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Article

The Common Pool Resource Heatmap: A Tool to Drive Changes in Water Law and Governance

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Abstract: Anticipated water-related impacts of climate change heighten the need for tools supporting proactive efforts to address current and future conflicts involving water. Analysing a regulatory framework for a water resource using Ostrom's (1990) Common Pool Resource (CPR) theory can assist in identifying regulatory weaknesses that may contribute to deterioration of the resource and conflicts between resource users. Equally, adopting adaptive management to transform the regulatory context can also have positive effects. However, if incentives drive resource extractor behaviours, a tool to communicate these initiatives with stakeholders, including state actors, could assist. This article presents the 'CPR heat map' to assist with efforts to drive changes in water governance. An example of the CPR heatmap is presented involving the governance of groundwater in the Surat Cumulative Management Area, Queensland, Australia. This example shows how perceived weaknesses and strengths of the governance framework can be illustrated. It also shows how initiatives that are transforming water governance can be presented to drive social learning. The CPR heat map illustrates the collective nature of the resource system and how to potentially resolve and manage water-related conflict. This research has implications for how we approach conflict involving water and may be also relevant for managing other CPRs.

Keywords: groundwater; common pool resources; adaptive management; Australia; stakeholder engagement; water governance; legislation

Citation: Robertson, J. The Common Pool Resource Heatmap: A Tool to Drive Changes in Water Law and Governance. *Water* **2021**, *13*, 3110. https://doi.org/10.3390/w13213110

Academic Editors: David Katz and Nidhi Nagabhatla

Received: 1 October 2021
Accepted: 2 November 2021
Published: 4 November 2021

1. Introduction

Tensions and conflict between water users occur when demand exceeds supply, and climate change and global warming [1,2] will likely act as accelerants to these dynamics. In Australia, predicted impacts of climate change are generally: higher evaporation of surface water, increasing droughts, varying rainfall, increasing flood events and severe storms [3]. This not only affects the quantum of future water resources available for consumptive use and for the environment, but also places pressure on our regulatory frameworks to manage competing interests.

Crises can be the catalyst to address water issues and enable difficult decision-making. The crisis in 2018 facing Cape Town in South Africa was arguably averted through rapid changes in respect of both demand and supply of water [4]. However, solutions adopted in crises are often short-term fixes which do not address inequitable sharing paradigms that have contributed to the crisis [5]. For example, in some regional areas of Queensland, water has been trucked over significant distances to provide immediate drought relief to residents [6]. Sustainable management of water resources requires the opposite: initiatives that manage both the long-term health of the overall resource as well as addressing conflict [7]. If the goal is sustainable management of water resources, this requires proactive initiatives outside of crisis management.

Conflict is already evident in respect of the governance of water in Queensland Australia. Continuing and growing conflict has been evident in relation to both access to water resources [8,9], and the management of water storage infrastructure in Queensland, Australia [10,11]. With the anticipated impacts of climate change in mind, tools are necessary to assist proactive efforts to manage both the current and anticipated future conflicts involving the management of water in Queensland, Australia.

Analyses using Ostrom's (1990) Common Pool Resource theory (CPR theory) [12] can assist in identifying regulatory weaknesses that appear to contribute to deterioration of water resources as well as potential conflicts between resource users [7,9,13–29]. Equally, adopting adaptive management (AM) as an approach to drive initiatives to transform the regulatory context can also have positive effects. However, if individual incentives drive resource extractor behaviours, as is suggested by CPR theory, then stakeholder understandings, values and expectations must also be transformed concurrently.

It is now recognised that there is a need for effective, thorough and well-informed community engagement to support reform in all aspects of water resource management and water services provision in Australia [30] (p. 11). An easy-to-use tool to communicate analyses and illustrate where regulatory weaknesses may lie, could assist in driving institutional change and broad stakeholder social learning. Better still, a tool which can clearly illustrate impacts of any practical measures adopted to address regulatory weaknesses, would also assist in this context. Furthermore, such a tool could be instrumental in educating resource users about their place in the regulatory framework and how the resource is managed. It may also assist in persuading policy decision-makers, as well as resource users, to adopt other more radical measures that may assist in avoiding future conflict as well as in protecting our precious natural resources. The purpose of this article is to present such a tool, developed using Ostrom's (1990) design principles [12] and termed the 'CPR heat map'.

Prior to presenting the CPR heat map, a discussion of CPR theory highlights the theoretical basis of the tool and why such a tool could be helpful. I then discuss the development of the natural resource theory adaptive management (AM) and the importance of communication in driving social learning and changes to governance arrangements. I then introduce the 'CPR heat map'. This is followed by a practical example illustrating an analysis of the regulatory framework for groundwater in the Surat Cumulative Management Area (Surat CMA) in Queensland, Australia as shown in Figure 1. The article concludes with a discussion of the Surat CMA CPR heatmap and how it illustrates perceived weaknesses and strengths of the governance framework. The example shows how the CPR heatmap can also be used to show AM initiatives that are positively impacting understandings about the groundwater resource as well as to evaluate other initiatives and consider how they might impact stakeholder incentives.

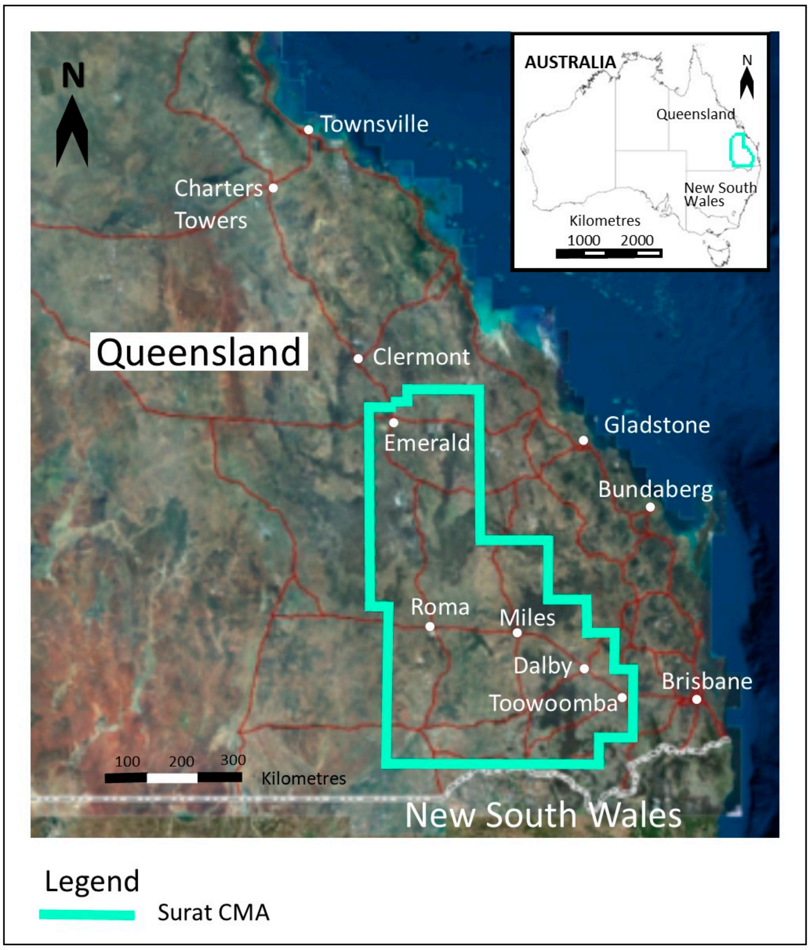

Figure 1. Surat Cumulative Management Area, Queensland, Australia.

2. Ostrom's Design Principles for CPRs

Evaluating a water governance framework is a complex process and there are various methods of analysis that are useful [31]. Ahmed and Araral explain that the three most prevalent methods used to evaluate sustainable water management are: indicators and indices, such as the Water Poverty Index, product-related assessments, such as the Ecological Footprint, and integrated assessments, such as system dynamic modelling, risk analysis, cost-benefit analysis and impact assessments [31] (p. 4). However, Ostrom's (1990) CPR theory is relevant to any initiative that seeks to manage conflicts of interests relating to water [12]. Water is a CPR, along with fisheries, forests and pastureland resources [12,32,33] (p. 5). CPRs are a type of resource that suffer governance or management issues due to the difficulty in excluding other users from accessing the resource, as well as the fact that each use or extraction of the resource, reduces the overall quantum available [12] (pp. 30–32). Overuse or even destruction of the resource system can easily occur through mismanagement [12]. CPRs are notoriously challenging to govern due to their features of 'non-exclusivity' and 'subtractability'. Thus, the management of these characteristics ultimately determines the success of a CPR governance framework.

Eminent theorists, such as Coase [34–36], Olson [37] and Hardin [38] have postulated that there are two 'silver bullets' to govern CPRs: a free market, or a central governing state 'command and control' model [12] (pp. 8–12). Essentially it has been argued that the conflict between individual interests and those with the group will always drive over-extraction to the detriment of the resource without markets or a state controlling entity.

But there have been challenges to these presumptions. For example, Hardin's predictions, using game theory and the 'prisoner's dilemma' game, only hold true for one-shot conditions where there is no communication between players [39] (p. 15183), as well as no capacity to change the external variables affecting them [40] (p. 646). The problem of successfully managing CPRs is now understood to be a coordination issue between resource users and the provision of collective benefits rather than a 'dilemma' per se [12] (pp. 42–43). That is, coordination of the users can assist with managing conflicts of interest in the resource. Therefore, communication between different stakeholders is extremely important where a CPR is involved. Furthermore, neither state control nor markets have actually proved to be particularly effective for governing CPRs [41]. By at least 1990, case-study research, where common property arrangements had been replaced by state-controlled frameworks, often revealed deteriorating governance of the resources because of difficulties in monitoring, enforcement of rules of access and even corruption [12] (p. 23). Similarly, the use of markets to address deterioration of a resource has been questioned in, for example, the groundwater context [41–44] (p. 202).

The importance of community mechanisms balancing both market and state powers is now recognised generally [45]. However, as early as 1990, Nobel laureate Elinor Ostrom had proposed that there was a third option for sustainable governance of a CPR: collective governance by the users of the resource [12,46]. Building on earlier research, Ostrom and other scholars concluded that, in some circumstances, CPRs could be managed successfully by collective arrangements rather than either the state or the market [40] (p. 649ff). Ostrom defined successful CPR governance by referring to the long-term sustainability of the resource system as well as the institutions that govern them [12] (pp. 58–60).

Ostrom compiled a set of eight design principles, or broad institutional regularities or 'best practices' which, she posited, are conducive to successful CPR governance. Ostrom's design principles are: 1- clearly defined boundaries in respect of (a) the users of the resource and rules for extraction and (b) the biophysical shared resource; 2- local rules and proportional costs and benefits; 3- collective choice arrangements; 4- monitoring of (a) the resource and (b) the monitors; 5- graduated sanctions; 6- rapid, low cost and local conflict resolution mechanisms; 7- users rights to organize themselves; and 8- nested enterprises [7,12,46–48]. The design principles 'explain under what conditions trust and reciprocity can be built and maintained to sustain collective action in the face of social dilemmas posed by CPRs' [47] (p. 39). Essentially, the design principles embed the conditions to enable cooperative efforts and thereby manage conflict.

Ostrom's design principles are not a cure-all for CPR governance [49]. The attributes of the resource and resource system, resource users, practicality of monitoring and enforcement measures, and the macro-political institutions, culture and economic environment are all key factors in determining effective governance arrangements [50–52]. Because each social ecological system (SES) is unique, not every variable will be relevant in every study [39] (p. 15182). Furthermore, the interactions of these factors may change over time. There is, therefore, a need for governance arrangements to be flexible and adaptive [39,52] (p. 255). Rather than a single-policy solution, hybrid systems combining aspects of state, market and communal arrangements are now seen as preferable [22,26,50,53,54]. Furthermore, such arrangements ought not to be considered a 'one-shot' effort; instead, they should be able to be adapted and revised over time to address dynamic situations [15]. Management initiatives must necessarily change over time as the SES changes.

Ostrom's design principles can provide a framework for evaluating water governance arrangements. They have, in fact, been put to the test in respect of water governance in different jurisdictions worldwide [7,9,13–19,21–23,25–28,55]. Current research supports the notion that an historic lack of recognition of the resource as a CPR has, at times, led to its deterioration [17] (p. 610), and that the design principles are generally conducive to success [17,18,21,25].

Analyses of a CPR regulatory context using CPR theory can assist governance measures in numerous ways. Such an analysis will obviously assist policy decision-makers understand where self-interest on the part of resource users may drive over-extraction. This will provide information about where regulatory change may drive more sustainable outcomes. However, the analysis would also be helpful for resource users to understand their place within the regulatory landscape. For example, an understanding about the status of a resource has assisted with the development of enduring collective governance [25,56]. Therefore, stakeholder understanding not only of the status of the resource but also the drivers for extraction, impacts of extraction, as well as the context around the rules for extraction for each type of resource user, will be essential in driving a change in resource extractor behaviour.

However, a robust and thorough analysis which describes the extent to which certain design principles are present in relation to a CPR will be complex and difficult to digest in a summary way. For example, the regulatory frameworks which govern a CPR that has diverse heterogenous extractors will inevitably have a number of factors or variables which relate to each design principle: such as, different rules for different types of extractors, different compliance action for different extractors or locations, or perhaps, a different level of monitoring of the resource or resource users. Many analyses have used the eight design principles as the yardstick against which the context of the CPR is measured. Many provide an overall narrative in respect of each design principle to discuss the regulatory framework or context and often resource user incentives [7,9,14,18,21,23,25,27,55]. In addition, Ostrom presented a multilevel, nested framework for analysing outcomes in SESs using four first-level core subsystems (resource system, resource units, governance systems and users) and at least a further 10 subsystem variables [51]. These types of analyses are extremely important diagnostic tools in understanding how a particular CPR is managed or governed as well as being able to accumulate knowledge more broadly, such as comparing frameworks relating to different CPRs. However, such work is difficult to present to ordinary resource users or even policy decision-makers such as departmental officers who ultimately influence access to the resource and regulatory provisions. Given that a fundamental issue in governing a CPR has been argued to be a coordination issue between resource users, a tool that can present this information simply would be worthwhile.

3. Adaptive Management (AM)

Another mechanism for managing natural resources in a context of uncertainty is the method known as AM. AM is applied by decision-makers at various levels and in various ways to address ongoing uncertainty in development. The approach has developed since the 1970s and relevant notable scholars include Holling [57], Walters [58] and Lee [59].

A broad policy of AM was adopted across Australia for water allocation and planning in 2004 [60] (cl 25) and is argued to be crucial given the context of a drying and more variable climate [30] (p. 99). Nevertheless, the dominant characterisation of the Queensland water framework is as a centralised 'command and control' framework: all rights to the use, flow and control of all water in Queensland are vested in the state, and any take or interference with water must be authorised by the *Water Act 2000* (Qld) or another Act [61] (ss 26 and 808). The main purpose of the *Water Act 2000* (Qld) is to provide a framework for the sustainable management of Queensland's water resources (among other things) [61] (s 2).

A 'command and control' approach is still the preferred approach of many stakeholders and decision-makers in respect of natural resources because it is decisive and assumes certainty; it relies on best-available technology requirements to control specific environmental problems (such as pollution) or crises (such as ozone depletion) and aims to maintain the status quo [62] (p. 263). Command and control regulatory frameworks tend to feature technical norms and legal prescriptions, which then dictate decision-making [63] (p. 54). The laws apply a classical paradigm of science and engineering: problems are definable, separable and may have solutions that are able to be found [64,65]. This kind of framework typically involves information that has been defined by technical experts and is not always shared: stakeholder engagement is mainly through passive channels [63] (pp. 54–55). Specific flaws in the 'command and control' approach include token consideration of socio-economic dynamics [58] (p. 2); overly conservative research [58] (p. 2); falsely assuming systems are linear, predictable and controllable [66]; decoupling of humans and natural systems [66]; and increased vulnerability in the whole system (such as with major droughts and floods) [67] (p. 5).

AM was developed in response to these flaws. It entails systematically learning through the management process and is both proactive and reactive. A key feature of the approach is the requirement for a built-in feedback loop so that monitoring data can allow for reassessment of management actions [62,68]. Due to this reassessment, changes in management direction or objectives are possible and even the status quo may be questioned. The process is distinguishable from trial-and-error approaches or ad hoc decision-making, which do not feature strategic planning in the first case, nor a reassessment of actions or objectives to reduce uncertainty [69].

Learning is the engine that drives the AM process, but 'social learning' (the combination of AM and political change) can transform governance. Just as Lee drew heavily on theories of public policymaking [59] (ch. 4), Pahl-Wostl has drawn from organisational learning [70–72] to describe social learning as either single-loop (incremental improvements), double-loop (revisiting assumptions) or triple-loop learning (reconsidering underlying values and beliefs) [73].

The AM approach has continued to be refined through an increase in published literature since 2000 [68], such as, focussing on ecosystem resilience [68,74] or structured decision-making [75,76]. In addition, since at least 2005, adaptive co-management [61] (p. 6), integrated AM [77] and adaptive governance [78] have evolved as other (broadly similar) approaches, which focus on stakeholder collaboration (both formal and informal) throughout the entire process. This broader interpretation of AM is relevant even where key decisions about the system are made centrally by an overarching government. There are many other stakeholders who do, in fact, influence decision-making through less formal mechanisms, for better or for worse [79–82].

In this context, wide stakeholder participation has been promoted as beneficial [73,83,84]. The logic is that more effective participation will result in improvements to governance as expressed in, for example, Arnstein's [85] ladder of participation [86]. Research in respect of effective participation in environmental decision-making is nascent; however, key principles for effective public participation involve ensuring that all relevant stakeholders are included in 'collaborative problem formulation and process design, transparency of the process and good faith communication' [87,88]. Where there is scientific uncertainty, transparency of information relating to decision-making (including facts, assumptions and uncertainties), along with providing opportunities for independent review, and reconsideration of decision-making, are also important procedural processes [87] (p. 234).

There is growing research for when public or stakeholder participation is helpful, and when it can be detrimental to governance [86,89,90]. Two-way communication can be costly, unpredictable and can erode existing power bases [86,89]. Conversely, existing vested interests and power inequalities may be reinforced by ineffective participatory measures [90] (p. 12). Broad engagement will no doubt increase decision-making costs, but it can ultimately decrease the costs of implementation of policy [82] (ch. 4). Contextual factors such as the rationale for participation [91], the social or cultural context and the existing institutional framework are important in determining the degree of participation that will be effective [89]. However, higher levels of participation have been shown to impact levels of trust positively [86,92], and have had positive outcomes in respect of water governance [26,28,83,93–96].

AM can occur within the context of simply the State regulator's management of a resource, for example, in settling rules for access to water over time. This process can still be genuine, even if it is not more widely transparent to the actual resource users. Nevertheless, without including resource users, stakeholders and the public in the learning that results from AM, the other users of the resource will not share in that learning process. This will be at odds with managing a CPR, which depends on coordination between users. Simple transparency relating to decision-making, particularly where it involves scientific uncertainty, is associated with increased social learning [87,91,97]. Information about decision-making can improve understanding about the relative scarcity and importance of a resource, as well as the rationale for certain governance measures [94]. This has been the impetus for the development of enduring collective governance in other jurisdictions [25,56].

Furthermore, as already mentioned, the development of rules governing a CPR should not be considered as one-shot exercises. We can never know in advance all the factors that may incentivise users, or those which may impact the resource or how it will behave. An AM approach is necessary, therefore, in the development of rules, preferably with some input by the users. This will ensure that the rules are perceived as legitimate and fair by the users. Moreover, it will enable the regulator to appropriately respond to changes in user behaviour and the resource system. This points to a need for the collaborative style of AM known as adaptive governance. A tool to assist communication with stakeholders would seem to be beneficial in this context.

4. The CPR Heat Map

The CPR heatmap is presented in this paper to assist communicating regulatory analyses using CPR theory and any AM initiatives adopted, or perhaps proposed to be adopted. By displaying the eight design principles in a circular chart, a 'heat map' can be produced. A detailed analysis of a CPR context which involves a review of the rules for accessing the resource, the political institutions, management arrangements and the characteristics of the resource and resource users can be reflected in the CPR heat map. The heat map can be used in either very basic or quite detailed analyses. After the CPR context has been analysed, a shading can be attributed to each aspect of the design principles in the chart, reflecting whether the design principle is present (green), somewhat present (amber) or absent (red). This would provide a summary of the relevant governance framework for analysis. The resulting heat map would clearly show whether the design principles are present or absent in the regulatory context, where weaknesses or strengths may lie and provides an overall picture for the jurisdiction at a glance. Moreover, a circular chart highlights the notion that each design principle works in conjunction with the others rather than being important on its own or as part of a 'shopping list'. The research by Baggio et al. [7] on 'clusters' of design principles can be readily considered if a circular 'heat map' is produced.

To produce a circular chart that represents the CPR design principles, each of the original eight design principles by Ostrom have been given equal weighting in a primary chart (Figure 2, below). The equal weighting is given, despite the relatively recent research that some of the design principles can be seen to have more of an impact than others. No research has yet determined how much more important these particular variables are in the different contexts. For the present, until that research can be conducted, the relative importance of each of Ostrom's original eight design principles are allocated equal weighting. Some of these original eight design principles have been divided by scholars [7,12,46–48]. Thus, Figure 2, below shows each of the eight general design principles divided into these further detailed aspects to represent the CPR design principles more fully. If there are more than one set of governance arrangements that are relevant to each of these key design principles in any given context, these can also be acknowledged using a more detailed chart to reflect the additional aspects.

Admittedly, any map is necessarily an abbreviation of the landscape, which is both a strength and a limitation [98]. Attributing a grading of green, amber or red may be difficult at times because there will often be some elements of a design principle present (or absent). Each governance framework will have its own strengths and weaknesses. Only using three colours has the advantage of highlighting areas where the design principles are largely absent or present, leaving amber for the cases where design principles are partially present or partially absent. Where not enough information can be retrieved, a segment can be either left blank or a coloured question mark (green, amber or red) can suggest the likely finding in the absence of further data. At a glance, the resulting 'heat map' will then highlight areas of weakness and strength, in terms of Ostrom's design principles [52] (p. 270). Disagreement and debate about the categorisation of any particular design principle as red, amber or green, will enable discussion and more detailed analysis. The subjective nature of any categorisation is therefore a strength rather than a flaw of the CPR heatmap. It can be used as a consultative tool to gather further information from stakeholders, discuss the findings and even to refine understandings about their own perspectives of the resource and the rules about extraction and even other resource user behaviours.

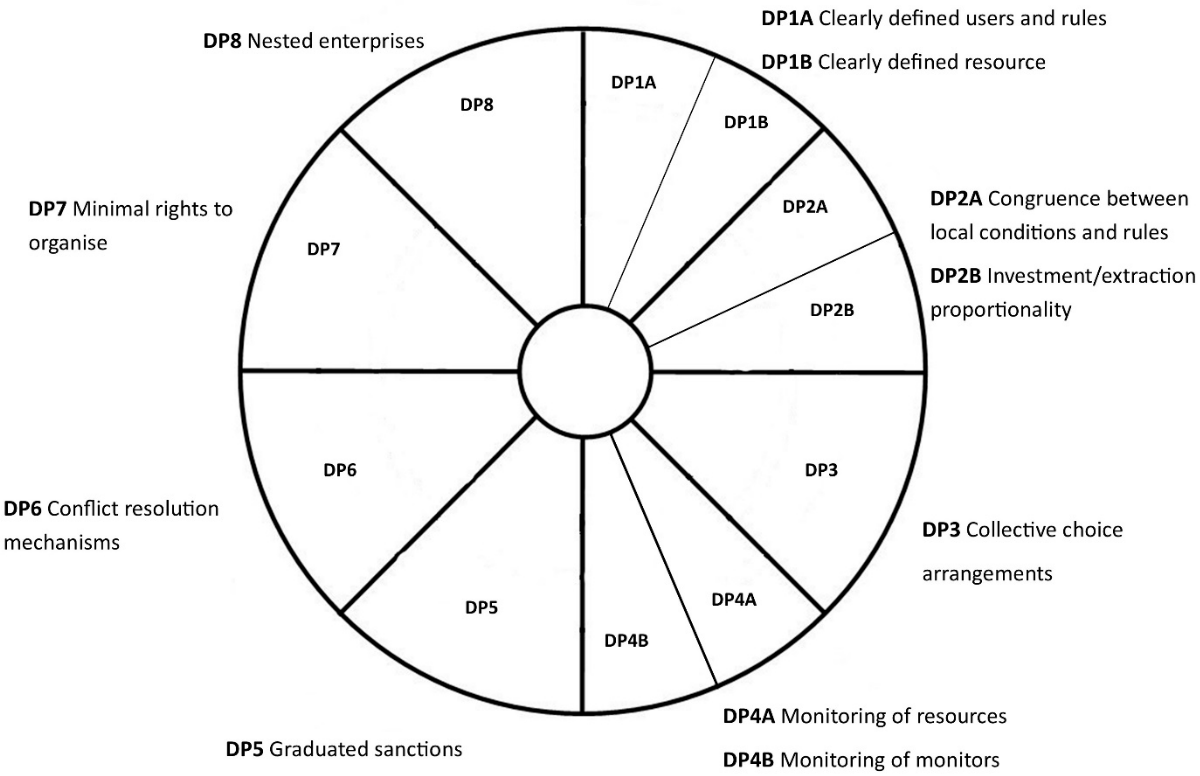

Figure 2. Primary chart for the CPR heatmap.

In addition, and just as importantly, a circular illustration contrasts to a list of variables or factors. This is important to ensure that stakeholders and policy decision-makers do not simply cherry pick the list for the simplest solutions which may not necessarily transform the arrangements or resource user behaviours. The circular illustration may encourage stakeholders to think holistically about how the different variables associated with the regulatory context drive certain incentives that influence resource user behaviour. This will focus attention on the underlying factors that contribute to conflict in a given context, rather than look for 'silver bullets' or one-shot solutions.

Moreover, if an AM approach has been adopted for any particular aspect of a design principle (for example, for monitoring or rules to access the resource), it can be noted specifically on the chart adjacent to that sub-design principle.

5. Extraction of Groundwater from the GAB in the Surat CMA Queensland Australia

An example of how the heat map could be used to reflect a current CPR context is presented below, based on my analysis of the governance arrangements for extraction of groundwater in the Surat CMA of Queensland. Groundwater is essential to development in regional Queensland, Australia, as access to surface water is limited. I have more fully detailed the governance arrangements relating to groundwater, specifically from the Great Artesian Basin in the Surat CMA elsewhere [9]. As the groundwater resource is managed in a highly centralised 'command and control' approach, the rules for accessing the resource and the political institutions involved in managing the resource are constituted by the legislative framework. In order to attribute a grading (green, amber or red) to reflect the presence of a design principle, I applied a doctrinal legal research methodology to analyse this legislative context. This required a thorough and in-depth knowledge of the legislative framework that governs groundwater extraction in Queensland, Australia. I also conducted a literature review in relation to the governance framework which included analysis of various government reports, independent legislative reviews, and academic literature which are referenced within the discussion. The benefit of the three-colour grading system became evident in this process. Where there was difficulty in determining whether a design principle was either clearly present or absent, or if there were different aspects that were either present or absent, the colour amber was used.

This context is provided here to illustrate the use of the CPR heat map in respect of a large groundwater resource where there has been intense conflict between heterogenous water users (the coal seam gas (CSG) or coal bed methane industry, pastoral, agricultural and domestic users) [99–102], who share the resource, and a complex regulatory framework with different rules relating to different resource users [103]. There have also been initiatives which have been undertaken to address uncertainty, particularly around the status of the groundwater resource where CSG is extracted. These efforts can also be displayed on the CPR heat map.

Figure 3 illustrates the regulatory context relating to extraction of groundwater in the Surat CMA Queensland Australia. On my analysis, the Surat CMA regulatory context for groundwater extraction appears to be relatively unsuccessful due to ongoing conflict [99–102] as well as continuing deterioration of key aquifers in certain areas [104–106]. Put simply, based on this analysis, many of the design principles are absent in the regulatory context that governs extraction of groundwater in the Surat CMA of Queensland. The CPR heatmap makes this obvious. Acknowledging that more than a third of overall groundwater extraction in the Surat CMA is due to CSG extraction of groundwater [106] (p. v) and there are different rules and responsibilities relating to extraction of groundwater by CSG operators and non-CSG extractors [103], I have divided each of Ostrom's design principles, where relevant, to distinguish between these two broad contexts of extraction of groundwater: CSG and Non-CSG users. I briefly discuss each of the components of the heatmap below.

DP1—Clearly defined boundaries—In the Surat CMA, the identity of resource users and the rules around extraction are not ideal. In relation to non-CSG extraction (DP1A(i)), the identity of the resource users is opaque with many extractors not requiring a licence [61] (s101(1)(c)) and where they are licenced, are non-volumetric or are unmetered, and aquifer attribution can be unreliable [107,108]. However, rules for access to the resource have been described as 'well developed' [109]. Therefore, this part of the heatmap (DP1A(i)) is coloured amber. In relation to CSG extraction (DP1A(ii)), all CSG wells that produce groundwater are readily identifiable through publicly available webpages and reports [110–112]. The rules for extraction are clear, in that the CSG operators have a state-wide statutory right to extract groundwater [113] (s. 185). Even though such a broad statutory authorisation could arguably be so wide that there is, in fact, no rule at all, the transparency around where wells are located and the quantum of extraction mean that it is appropriate to shade this part of the heatmap green (DP1A(ii)).

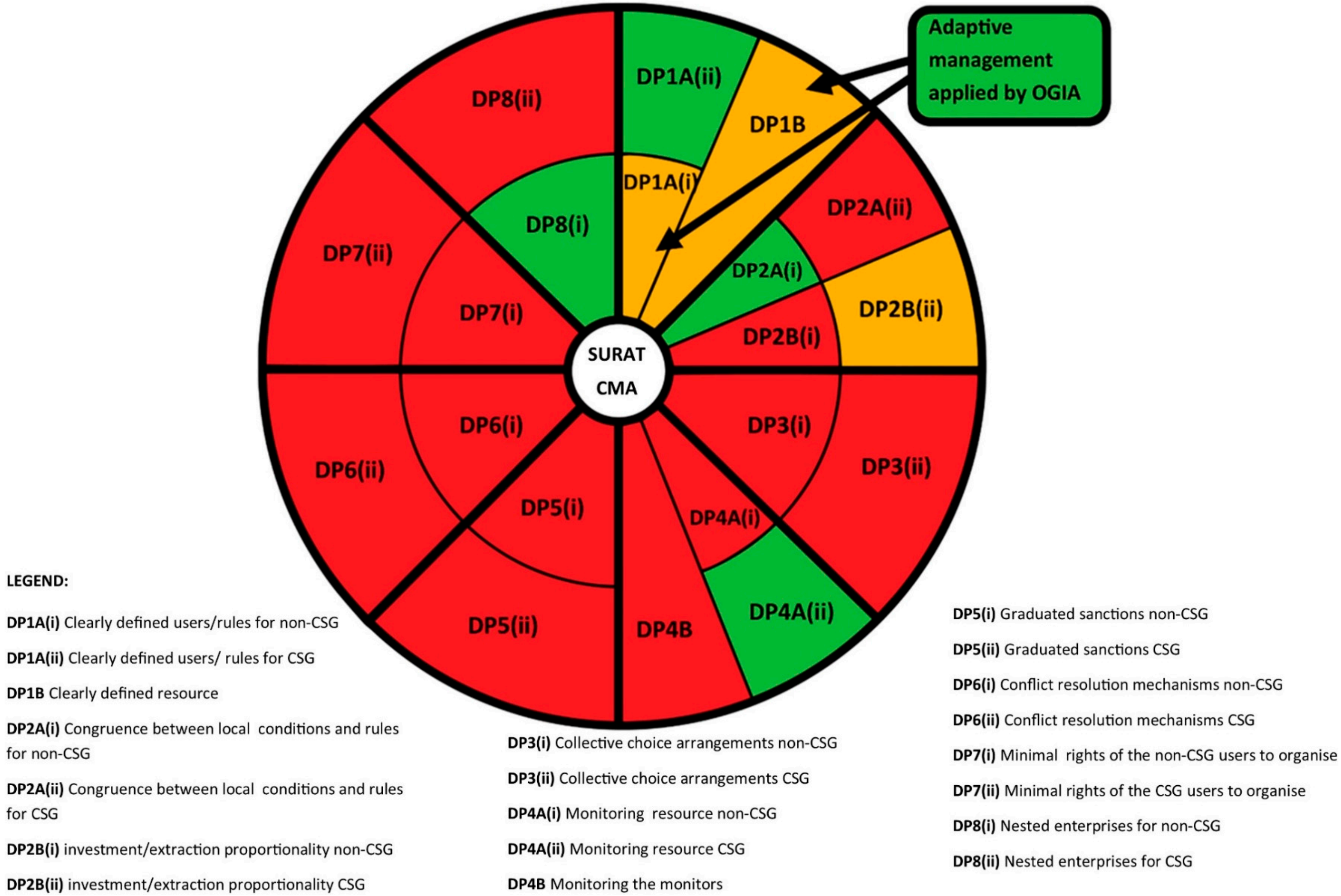

Figure 3. More detailed CPR heatmap illustrating governance framework for extraction of groundwater in the Surat CMA, Qld, Australia.

The criterion relating to the physical groundwater resource as a whole (DP1B) has not been divided in relation to CSG and non-CSG extraction, because this design principle relates to the physical characteristics of the resource as a unit. Missing information, particularly relating to non-CSG extraction, detracts from the efforts to clarify the boundaries of the resource by experts. There is extensive and ongoing work by experts, especially in relation to the adaptive groundwater model by the statutory entity, the Office of Groundwater Impact Assessment (OGIA). OGIA is an independent statutory entity create by chapter 3A of the *Water Act 2000* (Qld) (discussed below). In relation to the aquifers affected by CSG extraction, extensive work is being undertaken, such as, for example, a hydrogeological model [114], and in respect of contact zones between the Surat and Bowen Basin [107]. On balance, the criterion relating to the knowledge about the physical characteristics of the groundwater resource in the Surat CMA has been attributed an amber grading (DP1B).

AM to clarify the behaviour and status of the groundwater resource—The creation of the hydrogeological model created by OGIA is an example of an AM measure that has been adopted to reduce uncertainty around knowledge of the groundwater resource as well as prevent ongoing conflict between resource users. OGIA prepares an underground water impact report (UWIR) for the Surat CMA every three years, due to the large number of CSG extractors in that area [61] (s370(2)(c)). There have been three UWIRs to date: 2012, 2016 and 2019 and a new draft UWIR 2021 is available for consultation [115]. The purpose of the UWIR is to predict impacts on non-CSG bores and groundwater-dependent ecosystems by CSG development and to allocate responsibility to specific CSG operators for monitoring, bore assessments and making good arrangements [61] (s.376(i)(h)). Since January 2020, the impact of coal mines within the Surat or Clarence Moreton basins on water resources and water levels in aquifers in the Surat CMA will also be included in the next UWIR [116] (p. 97). The UWIR is underpinned by the hydrogeological model prepared by OGIA [106] (p. v). The purpose of the model is to predict the regional cumulative impact of CSG extraction on water pressures and water levels in aquifers in the Surat CMA [114]. The hydrogeological model enables predictions of groundwater impacts so that OGIA can allocate responsibility for these impacts. The model also contributes to the current knowledge about the groundwater resource in that area. In order to determine CSG impacts, general background aquifer conditions and trends must be first assessed [105]. However, it should be highlighted that OGIA has needed to undertake additional work to establish background trends in the relevant groundwater systems, due to the extensive unmetered current and historical non-CSG water use [105,106] (p. 53). OGIA also undertakes specific technical research projects (such as relating to groundwater flows) [108].

There appear to be all four required steps for an authentic AM approach in relation to the groundwater model (as well as the UWIRs): monitoring, research, periodic evaluation and compliance measures. The groundwater model is created using data provided by operators (on a mandatory basis) [61,114]. This model is continually updated and refined with the steady stream of information being supplied by industry monitoring. The model is made available to the public and explanations as to how it has been updated, including the forecasted predicted impacts, are clearly communicated by OGIA in annual reports and the additional technical reports [117].

The clearly adaptive approach by OGIA in updating its model and publicly reporting this information, contributes to the knowledge of groundwater resources. This process has been a positive step in increasing the collective knowledge about the groundwater resources in the Surat CMA and managing future conflicts. It is represented as a separate part of the heatmap and is shaded green. Lee demonstrated that 'without experimentation reliable knowledge accumulates slowly, and without reliable knowledge there can neither be social learning nor sustainable development' [59] (p. 54). The approach applied by OGIA in the Surat CMA and reported in annual reports and the updated UWIRs presents reliable knowledge that facilitates social leaning about the impact of development in the Surat CMA.

The work being undertaken as part of the preparation of the UWIR, has also clarified knowledge about non-CSG bores. As part of the work to identify bores that may be affected by CSG development within short term and longer term affected areas, 250 new bores were identified in the 2019 UWIR [106] (p. 50). Therefore, an arrow also indicates this positive impact in relation to the part of the heat map that relates to the clarity around non-CSG water users (DP1A(i)).

DP2—Congruence between appropriation and provision rules and local conditions—Congruence between the rules of extraction and local conditions can be distinguished between non-CSG extractors and CSG extractors. The rules for non-CSG groundwater extractors are location- and aquifer-specific and therefore are shaded green (DP2A(i)). The rules for CSG extractors are however state-wide in application and are therefore shaded red (DP2A(ii)). In terms of the cost versus benefits of extraction, costs associated with non-CSG groundwater extraction do not reflect quantum extracted: a minimal uniform water licence fee is incurred by all users regardless of quantum of groundwater extracted [118] (Sched. 12), and therefore DP2B(i) is shaded red. In contrast, CSG extractors do contribute somewhat to the management of the resource, for example, through funding OGIA directly [59,118]. Therefore, I have shaded this part of the heatmap orange (DP2B(ii)).

DP3—Collective choice arrangements—Consultation of already drafted rules rather than participation occurs in respect of formulation of the rules around extraction, for both non-CSG extraction as well as CSG extraction in the Surat CMA. Therefore, this part of the heatmap is shaded red (DP3(i) and (ii)).

DP4—Monitoring of the resource and users as well as the monitors—CSG extraction of groundwater is intensely transparently monitored and reported in the Surat CMA and is shaded green on the heatmap (DP4A(ii)). This contrasts with non-CSG extraction of groundwater, where a lack of metering and transparent reporting results in this part of the heatmap being shaded red (DP4A(i)). In addition, there is no ability to monitor the monitors, as the resource is largely managed and monitored by the Queensland State Government in a non-transparent way. For example, information about compliance action is not readily available. Therefore, this part of the heatmap is shaded red (DP4B).

DP5—Graduated sanctions—While there are technically graduated sanctions for non-CSG groundwater user rule-breakers, the lack of metering and monitoring and a lack of compliance activity by the regulator [109] mean that in reality there are minimal sanctions for rule-breakers. Therefore, this part of the heatmap is shaded red (DP5(i)). For CSG extractors of groundwater, because there is a broad statutory authorisation to extract unlimited groundwater, there cannot be rule-breaking behaviour, therefore there are no relevant sanctions. Again, this part of the heatmap is shaded red (DP5(ii)).

DP6—Conflict resolution mechanisms—The conflict resolution mechanisms for non-CSG groundwater extractors where they are affected by either CSG extraction or other non-CSG groundwater extractors are not low-cost mechanisms in a local arena. Generally, reductions in bores are shared equally throughout the basin, with no recourse to either other users or the state government. Where CSG operations affect a non-CSG groundwater user, a statutory scheme of 'make good' has been implemented, which is far from being low-cost or local, and has been widely criticised [119]. Therefore, both parts of the heatmap relating to conflict resolution mechanisms (in respect of non-CSG and CSG extraction) have been shaded red (DP6(i)and(ii)).

DP7—Rights to organize—For both CSG and non-CSG groundwater extractors in the Surat CMA, rules are established by the regulators in a centralised 'command and control' way in Toowoomba, Brisbane and Canberra. Therefore, this part of the heatmap is shaded red (DP7(i)and(ii)).

DP8—Nested enterprises—A nested organisational structure exists for non-CSG groundwater extractors in the Surat CMA, where the regulator has local offices in regional areas. Hence, this part of the heatmap is shaded green (DP8(i)). In contrast, the regulators controlling CSG extraction, are centrally located in Brisbane and Canberra. DP8(ii) is therefore shaded red.

6. Discussion

The resulting heatmap produced by this analysis clearly shows at a glance some of the theoretical weaknesses of the regulatory context impacting groundwater in the Surat CMA of Queensland. This may explain the ongoing conflict between resource users in that context and why the resource continues to deteriorate in some areas. For example, the lack of clarity around non-CSG water extraction, in terms of the users and the quantum of extraction, is a key weakness that impacts a number of the design principles. A lack of transparency around non-CSG water extraction means that individual users are not accountable for their own impact on the resource. This affects not only the knowledge about the resource but also monitoring the users and, of course, the ability to enforce rules. It also means that non-CSG water users are not accountable for the overall detriment to the resource that may be caused by their activities.

The heat map clearly also highlights other key flaws in the regulatory framework. The regulatory framework for CSG development does not take into account the local conditions in a direct and upfront way. Another weakness is the lack of effective, local and cost-effective conflict resolution mechanisms for all concerned.

However, the heat map also reveals relative strengths which ought to be acknowledged. For example, the rules for non-CSG extraction are local, and there are nested entities which regulate non-CSG water extraction. For CSG extraction there is an extremely transparent reporting regime.

While usually a map does not reflect the temporal aspects, nevertheless, it is possible to also show how AM is transforming particular variables which can positively influence resource user behaviour. For example, the approach by OGIA in relation to knowledge about both the groundwater systems as well as non-CSG water use, is transforming particular design principles (knowledge about the resource and non-CSG water user information) for the better. The clear information made available through the work of OGIA about how non-CSG extraction is affecting groundwater levels ought to give landholders pause for thought. However, where non-CSG water use remains opaque, behaviours may not change.

The heatmap can also be used to measure other initiatives to explore the ways these may impact incentives that drive behaviour. For example, it is clear that transparent information about non-CSG water use is needed. However, water users have resisted this for many years [9]. Work is underway in respect of what was termed the 'Rural Water Management Program' and now is the 'Rural Water Futures Program' to develop transparent water information, strengthening metering, adjust regulatory frameworks and adopt more robust compliance activity [120]. There have been two publicly available reports on this program (in 2019 [121] and 2020 [122]). Initiatives undertaken include: completion of a trial online portal supplying water accounting data to entitlement holders; development and consultation in respect of a new measurement policy; release of a new online platform called the 'Water Entitlement Viewer', which displays information relating to licences and unallocated water volumes (but not extraction data); and a water dashboard trial for two unnamed water management areas, which provides information about water usage (2019) [121]. In 2020, initiatives include a departmental compliance policy (called 'Our role as regulator'), and analysis and reporting on the 324 written submissions and 22 stakeholder meetings undertaken in relation to metering initiatives [122]. Departmental deliberation is ongoing about the final content of a new metering policy [122] (p. 8).

While these appear to be positive initiatives at first blush, it is uncertain whether they will be transformative. For example, there have been regulatory changes as a result of the program: amendments to the *Water Regulation 2016*, in respect of faulty meters and the validation requirements for meters [118] (Pt. 11), and to the *Water Act 2000* in respect of deeming liability where a meter or licence is shared [61] (s. 829). Neither of these amendments will necessarily change behaviour where the licence is not required to be metered or is non-volumetric. It is, therefore, unclear how this will assist underlying incentives to over-extract. Moreover, if the water use data is not publicly available, compliance with the rules by individual water users must be enforced by the state regulator alone and any concept of accountability and buy-in by resource users is likely to be absent.

The state regulator has described an AM approach being undertaken in respect of these initiatives. However, it is difficult to independently assess whether a true AM approach is occurring without further information about the trials in the unnamed areas. Therefore, this initiative is not included on the heat map. Furthermore, broader learning such as that described by Pahl-Wostl as double and triple loop learning [73], is not apparent. For example, there is no information available to the wider public about the trials of the water dashboard in the two unnamed water plan areas. Whatever the results, there may be learning occurring at the state regulator level. However, without any transparency around the actual trials (where they occurred and what the results were), it is impossible for stakeholders to gauge whether this adaptive process is legitimate and for the broader stakeholder group to take advantage of the learning that has occurred. Any opportunity for stakeholder buy-in and deeper social learning appears stifled.

Finally, the extensive consultation that occurred with respect to the proposed metering policy is now being considered by the state regulator. While the state regulator has been open about the consultation that has taken place, and summarised the submissions in a report [123], it will not be until the ultimate policy is released and delivered that it will be possible to gauge whether there has been higher order degrees of citizen power or simply tokenism in respect of consultation [85].

The heatmap is presented in this paper, not to replace detailed analyses, but as an additional tool to activate discussion and policy reform around some of Ostrom's (1990) design principle variables. The heatmap provides a bird's eye perspective over the regulatory landscape, viewed through the lens of Ostrom's (1990) CPR theory and AM. The aim is to assist with resolving and perhaps preventing future conflict around water resources. If we are serious about sustainable management of the resource and being proactive about avoiding future conflicts, the incentives embedded in the current management of the resource by all stakeholders requires transparent discussion and consideration. In order to be seen as taking decisive action, it is tempting to cherry-pick initiatives from a shopping list that seem easy to implement but may not necessarily adjust inherent incentives. By considering, for example, initiatives as mechanisms that may change drivers of behaviour in a variety of ways, rather than as discreet actions, we have a better chance of transforming behaviours and values.

For example, if the regulator were to apply a truly adaptive and transparent approach to addressing the lack of extraction data for non-CSG users, this would have an impact on a number of the design principles. This one potential initiative is displayed in the heatmap in Figure 4 below. If all non-CSG groundwater extraction were measured and transparently reported, this would clarify the identity of the non-CSG groundwater users (DP1A(i)) as well as assist efforts in identifying the boundaries of the ground water resources (DP1B). It might even assist the work by OGIA in predicting the impacts of CSG development. It could enable studies to predict the future impacts of non-CSG extraction through modelling. It would also enable monitoring efforts of the non-CSG groundwater users (DP4A(i)). If extraction data were publicly available, compliance action would be assisted, and this would transform DP5(i). Finally, it would also then provide an opportunity to consider whether proportional costs for water use ought to be imposed (DP2B(i)).

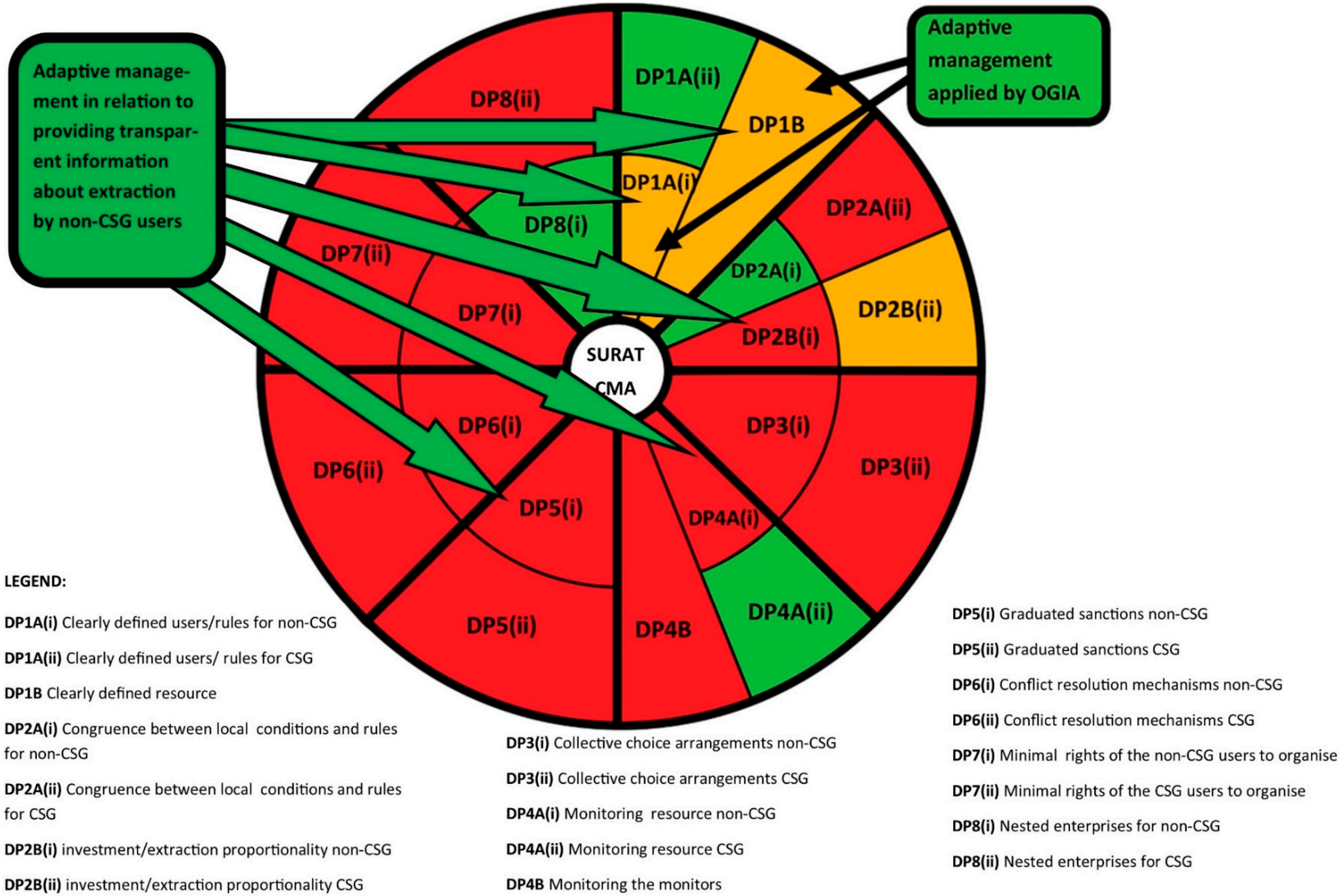

Figure 4. CPR heatmap showing proposed initiative addressing lack of extraction data for non-CSG users.

An adaptive approach to such an initiative could include transparently trialing making the data publicly available for a subset of users in certain areas. Appropriate areas for such initiatives could be areas which have declining groundwater pressures and existing conflict between users. An authentic AM approach would require this information to be transparently made available and discussed and reviewed, rather than internally considered by departmental officers. However, it should be acknowledged that such an initiative would run counter to notions of individual entitlement to the groundwater resources as well as privacy. These are perhaps key issues that influence resistance to such measures on the part of non-CSG groundwater users and need to be openly considered and discussed in consultation. Key questions remain: why and when would individual non-CSG users consent to such measures? What incentives would drive cooperation?

In addition, a heatmap could be used to compare different regulatory landscapes for a similar CPR in different settings. This provides a high-level comparative tool to drive discussion around different regulatory rules or structures. For example, a heat map was produced by the author to illustrate the regulatory context for groundwater extraction and aquifer injection of CSG produced water in the Powder River Basin, Wyoming, USA to compare with the context in the Surat CMA. There was also notable CSG development and conflict during a particular period in Wyoming, USA [124]. That study applied a four-phase sequential mixed method research methodology which involved: a preliminary literature review, a comparative doctrinal black-letter law approach for analysing the regulatory frameworks, analysis of empirical data from permits and monitoring reports and qualitative data from relevant stakeholders. The analysis of empirical data involved collecting data from permits and licences, secondary management plans and monitoring reports. This enabled a comparison of the quantities of groundwater that were extracted and reinjected in each jurisdiction, and identification of the scope of any non-compliances with the permits. Qualitative data was collected by conducting semi-structured interviews in the two jurisdictions as well as from submissions made to various government inquiries. The qualitative data informed the overall analysis of the legislative context and the classification of each of the design principles as either present, partially present, or absent. Such an approach provided a very detailed analysis which was summarised in corresponding heatmaps. The heatmaps highlighted areas for legislative reform: such as around the rules for extraction, or methods of conflict resolution. For example, while the identity of non-CSG groundwater users in Queensland is opaque, all groundwater users including stock and domestic users in Wyoming are required to have a water permit [125]. That analysis highlighted mechanisms that had been adopted in each jurisdiction that could be emulated more broadly and which could be the subject of deliberative reform.

7. Conclusions

Finding a balance between using and conserving a resource can be enabled by interactive and flexible governance arrangements, which complement centralised governance, and which provide for joint knowledge production and exchange [126]. Therefore, the heatmap may be the tool that could illustrate to policy decision-makers the need to strengthen the relationship with resource users. It highlights, for example, why particular resource users may be incentivised to over-extract or view the resource as a private resource or 'entitlement' rather than a collective or communal CPR. Moreover, the tool can be used to obtain information from stakeholders which would clarify uncertainties and better overall understandings. Where there are disagreements as to the categorisation of a particular design principle, this will activate further discussion. For example, the categorisation of DP3(i) and DP3(ii) relating to collective choice arrangements in the Surat CMA, Queensland, as being generally absent may be debateable. Further empirical studies may actually reveal previously unknown informal networks that in fact influence decision-making for either CSG or non-CSG groundwater extractors.

However, the heatmap may also uncover 'inconvenient truths' about the status quo, where certain actors within the CPR context have vested interests and where the individual incentives are revealed. Centralised command and control approaches to a CPR may seem to be comforting for many, as it places all responsibility for the sustainable management of the resource in the state. Highlighting the communal nature of the resource may be at odds with the interests of individual extractors, but also the state. For example, if users are confronted with the communal nature of the resource and are made accountable for their use of the resources, a legitimate demand by all resource users would be to transparently participate in some way in the rules in which it is managed. This would dilute centralised power and reduce the opportunities for partisan or political decision-making on the part of the state.

Therefore, the most important use of the heatmap may even be to first persuade state regulatory policy decision-makers, such as government heads of department or members of the legislature, why certain water governance policy initiatives may be important, including more participatory approaches to governance. By enabling a high-level and holistic consideration of the various incentives embedded in a CPR regulatory landscape, the CPR heatmap can assist with the development of strategies to manage inherent conflicts of interests. As the legendary investor Charlie Munger has been attributed as saying: 'Show me the incentives, and I will show you the outcome.'

Funding: Part of this research was funded by an Australian Government Post Graduate Award.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: I would like to thank the two anonymous reviewers and the editors for their valuable and thoughtful comments which have improved the manuscript immensely.

Conflicts of Interest: The author declares no conflict of interest.

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