state by the Rights in Water and Water Conservation and Utilisation Act 1910 (Qld; RWWCU Act; Queensland Hansard 1910). This initiative was the beginning of direct management of water resources by the Queensland state government.

Outcomes for natural systems are not just a function of the natural and technical processes of ecosystem behaviour but also the result of the management of the ecosystem by the relevant institutions and the society (Gunderson et al. 1995). The sustainable management of water has been recognised as a *governance* problem rather than a *scarcity* problem per se (Gunderson et al. 1995; Silliman et al. 2008; InterAction Council 2012; United Nations 2018). Brundtland noted that we "have yet to arrive at a mechanism for evolving our [water] governance structures fast enough to keep up with the rapid pace of change" (InterAction Council 2012). To achieve this, it is necessary to understand not only ecosystem changes but also the behaviours of the institutions, water users and the society generally. Cross-disciplinary research which considers the governance (or management) arrangements and their impact on the relevant water resource is therefore a key part of

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achieving sustainable management of the resource. Analysis of governance arrangements is now acknowledged as being extremely relevant to the scientific groundwater community as well as other experts, practitioners and stakeholders (Silliman et al. 2008; Mitchell et al. 2012; Curtis et al. 2016; Barthel 2017; Barthel et al. 2017).

A case in point is the growth of coal seam gas (CSG) development within the GAB in the state of Queensland, Australia. During the last two decades, the CSG industry has become a significant groundwater user within the Queensland context. The industry in Queensland is largely based in the Surat Cumulative Management Area (CMA) as shown in Fig. 1. The Surat CMA is an area of land that includes part of the Surat and Southern Bowen geological basins and is managed in a cumulative way by the government (Queensland Government 2011). Coal seam gas is extracted from coal measures that are within (and below) the GAB. The Walloon Coal Measures, the source of the CSG in the Surat Basin (OGIA 2016b), is itself a GAB aquifer regulated by the Water Act 2000 (Qld). It is also the source of groundwater for stock and domestic, agricultural, industrial and town water uses (OGIA 2016b), and underlies the Condamine Alluvium which is the largest allocated groundwater resource in the state (OGIA 2016b). In 2016 it was estimated that the CSG industry extracts approximately 46% of all GAB groundwater extraction from the Surat portion of the basin (KCB 2016). The same studies revealed that all aquifer formations in the Surat CMA area have more water leaving the system than is being recharged and that key GAB formations such as the Hutton Sandstone, the Precipice Sandstone and parts of the Gubberamunda Sandstone aquifers, have declining trends (KCB 2016).

Significant community concern in relation to the impacts of CSG extraction on water resources has emerged during this period of rapid development. Four government inquiries and an independent review have examined water extraction by the petroleum and gas industry (Senate Rural Affairs and Transport References Committee 2011; Senate Rural and Regional Affairs and Transport References Committee 2013; Senate Select Committee 2016; Senate Environment and Communications References Committee 2018; Hunter 2017). Anti-CSG and citizen organisations such as ‘Lock the Gate’ and the ‘Basin Sustainability Alliance’ have emerged in response. Moreover, substantial scholarly works have critiqued the governance arrangements relating to the impacts of the CSG industry on water resources (Robertson 2018). These circumstances indicate a certain level of conflict and there is a lack of trust in the CSG industry and the overall governance framework relating to water resources and the environment in the context of CSG extraction (Gillespie et al. 2016; Hunter 2017; Witt et al. 2018; Walton and McCrea 2018).

Research which analyses the relevant governance arrangements can therefore facilitate sustainable management of the basin. This paper considers the governance

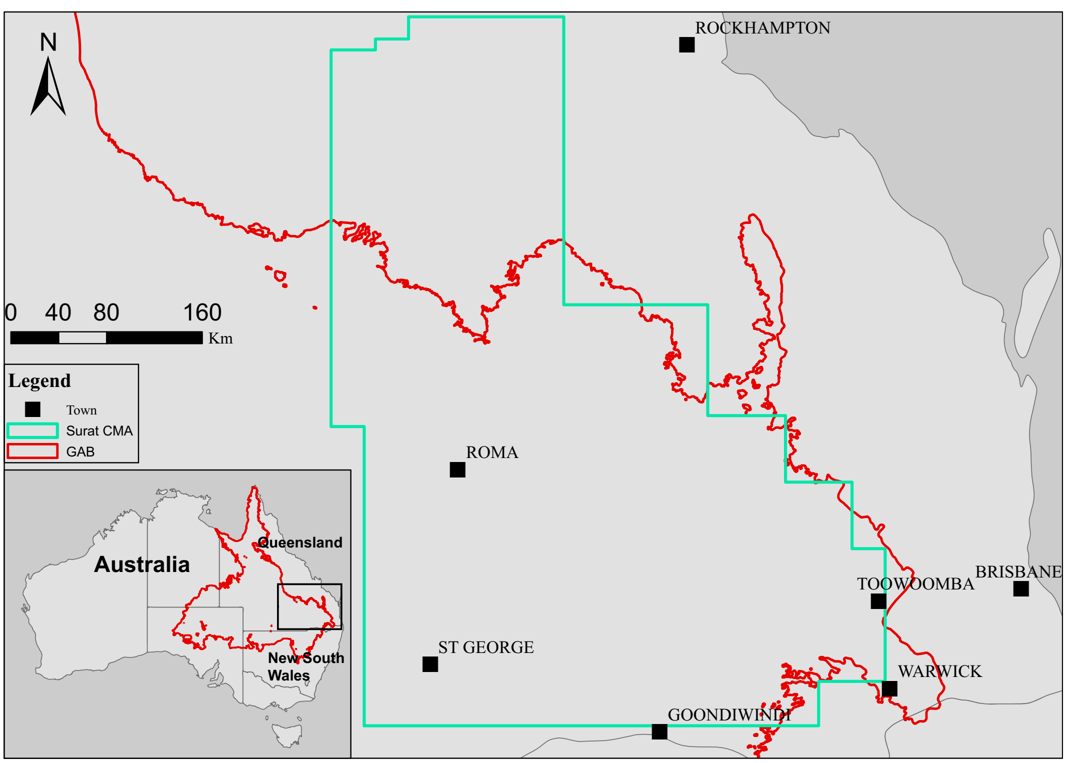


**Fig. 1** Map of the Surat Cumulative Management Area (CMA) in Queensland, Australia

framework regulating the GAB in Queensland, focussing on the Surat Basin where there is extensive development involving heterogenous water users (domestic, pastoral, agricultural, CSG and town water; KCB 2016). The aim of this paper is to provide insight into why this framework has resulted in both deteriorating water levels in some parts of the basin, as well as the evident conflict and lack of trust. Both outcomes suggest difficulties in balancing competing interests in the resource. They are indicative of a common pool resource (CPR) problem. Although, no scholars have yet sought to understand these negative outcomes through the lens of CPR theory. This paper first considers the objective of sustainability in the context of groundwater resources and CPR scholarship. It then presents a summary of the regulatory framework governing access to water in the Surat Basin of the GAB before analysing this framework in terms of Ostrom's (1990) CPR design principles. These design principles provide insight into why there seems to be continued unsustainable groundwater extraction in parts of the GAB. The historic legislative approaches provide further explanation of current negative outcomes. The paper concludes by offering some recommendations for future management initiatives in the GAB.

## Sustainability and groundwater

Queensland's water governance framework has an overall objective of sustainability (Water Act 2000, s.2). Broadly speaking, sustainable development "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987; United Nations 1992; Commonwealth of Australia 1992; Water Act 2000, s.7). When considering groundwater, this translates to ensuring that extractions of groundwater do not impact the future use of the groundwater resource, at least, until sustainable alternatives are developed and made available for the future. The (contested) term "safe yield" is often used to reflect the amount that water users can extract without compromising water levels and usually equates to a percentage of the basin's natural recharge (Zhou 2009; Molle et al. 2018).

A "sustainable" yield also takes into account the impacts of the water extraction on society, the economy and the natural environment (Zhou 2009; Wester et al. 2011). Where development of fossil aquifers occurs, Foster and Loucks (2006) highlight that there should be trade-offs such as improvements in well-being, enhancement in social capital and opportunities to younger generations (that may provide technological breakthroughs). That is, there must be clear improvements in social well-being and short-term socio-economic benefits must outweigh the longer term "negative impacts" (Foster and Loucks 2006; Ross and Martinez-Santos 2010). Maintaining water levels and ignoring the flow-on benefits to the community from water use, where there are plausible expectations of future technological improvements, may result in reducing the welfare of the current generation without a comparable improvement for future generations (Tan and Quiggin 2004). Van der Gun and Lipponen (2010) argue that "as long as groundwater pumping does not threaten to exhaust the aquifer and society considers the benefits from pumping to outweigh the associated negative impacts—both integrated over a prolonged period of time, one may speak of sustainable groundwater development". Ultimately, the sustainable limit will be a function of political processes (Molle et al. 2018). Hence, both a lack of deterioration of the resource and an absence of conflict and trust issues are important measures for evaluating governance frameworks (Baggio et al. 2016). Where the extraction involves a "fossil aquifer", robust political processes which engender trust and manage conflict will therefore be paramount in ensuring that the appropriate trade-offs (for the inevitable reduced aquifer levels) occur. They will also ensure consideration of local unintended consequences. On these measures, the Queensland groundwater governance arrangements for the GAB do not appear to be successful.

## Ostrom and CPRs

Common pool resources are a type of resource that suffer governance or management issues due to the difficulty in excluding users from accessing the resource and where each access or use of the resource, reduces the quantum of the resource that is available (Ostrom 1990). Common examples are fisheries, forestry and water resources. These characteristics of "non-excludability" and "subtractability" are what make CPR governance difficult. Overuse or even destruction of the resource system can easily occur through mismanagement (Ostrom 1990). In this context, various scholars theorise that either state control or a market is required for effective governance (Olson 1965; Hardin 1968).

As mentioned, state control of water was introduced in Queensland in 1910 and it is debateable whether the state control has resulted in the sustainable management intended by the legislative framework. This is unsurprising, as states commonly underperform in respect of groundwater governance for a variety of reasons (Molle et al. 2018). Similarly, the efficiencies of a market have been questioned in the groundwater context (Abildtrup et al. 2012). The introduction of market mechanisms have been part of a reform agenda in Australia since 2004 through the National Water Initiative (agreed to by the Commonwealth, the Australian Capital Territory, New South Wales, Victoria, Queensland, South Australia, Northern Territory in 2004 and Tasmania in 2005 and Western Australia in 2006). The reforms included unbundling of water instruments from land ownership, statutory water plans for basins/catchments, the creation of separate instruments for access to water (through entitlements to a share of the common pool, allocations of a quantum of water for each share) and the creation of a water market (Commonwealth of Australia 2004). The reforms have been gradually adopted in Queensland including the conversion of water licences into tradeable water allocations in some areas; however, tradeable water allocations have not been adopted for groundwater in the GAB.

Ostrom (1990) proposed that there was a third option for sustainably governing a CPR: self-governance by the users of the resource in certain circumstances. After extensive empirical research involving a wide array of real-world examples of management of CPRs, Ostrom and other scholars concluded that, in some circumstances, CPRs could be successfully managed by collective arrangements, rather than by either the state or the market (Ostrom 1990, 2005, 2010; Cox et al. 2010; Wilson et al. 2013). In 1990, Ostrom (1990) compiled a set of design principles (see Table 1) which are conducive to successful CPR governance. When these design principles are present in a CPR governance system, the opportunity for free riders benefitting at the expense of the other users is reduced (Wilson et al. 2013).

The CPR design principles have been found to be well supported empirically: robust resource governance systems are characterised by most of the design principles, whereas the failures are not (Cox et al. 2010). Nonetheless, they are not a panacea for CPR governance (Ostrom 2007; Ostrom et al. 2007). The attributes of the resource and resource system (scale, renewability, stability and mobility), the resource users (heterogeneity, discount rates, scale and number), the practicality of monitoring and enforcement measures as well as the macro-political institutions, culture and the economic environment, are key factors in determining effective governance arrangements (Ostrom et al. 2002). In different contexts, different groups or clusters of design principles will be important and no particular design principle on its own leads to success (Baggio et al. 2016). Rather than a single-policy solution, hybrid systems combining aspects of state, market and communal arrangements are now seen as preferable (Ostrom et al. 2002; Meinzen-Dick 2007; Skurray 2015).

Ostrom's design principles are helpful in that they can provide a framework for evaluating water governance arrangements and have in fact been used as such in respect of different jurisdictions' governance arrangements across the world (Baldwin 2008; Sarker et al. 2009; Ross and Martinez-Santos 2010; Schlager and Heikkila 2011; Heikkila et al. 2011; Babbitt et al. 2015; Skurray 2015 (considering Ostrom's 'situational variables'); Afroz et al. 2016; Baggio et al. 2016; Jadeja et al. 2018; Boone and Fragaszy 2018; Seward and Xu 2018; Shalsi et al. 2019). While caution needs to be taken with applying Ostrom's design principles to large-scale CPRs such as the GAB (Young 2002; Schlager 2007; Ross and Martinez-Santos 2010), the design principles have nonetheless been found to be relevant in these circumstances (Ross and Martinez-Santos 2010; Skurray 2015). Ross and Martinez-Santos (2010) highlight that the challenges for large groundwater systems include the remote impacts of groundwater pumping, water user heterogeneity, cross scale coordination and collaboration, monitoring and enforcement. Theesfeld (2010, p. 137) stresses that where the groundwater resource is large, the "key is a collective understanding of the scarcity of the resource and effective operational rules".

The usefulness of the design principles for such an analysis has been recognised even in jurisdictions that feature primarily state ownership or control of water, for example in Australia and the USA (Baldwin 2008; Sarker et al. 2009; Ross and Martinez-Santos 2010; Schlager and Heikkila 2011; Heikkila et al. 2011; Babbitt et al. 2015; Shalsi et al. 2019). Examining the congruence of a governance system or framework for CPRs with the design principles helps to identify underlying weaknesses (or strengths) in the regime (Ostrom 2005).

While keeping in mind the specific management challenges commonly faced by large groundwater systems, and the importance of contextual factors, the design principles may provide guidance as to why the water governance relating to the GAB does not appear to be currently meeting its objective of sustainability.

## Governance framework for GAB

The transboundary nature of the GAB relies on cooperative management through an overarching strategic management plan between the commonwealth, relevant states and territory, which is now being updated and replaced (Australian Government 2018). This plan aims to establish a strategic framework for addressing key issues such as the declining pressure of the aquifer (GAB Consultative Council 2000–2015; Australian Government, Department of Agriculture and Water Resources 2018a). The separate states and territory retain the responsibility to provide legislative frameworks that are consistent with the plan's policies and otherwise govern access to the resource for their respective parts of the GAB.

The Queensland state-controlled permit system legislated in 1910 introduced Dr. Mead's recommendations. It was argued that to avert the "evils" of over extraction, legislation was necessary to vest control of all water (including groundwater) in the state and to provide for: "a record of all existing bores, the measurement of their pressure and flow, regulation of the flow to prevent waste, state permits for every new and existing bore, and restriction, if not stoppage, of all new bores where the pressure is diminishing" (Mead 1910; Queensland Hansard 1910). No exemption for any groundwater users, even stock and domestic users, was provided. The new

**Table 1** Ostrom's CPR design principles (Ostrom 1990; Cox et al. 2010; Wilson et al. 2013)

| Design principle (DP) | Criteria |
|---|---|
| DP 1 | Clearly defined boundaries: |
| | a. Clearly defined social boundaries (users) |
| | b. Clearly defined biophysical boundaries (the shared resource) |
| DP 2 | Local rules and proportional equivalence between benefits and costs: |
| | a. Congruence between local conditions and rules |
| | b. Investment/extraction proportionality |
| DP 3 | Collective-choice arrangements: the users of the resource help tailor the rules of use |
| DP 4 | Monitoring: |
| | a. Monitoring the resource |
| | b. Monitoring the monitors |
| DP 5 | Graduated sanctions: The violation of the operational rules attract graduated sanctions (depending on severity) by either the users or officials who are accountable to the users |
| DP 6 | Conflict resolution mechanisms: Users and officials have rapid access to low cost, local arenas to resolve conflicts |
| DP 7 | Minimal recognition of rights to organise: The rights of the users to devise their own frameworks for governance are not challenged by external governmental authorities |
| DP 8 | Nested enterprises: For groups that are part of larger social systems, there is appropriate coordination among relevant groups so that allocation, provision, monitoring, enforcement, conflict resolution and governance are organised in multiple layers of enterprises. Smaller, local-scale agencies or organisational units are coordinated with each other and are "nested" within ever larger agencies or organisations |

legislative rights governing the use of water, including artesian water, replaced the existing common-law riparian rules (RWWCU Act, s.5; ICM Agriculture Pty Ltd. v Commonwealth (2009) 240 CLR 140). However, despite the original intention behind the legislative framework and the powers granted to curtail extraction, the objectives sought in 1910 remain elusive.

The Water Act 2000 (Qld) now regulates water extraction in Queensland by requiring any take or interference with water to be authorised by that Act or another Act (Water Act 2000, s.808). A general statutory authorisation permits the taking or interference with underground water for any purpose across the state, subject to the provisions of the relevant water plan for the area or the regulation (Water Act 2000, s.101(1)(c)). Water plans for different catchment areas of the state are prepared by the regulator, the Queensland Department of Natural Resources, Mines and Energy (DNRME 2018; Water Act 2000, chapter 2). The plans allocate the quantum of water provided for consumptive and environmental purposes and are created following a planning and consultation process for each catchment. The plans are implemented through water management protocols for the relevant catchment which set out, for example, water dealing, trading and sharing rules and reservations of unallocated water.

In the case of the GAB, the general authorisation to take or interfere with groundwater for any purpose is restricted by the Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017 (GABORA 2017). In the GABORA 2017 plan area, domestic use and stock use (in some areas) is only generally authorised where the bore is controlled by a water tight delivery system and the extraction would not affect groundwater dependent ecosystems or other groundwater users by certain drawdown levels (GABORA 2017, s.26). There is a simple calculation for determining impacts on ecosystems or neighbours set out in the water management protocol. A general authorisation also exists relating to economic or social purposes for Aboriginal or Torres Strait Islanders or prescribed activities, as long as it is no more than 2 ML annually, the bore is controlled and the predicted cumulative drawdown for a groundwater dependent ecosystem or another person is less than the relevant trigger levels (GABORA 2017, s.28).

The petroleum and gas industries also hold a statutory authorisation to extract groundwater without a specific licence. Since 2004, extracting groundwater as part of CSG extraction in the GAB, as well as other areas of the state, has been authorised under the Petroleum and Gas (Production and Safety) Act 2004 (Qld) (P&G Act 2004)(P&G Act 2004 reprint 1, s.185). There is no limit to the amount of water that may be extracted and it may be used for any purpose within or outside the area of the CSG tenure, subject to the provisions in the Environmental Protection Act 1994 (Qld) (EP Act 1994) and the Waste Reduction and Recycling Act 2011 (Qld) (Waste Act 2011; P&G Act 2004, s.185(3)–(5)). There are corresponding "underground water obligations" to these "underground water rights" set out in chapter 3 of the Water Act 2000 which apply on the grant of the CSG tenure. Generally, they involve operators conducting baseline assessments of water bores before development, monitoring groundwater, preparing an underground water impact report (UWIR) and also committing to "make good" arrangements with affected landholders (such as supplying water from alternative sources or monetary compensation). Within the Surat CMA, to address cumulative impacts of multiple operators, the Office of Groundwater Impact Assessment (OGIA) has been established to monitor and advise on the cumulative impacts of CSG production and to prepare the relevant UWIR which is updated at least every 4 years (Water Act 2000, chapter 3A).

Since December 2016, the statutory authorisation to extract groundwater as part of extractive activities was extended to the mining industry, after the commencement of the Water Reform and Other Legislation Amendment Act 2014 (Qld) and the Environmental Protection (Underground Water Management) and Other Legislation Amendment Act 2016 (Qld)(Tan and Robertson 2018). Mining in the Surat CMA has not had the same impact on groundwater as CSG activities, and most mines generally already had water licences for the necessary interference with groundwater as part of extraction. Nonetheless, the consequence of exemptions in water licensing, will also be relevant to mining going forward.

Apart from the exemptions previously described (for stock and domestic, Aboriginal and Torres Strait Islander or CSG, petroleum or mining users), in all other cases a water licence, permit or seasonal water assignment will be required for access to GAB groundwater. Both latter authorisations are for short term uses. Licences attach to land and can only be relocated if the relocation complies with the rules in the water management protocol (GABORA 2017, s.58; GABORA Water Management Protocol 2017, chapter 5). Therefore, there is not a real "water market", which drives efficiencies. New rules in the GABORA 2017 encourage relocation away from areas of stress. Each licence has a nominal volume, which can be adjusted by an announcement by the regulator in times of scarcity (Water Act 2000, s.29). A development permit under Queensland planning legislation is required for the works associated with an artesian bore in the GAB, whether or not it requires a licence (Planning Regulation 2017 (Qld), Schedule 10, Part 19, s.29(b)).

The most usual way to obtain a new groundwater licence in the GAB is the method prescribed in the GABORA 2017 through purchase of unallocated water when released by DNRME through the tender process (Water Act 2000 s.116, GABORA 2017 s.22, Water Regulation 2016, s.16). Since the GABORA 2017 commenced, the quantum of unallocated water in the basin has been significantly reduced (from 17.2 to 2.225 GL). It is also technically possible to obtain a water licence through an application to the DNRME that may undergo public advertisement (Water Act 2000, ss.107–112) and is assessed against the water plan, any additional information provided, and any properly made submission (Water Act 2000, s.113). As the amount of unallocated water reduces, purchasing and relocating existing licences will be more common. Although relocating licences into areas of existing stress is not possible under the new water management protocol (GABORA Water Management Protocol 2017).

The power to require metering of extraction has existed since the 1910 legislation (RWWCU Act 1910, s.42). The water extracted during CSG extraction is metered and regularly reported (P&G Act 2004, s.186(4); Water Act 2000, s.376). However, most non-CSG extraction of groundwater in the GAB is actually unmetered, even where licences state volumetric limits. Only a few GAB groundwater units and sub-areas in the south-east of the basin generally require metering: the Mulgidie North Hutton groundwater unit, Mulgidie North Precipice, Mulgidie South Precipice, Gatton Esk Road Marburg, and Gatton Esk Road Woogaroo subareas (Water Regulation 2016, Schedule 11.) Therefore, agricultural, industrial and town water extraction from the GAB is unmetered unless they extract from these listed formations or are specifically conditioned (which is now rare). Since the GABORA 2017 was introduced, metering is required for seasonal water assignments or where a GAB water licence is relocated or traded (GABORA Water Management Protocol 2017, cl. 40, 41, 54, and 55).

## Analysis of the current Queensland framework

An analysis of the Queensland governance arrangements for the GAB in terms of Ostrom's design principles reveals that most of the design principles are largely unmet.

### Clearly defined boundaries (DP 1)

Ostrom's first design principle (DP) involves clarity in terms of who is extracting, how they are extracting, how much is extracted and what is authorised by which rules, and not just the physical boundaries of the CPR resource. In short, the design principle relates to certainty about how a CPR is being impacted and whether that impact is authorised or not. In Queensland, the identity of all groundwater users and how the resource is being impacted is not entirely clear. Not only are there unlicensed extractors (mainly for domestic users, stock use and CSG activities), extraction data is weak, water licence information is not readily and inexpensively available to the public, and where available, aquifer attribution is not reliable (OGIA 2016a). Furthermore, the lack of extraction data in turn impacts on compliance measures. If the rules cannot be enforced, this calls into question their efficacy.

Nonetheless, since the development of the CSG industry, there has been significant ongoing research into the boundaries, behaviour and current status of the physical groundwater resource in the GAB. A hydrogeological atlas has been produced by Geoscience Australia (Ransley et al. 2015). A hydrogeological model has been created by OGIA (2016c) which is updated and refined with the steady stream of information being supplied by the CSG industry (OGIA 2016b). In addition, the Commonwealth Government's Bioregional Assessment Program has contributed to knowledge of the resource (Sander et al. 2014; Holland et al. 2017). Understandings of the groundwater flow within the GAB have developed (Habermehl 1980; Radke et al. 2000; OGIA 2016a; KCB 2016). Work is being undertaken to clarify the basin's recharge (Reading et al. 2015; OGIA 2016a; KCB 2016). Clarity around regional groundwater trends is also developing (KCB 2016; OGIA 2016a; Martinez et al. 2017), and in respect of the contact zones between the Surat and Bowen basin formations (OGIA 2016a), the Condamine Alluvium/Walloon Coal Measures (Iverach et al. 2015; OGIA 2016d; Owen et al. 2016) and the Walloon Coal Measures and Springbok Sandstone and Hutton Sandstone aquifers (OGIA 2016a).

## Congruence between appropriation rules, local conditions, costs and benefits (DP 2)

Any general statutory authorisation which exempts water users from the requirement for a licence cannot provide for congruence between that rule and any specific attributes of the location of extraction. The existing exemptions therefore cut across the strength of the catchment based planning otherwise adopted in Queensland. For example, the CSG industry's state-wide entitlement to extract the water does not take account of locally relevant environmental, social or economic issues. The CSG permitting regime through the environmental legislation seeks to address this issue but it is not ideal. Existing local environmental, social or economic issues are considered on the grant of the environmental authority for CSG extractive activities under the Environmental Protection Act 1994 (Qld) (EP Act 1994) and the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (Cwth) (EPBC Act 1999) (EP Act 1994, ss.125 and 126; EPBC Act 1999, ss.24D and 24E). Yet, the approvals for many of the CSG projects in the Surat CMA were granted prior to the impacts of extraction becoming known. To address this problem, an adaptive management approach to the impacts of development was adopted in 2009 (Letts 2012; Lee 2014; DES 2017). This approach has been largely applied to mitigate impacts (such as in respect of the management of CSG produced water) rather than curtailing extractive activities even when the impacts are irreversible (Swayne 2012; Lee 2014). This is sensible from an economic perspective, because mining and gas project investment decisions require a degree of certainty for future extraction. However, it can lead to consequences for other land users and the environment (Randall 2012). The state government's application of the adaptive management approach in this context has been criciticised (Swayne 2012; Lee 2014).

In some parts of the GAB, notably at the south-eastern margins of the Surat Basin in the Surat CMA, some landholders within CSG production areas have limited physical recourse to deeper formations such as the Precipice Sandstone, and very limited legal recourse to 'capped' resources, such as the Hutton Sandstone. When CSG extraction extends to these properties, the ability to "make good" impacts from these deeper aquifers or other water sources will be extremely limited. "Make good" arrangements are generally required to be agreed between landowners and operators in advance where bores are predicted to be impacted by CSG operations within the following three years (Water Act, s.423). The make good agreement sets out the outcomes of the bore assessments, whether the bore is impaired (or likely to be impaired), and intended make good measures such as agreeing to provide an alternative supply of water, to continue to monitor bores, to construct new bores or provide monetary compensation (Water Act, ss.420 and 421).

Even if in the short-term, treated CSG produced water (or other surface water) can be provided to remedy the impacts to groundwater resources, these remedies are not likely to be practical or feasible over the longer term where there are already existing water security pressures. Additionally, monetary compensation cannot fully remedy the loss in total future earnings of existing agricultural enterprises reasonably expecting to continue into future generations. Therefore, for some areas, this state-wide statutory authorisation will have drastic longer-term impacts simply because it does not account for variations in geography and groundwater and surface water availability. In contrast, rules for other water users who require licences do account for local circumstances because they are catchment and aquifer based. Furthermore, in contrast to the environmental approvals for CSG activities that authorise unlimited water extraction across the entire CSG project tenure, the nominal licence volumes in particular areas can be adjusted depending on scarcity.

The framework also does not appear to provide congruence between the volume of water extraction and water charges for utilising the groundwater. The CSG operators are responsible for almost half the GAB groundwater extraction in the Surat

CMA, and they do significantly contribute financially to the management of groundwater resources. The costs of the underground water obligations in chapter 3 of the Water Act are costs to redress cumulative impacts associated with CSG water extraction. The CSG operators entirely fund the OGIA (Water Act 2000 s.479, Water Regulation 2016 (Qld) Part 7). Additionally, there are recharge projects that have already replaced approximately 15 GL of water to the GAB (Origin Energy 2017). The Australian Petroleum Production and Exploration Association (APPEA) states that the CSG industry has invested $3 billion in water treatment and recycling infrastructure where 41.8 GL of water was provided for further beneficial use (mostly for irrigation) (APPEA 2018). QGC highlights that it has spent "more than $1 billion on water-related treatment facilities, research, modelling and management including more than $120 million on groundwater research and monitoring in the Surat Basin to support sustainable water management practices" (QGC 2016, 2018). A significant amount of research is funded by the operators (OGIA 2018; CCSG UQ 2018). Monitoring conducted by industry is extensive (OGIA 2016b). Many of these costs and activities provide benefits for all Surat CMA water users, not just to address impacts directly related to CSG activities. In comparison, water licence fees for non-CSG water users are minimal ($82 per licence: Water Regulation 2016, schedules 12 and 14), and do not contribute to half of the costs of managing the resource (Australian Government Department of Agriculture and Water Resources 2018b).

## Collective choice arrangements (DP 3)

This design principle provides that "most of the individuals affected by a resource regime are authorised to participate in making and modifying the rules" (Ostrom 2005, p. 263) and accords with the higher levels of participation as enumerated by Arnstein (1969) and the spectrum of the International Association for Public Participation known as "IAP2" (IAPP 2016). Certainly, this level of participation is not always warranted or beneficial (Hurlbert and Gupta 2015; Baker and Chapin 2018). Nevertheless, the higher levels of participation have been shown to positively impact levels of trust (Hurlbert and Gupta 2015) and have positive outcomes in respect of groundwater governance (Wester et al. 2011; Shalsi et al. 2019). Where collective choice arrangements (and rights to organise) are coordinated within a nested organisational structure, the higher-level agencies can protect against 'elite' local capture (Ostrom 2005).

Arguably, collective choice arrangements as envisioned by Ostrom (1990) are missing in Queensland, or at best "patchy". Stakeholders are not involved in the ongoing management of the resource. As already mentioned, it is the Queensland state government that controls all water usage. Rules are not necessarily jointly framed by government agencies and relevant stakeholders. Rather legislation and statutory instruments are enacted (or tabled) through parliament and administered by government agencies. Governments can be replaced through the normal democratic processes, but management of a CPR like the GAB, may not be optimised within election cycles and amidst the broad issues that often determine democratic elections. Investigations of agency administration may occur under the Ombudsman Act 2001 (Qld). However, such investigations will not necessarily cure defects in the existing legislative framework and policy. If an administrative action is in accordance with the legislative framework, the Ombudsman must first consider that it was "unreasonable, unjust, oppressive, or improperly discriminatory in the particular circumstance" (Ombudsman Act 2001 (Qld), s. 49). If the Ombudsman makes an adverse finding and appropriate steps are not taken by the agency, a report is made to the Premier and tabled in Parliament (Ombudsman Act 2001 (Qld), s.51). If the administrative actions are in accordance with current government policy, this remedy may be ineffectual.

Participatory arrangements for water planning and allocation in Queensland are not the higher levels of participation, such as "partnerships", "delegated power" or "citizen control", as enumerated by Arnstein (1969). It is also questionable as to whether such arrangements equate to the higher levels of participation in the IAP2 framework, where stakeholders are "involved", "collaborate' or are "empowered" (IAPP 2016). Generally, governance arrangements are made via consultation which ensures that stakeholders may be heard, but not necessarily heeded (Arnstein 1969). For example, the creation of the statutory authorisation to extract water by CSG operators and particularly the later extension of that right to the mining sector in 2016, certainly underwent community consultation (Explanatory Notes 2004, 2014). A Water Engagement Forum and Groundwater Management Working Group was established during 2012 and 2013, and targeted consultative sessions occurred with peak stakeholder groups such as Queensland Farmers' Federation, Agforce, Queensland Resources Council, the Australian Petroleum and Production and Exploration Association and others (Explanatory Notes 2014). The minutes of these meetings were not made publicly available, although many of the same organisations involved subsequently made public submissions on the Bills before Parliament (Tan and Robertson 2018; QRC 2014, 2015; Basin Sustainability Alliance 2014; Queensland Farmers' Federation 2014; Agforce 2014). Despite many submissions criticising the inherent unfairness of some water users being exempted from the water planning and allocation system (EDO Qld 2014; WWF 2014), the government continued its support of the statutory authorisation for groundwater extraction during CSG, petroleum and mining activities to reduce red tape for the mining industry (Agriculture, Resources and Environment Parliamentary Committee 2014;

Infrastructure, Planning and Natural Resources Committee 2016; Tan and Robertson 2018).

Similarly, landholder stakeholders have criticised the consultative process relating to the GABORA Water Management Protocol 2017 by arguing:

> As the WMP [Water Management Protocol] is made under the Chief Executive's authority and he/she has no requirement to develop a Consultation Report about how they dealt with stakeholder submissions - they are able to make any changes they like without being publicly accountable or providing any explanation as to why the changes were made…. (Basin Sustainability Alliance 2017, pp. 12–13)

Moreover, it is very difficult for the community to have an input in respect of individual decisions relating to water licences. The usual process of acquiring unallocated water through the tender process does not involve public notification. The less common avenpue of applying for a water licence may require public notification, but not for stock and domestic purposes (Water Act 2000, s.112). Even where the application is publicly advertised, only interested parties who made a submission have review and appeal rights (Water Act 2000, chapter 6).

## Monitoring (DP 4)

A significant issue for monitoring and compliance activities in Queensland is the lack of sufficient measurement of extraction in the first place (Waldron et al. 2018; South Australia 2019). Without an adequate system of water measurement and accounting, quality assurance in respect of water metering and a commitment to transparency and open information of data, monitoring in Queensland will be flawed.

There are widespread efforts to provide monitoring data in respect of extant water levels and water quality by various levels of government and operators, but they are disaggregated. There is monitoring information made available by the Commonwealth Bureau of Meteorology (BOM; Water Act 2007 (Cwth), s.120; Water Regulations 2008 (Cwth) Part 7) through various tools such as a National Groundwater Information System, the Australian Groundwater Explorer, the Australian Groundwater Insight and the Groundwater Dependent Ecosystems Atlas (BOM Undated). Although, BOM is prevented from disclosing information that relates to an individual's water use (Water Act 2007 (Cwth)s.123). The location of monitoring bores operated by DNRME, (and some by CSG operators), private bores and gas wells and some of the relevant monitoring data from those bores is available on Queensland Globe (Queensland Government 2019c), and DNRME's Water Monitoring Information Portal (Queensland Government Undated). Whilst the data on Queensland Globe can be out of date, in some cases it is almost a year old, the data on the water monitoring information portal is relatively current, albeit with respect to a smaller proportion of wells and bores. OGIA receives a wealth of information about water extraction and groundwater data from the CSG industry, and this is presented in a cumulative way in the UWIR (OGIA 2016b) and also per CSG well on the Internet (Queensland Government 2019b).

Furthermore, the location and breadth of monitoring has been criticised—for example, the Surat CMA does not cover the entire Surat Basin, and therefore OGIA manages some of that area whilst DNRME manages monitoring in the remainder (Basin Sustainability Alliance 2017). The Independent Expert Scientific Committee on CSG and Large Coal Mining Development (IESC), an independent national government agency which provides advice on development, has argued that there is a lack of monitoring wells in the proximity of certain spring complexes (IESC 2017). An independent review of the Commonwealth requirements conducted in 2017 recommended that there be a review of monitoring (and compliance) activities (Hunter 2017). Additionally, it has been recommended that the number of DNRME monitoring sites (including relating to groundwater), which had recently been reduced, be reviewed (Waldron et al. 2018).

A key feature of the design principle relating to monitoring is that the monitors themselves be monitored (Ostrom 1990). The government agencies that are responsible for making the monitoring data available, are largely unaccountable to the public in Queensland. Some CSG operators publish monitoring data themselves (Santos 2016; Shell Undated). Although, there is no ability for the public to question and analyse this data.

## Graduated sanctions (DP 5)

There are graduated sanctions for noncompliance with water allocation rules (Water Act, chapter 5, part 3), but compliance measures exercised by the DNRME have been found to be wanting (Waldron et al. 2018). An independent review of nonurban water measurement and compliance conducted in 2018 found that DNRME has had a "weak enforcement and compliance culture leading to ineffective water management" (Waldron et al. 2018). Compliance measures undertaken by DNRME are not publicly reported. Furthermore, where the entitlement is so broad that there are no volumetric limits on a water entitlement, or where metering is not required, offenses are difficult to identify. Graduated sanctions appear to be applied to CSG activities through the compliance activities of the Queensland Department of Environment and Science (DES), but only the more serious offences are transparently published (Queensland Government 2019a).

### Conflict resolution mechanisms (DP 6)

Unfortunately, the existing conflict resolution mechanisms in respect of both CSG and non-CSG groundwater extraction are not ideal. The unique conflict resolution mechanisms in place in respect of the impacts of water extraction by the CSG industry, the "make good" arrangements, are not "rapid, low-cost, local arenas" (Ostrom 2005, p. 267). The arrangements require CSG operators (and in the Surat CMA, the OGIA) to first undertake baseline assessments, monitor, prepare UWIRs to enable predictions, which in turn trigger requirements for "make good" arrangements. "Make good" agreements, which determine how future impacts will be remedied, must then be reached between landholders and operators. Alternative dispute resolution, arbitration or Land Court appeals are available in the event that an agreement cannot be reached (Water Act, chapter 3, part 5, div. 4). The overall inequity and efficacy of the framework is an issue for many landholders as well as industry (Janjua 2017).

Disputes between non-CSG water users have extremely limited avenues for redress. The GABORA 2017 and the accompanying water management protocol requires an assessment of future impacts on existing water users and groundwater dependent ecosystems at the time of a water licence application. However, if the water licence application is not publicly notified, there are minimal opportunities for third party reviews and challenges of a decision to grant a specific water licence. As granting water licences through tender for unallocated water is the preferred method in the GAB, the reality is that there are very few avenues to challenge the grant of a water licence. There are processes for reviewing water plans and these reviews can address impacts. Yet, reviews of water plans generally only occur every decade. Therefore, there are no readily available means of addressing the current impacts felt by water users due to historic allocations or unlicensed non-CSG extraction, and all groundwater users share in subsequent groundwater scarcity when adjustments across the subbasin are announced by the regulator.

### Minimal recognition of rights to organise (DP 7)

At least some minimal rights to organise are recommended so that local efforts to manage the resource are supported (Ostrom 2005). However, water users do not have any ability to self-organise in Queensland: governance is through the DNRME and the DES(for CSG extraction) in a centralised "command and control" way. As mentioned, water plans are developed through consultation not the higher orders of participation enumerated by Arnstein (1969) and the IAP2 (IAPP 2016). There are stakeholder groups such as the Local Government Association Queensland, the Condamine Alliance, the Basin Sustainability Alliance, AgForce, APPEA and Queensland Resources Council. There are laudable "citizen science" initiatives such as the DNRME's Groundwater Online and Groundwater Net, where a number of both GAB and non-GAB groundwater users (approximately 70 and 100 respectively) participate in groundwater monitoring initiatives: supplying information from private monitoring wells and receiving information about water levels and trends (OGIA 2016b, 2019). These groups and individuals can only influence the rules through informal and formal consultation. Ultimately, the rules are established by the regulators in Toowoomba, Brisbane and Canberra.

### Nested enterprises (DP 8)

A nested organisational structure exists for non-CSG extraction of GAB groundwater. Anyone wanting to access groundwater from GAB formations, starts the process with their local DNRME business centre (in the Surat subbasin: Goondiwindi, St George, Warwick or Toowoomba and sometimes Rockhampton). The application to either relocate a licence or apply for a new licence will be dealt with by local officers in these regional centres. Purchasing unallocated water follows the tender process and is managed in a centralised way by the DNRME in Toowoomba and Brisbane. In contrast, groundwater extraction occurring during CSG (petroleum and mining extraction) is generally regulated by the DNRME CSG compliance unit in Toowoomba and the environmental regulators: DES, based in Brisbane and Toowoomba and the Commonwealth Department of Environment in Canberra.

## Discussion in respect of Ostrom's design principles

As seen through the preceding analysis, most of Ostrom's criteria are largely unmet in respect of governance of the GAB in Queensland. Whilst there are some nested organisational arrangements and developing clarity around the physical nature of the basin, the design principles are otherwise absent. Systems that incorporate certain clusters of design principles have been seen to have important consequences (either for good or bad) in other studies (Baggio et al. 2016) and this is apparent in the Queensland context.

The boundaries in respect of the water users, the resource itself, and the rules associated with its use (DP 1) have a significant flaw: a lack of measurement of extraction by most non-CSG users. This is not uncommon for groundwater systems (Martinez-Santos et al. 2018; Molle et al. 2018). However, where the resource is clearly pressured, it can have considerable impact. The lack of extraction data detracts from the knowledge about the groundwater resource which can in turn impact on the legitimacy of rules. The relatively uncapped stock and domestic use, a lack of transparency around licence conditions, a lack of measurement of extraction (DP 1) and the lack of compliance activity (DP 5) relating to over-extraction, are factors that contribute to an almost de facto open access resource (Theesfeld 2010). This context provides opportunities and incentives for rule-breaking (due to the lack of measurement as well as a lack of enforcement activity). Without clear boundaries and enforcement of rules, the first CPR problem of "non-exclusivity" is impossible to address.

A lack of congruence between local rules and costs and benefits (DP 2) has also had deleterious effects. The lack of cost recovery from most water users does not provide incentives for those users to conserve the resource. Additionally, the state-wide statutory authorisation held by the CSG industry is in theory constrained in the accompanying environmental approval process, but as already discussed, local conditions or existing water use have not always been considered or protected. Calls for licensing of the CSG industry (and now applicable also to mining; Randall 2012; Productivity Commission 2018) directly address this issue.

There are indications that notions of collective responsibility on the part of groundwater users may be missing. There are only a relatively small number of landholders voluntarily participating in the "citizen science" initiatives relating to monitoring compared to the number of groundwater appropriators. There are 22,471 non-CSG groundwater bores in the Surat CMA (approximately 8,000 groundwater bores extract from the GAB; OGIA 2019). Although, many landholders have voluntarily contributed to the bore capping program which has benefited not only their own water security, but also other users in the basin (Habermehl 2019). Nonetheless, a lack of any rights to organise (DP 7) coupled with weak collective choice arrangements (DP 3) may contribute to any possible missing collective responsibility. The absence of these design principles must be understood within the cultural legacy of the state permitted system. The regulator permits water use without the constraints of a public trust doctrine (Gardner et al. 2017) or correlative rights—where surface water users are limited to a reasonable share of water resources: Embrey v Owen (1851) 6 Exch. 353; 155 ER 579. Neither the government nor water users are accountable to other water users for over-extraction. This is in direct contrast to the transparency in respect of landholder water rights and the ability to enforce priority in other jurisdictions such as, the western states in the USA. (Nevertheless, aspects of US western water law can also produce individualistic behaviours (Lee 1993; Schlager 2006)). Furthermore, there are adopted notions of privacy and confidentiality relating to water use in Australia (McKay and Gardner 2013), which are based on individual concerns and do not reflect the communal nature of the groundwater resource (Skurray 2015). These factors in Queensland would seem to compound individualistic behaviours. As the conflict resolution mechanisms (DP 6) between water users (including relating to CSG extraction) appear to be problematic, this can add to a lack of accountability and absence of responsibility for the common groundwater resource by individual water users (Skurray 2015). The context becomes akin to a prisoner's dilemma (as described by Ostrom 1990,) whereby incentives are present to maximise short-term individual gains at the expense of the basin as a whole.

Despite impressive efforts to monitor the resident groundwater resources, monitoring (DP 4) is also hampered by the lack of transparency relating to many water users and the actual quantum of extraction (DP 1). Measurement of use is vital in order to address the second issue CPRs face: the "subtractability" of the resource. This is essential where the resource is effectively nonrenewable. It is widely accepted that the impacts of extraction will be delayed by many years and yet the focus of monitoring is on the resource in the ground rather than the actions that will cause the delayed impacts: extraction. Arguably the reporting of data by CSG operators to OGIA which in turn creates the groundwater model and predicts impacts of CSG produced water extraction goes some way to address this. However, without measuring the other half of extraction in the Surat CMA, OGIA's efforts can only tell part of the story. Moreover, much of the information that is presented is collected by the operators rather than government. This not only impacts the confidence in the integrity of this data, but as it is disaggregated, it is difficult for the public to gain a thorough overall picture or have a high degree of confidence in the available monitoring data (Hunter 2017; Nelson 2019).

Without measurement one cannot easily manage a resource (South Australia 2019). The inability for monitoring of the monitors (DP 4) coupled with a lack of transparency with respect to compliance activities (DP 5) and extraction data (DP 1), has not provided incentives in the past for the regulator to address over-allocation and over-extraction in the GAB—for example, large tranches of unallocated water were made available in 2014 out of the Hutton Sandstone and Evergreen Formation (totalling 785 ML; DNRM 2014). The release occurred despite the predicted need to service the predicted "make good" arrangements for impacted bores in the Walloon Coal Measures from the Hutton Sandstone. The release was also at odds with the current and historic declining status of that formation (KCB 2016).

Nested enterprises (DP 8) generally tighten feedback loops between resource changes and response, and they also increase the proximity between knowledge of the resource, response capacity and decision-making (Marshall 2008). Therefore, in nested organisational structures, decision makers are in close proximity to the users. This not only provides information about the resource (DP 1), it provides the stakeholders an opportunity to know each other and build trust. A strength of the governance framework relating to the GAB is the nested structure for non-CSG water extraction. The exemption provided by the statutory authorisation to the CSG industry divorces that industry from the community of other users and this can impact the level of trust between these different water user groups and government.

Ostrom's framework can also assist in considering the strengths and weaknesses of this bifurcated regulatory regime for non-CSG extraction and CSG extraction. A summary table (Table 2) is presented which highlights some of the different strengths and weaknesses attributable to these separate governance arrangements.

The contrasting strengths and weaknesses in the governance frameworks create different incentives for the various groundwater users depending on the context—for example, the lack of measurement of extraction, cost recovery and compliance activities relating to non-CSG extraction does not encourage water efficiency by those users. The bifurcated approach may mean that it is very difficult for groundwater users to arrive at shared purpose and objectives because it heightens the heterogeneity of users rather than unifies them. This can lead to vested interests or capture by an 'elite' that may resist change where there are inadequate conflict resolution mechanisms (Theesfeld 2010). The Queensland Gasfields Commission, an independent statutory body established in 2012, is charged with facilitating relationships between stakeholders (Gasfields Commission Act 2013 (Qld), s.3). Nevertheless, trust issues remain (Gillespie et al. 2016; Hunter 2017; Witt et al. 2018; Walton and McCrea 2018). In addition to reform of conflict resolution mechanisms, a universal and transparent water licensing, monitoring and proportional cost sharing regime could in part address this issue. Yet, it would have different consequences for the different broad stakeholder groups. It would mean CSG wells would require water licences and would therefore have local impacts of wells expressly addressed. For most of the state, this would not necessarily impact extraction but would assist where predicted impacts are difficult to remedy. It would also mean (at the very least) openly available and transparent non-CSG water licence information, water usage, sanctions and proportional cost sharing. This reform measure would affect many existing groundwater users.

This analysis shows why some water users in the GAB may be predisposed to continue to extract and may resist governance changes, while water levels decline within their area. Ostrom's CPR theory shows how the absence of particular design principles in certain contexts can incentivise individual extractors. A logical reform agenda would include addressing at least some of the missing design principles. Given the state vesting of groundwater, it seems sensible to start with measures that do not erode that power: requiring all water users to be licensed, making licences readily available for public scrutiny, measuring and accounting for all extraction and strengthening compliance activities. These reforms appear to be the "low-hanging fruit". Ironically, they were first recommended and legislated in 1910 and were reiterated in the GAB Strategic Management Plan 2000 (GAB Consultative Council 2000–2015) and the draft GAB Strategic

**Table 2** Summary of governance arrangements for non-CSG extraction and CSG extraction of water in terms of Ostrom's common pool resource (CPR) design principles

| Design principle | Governance of non-CSG extraction | Governance of CSG extraction |
|---|---|---|
| DP 1. Clearly defined boundaries | Weakness: Lacks transparent extraction data, licence information, aquifer attribution and there are unlicensed users | Strength: Although CSG wells are not individually licensed, they are clearly identified, and extraction is transparently reported |
| DP 2. Congruence between rules, local conditions and costs and benefits | Strength and weakness: Rules are drafted for local conditions, and extraction rules can be modified depending on scarcity, but costs of extraction are not proportionally shared | Weakness: Broad statutory authorisation does not adequately account for local impacts but significant costs to manage impacts are borne by CSG industry. |
| DP 3. Collective choice arrangements | Weakness: Rules are formulated by government agencies with some consultation | Weakness: Rules are formulated by government agencies with some consultation |
| DP 4. Monitoring | Weakness: Extraction data not available and monitors cannot be monitored. | Strength and weakness: Extraction data available but monitors cannot be monitored |
| DP 5. Graduated sanctions | Weakness: Compliance activities not apparent | Weakness: Not all compliance activities are made openly, publicly available |
| DP 6. Conflict resolution mechanisms | Weakness: There are minimal avenues for groundwater users to address conflicts between users | Weakness: Make good framework is not low-cost or efficient, and efficacy has been questioned. |
| DP 7. Minimal recognition of rights to organise | Weakness: Regulation is via 'command and control' centrally located decision-making in Toowoomba and Brisbane | Weakness: Regulation is via 'command and control' centrally located decision-making in Toowoomba, Brisbane and Canberra |
| DP 8. Nested enterprises | Strength: More agencies are located locally | Weakness: Agencies are located in Toowoomba, Brisbane and Canberra |

Management Plan 2018 (Australian Government 2018). Although, both strategic management plans stop short in requiring all water users to have a licence. Incorporating extractive industries into water law frameworks, were also recommended by the Productivity Commission in its inquiry report regarding national water reform (Productivity Commission 2018). These objectives have been sought, but not necessarily achieved, for over a century. In response to an independent review, the DNRME has now recently committed to strengthening compliance provisions, metering and investment in water information systems (DNRME 2018).

In theory, there appear to be benefits in a state permitting system like the Queensland framework (Schlager 2006). It has been argued that "under a permitting system, states would be allowed to refuse to issue permits, even if water was available, and revise and rescind existing permits in order to realize a broad range of social values" (Schlager 2006, p. 359). However, the experience to date in Queensland has shown that this is easier said than done. It has proved very difficult to curtail extraction from parts of the GAB. It has taken much effort along with significant Queensland and Commonwealth government funds (Tan and Quiggin 2004; GAB CC Undated), to begin to address the problem of uncontrolled bores and open bore drains. Remaining uncontrolled bores and open drains have until 2027 before they must be addressed (GABORA 2017, s.33). Exemptions for water licences relating to stock and domestic and of course, petroleum, CSG (and now mining) extraction still exist. The cumulative growth in non-CSG bore construction and water extraction in the Surat CMA has been significant since the 1950's and 60's (OGIA 2016a; KCB 2016). Moreover, the CSG industry has effectively matched all other water extraction during a very short period (OGIA 2016b). We are using more groundwater than ever, which has nonetheless contributed to significant economic benefits to the state (Frontier Economics 2016).

When legislative reform was initiated in the past, doubts as to the need for the reform by representatives of water users led to resistance to those changes. Members of arliament highlighted the uncertainty relating to reduced bore yields and what would happen if uncontrolled bores were controlled (Queensland Hansard 1910). They also highlighted that the provisions requiring licensing and curtailing wastage had rarely been enforced in the past (Queensland Hansard 1930, 1954). A repeated argument highlighted the unsuitability of rules being made in Brisbane for water users located in Western Queensland (Queensland Hansard 1910, 1930). These historic debates suggest that a key issue for Queensland water governance has been a lack of buy-in by some water users who have pointed to scientific uncertainty relating to the relative scarcity of the resource. Political and social resistance has meant that reforms have been difficult to achieve in reality.

In contrast, even contrary to state leadership, at times water users have been able to formulate rules and enforce them so as to sustainably manage CPRs (Ingold 2018). In other jurisdictions, the relative scarcity and importance of a resource has been the impetus for the development of enduring collective governance (Ingold 2018; Boone and Fragaszy 2018). Therefore, research that clarifies the nature, behaviour and extent of the resource and impacts by water users is extremely important, especially where scarcity may exist (such as where a fossil aquifer is involved). Successful relationships between the regulator and regulated have been at the heart of positive collaborative efforts (Lopez-Gunn and Cortina 2006). Therefore, despite the state's pivotal role and power with respect to groundwater, communicating research to water users is crucial in introducing new rules for sustainably managing that resource (Gunderson et al. 1995; Theesfeld 2010; Gross and Dumaresq 2014; South Australia 2019).

As mentioned, sustainability requires a balancing of not just impacts to the physical properties of the resource but also the economic and social consequences of actions. For "fossil' aquifers, as mentioned previously, robust political processes are extremely important because they ought to ensure that adequate trade-offs for the depletion in the resource occur. Participatory governance arrangements involving all stakeholders from the different economic sectors and the environment are essential (Martinez-Santos et al. 2018). There may be some valid reasons as to why exemptions to water licences are in place, why metering may be difficult or unfair or why the remaining free-flowing bores or bore drains ought to remain free-flowing. Often policies relating to measurement of extraction appear straightforward and necessary but are adopted without understanding the costs and logistical or legal difficulties involved (Molle and Closas 2017; Molle et al. 2018). Therefore, robust and transparent discussion about the *collective detriments* to some of the existing activities (and governance arrangements), highlighted by the current scientific research, could provide the support needed to underpin future actions. Out of all the missing design principles, the combination of Ostrom's design principles relating to collective decision-making (DP 3) and clear boundaries and information (DP 1) seem the most important in this context. Given the history of governance, these two design principles would appear to provide the best chance for overcoming resistance to and even facilitating new rules for the basin. Certainly, the state has a significant role to play in the groundwater context (Schlager 2007; Baldwin 2008; Ross and Martinez-Santos 2010; Theesfeld 2010; Wester et al. 2011). Nevertheless, this research supports other recent research highlighting the need for best practice in public participation strategies (Afroz et al. 2016; Witt et al. 2018; Shalsi et al. 2019).

## Conclusions

With new information in respect of the groundwater resource, there is an opportunity to reconsider how the resource is managed. This paper highlights how the absence of some of Ostrom's design principles may have contributed to unsustainable outcomes in the Surat Basin of the GAB. Avenues for reform could relate to water licensing requirements and the bifurcated nature of governance, the public availability of licence and monitoring information, the measurement and accounting of extractions, and compliance activities by the regulator. However, on the basis of the history of governance of the GAB, applying the institutional design principles and ignoring political and social aspects will be counter-productive to improving governance arrangements.

The most important gap in the Queensland framework to date relates to information about the resource (DP 1) and aspects of collaboration and collective decision making (DP 3) which would otherwise drive social learning (Lee 1993). Ironically, it seems that in order to govern more effectively, the state first needs to relinquish some power and allow properly informed stakeholders to take *some* degree of responsibility for directing future management arrangements. Moreover, blaming government and requiring government to be solely responsible for governance arrangements may ultimately prove ineffective. Moving beyond a simple state or market approach would seem warranted in these circumstances and is supported by recent research in another Australian context (Shalsi et al. 2019). Therefore, prior to any new measures being instituted by the state, authentic, respectful and effective engagement with water users ought to occur and citizen science initiatives ought to be encouraged. Presenting any new information relating to the status of the GAB can facilitate engagement that stimulates collectively supported outcomes that are equitable. Collective learning is difficult and fragile (Lee 1993; Shalsi et al. 2019). If there is going to be real seriousness about sustainable management of the GAB, what is needed is to learn from the history of its management, acknowledge these challenges and work to build a relationship between the regulator and the regulated, which empowers all groundwater users.

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