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The challenge of groundwater governance: case studies from Spain and Australia

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Abstract This paper examines the relevance to groundwater management of Ostrom's design principles for managing common property resources. Experience in four case studies of groundwater management in the Murray Darling Basin in Australia and the Upper Guadiana Basin in Spain suggests that while Ostrom's design principles are relevant, sustainable groundwater management depends on the effective collaboration between government authorities and water users. A flexible and adaptive management approach is required, with collaboration between scientists, policy makers, water suppliers, and water users. Key management challenges include agreeing on a sustainable level of extraction, and establishing effective coordination and collaboration, and monitoring and control systems. Further case studies of groundwater management and their synthesis could make a useful contribution to the transition towards sustainable groundwater management regimes.

Keywords Sustainable groundwater management · Common pool resources · Irrigation · Aquifer · Design principles · Collaboration

Introduction

Irrigation is responsible for about 70% of the world's freshwater withdrawals, a proportion that increases up to 80–90% in semiarid countries. These countries have experienced a large increase in groundwater development for irrigation during the last half century (Villholth and Giordano 2007; Ragone et al. 2007). Surface water management has traditionally received much more attention than groundwater management. This reflects the historical development of water resources. Surface water is a "visible" resource, which has been well understood since the early civilizations. On the other hand, the properties and peculiarities of groundwater have not been understood until relatively recent times (Fetter 1994). Thus, a lot more effort has gone into developing surface water management regimes and the underpinning science. A determined push is needed to develop adequate groundwater management systems.

Groundwater has a number of beneficial features. Groundwater is not subject to the same evaporative processes as surface water. It moves comparatively slowly, and can be tapped close to its place of use. It also remains available year-round, even during droughts. As a result, many irrigators have turned to groundwater as an alternative source or a buffer to cover peak, seasonal, and drought water demands. However, groundwater is more difficult to govern than surface water. The movements of groundwater are not visible, and more difficult to map. Hydrogeological boundaries are often diffuse, as is the connection of individual aquifers with other aquifers and with surface water. Groundwater use is also diffuse, with a high proportion extracted by individual users on their properties. There are often shortfalls in data on groundwater resources, and their extraction and management needs to be adjusted as new information becomes available (Moench 2004, 2007). Adverse impacts of excessive groundwater extraction are often separated in space and time from the pumping that caused the problem. Therefore, there are often significant

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uncertainties involved in determining the individual effect of groundwater users on one another, on the aquifer system and on surface stream flows (Schlager 2007). Consequently, the sustainable yield of groundwater resources and the causes of resource depletion are often disputed.

In addition, groundwater tenure rights are often contested. Landowners have historically assumed the right to pump groundwater from their land, and have been allowed to pump groundwater with minimal control. As groundwater irrigation mounts, farmers form increasingly strong lobbies to protect their own interests, to the point that social conflicts may arise when governments intervene to deal with aquifer overexploitation or quality degradation (Garrido et al. 2006). These issues have become particularly widespread in arid and semiarid regions (Llamas and Custodio 2003). Monitoring and enforcement of groundwater use also presents special problems. Because of the diffuse nature of groundwater extraction it is relatively difficult for either users or government authorities to reliably monitor resource extraction or prevent cheating.

Effective groundwater governance remains an important challenge to ensure long-term sustainability (Shah 2005; Llamas and Martínez-Santos 2005; Wang et al. 2006; Kretsinger and Narasimhan 2006). Governance refers both to setting objectives, principles, and rules for managing the resource, and to processes for implementing the rules. Ostrom (1990) derived eight design principles for self governing common property resource management systems from studies of long enduring resource management institutions. Although Ostrom's principles remain a good starting point for thinking about groundwater governance most of the empirical work has been on small-scale resources. This paper examines the application of Ostrom's principles in the management of larger scale groundwater resources where robust governance systems depend on effective collaboration between governments and water users.

The remainder of this paper proceeds as follows. The next section briefly reviews Ostrom's design principles, and some of the issues that have been raised about their application in large or complex common property systems. The following section explores the application of Ostrom's principles in four case studies of the management of groundwater irrigation systems in Australia and Spain, with particular attention to the interaction between governments and water users. The final sections of the paper further explore some problem areas for groundwater management that are evident from the case studies, and draw out implications for the further development of groundwater governance systems.

Principles and framework for sustainable governance of water resources

Ostrom has derived eight design principles for sustainable governance of natural resources, from studies of long-enduring institutions for governing sustainable resources—see Table 1 (Ostrom 1990, 2005). Ostrom warns against a "one size fits all" approach based on design principles. Nevertheless, she suggests that these design principles (or questions derived from them) can provide a starting point for searching for appropriate means of solving common property resource management problems. The cases studied by Ostrom also suggest that small-scale community governed resource institutions may be more effective than

Table 1 Design principles for governance of common pool resources

1	*Clearly defined boundaries*: The boundaries of the resource system, and the individuals or households with rights to harvest resource units are clearly defined
2	*Proportional equivalence between benefits and costs*: Rules specifying the amount of resource product that a user is allocated are related to local conditions and to rules requiring labour, materials and/or money input
3	*Collective choice arrangements*: Many of the individuals affected by harvesting and protection rules are included in the group who can modify these rules
4	*Monitoring*: Monitors who actively audit biophysical conditions and user behaviour, are at least partially accountable to the users and/or are the users themselves
5	*Graduated sanctions*: Users who violate rules in use are likely to receive graduated sanctions (depending on the seriousness and context of the events) from other users, from officials accountable to these users, or from both
6	*Conflict resolution mechanisms*: Users and their officials have rapid access to low-cost, local arenas to resolve conflict amongst users or between users and officials
7	*Minimal recognition of rights*: The rights of users to devise their own institutions are not challenged by external government authorities, and users have long term tenure rights to the resource
8	*Nested enterprises*: Appropriation, provision, monitoring, enforcement, conflict resolution and governance activities are organised in multiple layers of nested enterprises

centralised government in achieving many aspects of sustainable common pool resource management.

Ostrom's principles appear to be linked with successful common property resource management to varying degrees in a large number of cases, but studies by both Ostrom and others reveal that community based management of common property resources may only work adequately under a limited range of conditions (Balland and Platteau 1996). The success of community-based groundwater governance can vary according to the type of management problem being faced, the characteristics of resources and resource users, and relationships between users, governments and other affected parties.

Historically, water management regimes have been centralised top-down systems. Most water management problems were addressed by additional supply infrastructure. Now water management is seen as including a much broader range of issues including water for the environment, diffuse pollution from agriculture, climate change, and its impact on the variability of water supply. Given the complexity of water management and the increase in climatic and other uncertainties, adaptive management has been widely presented as an approach that should be adopted by natural resource managers (Gunderson and Holling 2001). Adaptive management processes include the design and implementation of management programmes that enable social learning through experiments, analysis and comparison of selected policies and practices (Pahl-Wostl 2007).

Schlager (2007) concludes that groundwater irrigators face information shortfalls that constrain their ability to address some groundwater governance problems. Groundwater irrigators may never grasp the boundaries, structure or capacity of groundwater resources or the effects of their pumping on the overall productivity of the resource, without external assistance from engineers and hydrologists. Schlager reasons that irrigators are more likely to organise themselves to manage "appropriation' issues that have an immediate impact on the resource, such as new wells, well depth and seasonal timing of extractions, than "provision" problems that emerge in the longer term as water tables decline. Single well owners and small communities may not have the knowledge, motivation, expertise or resources to manage inter-temporal river basin scale impacts of resource use. They are only likely to address these impacts in collaboration with higher-level governments. These impacts include soil subsidence, water pollution, and degradation of aquatic ecosystems that may emerge far away from the location of pumping and/or after a long period of time. These impacts are often uncertain. Adaptive management mechanisms are needed with inbuilt mechanisms whereby management tools and objectives of management can be adjusted as new information becomes available or other conditions change (Moench 2007).

Young maintains that Ostrom's principles cannot necessarily be scaled up from small-scale common pool resources with homogeneous actors to apply to a broader range of resource and environmental management cases (Young 2002). Young proposes a diagnostic approach that differentiates resource management issues, identifying elements of individual problems and design features necessary to address each element. For example, Young's analysis suggests that when aquifers connect with other water resources and/or cross a number of jurisdictions, management is likely to require relatively sophisticated administrative (coordination and funding) mechanisms at multiple scales and levels. When actors (e.g., water users, government agencies) have heterogeneous values and interests, broad participation by users, governments, and other affected parties, and effective adjudication mechanisms are needed to ensure that actors perceive the water management regime as being legitimate, and to improve prospects for compliance. Moreover, adaptive management requires sharing of information and responsibilities between governments, water providers and users, and other stakeholders such as environmental groups (Falkenmark et al. 2004). In these circumstances, collective management by water users is unlikely to be successful without collaboration with government authorities and vice versa.

Balland and Platteau conclude that successful community management is more successful with small and homogeneous groups and is positively influenced by good leadership and past experience of successful collective action. They also conclude that externally provided sanction systems are required to make up for the deficiencies of decentralised punishment mechanisms, and that economic incentives/compensation from external sources are often required to motivate communities to reduce resource use or invest in resource maintenance schemes (Balland and Platteau 1996).

Ostrom recognises that local appropriators have substantial difficulties regulating only part of a larger scale resource, without access to larger scale jurisdiction. Hence her principles include a requirement for complex administrative mechanisms (nested enterprises) in which a higher level authorities deal with problems that exceed the capacity of lower-level units, such as the provision of reliable information, and conflict resolution mechanisms.[1] She makes a theoretical argument for polycentric management systems; multiple governing authorities at different scales in which each unit can make and enforce rules in a specific domain of authority within a specified

[1] Her latest work is moving towards a more diagnostic method for analysing institutional change, differentiating between resource systems, resource units, resource users and governance systems (Ostrom 2007).

geographical area. In a polycentric system some units will be general-purpose governments, while others will be highly specialised such as river basin authorities or water user associations (Ostrom 2005). In practice, while polycentric governance shows considerable promise in dealing with cross scale resource management problems, higher-level government authorities are often reluctant to yield their decision-making power or to build the capacity at lower levels to tackle complex resource management tasks (Ross and Dovers 2008; Marshall 2008).

The remainder of this paper explores the way that governments interact with users in dealing with complex water resource management problems under uncertainty. Are government interventions and government collaboration with water users more successful when they lead to conditions consistent with Ostrom's design principles? Do government interventions lead to clearer definition of harvesting rights and extraction rules, and how do they combine clarity with flexibility in order to adapt to changing knowledge and conditions? Do they encourage participation of users in defining harvesting rights and extraction rules, monitoring water use and sanctioning illegal users? How do government interventions affect incentives for water users, and the collaborative interaction of multiple levels of individuals and organisations involved in water governance?

In the next section, these issues are explored in four case studies in Australia and Spain. Case studies from Australia and Spain are chosen because both of these countries have substantial water supply challenges (which are likely to increase owing to climate change), large and varied irrigated agriculture, areas with significant reliance on groundwater, and substantial experience with decentralised catchment-based management. At the same time both countries have significantly different institutions and policy preferences, and important internal variations. This enables groundwater management to be compared in a variety of circumstances within a small number of case studies. Specific resources at the sub-basin level have been chosen because many of the important details and relationships affecting the success or otherwise of water management and governance arrangements are masked when larger and more aggregated comparisons are made.

Comparative studies of groundwater management in Spain and Australia

Spain and Australia are both relatively large users of water. In 2002, Australia consumed 1,300 m^3 per person (fourth in the OECD) and Spain consumed 950 m^3 per person (sixth the OECD) (OECD 2006). This can be explained by the large share of water consumed by agriculture. Irrigation is the largest user of water in both countries, 68% in Spain (MMA 1998, 2000) and 65% in Australia in 2004–2005 (ABS 2005). Since 1980 irrigation as a proportion of cultivated land has increased by 51% in Australia and 43% in Spain (OECD 2006). In Australia, the volume of groundwater use increased by over 200% in New South Wales, Victoria, and Western Australia between 1983 and 1984 and 1996 and 1997 (NLWRA 2001), while in Spain it nearly doubled between 1970 and 2000 (MMA 2000).

The following subsections analyse and compare groundwater management in four catchments; the Namoi and the Murray in the Murray Darling Basin, Australia, and the Western Mancha and Campo Montiel in the Upper Guadiana basin, Spain. These case studies include a range of resource conditions, actor attributes, and implementation problems.

The upper and lower Namoi groundwater source (New South Wales, Australia)

The Namoi catchment in northern NSW covers approximately 42,000 km^2 and is home to 88,000 people. Rain is highly variable, from 1,100 mm/year over the Great Dividing Range in the east to 470 mm/year in the west. The Namoi groundwater resource accounts for about 40% of NSWs total groundwater use (Turral and Fullagar 2007). In the period between 1991 and 1992 and 2003 and 2004 average irrigation use was less than annual average aquifer recharge of about 200 Mm^3. In the drought years of 1992–1993 to 1994–1995, and after 2000 annual aquifer extraction increased substantially above the annual recharge (Fig. 1). Total extraction was 255 Mm^3 in 2004/2005 (CSIRO 2007). Although aquifer extraction has only exceeded recharge during prolonged droughts, water use entitlements substantially exceed both actual use and recharge. In 2003, groundwater use entitlements (463 Mm^3) were over double the estimated 191 Mm^3 sustainable yield (Government NSW 2003). Over-allocation has occurred partly because the NSW government encouraged water use and issued entitlements well in excess of annual recharge, and partly because of the lack of information on recharge and the low cost of obtaining water. In drought periods many farmers activated inactive licences to counter drought (Kuehne and Bjornlund 2006).

The New South Wales (NSW) Water Act 2000 provides for the establishment of Water Sharing Plans. These set the rules to divide water between domestic users, livestock, the environment, irrigators, and industrial users. A Namoi Groundwater Sharing Plan was developed during the period 2001–2003, taking into account economic impacts of reduced groundwater use (Wolfenden and Van der Lee 2002; Government NSW 2003). The 2003 plan was based on a 100% annual average recharge less an allowance for

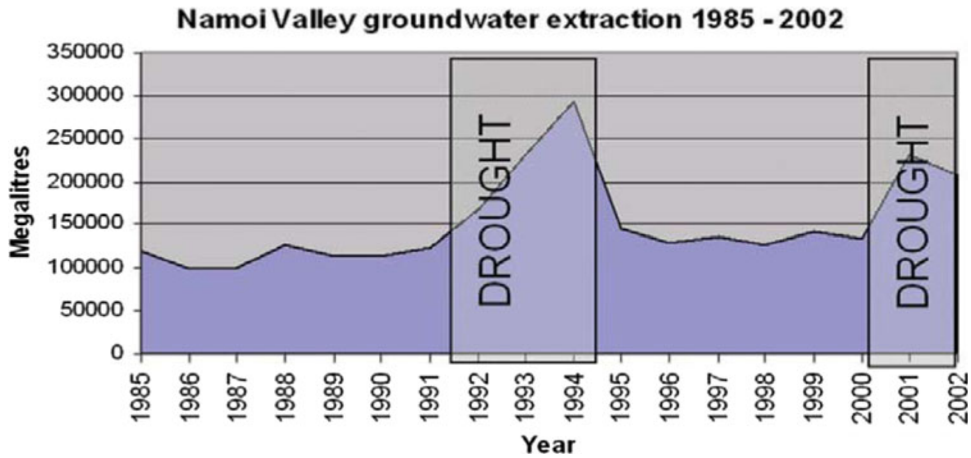

Fig. 1 Graph adapted from Namoi groundwater taskforce final report with additional data provide by Department of Natural Resources (Kuehne and Bjornlund 2006). 1 Megalitre = 1 Mm^3

environmental health (approximately 30%). Aquifer access licences were reduced by 51% in the Lower Namoi and by 61% in the Upper Namoi. Nearly 300 irrigation licence holders received aquifer access licences with a reduced share component (the relationship between the entitlement and the share component had previously be 1:1).

Water licence holders were strongly critical of the process for developing the Namoi Water Sharing Plan. The main argument was about whether entitlement reductions should be equalised "across the board", or adjusted in favour of irrigators who had developed their enterprise and were regularly using more than their reduced entitlement (active users) compared with those who had used little or none of their entitlement (inactive users). There were also questions raised about the definition of sustainable extraction (based on estimated annual average recharge), and the allowance for environmental purposes. Some stakeholders criticised the procedural fairness of the process, and a number of users took legal action against the government (Kuehne and Bjornlund 2006).

Following prolonged consultation, the Namoi Catchment Management Authority (CMA) recommended a revised water entitlement reduction formula. The Namoi CMA is one of the national set of regional bodies established to implement catchment based natural resource management plans, and provide a bridge between national programmes and local action (Ross 2008). The Authority recommended that entitlement reductions should take account of historical use, with a 75–25% weighting between active and inactive users, and this formula was accepted by the government (Government NSW 2004). Irrigators have been issued with a new licence to use groundwater that provides entitlement to a share in the groundwater resource, rather than a fixed amount of water, thus allowing the use entitlements to be varied in accordance with changes in water supply, e.g. owing to climatic factors. The licence provides a perpetual right to access groundwater and is fully tradable. In order to assist high water users to adjust to lower water entitlements they received supplementary water access licences that are being progressively reduced until year 10 of the plan when supplementary water will no longer be available (Pigram 2006). An Achieving Sustainable Groundwater Entitlements Program, jointly funded by federal and state governments and water users, is providing financial assistance to help compensate irrigators for the loss of water entitlements and restrictions on extractions.

The lower Murray groundwater source (New South Wales, Australia)

The annual sustainable yield for the lower Murray groundwater source is estimated at 83.7 Mm^3. Groundwater use in the period 2001–2002 to 2004–2005 averaged 71 Mm^3 except for 2002–2003 when it jumped to 130 Mm^3. Groundwater entitlements then totalled 263 Mm^3 (MCMA2006b).

The groundwater sharing plan for the lower Murray was initiated in 2005 in the second round of groundwater sharing plans in New South Wales under the ASGEP Program. The Murray catchment management authority (MCMA) had responsibility for developing details of the planning consultation with stakeholders. In February 2006, the MCMA issued a discussion paper on options for entitlement reduction and held consultation meetings with water licence holders. Following consultations, it was agreed to reduce licence entitlements to the sustainable yield giving a weight of 78% to active entitlements and 22% to inactive entitlements. Under this formula, it has been estimated that licence holders previously using 75% of their entitlements will retain 44%. In addition, 48.5 Mm^3 were granted as supplementary entitlements to be phased out over 10 years (MCMA2006a). Like the Namoi licences, water entitlements are expressed as a share of the available resource, are granted in perpetuity and are tradable (MCMA2006b).

The Murray groundwater planning process had the advantage of learning from experience in the Namoi and was less divisive than the Namoi process for a number of reasons. First, the number of groundwater irrigation areas and irrigators was less than in the Namoi. Secondly, the process was not delayed by debates over the basic formula for water sharing entitlements (historical entitlements versus across the board). Finally, the NSW Department of Natural Resources and the MCMA showed leadership by making sure that stakeholders were well informed about options for reducing entitlements, and also about the parts of the package which were non-negotiable such as the assessment of sustainable yield, the timing of entitlement reductions, and the amount of financial assistance payments. Although some concerns remained about formula for calculating sustainable yields, the establishment of resource boundaries, the legality of the entitlement reductions and the adequacy of compensation for the loss of water, the package achieved general acceptance by the community. The availability of supplementary entitlements and financial assistance as part of the package from the outset were important factors in gaining support for the process. Despite legal action against the plan by a few irrigators, authorities consider that the planning process was a success.

The Western Mancha aquifer (Castilla-La Mancha, Spain)

The Western Mancha aquifer is located in the Castilla-La Mancha region, central Spain. The aquifer spans 5,500 km^2 of flat lands and is home to 300,000 people. Climate in the region is typically semiarid. Long dry periods alternate with short wet sequences, while average rainfall amounts to 415 mm/years. Surface water resources are limited, as rivers run dry most of the time. Groundwater supplies over 90% of the catchment water demands (Guadiana Water Authority 2005).

Over the past 30 years, intensive groundwater-based irrigation has not only offset the region's endemic drought problems, but also acted as the main driver for the region's economic prosperity (Hernandez-Mora 2002). During this period, irrigation increased from barely 30,000 to over 200,000 ha (Guadiana Water Authority2006). Most of this development was uncontrolled. As a result, there are no accurate estimates of yearly water abstractions, total irrigated surface or crops patterns. Sixty percent of the existing wells are unregistered (Guadiana Water Authority 2005). It is nevertheless safe to assume that abstraction consistently exceeds recharge (Guadiana Water Authority2006). Intensive pumping caused the water table to drop at roughly 1 m/years since 1970s (IGME 2004), degrading valuable wetland ecosystems such as UNESCO's *Mancha Humeda* Biosphere Reserve and Ramsar-listed *Las Tablas de Daimiel* National Park (De la Hera 2003; Martinez-Cortina 2003).

In 1985, the Spanish government declared groundwater as part of the public domain and gave river basin agencies broad powers for the management of aquifers. Since the late 1980s basin authorities have attempted to establish legal controls on water use. This includes legal "declarations of overexploitation" linked with annually established pumping restrictions (also named "pumping plans"), an obligation to constitute water user associations and a ban from drilling new wells. But the establishment of uniform property rights has been constrained because pre-1985 well owners have been allowed to maintain private wells. The lack of a clear inventory of groundwater rights has also played its part. Owners drilling their wells after 1986 have been able to claim that they did so before the new law came into place.

More recently measures co-funded by the European Union have provided compensatory payments to encourage Western Mancha farmers to voluntarily cut down on water use (Fornes et al. 2005). While this has had more impact than controls by the river basin authority (Martinez-Santos et al. 2007), over 20,000 unauthorised boreholes still exist within the aquifer (Guadiana Water Authority 2005), and downward water table trends have not been reversed (IGME 2004).

There have been long-standing disputes amongst the water actors (Llamas 1994; Fornes et al. 2005; López-Gunn 2003) centered around a debate between water for development and water for the environment. In other words, to what extent should farmers cut down on their production in order to bring back the wetlands? Solution of this problem is intrinsically difficult, and is further complicated by the inability of the Water Authority to manage pumping. However, the resource management failures cannot be attributed to the Water Authority alone. First, controlling users is extremely resource-intensive. It is beyond the means of the Water Authority and requires a coordinated effort by governments and water users. Secondly, fining illegal pumpers and closing unregistered wells is a highly unpopular task, and hence it requires strong political leadership. But governments are rarely prepared to overrule the farmers who exert a significant influence in the political arena of the region. Thus, the Water Authority is often obliged to negotiate the regulatory regime with the farmers.

Farmers, however, are too fragmented a collective to uphold a common view. This means that they cannot fully profit from the strength of their position. Farmers include legal and illegal pumpers, and large and small landowners. The interests of those farmers who work the land directly often rival those of the farmers who can afford to employ labourers. Farmers who live on their farms often have different interests from city dwelling investors. Similarly those who rely on farming to make a living tend to oppose those for whom farming is a secondary activity. These differences emerge whenever important water management decisions are to be made. Environmental NGOs complicate dispute resolution between farmers and the Water Authority, arguing that the Authority should simply concentrate on applying the law and fining those who do not comply. Their position is supported by the requirements of the EU Water Framework Directive, which established the need to recover the aquifer and its associated wetlands by 2015.

In summary, many factors contribute to the groundwater management problems in the Western Mancha aquifer, but the key factor is the conflictual relationship between the Water Authority and the users (López-Gunn 2003; Lopez-Gunn and Martinez-Cortina 2006). Rather than facilitating the role of water managers, irrigation communities have openly contested the provisions made by the Water Authority, and even encouraged their members to challenge these in court. Legal enforcement is complicated by the co-existence of public and private groundwater rights.

The Campo de Montiel Aquifer (Castilla-La Mancha, Spain)

The Campo de Montiel aquifer is located immediately southeast of the Western Mancha, and accounts for approximately half the surface area. This limestone system provides part of the Western Mancha's natural recharge, and also presents some valuable wetlands (the Lagunas de Ruidera).

Unlike the Western Mancha aquifer, the Montiel region is hilly and, therefore, less than optimal for irrigated agriculture. That, together with a population that does not exceed 20,000 people, is perhaps the main reason why irrigation has not become as widespread. Irrigation grew from 200 ha in the early 1980s to 8,000 ha at the end of the 1980s, and has not grown much since then. It is, nevertheless, the aquifer's main water consumer, accounting for approximately 90% of the total use (AEUAS 2004; Guadiana Water Authority2006).

Overall pumping in the Montiel aquifer is substantially less than recharge. Historical records show that pumping peaked at 35 Mm^3, whereas the estimated renewable resources of the system are in the order of 130 Mm^3/years (MMA 2000). Thus, the water use debate in this case is mainly about how irrigation can affect particular sectors of the system, including springs that supply water to villages and, to a lesser extent, to the Lagunas de Ruidera wetlands (Llamas 1994; López-Gunn 2003).

López-Gunn (2003) argues that there are three main reasons why collaboration between the Water Authority and water users has been more successful than in the Western Mancha. The first one is the relatively low number of users. Working with Montiel's 200 irrigators is relatively easy compared with the 15,000 users in the Western Mancha. The former have much more homogeneous interests and comparatively simpler problems. They are included in a single water user association as opposed to the 20 different associations that exist in the Western Mancha case. Secondly, Western Mancha water user communities have traditionally not denounced illegal pumpers, partly because they are unwilling to "turn each other in" and partly because illegal well owners have taken up prominent positions within some water user associations. In contrast, Montiel irrigators have traditionally denounced illegal users quickly, thus, preventing illegality from becoming the norm. Finally, Western Mancha water user associations have largely adopted a defensive attitude, shielding farmers from water policy initiatives rather than facilitating dialogue with managers. In the Campo Montiel, strong leadership in the water user association has enabled greater cooperation with the Water Authority. Institutional arrangements in the Montiel are robust, but not flexible enough to take full account of non-farming water uses (Schlager and Lopez-Gunn 2006).

Comparative analysis of the Australian and Spanish case studies

Each of these case studies shows how progress or lack of progress towards sustainable groundwater management can be linked with Ostrom's design principles—see Table 2.

Greater success has been achieved when groundwater use entitlements have been clearly defined, and when governments have been able to collaborate with water users to establish and implement extraction limits. In the Australian cases, collaboration has been assisted by the role of catchment management bodies in providing a bridge between local water users and higher level government authorities, and by the provision of incentives (compensation) to persuade farmers to reduce water use. A crucial breakthrough was made in the Namoi case when the NSW State government accepted a groundwater and distribution formula nominated by water users. In the Spanish cases, the lack of a broadly accepted framework for water entitlements, and divisions within and between government authorities and water user groups has hindered the development of effective groundwater management regimes. Neither the Australian nor the Spanish cases include mechanisms to align the costs of maintaining the groundwater system with water extractions, or graduated sanctions.

Each of these case studies demonstrates the importance of effective collaboration between government authorities

Table 2 Comparison of the Australian and Spanish case studies

Design principle	Australian cases	Spanish cases
Boundary conditions/rights to use water	Well-defined long term user rights	Two tier user rights system, many unregistered and illegal users, especially in the Western Mancha
Collective choice/user involvement in setting rules	Government authorities set extraction limits, users decide on water use entitlement reduction formula	Government authorities set extraction limits
Benefits proportional to costs	Compensation for reduced entitlements linked to levels of investment and use	EU incentives for reduced water use
Monitoring	Monitoring by water supply companies	Monitoring by government authorities
Dispute resolution	Catchment management processes	Water juries embodied in Spanish Water User Associations (inactive)
Graduated sanctions	No	No
Nested enterprises	Nested structure of state, and catchment authorities and local user groups	Fragmented structure with conflicts within and between authorities and user groups, especially in the Western Mancha

and water users. Government authorities have been unable to establish robust groundwater management arrangements without cooperation from water users. Similarly local appropriators have not been able to regulate even quite small groundwater resources without access to larger scale jurisdiction.

These case studies confirm a number of theoretical reservations about scaling up Ostrom's design principles for "self managed" systems for application in large and/or complex groundwater systems, and provide practical examples of some of the challenges involved meeting Ostrom's principles. These challenges: dealing with the remote effects of groundwater pumping, user heterogeneity, cross scale coordination and collaboration, and monitoring and enforcement are discussed further in the following section.

Discussion

Dealing with remote impacts of groundwater pumping

Users of a small aquifer may be sufficiently aware of the impact of their pumping on water tables, other resources and the surrounding environment to self regulate water abstraction to avoid adverse external impacts. In larger and more widely distributed aquifers there are likely to be significant effects on remote water users and the natural environment, although these impacts are often delayed—they are remote in time as well as space. Water use entitlements then depend on scientific calculations of water balances and sustainable aquifer yields, but estimates of sustainable aquifer yields are often disputed for a variety of reasons, both by scientists (Sophocleous 1997, 2000; Custodio 2002; Moench 2004), and also by users (Turral and Fullagar 2007; Guadiana Water Authority 2007).

A distinction can be made between hydrogeological sustainable yields, set to maintain the volume of a groundwater resource, and socioeconomic sustainable yields that may allow some depletion, at least in the short term. The socioeconomic sustainable yield reflects a political calculation of long-term community welfare, taking account of environmental impacts. Such calculations are further complicated by uncertainty about future climatic, social and economic conditions. Experience in the Australian and Spanish case studies indicate that great effort is needed to explain scientific outputs, and to get affected parties to accept scientific uncertainty and iterative solutions (Martinez-Santos et al. 2007). Gaining feedback through public seminars and discussions is insufficient, and an ongoing engagement between scientists and practitioners is needed (Letcher and Jakeman 2002).

Demands for groundwater use will continue to increase, and further problems are likely to become evident because of ongoing land use and climate change. Social acceptance of the need for limitations on groundwater use involves a change in values that takes a substantial amount of time and effort to achieve. Therefore, it is important to prepare the ground and gain acceptance for adaptive strategies, even if these are difficult to implement in a world of short-term political cycles (Allan and Curtis 2005).

Heterogeneous users

At first sight heterogeneity increases the difficulty of achieving self-governing aquifer management because it increases the difficulty and costs of reaching agreements amongst users. Further analysis reveals a more complex relationship between heterogeneity and the capacity of users to organise. Both Ostrom (2000) and Balland and Platteau (1996) distinguish between differences in cultural backgrounds, perceptions, interests and endowments. Balland and Plateau argue that differences in the endowments do not prevent uniformity of interest in collective agreements and both they and Ostrom note the potential for users who possess greater economic assets and political power to contribute strongly to collective action. The impact of this action on resource sustainability depends on the position and strategic interests of well endowed resource users. Users with a common perception of their situation and interests such as the costs of not dealing with falling water tables, may be prepared to act collectively even if their cultural backgrounds and endowments are different, as illustrated in the Australian case studies.

Ostrom points out that users with a strong ties to the land are more likely to pursue long- term sustainability, while landowners who manage their properties as investments are likely to be more interested in short-term profitability. The divergence between the values and interests of owners who live on the land and absentee owners is an important factor in explaining the failure of water users to agree on a collective position in the Western Mancha.

Coordination and collaboration

Although external (usually government) intervention is required to coordinate information and water users, and adjudicate disputes, top-down government intervention is unlikely to achieve sustainable resource management without support from the main water users. For example, in the cases studied governments have set legal limits on total groundwater use, but legal limits have not been, and are unlikely to be enforced successfully without active cooperation from water users.

The establishment of collaborative management processes remains a major challenge. The shape and form of productive and complementary relations between different resource users, governments and other organisations is not well understood and requires substantial investigation (Schlager 2007). Many government authorities and users at multiple scales are involved in managing large aquifers, and is not easy to achieve effective cross scale coordination and collaboration (Marshall 2008). Moreover, farmers are an influential group, and strong political leadership is often needed to impose restrictions on their water use. Consultative processes have been introduced in each of the case studies, but public consultation by water authorities often appears more symbolic than real, because it does not take sufficient account of stakeholder views and/or takes place after major policy changes have been made. Consequently, management regimes have not been perceived as legitimate by some users. In the Australian cases, authorities and water users were unable to agree before transparent and inclusive rule setting processes were established (Turral and Fullagar 2007). Lopez-Gunn and Martinez-Cortina (2006), report similar results in Spain. This poses a big challenge in the Western Mancha where the interests of thousands of heterogenous water users have to be taken into account.

In the Australian cases initial government proposals failed to allow for the different impacts of the proposed entitlement reductions on active and inactive licence holders, and reduced entitlements were only accepted when users were allowed to choose their own reduction formula. Later, progress was achieved by including all water users in the process of developing groundwater use plans, developing shared perceptions and trust amongst participants and establishing agreed principles for allocating water—consistent with Ostrom's recognition of rights and collective choice principles. In the Western Mancha multiple water user associations have not been able to cooperate, either with each other or with water authorities, leading to widespread disregard of pumping restrictions. In the Montiel area, in contrast, effective leadership and coordination of water users has enabled collaboration between the water authority and water users, improved monitoring and denouncing of illegal use.

The development of groundwater regimes in Australia has been strongly influenced by the prior development of water management institutions based on apportionment of supply to water users. Existing water conservation rules are often built around "apportionment" institutions such as the Murray-Darling basin "Cap" (Heinmiller 2004). A considerable mind shift is still required to establish sustainable groundwater regimes, under which it is accepted that it is legitimate to limit pumping by landowners to maintain environmental values. Such institutional learning and adaptation plays a critical part in the transition to sustainable water management (Pahl-Wostl 2007). The case studies illustrate the role of effective leadership by both government authorities and water user associations in articulating and developing community values and norms and overcoming resistance from vested interests.

Monitoring and compliance

Monitoring and enforcement of groundwater use presents special problems because, unlike a surface water irrigation schemes where water is supplied to users through a regulated system, there are large numbers of extraction points, mostly on private farms. Historically, it has been difficult to monitor groundwater use, especially in aquifers with thousands of wells. Although new technologies such as remote sensing are improving the possibilities of estimating groundwater use, metering provides more direct and potentially accurate measurement of groundwater use, and meters can even be set up to report direct to centralised databases. The implementation of a metering, monitoring and compliance system presents some dilemmas concerning the system design and choice of implementing agents.

It is easy to justify the principle that water users should pay for metering consistent with Ostom's principal of proportional equivalence between benefits and costs. However, meters are quite expensive to install, and the cost may trigger resistance from water users. On the other hand, if water authorities bear the cost of metering users have little incentive to maintain the system. Whoever pays for metering, it is a challenge to prevent abuses such as tampering with metering devices and incorrect recording, and to ensure comprehensive collection of results. There is a considerable debate about whether and under what circumstances legalistic approaches to compliance are more effective than voluntary and user organised approaches. User organised approaches coupled with incentives are most likely to gain user support and overcome resistance, although controls and negative incentives may be needed if non compliance persists (Gunningham and Sinclair 2005). Compliance can also raise equity issues. Imposing strict reporting restrictions on legal users is seen as unfair in the Western Mancha, as it places a significant burden on those who register their wells while exempting illegal users—thus breaking the equivalence between benefits and costs.

The choice of agents for implementing groundwater monitoring and compliance presents a dilemma. Government authorities do not have enough information or resources to meter and monitor the use of thousands of wells, and have substantial difficulties in enforcing use limits without active collaboration from users. Groundwater users have the potential to organise themselves to meter and monitor water use, and to identify illegal users, but user associations often face difficulties such as conflict between users, distrust of authorities and reluctance to denounce illegal users. Also, metering imposes a significant additional cost for some users. Incentives may be needed to make it worthwhile for users to engage in monitoring and compliance. Thus, the transition to effective groundwater use monitoring and compliance is likely to require integrated action by authorities and users. This will in turn require improved relationships and trust between various water users and authorities.

Given the above issues of cost sharing and compliance it may be useful to consider options for phased transitional arrangements to promote metering, monitoring and compliance in groundwater management regimes in Australia and Spain. For example, transitional assistance could be provided for the establishment of a monitoring system and installation of meters under government supervision, but in the long term the system could be financed by a user levy and users could take responsibility for compliance, backed by independent auditing.

Conclusions

This paper has examined the relevance to groundwater management of Ostrom's design principles for managing common property resources. Experience in four case studies of groundwater management in the Murray Darling Basin in Australia and the Upper Guadiana Basin in Spain suggests that while Ostrom's design principles are relevant, sustainable groundwater management depends on a flexible and adaptive management approach, with strong collaboration between scientists, policy makers, water supply agencies and water users.

The case studies illustrate the influence of water resource and user attributes and implementation issues on water management outcomes. Uncertainties about sustainable yields, the diffuse nature of groundwater resources and their extraction and the fragmentation of authorities and user groups constrain the achievement of sustainable groundwater management to a varying extent in different cases. This supports the case for diagnostic approaches that take account of different resource and user characteristics. Adaptive management approaches are needed in response to evolving knowledge about groundwater availability, the impacts of groundwater use, and the effectiveness of various rules, incentives and management organisations in promoting collaboration to achieve sustainable groundwater management.

As pressures on groundwater resources increase the need for effective metering, monitoring and sanctions also increases. Although there are in principle and practical arguments for groundwater users to take a leading role in monitoring and compliance, the case studies underline the importance of collaborative efforts by responsible authorities and users.

Further case studies of groundwater management and their synthesis could elaborate and refine the classification and analysis of groundwater governance systems. This could make a useful contribution to the transition towards sustainable groundwater management regimes.

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