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PAPER

The case for making more use of the Ostrom design principles in groundwater governance research: a South African perspective

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Abstract

This study investigates whether increased use of the Ostrom design principles could improve groundwater governance research. The principles relate to self-organizing governance systems of common-pool resources, which are more likely to be sustainable if all eight design principles—e.g. clear resource and user boundaries, collective-choice arrangements, monitoring, sanctions, conflict-resolution mechanisms—are present. Empirical studies have proven the relevance and effectiveness of the Ostrom design principles for a range of common-pool resources. However, the application of the design principles to groundwater has been limited. The South African institutional landscape was therefore chosen as a case study to investigate the relevance of the design principles. The case study involved (1) comparing the design principles with established global governance benchmarking criteria, (2) assessing how implementable the design principles would be in South Africa, and (3) comparing the aims of the design principles and the broad aims of groundwater governance in South Africa. It was found that the Ostrom design principles provide researchers with a common 'language' for learning about the specific issues of a particular setting, learning from experiments in that setting, and learning from the experience of others. The Ostrom design principles and associated adaptive management, social learning, use of the diagnostic approach, and more specific hydrogeological principles are not mutually exclusive and can be complimentary. The implementation of groundwater governance in South Africa has been poor and few Ostrom design principles have been adopted. More use of the Ostrom design principles could improve groundwater governance in South Africa and globally.

Keywords Socio-economic aspects · Groundwater governance · Groundwater management · South Africa · Sub-Saharan Africa

Introduction

The purpose of this paper is to investigate the case for making more use of the Ostrom design principles (subsequently referred to as 'the design principles') in groundwater governance research and design. Ostrom (1990) posited, after extensive case study analysis, that self-organizing governance systems of common-pool resources (subsequently referred to as 'collectives') were more likely to be sustainable and effective if all the design principles were present. Cox et al. (2010) conducted a meta-analysis of 91 case studies that had used the design principles and concluded that the design principles were well supported empirically.

There would appear to very good reasons for transferring this generic common-pool governance knowledge to the groundwater governance field because:

- Groundwater is a common-pool resource (Llamas and Martínez-Santos 2005a; Ostrom 2005; Foster et al. 2010; Sophocleous 2010; Giordano et al. 2012; Foster and Garduño 2013). A common-pool resource is characterized by high 'subtractability' (one person's use subtracts from another person's use), and low 'excludability' (it is difficult to exclude additional users and additional use)
- Globally, there has been a dramatic increase in groundwater use in the past half century, bringing significant social and economic improvements, but also creating many indirect problems such as ecosystem damage, drying-up of surface water, and seawater intrusions (Custodio and

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Llamas 2003; Llamas and Martínez-Santos 2005; Konikow and Kendy 2005)

- Determining the best compromise between the benefits of groundwater use and problems caused by groundwater use is primarily a governance challenge rather than a technical issue (Custodio and Llamas 2003; Llamas and Martínez-Santos 2005; Foster and Garduño 2013)
- Groundwater governance research is still in its infancy compared with the physical science aspects of hydrogeology (Mukherji and Shah 2005; Llamas et al. 2006; Moench et al. 2012; Foster and Gunn 2016), and there is a lack of systematic, nonanecdotal data on groundwater governance research (Faysse and Petit 2012)

However, significant transfer of the design principles to groundwater governance research and design has not taken place, apart from notable exceptions such as the studies by López-Gunn (2003), Ross and Martínez-Santos (2010), and Verma et al. (2012), and the discussion to strengthen groundwater governance (Foster and Garduño 2013). The South African groundwater institutional landscape was chosen as a case study to investigate the relevance of the design principles. South Africa's (Fig. 1) water legislation has been described as 'progressive', 'advanced', 'forward-looking', and even 'revolutionary' (Postel and Richter 2003; Burns et al. 2007; Funke et al. 2007). Yet the tangible implementation of groundwater governance has been characterised as weak to nonexistent according to both perception (Seward 2011; Levy and Xu 2012) and research (Parsons 2009; Pietersen et al. 2011; Knüppe 2011). The implementation of the National Water Act (NWA—Republic of South Africa (RSA) 1998— regarding the groundwater licensing process has been described as a 'nightmare' (Coetsee 2010).

The Ostrom design principles

Ostrom (1990) posited the design principles (Table 1) after extensive studies of self-organizing, governance systems of common-pool resources, including groundwater (Ostrom 1965; Blomquist 1987). Of the governance systems that Ostrom studied, those that had survived and adapted to various social, economic, and environmental issues had all, or most, of the design principles in place. Ostrom therefore postulated a general rule that if all the design principles were present in a common-pool governance system, then the probability that this governance system would remain effective was high; thus, this is a probabilistic not a deterministic rule (Cox et al. 2010).

The choice of the term 'design principles' for this postulate may be unfortunate, as Ostrom (2009) has recognized. The design principles were never consciously or deliberately designed by the self-organizing governance system, nor were they designed, implemented, or imposed by an external agency. The design principles may have simply been the unwitting result of trial and error governance experiments over time. Ostrom (2009) suggested that the term 'best practices,' rather than design principles, might have been a better term to encapsulate the rules and structures that are characteristic of sustainable institutions. The design principles are also not a blueprint, and there is no intended suggestion that they could be used to design a sustainable governance system (Ostrom 2005). Rather, the design principles merely refer to broad, structural characteristics that enduring and effective governance systems appear to have in common. The conceptual thinking behind the design principles is that common-pool resource governance is too complex to allow a complete analysis to determine an exact set of rules that will enable precise outcomes (Ostrom 2005). Thus, all specific rules and specific

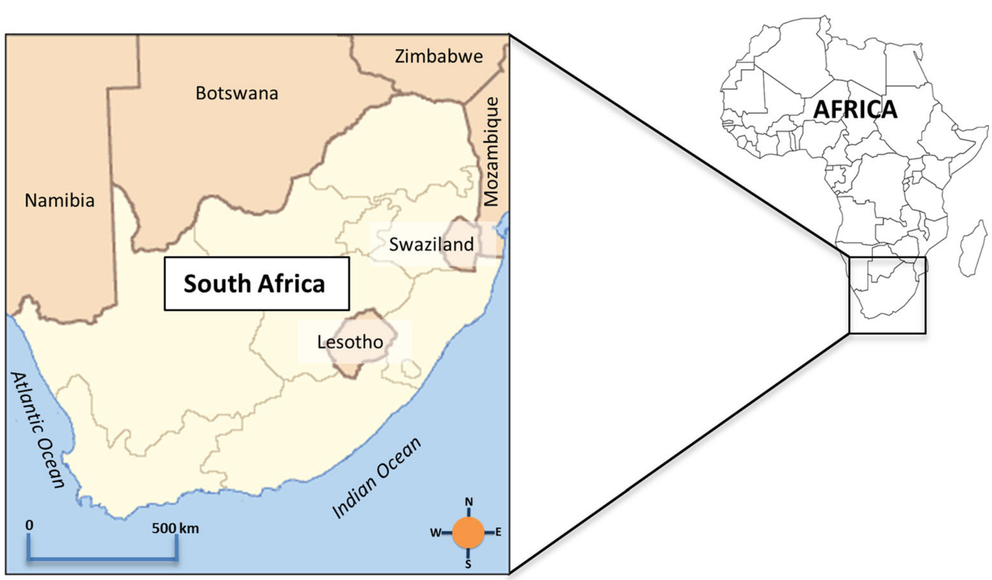

Fig. 1 Regional location of South Africa

Table 1 Ostrom design principles

Ostrom design principals (Ostrom 2009)	Comments/explanations
1A. User boundaries. Clear and locally understood boundaries between legitimate users and nonusers are present	In the case of groundwater, the user boundary is understood to mean, for example, membership or not of a Water User's Association (WUA), rather than having a clear water right/permit
1B. Resource boundaries. Clear boundaries that separate a specific common-pool resource from a larger social-ecological system are present	In the case of groundwater, this could be an aquifer unit
2A. Congruence with local conditions. Appropriation and provision rules are congruent with local social and environmental conditions	Rules about using groundwater are consistent with the capacity of the resource to provide that supply, and are consistent with local socioeconomic norms
2B. Appropriation and provision. Appropriation rules are congruent with provision rules; the distribution of costs is proportional to the distribution of benefits	In the case of groundwater, this could mean that the benefits of belonging to a WUA must exceed the costs and disadvantages, and that the benefits are fairly distributed
3. Collective-choice arrangements. Most individuals affected by a resource regime are authorized to participate in making and modifying its rules	–
4A. Monitoring users. Individuals who are accountable to or are the users monitor the appropriation and provision levels of the users	–
4B. Monitoring the resource. Individuals who are accountable to or are the users monitor the condition of the resource	–
5. Graduated sanctions. Sanctions for rule violations start very low but become stronger if a user repeatedly violates a rule	–
6. Conflict-resolution mechanisms. Rapid, low-cost, local arenas exist for resolving conflicts among users or with officials	–
7. Minimal recognition of rights. The rights of local users to make their own rules are recognized by the government	Rules in this case would mean rules about the management of a groundwater resource, rather than (just) the internal institutional operating rules of a groundwater WUA. Higher levels of government must provide at least *some* recognition of these rights
8. Nested enterprises. When a common-pool resource is closely connected to a larger social-ecological system, governance activities are organized in multiple nested layers	In an earlier formulation (Ostrom 1990) this rule was explained as "Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises" In some cases, this rule is needed because a local collective is unable to meet its objectives without external support. In other cases, this rule is needed because a local collective might not take broader societal objectives into account without external guidance

rule changes for these resources must be regarded as experiments. Ostrom's design principles are, in effect, a guide for creating the best 'laboratory' for conducting these experiments. The design principles offer an opportunity to create governance systems that can learn, experiment, and adapt in an uncertain environment (Ostrom 2005).

The definitions for the design principles in Table 1 are those proposed by Cox et al. (2010) and adopted by Ostrom (2009). They do not differ significantly from the original design principles (Ostrom 1990), although rules 1, 2, and 4 have been subdivided by Cox et al. (2010).

Defining groundwater governance

Mukherji and Shah (2005); Moench et al. (2012); Foster and Gunn 2016) draw a distinction between groundwater management and groundwater governance. Groundwater management is seen as the more restrictive concept, and involves groundwater scientists determining rules about groundwater availability and water managers implementing these rules. In contrast, groundwater governance is seen as a broader and more inclusive process that takes into account the concerns of scientists, policy makers, and the users of a groundwater resource. Making a broad distinction between groundwater management and groundwater governance is not difficult. Reaching consensus on a more precise definition of this 'broader and more inclusive process' is, however, not easy.

Consider the following definitions of groundwater governance:

- "The process through which groundwater related decisions are taken (whether on the basis of formal management decisions, action within markets, or through informal social relations) and power over groundwater is exercised" (Moench et al. 2012).

- "…comprises the promotion of responsible collective action to ensure socially-sustainable utilisation and effective protection of groundwater resources for the benefit of humankind and dependent ecosystems" (Foster and Garduño 2013).
- "Groundwater governance consists of the processes and institutions by which decisions that affect groundwater are made. Groundwater governance does not include practical, technical and routine management functions such as modeling, forecasting, constructing infrastructure and staffing. Groundwater governance does not include groundwater resources outcomes" (adapted from Lautze et al. (2011) by replacing 'water' with 'groundwater').

All three of these definitions broadly concur with the findings based on extensive analysis of governance definitions (Lautze et al. 2011): governance is the *process* involved in decision-making; the process takes place through *institutions*; and the process and institutions of governance involve *multiple actors*. However, Lautze et al. (2011) also assert that governance is not the outcome of the decision-making. This appears to be at odds with the Foster and Garduño (2013) definition in which outcomes are, albeit in broad societal terms, specified. The Moench et al. (2012) definition is neutral on this issue. To further investigate this issue, each team's definition of 'good' groundwater governance is now considered:

- "A 'good' groundwater governance environment is one where governance processes equitably reflect the voices and interests of stakeholders (including regional and global stakeholders with interests in resource sustainability) and where broadly supported courses of action can be implemented in an effective and equitable manner" (Moench et al. 2012).
- "Good groundwater governance qualities can be proposed as: openness and transparency; broad participation; rule of law (predictability); and ethics, including integrity (control of corruption)" (adapted from Lautze et al. 2011 by replacing 'water' with 'groundwater').

Foster and Garduño (2013) do not formally define 'good' groundwater governance, but instead provide a checklist of 20 benchmarking criteria (Table 2) for evaluating whether governance provisions are being implemented effectively. None of the benchmarking criteria specify an outcome. This can be taken to imply that good governance can be in place if an acceptable process is in place.

It is suggested that outcomes should not be a part of the definition of groundwater governance or good groundwater governance because (1) these outcomes will be negotiated locally depending on local circumstance as part of the governance process, and (2) the outcomes cannot be predicted with any degree of certainty because groundwater governance involves operating in, and dealing with, an uncertain environment. It is also suggested that outcomes, especially resources outcomes, should not be part of a *good* governance definition either, because these outcomes are so uncertain and beyond the control of the collective. It is suggested that 'good' groundwater governance should instead be resilient enough to be able to respond to outcomes, planned or otherwise, by making new decisions and implementing them. It is suggested that 'good' governance also needs to be sustainable. A once-off initiative that leads to a desired outcome is thus not inherently an indicator of good governance. The working definition of good groundwater governance adopted by this paper is essentially that of Moench et al. (2012) with 'that is sustainable and' inserted:

> A 'good' groundwater governance environment is one that is sustainable and where governance processes equitably reflect the voices and interests of stakeholders (including regional and global stakeholders with interests in resource sustainability) and where broadly supported courses of action can be implemented in an effective and equitable manner.

Taking into consideration this working definition, it is suggested that the Foster and Garduño (2013) governance definition is, in fact, part of a management plan for promoting groundwater governance, and for inputting global sustainability issues into local decision-making, rather than a definition of groundwater governance per se.

Literature review

Overview of groundwater governance research

An extensive review of the literature revealed that there is a reasonable degree of consensus on some of the basic and broad heuristics pertaining to groundwater governance. The heuristics are listed below with some examples of supporting references:

1. Groundwater governance research is in its infancy compared with the physical science of hydrogeology (Mukherji and Shah 2005; Llamas et al. 2006)
2. There are very few examples, if any, of good groundwater governance (López-Gunn and Cortina 2006; Ross and Martínez-Santos 2010; Wester et al. 2011)
3. A solely top-down, command-and-control approach to groundwater governance is unworkable (Llamas 2005; Llamas et al. 2006; Mukherji and Shah 2005; van Steenbergen 2006)

Table 2 Benchmarking criteria for the evaluation of groundwater governance and capacity (Foster et al. 2010)

Criterion	Context
1. Existence of basic hydrogeological maps	For identification of groundwater resources
2. Groundwater body/aquifer delineation	With classification of typology
3. Groundwater-piezometric monitoring network	To establish resource status
4. Groundwater-pollution hazard assessment	For identifying quality degradation risks
5. Availability of aquifer numerical 'management models'	At least preliminary for strategic critical aquifers
6. Groundwater-quality monitoring network	To detect groundwater pollution
7. Waterwell drilling permits and groundwater use rights	For large users, with interests of small users noted
8. Instrument to reduce groundwater abstraction	Waterwell closure/constraint in critical areas
9. Instrument to prevent waterwell construction	In overexploited or polluted areas
10. Sanction for illegal waterwell operation	Penalizing excessive pumping above permit
11. Groundwater abstraction and use charging	'Resource charge' on larger user
12. Land-use control on potentially-polluting activities	Prohibition or restriction because of groundwater hazard
13. Levies on generation/discharge of potential pollutants	Providing incentives for pollution prevention
14. Government agency as 'groundwater-resource guardian'	Empowered to act on cross-sectorial basis
15. Community aquifer management organisations	Mobilizing and formalizing community participation
16. Coordination with agricultural development	Ensuring real water saving and pollution control
17. Groundwater-based urban/industrial planning	To conserve and protect groundwater resources
18. Compensation for groundwater protection	Related to constraints on land-use activities
19. Public participation in groundwater management	Effective in control of exploitation and pollution
20. Existence of groundwater-management action plan	With measures and instruments agreed

4. The presence of some form of local 'collective' is a prerequisite for good groundwater governance (Llamas et al. 2006; López-Gunn and Cortina 2006; Aarnoudse et al. 2012)
5. The presence of a collective does not guarantee good groundwater governance (López-Gunn and Cortina 2006; Ross and Martínez-Santos 2010; Wester et al. 2011; Verma et al. 2012)
6. It is possible for a collective to effect good groundwater governance without the support of higher institutions (Mukherji and Shah 2005; van Steenbergen 2006; Taher et al. 2012; Foster et al. 2010)
7. For the purposes of good groundwater governance, it is highly desirable that a collective has support from higher-level institutions (López-Gunn and Cortina 2006; López-Gunn et al. 2013; Aarnoudse et al. 2012)
8. Usually some kind of 'trigger' is needed for a collective to be formed such as a groundwater supply or quality problem, the initiative of a charismatic individual; a request from a higher institution to form a collective or even a reaction against a request to form a collective on the grounds that it will reduce water rights (Rica et al. 2012; Mukherji and Shah 2005; van Steenbergen 2006)
9. There are no generally applicable rules, no blueprints for success, just anomalies (Mukherji and Shah 2005; Llamas et al. 2006; Foster and Ait-Kadi 2012; Moench et al. 2012) Note: Almost all papers that address groundwater governance either explicitly or tacitly support this point.

The final point appears to contradict the previous eight points. It could be interpreted as indicating that all the previous heuristics in the bulleted list are just anomalies and of little value. It could also be interpreted as saying that the design principles, being 'rules', would simply provide anomalous examples of good governance if applied to groundwater. It would appear, however, that two distinct types of rules are involved. First, there are the specific, and/or deterministic rules that could be assembled to form a blueprint. It is deterministic rules such as these that point 9 is referring to. These rules require that they be adhered to in order to achieve a specific result. Secondly, there are general and/or probabilistic rules. If these general rules are reflected on, they may lead to insights, and hence to more specific rules, structures, and actions that may increase the probability of success. To avoid confusion, these general rules are referred to as 'heuristics' in this paper.

If the distinction between 'heuristics' and 'rules' (as defined for the purposes of this paper) is accepted, the nine preceding points are correctly referred to as 'heuristics'. These heuristics cannot be assiduously followed as a blueprint for creating good groundwater governance, but they can be reflected on and implemented in a manner suitable for, and specific to, a given location, with a view to increasing the chance that good groundwater governance will ensue. They belong to the same 'family' as the 'pillars' proposed by Custodio and Llamas (2003) on which good governance systems can be built, even though such systems will be unique for every location. The same argument can be applied to Ostrom's design principles. Thus, the design principles cannot be dismissed by point 9 on the grounds that they comprise a blueprint.

It is suggested that the heuristics previously listed have a conceptual basis: groundwater governance is essentially an attempt to reconcile all the different facets of 'sustainability' that are involved. Llamas et al. (2007) discuss nine aspects of sustainability—hydrological, ecological, economic, social, legal, institutional, inter-generational, intra-generational, and political—for example, hydrogeologists might determine a sustainable hydrological abstraction rate for a given groundwater reservoir. Farmers might require a much higher abstraction rate for economic sustainability, while ecologists might insist that a sustainable ecological abstraction rate would be no abstraction. There is no 'right' answer to these diverse requirements. There is just a weighing-up of the pros and cons in each specific setting and an attempt to reconcile the differences. There is also no generic formula for reconciling differences for all aquifers, as each local setting will have different issues (Llamas and Martínez-Santos 2005; Ragone and Llamas 2006). Thus, it is clear that there is no 'right answer' that can be implemented in a top-down command-and-control fashion, rather there has to be local negotiations. It is further suggested that the need for groundwater governance to be defined as a *process*, rather than as *outcomes*, is re-enforced by the conceptual basis of multi-faceted sustainability. Resource, environmental and social outcomes, and consequently the collective's *decisions* regarding desired outcomes, cannot be predicted with any certainty. Thus, the emphasis has to be on an effective process, rather than on effective outcomes.

Groundwater governance research and the design principles

The design principles have been used to better understand, characterize, and contextualize groundwater governance (López-Gunn 2003; Ross and Martínez-Santos 2010; Verma et al. 2012). Ross and Martínez-Santos (2010) also investigated the relevance of the design principles to groundwater governance. To facilitate meaningful comparisons of the three studies (Table 2), each study's results were re-interpreted and standardised to the format and definition of the design principles as used by Cox et al. (2010).

The design principles would be irrelevant to good groundwater governance if: (1) all or most of the design principles were present yet groundwater governance was considered 'bad', or (2) none or only a few of the design principles were present and groundwater governance was considered 'good'. Because the design principles did not fail either of these tests in any of the case studies, they remain relevant.

An indication of the relevance of the design principles can be obtained by considering whether there is any proportionality between 'better' governance and the number of design principles present. This appears to be the case in López-Gunn's (2003) study in which a detailed institutional analysis revealed that groundwater governance in Eastern Mancha, Spain had progressed much further than in Western Mancha or Campo De Montiel. A comparison of the results of López-Gunn (2003), Ross and Martínez-Santos (2010), and Verma et al. (2012) for different geographical areas is difficult to make because all the studies either omitted some of the design principles or modified some of the design principles. For example, Ross and Martínez-Santos (2010) have re-interpreted the 'user boundary' design principle to mean whether the user had a permit or license to use groundwater. The original intention of this principle appears to have been to broadly distinguish between users that belonged to a collective and those that did not; determining whether users had obtained a water use license from a higher authority or not appears to be a very narrow interpretation of this intention. However trivial, modifications such as this may prevent a fair test of the relevance of the design principles.

Verma et al. (2012) used the Ostrom design principles to analyse the success of the Andhra Pradesh Farmer Managed Groundwater System (APFAMGS). The rationale behind the APFAMGS was that if hydrological science could be simplified and made available to farmers so that they could do their own monitoring and do their own crop water budgeting, then sustainable resource use would be made possible. The driving force behind the APFAMGS was a group of NGOs; at one stage, this experiment was regarded as very successful (Garduño et al. 2009). Table 2 refers to governance performance at this stage, and the high number of design principles present correlates well with the perception of good governance. Rules were enforced and conflicts resolved largely as result of social pressure from the NGOs. When the NGOs left, the hydrological monitoring and community-based decision-making virtually collapsed, and most farmers reverted to their original, individual heuristics regarding the management of the water resource. It would have been informative to conduct a second assessment using the design principles after the NGOs had left.

Ross and Martínez-Santos (2010) expressed the following reservations about the application of the design principles in large and/or complex groundwater systems:

> *Remote impacts of groundwater pumping*. Many groundwater users are unaware of the impacts of their pumping. Scientists have difficulty reaching consensus with other

scientists and with users regarding what the sustainable yield should be. Adaptive management strategies are proposed as the solution.

Heterogeneous users. Different users of a specific groundwater resource can have quite different attitudes to the use of the resource: some prefer short-term gain, while others take a long-term sustainable approach.

Coordination and collaboration. The establishment of collaborative institutional arrangements between all the different government departments, resource users, and other organisations across various scales remains a major challenge. They propose institutional learning and adaptation as the solution.

Monitoring and compliance. Groundwater use needs to be monitored using water volume meters. The meters are expensive. It is difficult to motivate either the users or higher authorities to pay for the installation and monitoring of these meters.

These reservations are not disputed by the present study. What is disputed, however, is that these reservations reflect challenges caused by shortcomings in the design principles, and the design principles are therefore irrelevant. It could also be argued that these challenges represent the shortcomings of not properly considering the design principles, as suggested in the following arguments:

- The aim of the design principles is to facilitate adaptive management and reduce the impacts of uncertainty (Ostrom 2005). Thus, concerns about the uncertainty of sustainable yields are covered by the design principles.
- Heterogeneous attitudes to a resource are to be expected; design principle 3 (see Table 1) allows these diverse views to be reconciled by allowing users to participate in making and modifying rules.
- Design principle 8 (nested enterprises) is the 'umbrella principle' for coordination and collaboration. An older formulation of this principle (Ostrom 1990) makes this clearer by stating that "Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises". Addressing the details of the coordination and collaboration covered by design principle 8 could be very difficult, but this does not make the design principle inherently irrelevant (Table 1).
- If the use of water meters is made the sine qua non of the monitoring debate, other perspectives, including those offered by the design principles, are lost. For example, if the users were authorised to make their own rules (design principles 3 and 7), and if the monitoring of the users (design principle 4A) and the monitoring of the resource (design principle 4B) were undertaken by the users, or by individuals accountable to the users, it is possible that other solutions would have been found, and it is also possible that these solutions might not have included water meters (Table 1).

The preceding four arguments addressing the four reservations of Ross and Martínez-Santos (2010) may or may not be applicable in the local studies by Ross and Martinez-Santos. The four arguments suggest, however, that there is value in reflecting on missing design principles that are related to a specific problem. These reflections may suggest solutions that would otherwise not be considered. It is therefore suggested that there is more to be gained by reflecting on the design principles than by ignoring them. If a detailed governance issue is not addressed by the design principles, a more productive response might be to do research on the detailed issue using the design principles as a reference, rather than to abandon the design principles.

Methodology

Three tests were applied to investigate the relevance of the design principles:

1. *A comparison between the design principles and Foster et al.'s* (2010) *governance benchmarking criteria* (Table 3). The aim of this comparison was to give insight into the relevance of the design principles to groundwater governance. The benchmarking criteria are based on "extensive worldwide experience of assessing the effectiveness of provisions and capacity for groundwater governance, in both urban and agricultural areas with significant hydraulic stress and/or pollution pressure on the local groundwater system" (Foster and Garduño 2013). The benchmarking criteria were used as the basis for the South African groundwater governance assessment carried out by Pietersen et al. (2011).
2. *A comparison between the design principles and their implementability in South Africa*. This test was carried out with the assumption that a specialised team such as an NGO, had been given the job of facilitating and fast tracking the creation of a Water User's Association (WUA). Two questions were then posited: (1) How many of the design principles would be implementable in the current institutional environment in South Africa; and (2) How many design principles could be implemented in the foreseeable future by revising priorities and strategies, but without major structural changes such as revisions to the NWA or significant increases in capacity? The scope of this study did not allow consensus-based answers to these questions to be obtained. Instead, subjective, but extensively experience-based, answers are provided based on the principal author's 32 years of experience as a hydrogeologist and groundwater manager with the national department responsible for water. These subjective answers

Table 3 Ostrom design principles applied to three case studies. *Y* yes, *N* no

Ostrom design principals	López-Gunn (2003)			Ross and Martínez-Santos (2010)		Verma et al. (2012)
	Western Mancha	Campo De Montiel	Eastern Mancha	Australian cases	Spanish cases	Andhra Pradesh
1A. User boundaries	N	N	N	Y	Y	Not considered
1B. Resource boundaries	Y	Y	Y	Arguably	Arguably	Y
2A. Congruence with local conditions	Not considered	Not considered	Not considered	Arguably	N	Y
2B. Appropriation and provision	Not considered	Not considered	Not considered	N	N	Y
3. Collective-choice arrangements	N	N	Y	Y	N	Y
4A. Monitoring users	N	N	Y	N	N	Y
4B. Monitoring the resource	N	N	Y	N	N	Y
5. Graduated sanctions	N	N	Y	N	N	N
6. Conflict-resolution mechanisms	N	N	Y	Arguably	N	N
7. Minimal recognition of rights	Y	Y	Y	Not considered	Not considered	N
8. Nested enterprises	N	N	Y	Y	Arguably	Limited

are not intended to be definitive, but merely to be plausible, and thereby permit a thorough discussion of the design principles.

This test should give general insights into the implementability of the design principles, the current health of the governance system, and the opportunities for improvement. This test should also help unravel whether the slow progress in the implementation of good groundwater governance is primarily due to lack of capacity (Parsons 2009; Pietersen et al. 2011) or whether it is due to using a top-down command-and-control type of approach that is essentially unimplementable (Llamas et al. 2006).

In the case of future scenarios, the test has to be hypothetical. A hypothetical approach was preferred to the current situation because there has been so little progress in giving effect to good groundwater governance; and, as a result of this limited progress, very little positive empirical data exists.

3. A comparison between the broad aims of groundwater governance in South Africa and the ability of these design principles to give effect to these aims. This test should give general insights into the effectiveness of the design principles. The effectiveness of the design principles was assessed by considering the broad aims of the NWA.

Results

Comparison with Foster et al.'s (2010) governance benchmarking criteria

For each design principle, corresponding benchmarking criteria were sought (Table 4). This comparison revealed very little equivalence between the design principles and the benchmarking criteria. To verify this conclusion, design principles were sought that matched the benchmarking criteria. Again, very little equivalence was found. The lack of equivalence initially suggested that either the design principles or the benchmarking criteria are not applicable to groundwater governance. This conclusion may, however, be premature and unfounded. Foster et al.'s (2010) check-list of 20 benchmarking criteria is relatively specific and technical, while Ostrom's (2009) design principles are more general and generic. The check-list and the design criteria are not mutually exclusive. For example, there is no reason why monitoring cannot meet the design principle requisites (done by the appropriators or individuals accountable to the appropriators), and also meet the check-list criteria (groundwater piezometric and quality monitoring networks). Thus, the lack of agreement between the two sets of criteria could be due more to scale than to one set of rules being intrinsically more appropriate than the other.

In contrast, the empirical evidence (Cox et al. 2010) supporting the design principles (albeit from generic common-pool research, rather than from groundwater governance research) seems more abundant and persuasive than the empirical evidence supporting the benchmarking criteria. There are several reported cases (van Steenbergen 2006; Taher et al. 2012) where effective groundwater governance is occurring without the presence of many of the benchmarking criteria such as hydrogeological maps, groundwater models, and water level monitoring. Therefore, it seems reasonable to suggest that the Foster et al. (2010) benchmarking criteria are not a prerequisite for effective groundwater governance, but rather a set of rules that will ensure groundwater governance will be of a sufficiently high hydrocratic standard once groundwater governance has been established.

Table 4 Comparison between the design principles and Foster et al.'s (2010) governance benchmarking criteria (see Table 2 for all numbers given under *Comments*

Ostrom design principles	Corresponding benchmarking criteria?	Comments
1A. User boundaries	No	This issue is not addressed
1B. Resource boundaries	Yes	- Existence of basic hydrogeological maps - Groundwater body/aquifer delineation
2A. Congruence with local conditions	No	This issue is not addressed
2B. Appropriation and provision	No	This issue is not addressed
3. Collective-choice arrangements	No	Although the criteria include community aquifer organisations (12) and public participation (19), these are not specifically assigned as authorities to make rules
4A. Monitoring users	No	No specific mention of monitoring groundwater use or groundwater users
4B. Monitoring the resource	No	Although piezometric (3) and quality (6) monitoring is specified, these are not made the responsibility of the appropriators and are regarded as a 'technical' provision
5. Graduated sanctions	No	A suite of sanctions and controls are listed, but there is no mention of them being used in a graduated way
6. Conflict-resolution mechanisms	No	Not specifically addressed, but the range of instruments described suggest conflicts would be referred to a higher authority
7. Minimal recognition of rights	No	Not specifically addressed, but the impression is created that local users would provide inputs to higher authorities rather than make rules
8. Nested enterprises	Yes	A range of nested enterprises are mentioned, including urban/industrial planning (17), coordination with agricultural development (1), government agency as a groundwater guardian (14)

It is suggested that the most useful thing that can be learnt from the benchmarking criteria is that they form part of the body of knowledge that believes there are rules, insights, and experiences that need to be shared and considered by those conducting 'experiments' in groundwater governance. Custodio and Llamas (2003) assert that there are "basic pillars … common to most solutions": monitoring; public education programmes; clear inventories of groundwater rights; and the capacity building of public institutions. The Alicante Declaration (Ragone and Llamas 2006) contains seven recommended actions that are regarded as essential for the governance of groundwater, but acknowledges that using these recommendations will lead to solutions that are unique to each specific place (a unique blend of social, economic, and cultural values present).

Implementability of the design principles in South Africa

Two questions were asked: (1) which design principles are currently implementable given the institutional environment, and (2) which design principles are potentially implementable using existing resources and legislation, provided some changes are made to strategies and deployment of resources (Table 5)? The reasons for the answers are then discussed.

1A: User boundaries. Most WUAs are old surface-water irrigation boards that have been transformed into WUAs and have little relationship to boundaries of groundwater users groups. However, there is no legal reason why new groundwater WUAs could not be established with clear user boundaries. This would take some time because new WUAs need ministerial approval and obtaining such approval can often takes many years.

1B: Resource boundaries. Existing WUAs do not correspond to groundwater resource boundaries, because they are not primarily concerned with groundwater. However, hydrogeological maps do exist, and most productive aquifer systems are well researched; therefore, groundwater governance could be based on clear resource boundaries.

2A: Congruence with local conditions. Groundwater allocation rules are currently based on a percentage of average annual recharge. This rule has been shown to be overly simplistic and unrealistic for local groundwater conditions (Theis 1940; Lohman 1972; Sophocleous 1997; Bredehoeft 2002; Custodio 2002; Alley and Leake 2004; Kalf and Woolley 2005; Seward et al. 2006; Balleau 2013). However, many groundwater researchers and managers in South Africa appear to prefer to continue to use the 'average annual recharge' rule, and appear unwilling to develop a better approach. The paradigm shift that would be required to change this thinking seems unlikely in the foreseeable future.

Table 5 Implementability of the design principles in South Africa. *Y* yes, *N* no

Ostrom design principles	Currently implementable	Potentially implementable
1A. User boundaries	Y	Y
1B. Resource boundaries	Y	Y
2A. Congruence with local conditions	N	N
2B. Appropriation and provision	N	N
3. Collective-choice arrangements	Y	Y
4A. Monitoring users	N	N
4B. Monitoring the resource	N	Y
5. Graduated sanctions	N	N
6. Conflict-resolution mechanisms	N	N
7. Minimal recognition of rights	N	N
8. Nested enterprises	Y	Y

2B: Appropriation and provision. Appropriators see little benefit in belonging to a WUA and fear that it will restrict their water allocations and income. Their short-term economic well-being is of far more importance to them than the sustainability of a groundwater resource.

3: Collective-choice arrangements. Each member of a WUA has voting rights as prescribed in the NWA that would allow them to participate in changing or modifying their rules.

4A: Monitoring users. The South African system of water permits is based on volumetric allocations. To monitor this would require water volume meters to be installed and monitored, and the data to be made freely available to the rest of the WUA. This is currently not being implemented, and it is unlikely that the situation will change in the foreseeable future.

4B: Monitoring the resource. Piezometric monitoring by appropriators is highly uncommon. Although many significant aquifers may be monitored hydrologically by regional offices of the Department of Water Affairs (DWA, presently the Department of Water and Sanitation), these data are not as a rule shared with the users and the DWA staff are not accountable to the users. Most of the hydrological data are uploaded to databases and are then rarely utilized meaningfully or disseminated any further. There is no legal or institutional reason why monitoring of the resource cannot be done by the users, or by agents accountable to the users.

5: Graduated sanctions. Sanctions, graduated or not, are currently very rarely encountered in a WUA or other water institution in South Africa. There are no signs that this situation is going to change in the future.

6: Conflict-resolution mechanisms. Local disputes often get delegated upwards to institutions like DWA, and the disputes remain unresolved for many years, with little prospect of resolution. While the direct costs may be minimal, the indirect costs can be excessive because of the time factor involved.

7: Minimal recognition of rights. WUAs in South Africa have no right to curtail or otherwise manage water use, but exist to optimise the entitlements allocated to them by higher institutions; they may do some watchdog activity for the higher-level institution or provide inputs to that institution, but that would normally be the limit of their authority. The NWA (RSA 1998) explains the role of WUAs as follows:

> Although water user associations are water management institutions their primary purpose, unlike catchment management agencies, is not water management. They operate at a restricted localised level, and are in effect co-operative associations of individual water users who wish to undertake water-related activities for their mutual benefit. A WUA may exercise management powers and duties only if and to the extent these have been assigned or delegated to it.

WUAs in South Africa have the right to create and modify their rules, but these rules, unless delegated to them by a CMA or the Minister of Water Affairs would not include water management. The default institutional relationship is, therefore, one of a paternalistic higher institution, and power-sharing with a local WUA is essentially tokenism (Arnstein 1969). Whether any meaningful power and rights would be delegated to a WUA seems unlikely given the paternalistic nature of an institution (DWA) that is reluctant to even devolve quite minor functional duties and responsibilities from the national head office to regional branch offices. For these reasons it is asserted that any rights of WUAs to make and change rules about groundwater use are unlikely to be granted or recognized for the foreseeable future.

8: Nested enterprises. There are many institutions in addition to the DWA that take into account use of, and impact on, water resources: e.g. The Department of Agriculture, The Department of Mineral and Energy Affairs, and The Department of Environment. These institutions attempt to obtain inputs from the WUAs regarding a variety of issues. The nesting of these multiple layers might not be ideal or effective, but the basics of polycentric governance do exist. There appears to be no defensible reason why these polycentric arrangements cannot be improved in the future.

Synthesis of the design principles assessment in relation to South Africa

The review of the implementability of the design principles in the South African context yielded negative results on the whole. Even with increased resources and revised strategies, it was found that the majority of the design principles would not be successfully implemented. Ostrom's dictum (Cox et al. (2010) is that the more design principles present, the more likely that governance will be sustainable. It is therefore suggested that sustainable groundwater governance in South Africa is unlikely without a major paradigm shift. It is further suggested that the lack of success of groundwater governance in South Africa could be explained by the lack of implantation of the design principles.

Can the design principles effect the broad aims of groundwater governance?

This section investigates the question: Would the aims of South Africa's NWA be met if all the design principles were in place? The main aims of the NWA are sustainability and equity. However, the NWA does not define sustainability and equity. Llamas et al. (2007) discuss nine aspects of sustainability: hydrological, ecological, economic, social, legal, institutional, inter-generational, intra-generational, and political. Intra-generational sustainability appears equivalent to equity in scope. It has been argued earlier that groundwater governance is an attempt to reconcile all these different facets of 'sustainability'. Farmers, ecologists, social engineers, and hydrogeologists might have interpretations of sustainability for every aquifer system. There is no 'right' or generic answer to these diverse requirements. Local negotiations to pursue unique local solutions are necessary.

The design principles can accommodate local negotiations, and can even be regarded as a way to optimise these negotiations. However, a concern is that a WUA, created around a community of interest, will focus on its interest—for example, optimal economic gain from a groundwater resource—and neglect the broader societal aspects of sustainability.

Design principle 8 (nested enterprises) could accommodate this concern if the broader societal aims were somehow incorporated into the WUA via nested hierarchies, but does not guarantee that this would happen. It is suggested that one way of ensuring that broad societal aims are considered by groundwater WUAs is for representatives from higher/external institutions that represent a specific aspect of sustainability to be accorded WUA user status. These representatives would then be 'agents' for the specific water 'use' they represent—e.g. nonconsumptive use for aquatic ecosystems, and would thus be allowed to participate in, and vote on, WUA matters. According to Thompson (2006), such a broad definition of water user is permissible: any interested and/or affected party could be allowed to be a member of a WUA, and not just those that are direct consumptive users.

This example of possible implementation strategies shows that WUAs operating according to the design principles could accommodate broader societal aims, but would not automatically do so. Therefore, the processes for taking these broader societal aims into account would have to be made explicit in water and groundwater strategies at the national and catchment levels.

Discussion

The purpose of this paper is to investigate the case for making more use of the design principles in groundwater governance research and design. Ostrom (1990) posited that common-pool resource governance was more likely to be sustainable and effective if all the design principles were present. This postulate has been substantiated by Cox et al. (2010). Because groundwater is a common-pool resource, the findings of Cox et al. (2010) should also apply to groundwater.

Only three papers—López-Gunn (2003); Ross and Martínez-Santos (2010); and Verma et al. (2012)—were found that made active use of the design principles in the groundwater field. In the analysis of these papers, it was found that some of the design principles were either omitted and/or changed, and thus do not provide a fair test of the relevance of these principles. Ostrom's postulate could, therefore, not be proven or refuted because no groundwater cases were found where all the design principles were considered. However, some support for the postulate was found since, in general, the fewer design principles present the less effective groundwater governance was found to be, and vice versa.

Concerns have been raised (Ross and Martínez-Santos 2010; Faysse et al. 2014) about the difficulties of implementing the design principles. These concerns address translating the design principles into site-specific rules, and then having to implement both the site-specific rules and the design principles without an established body of research or experience to provide guidance. The implication contained in these concerns was that, if it is almost impossible to implement the design principles, the principles do not have any value. The solutions proposed included abandoning the design principles in favour of adaptive management (Maimone 2004), a diagnostic approach (Young 2011), or social learning (Faysse et al. 2014; Pahl-Wostl et al. 2007). However, it could be argued that these approaches are just as, or more, difficult to implement than the design principles, and do not have a better 'track record' of success, and in some cases do not have a 'track record' at all. Moreover, these approaches and the design principles are not mutually exclusive. Indeed, adaptive management to minimise uncertainty has been stated as one of the objectives of using the design principles (Ostrom 2005). An alternative response to the difficulty of implementing the design principles would be a call for more research on implementing the design principles, rather than abandoning them.

There is one body of opinion that views general principles, of which the design principals are a subset, to be of no practical value when attempting to design and implement groundwater governance systems (Ross and Martínez-Santos 2010; Faysse et al. 2014). However, there is another body of groundwater opinion (Custodio and Llamas 2003; Ragone and Llamas 2006; Foster et al. 2010) that proposes general rules for facilitating good groundwater governance. The proponents of these general rules acknowledge that each local groundwater governance issue is unique, but maintain that the general rules will facilitate the finding of unique solutions, rather than impose a 'blueprint' solution. The proposed general hydrogeological governance rules, while not comprising a blueprint, are more specific than the (Ostrom) design principles. Because this difference is specificity, the design principles and general hydrogeological governance rules are complementary rather than mutually exclusive. Both the design principles, and any, or all, of the general hydrogeological sets of rules (including Foster et al.'s benchmarking criteria), should be considered when conducting groundwater governance 'experiments'. However, the (Ostrom) design principles, and the sets of rules provided by, inter alia, Foster et al. (2010) have not been extensively tested in the groundwater field. Therefore, there is a very good case for more research in this area. This research should be in the form of pilot projects that deliberately experiment with the design principles, and other principles, rather than research that passively observes scenarios that have a low probability of success.

It is suggested that if the design principles are to be fairly tested, whether in collaboration with general hydrogeological rules and/or with broad concepts like social learning or the diagnostic approach, then all of the principles need to be included, and they need to be included in the exact formulation they were posited.

The design principles encourage researchers to learn about the specific issues of a particular setting, and learn from their experiments in that setting and from the experience of others. The design principles provide a 'common language' for those researching, and those engaged in, governance experiments. This 'common language' provides a simple and consistent way of comparing the effectiveness of groundwater governance between and within different regions, and of comparing groundwater governance with other forms of governance. This could encourage more use of the design principles. In the South African context, this 'common language' was used to confirm the analyses of other researchers that groundwater governance in South Africa is very weak. A simple comparison with the design principles, and a reflection on the impediments to the implementation of specific design principles, suggested that the groundwater governance situation in South Africa is unlikely to change in the foreseeable future without significant changes to institutional strategies and to legal instruments. Knüppe (2011) argued that it could be many decades before groundwater governance would improve in South Africa. Use of the design principles could speed up the transition to good groundwater governance, both in South Africa and elsewhere. This possibility supports the argument that more attention be given to the design principles.

The design principles need not, and should not, replace, pre-empt, or prejudice a deeper institutional analysis, nor do they prevent more specific hydrogeological 'pillars' being considered. The design principles can provide a starting point for a deeper institutional analysis and the designing of institutions; this approach is supported by the design principles' proven robustness in the generic common-pool resource governance field.

Conclusions

The design principles are general, probabilistic heuristics. They do not comprise a deterministic 'blueprint' and, therefore, cannot be dismissed on these grounds.

The design principles have rarely been used in the field of groundwater governance research and design. The case for making more use of the design principles is based on:

- The strong need for more groundwater governance research because of the importance of groundwater and related issues globally, and because of the generally ineffective levels of groundwater governance that have been applied to these issues.
- The design principles have been demonstrated to be robust for common-pool resource governance. Because groundwater is also a common-pool resource the design principles should, by implication, be robust for groundwater governance.
- The other methodologies available for groundwater governance research and design have not been proven to be more effective than the design principles.
- The other methodologies available for groundwater governance research and design do not negate the design principles. The other methodologies offer the potential to complement the design principles, rather than exclude them—for example, the design principles could be used together with Foster et al.'s (2010) benchmarking criteria, or as the starting point for a diagnostic approach, or as a topic for reflection in social learning.
- The design principles provide a useful 'common language' for groundwater governance research and facilitation: meaningful comparisons between different localities, a standard initial diagnosis, and a standardised point of departure for additional analyses.
- In the South African context, it was found that very few of the design principles are currently being adopted, and that even with increased resources and strategy changes, it is

unlikely that the majority of the design principles will be implemented in the future. The lack of adoption of the design principles could explain the poor implementation record of groundwater governance in South Africa.

Thus, there are compelling reasons for making more use of the design principles in groundwater governance research and design. Given the embryonic nature of groundwater governance, and of groundwater governance research, there is a strong case for testing the design principles and other methodologies in pilot projects.

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