7 Community Management of Groundwater

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Introduction

Over the last 20 years, scholars have devoted considerable attention to the ability of farmers, fishermen, pastoralists and other types of resource users to organize, adopt, monitor and enforce institutional arrangements that govern their use of common pool resources (CPRs) in a sustainable manner (Ostrom *et al*., 2002). During this period, progress has been made in carefully identifying and defining key theoretical concepts, developing typologies that organize diverse types of problems and institutional arrangements, identifying factors that help explain the circumstances under which resources users are likely to engage in collective action to develop governing arrangements, identifying design principles that account for durability of self-governing arrangements, and developing an impressive body of empirical work devoted to theory development and hypothesis testing. According to Stern *et al*. (2002, p. 445) the study of institutions for managing CPRs is sufficiently developed to be recognized as a field within the social sciences. Surface irrigation systems have been a focal resource in the development of this field. Much attention and effort has been devoted to explaining the conditions that contribute to the emergence and persistence of farmer-managed irrigation systems. Comparative analyses of farmer-managed and government-managed systems have also been conducted.

This chapter extends the work of scholars on self-governance of CPRs to groundwater in irrigation settings. While work has been conducted by such scholars on groundwater basins in the USA, little focused attention has been paid to groundwater and irrigation. The first section of the chapter covers conceptual tools and theory from the field of CPR governance. The second section applies the conceptual tools and theoretical concepts to groundwater irrigation. The arguments are illustrated in two ways: first, by a comparative analysis of surface irrigation systems and groundwater irrigation; and second, through the use of several case studies. The final section explores promising types of linkages between communities of groundwater users and higher-level governments. Local-level governance is a key component of sustainably managing groundwater basins.[1] How higher-level governments can encourage and support local management efforts is an important topic.

A Theory of Common Pool Resources

Foundational concepts

CPRs are defined as natural or man-made structures characterized by costly exclusion and subtractability of units (Ostrom and Ostrom, 1977). Examples include surface irrigation systems, groundwater basins, fisheries, forests and grazing lands. Both exclusion and subtractability present challenges for governing CPRs sustainably. Exclusion involves defining who may enter a resource and who may not – making such a determination is rarely a straightforward process. Ideally, exclusion should occur in a manner that limits access to the number of users whose use will not threaten the resource. Physical, institutional and social issues often confound such efforts (Ostrom *et al*., 1994). The sheer size of some resources makes enforcing access limitations in any meaningful or cost-effective manner virtually impossible. In other instances, national or state constitutions forbid denying citizens access to natural resources. In other settings, there may be political or economic reasons for avoiding strict access controls. For instance, a number of surface irrigation systems have been described as long and lean – the goal being to provide at least some water to as much land as is possible. Rationales range from equity concerns, i.e. assisting many people, to cost–benefit analysis issues, i.e. the more land included in a scheme, the better the cost/benefit ratios. In either case, too much land can be included within a system with some farmers experiencing chronic water shortages.

Exclusion is critical for sustainability, but also for governance. Resource users are much less likely to undertake costly and time-consuming efforts to manage CPRs if they cannot capture many of the benefits resulting from good management. Why design a water allocation scheme that conserves water if the additional water supplies may be captured and used by someone else? Why invest in groundwater recharge projects if others can pump the recharged water? Inadequate exclusion promotes free riding, and free riding discourages collective action (Dietz *et al*., 2002).

Even if exclusion is adequately addressed in relation to a CPR, sustainability is not ensured because of substractability. Subtractability means that each 'unit' harvested from a CPR is not available for other users to harvest. The groundwater that a well owner pumps and uses to water his crops is not available for other well owners to pump. Since each resource user gains the value of each unit harvested but imposes some of the costs of harvesting on all resource users, resource users are likely to harvest more than is economically or ecologically desirable (Gordon, 1954; Scott, 1955; Dietz *et al*., 2002). Or, as Ostrom *et al*. (1994, p. 10) explain: '[I]ncreased water withdrawal by one pumper reduces the water other pumpers obtain from a given level of investment in pumping inputs'. The problem of exclusion may be adequately addressed but the CPR may still be overused because of the harvesting actions of the resource users. Consequently, if CPRs are to be governed sustainably, the challenges posed by difficult and costly exclusion and substractability must together be addressed.

Considerable attention has been devoted to the problem of overuse. The earliest formal models of resource use, such as those developed for fisheries (Gordon, 1954; Scott, 1955), focused on it, and many models since then have followed suit (e.g. Hardin, 1968; Clark, 1980; Norman, 1984). While overuse is problematic, resource users are likely to confront a host of CPR dilemmas (Ostrom *et al*., 1994). Ostrom *et al*. (1994) define CPR dilemmas as suboptimal outcomes produced by the actions of resource users and the existence of feasible institutional alternatives, which, if adopted, would lead to better outcomes (Ostrom *et al*., 1994, p. 16).

In addition to overuse, resource users may engage in a variety of actions that produce suboptimal outcomes in their use of a CPR. For instance, well owners may place their wells too close together, interfering with one another's pumping; a farmer may install a deep tube well near another farmer's shallow well, drying it up; farmers may fail to maintain a tank that would otherwise serve to capture rainwater and recharge it into the underground aquifer.

Ostrom *et al*. (1994) relax the implicit assumptions underlying formal models focused on overuse to develop a typology of CPR dilemmas. Most models assume a uniformly distributed resource. By relaxing that assumption and allowing resources to be patchy, so that some areas of a resource are more productive than others, assignment problems may emerge. Assignment problems involve resource users competing over productive areas and interfering with one another's harvesting (Ostrom *et al*., 1994, p. 11). Furthermore, most formal models assume identical harvesting technologies among resource users. By relaxing that assumption and allowing diverse technology utilization, technological externalities may emerge among resource users. Technologies used by harvesters interfere with one another causing conflicts among resource users. For instance, a high-capacity well may dry up a shallow tube well (Ostrom *et al*., 1994, p. 12). Thus, in addition to overuse, or what Ostrom *et al*. (1994) term appropriation externalities, resource users may experience assignment problems and technological externalities.

As Ostrom *et al*. (1994) note, appropriation problems stemming from when, where, how and how much to harvest are not the only problems resource users are likely to experience. Another class of dilemmas – provision problems – is also likely to emerge in many CPR settings. Provision problems relate to developing, maintaining and/or enhancing the productive capacity of the CPR. For instance, adequately functioning surface irrigation systems require that diversion structures, headworks, canals and outlets be regularly repaired and maintained. The productivity of an aquifer may be enhanced by capturing water during wet seasons and directing that water underground to be used during dry seasons. Provision problems are distinctly different from appropriation problems. Appropriation problems require resource users to coordinate their harvesting activities; provision problems require resource users to cooperate and contribute to the production of public goods.

Self-governing institutional arrangements

Ostrom (2001) argues that resource users are more likely to invest in designing and adopting rules to address CPR dilemmas if they perceive that (i) the benefits produced by the new sets of rules outweigh the costs of devising, monitoring and enforcement; and (ii) they will enjoy those benefits. Whether these two conditions hold depends on characteristics of the resource and characteristics of the resource users. For Ostrom (2001) four resource characteristics are crucial:

1. *Feasible improvement*: Resource conditions are not at a point of deterioration such that it is useless to organize or so underutilized that little advantage results from organizing.
2. *Indicators*: Reliable and valid indicators of the condition of the resource system are frequently available at a relatively low cost.
3. *Predictability*: The flow of resource units is relatively predictable.
4. *Spatial extent*: The resource system is sufficiently small, given the transportation and communication technology in use, that appropriators can develop accurate knowledge of external boundaries and internal microenvironments (Ostrom, 2001, p. 40).

There must be a sense among resource users that governance attempts will make a difference (attribute 1). If a resource is so degraded that users believe there is little they can do to positively affect the situation, they are unlikely to make the attempt. Conversely, appropriators may find little benefit in investing in governing arrangements if a resource is relatively abundant and of adequate quality. Whether resource users believe that feasible improvement in the productivity of the resource is possible depends on the information that they have and their ability to exercise some control over the resource. Information about a resource depends on availability of reliable and valid indicators of resource conditions, the spatial extent of the resource and the predictability of resource units (attributes 2–4). Indicators vary from resource to resource and may be as 'simple' as paying attention to wool or milk production of grazing animals or as complex as monitoring wells. The spatial extent of a resource affects both the ability of users to develop information and to assess their relative ability to capture the benefits of organization. Resource systems or subsystems that are more closely matched with the ability of resource users to monitor encourage investment in rules. Finally, predictability should be interpreted broadly to include volume and temporal and spatial patterns. Predictability provides resource users the opportunity not only to learn about the resource but also to govern harvesting activities in meaningful ways.[2]

In addition to characteristics of resources, qualities of the resource users themselves affect the benefits and costs of cooperation to devise governing arrangements. Ostrom (2001) posits the following attributes of resource users:

1. *Salience*: Appropriators are dependent on the resource system for a major portion of their livelihood or other important activity.
2. *Common understanding*: Appropriators have a shared image of how the resource system operates, and how their actions affect each other and the resource system.

3. *Low discount rate*: Appropriators use a sufficiently low discount rate in relation to future benefits to be achieved from the resource.
4. *Trust and reciprocity*: Appropriators trust one another to keep promises and relate to one another with reciprocity.
5. *Autonomy*: Appropriators are able to determine access and harvesting rules without external authorities countermanding them.
6. *Prior organizational experience and local leadership*: Appropriators have learned at least minimal skills of organization and leadership through participation in other local associations or studying ways that neighbouring groups have organized (Ostrom, 2001, p. 40).

These characteristics ease the costs of organizing, developing and adopting a common set of rules. Attributes 1 and 3 measure how appropriators value the resource. If resource users are heavily dependent on the resource for their livelihood and if they anticipate continued reliance on it well into the future, they are more likely to invest in new sets of rules. If appropriators share a common understanding of the resource and the effects of their actions on the resource and on each other, they are more likely to share a common understanding of the problems that they face and are more likely to agree upon a set of rules to address those problems. Trust and reciprocity and leadership provide resource users with 'social capital' that they can draw upon to ease bargaining and negotiation costs. Autonomy provides appropriators with the 'space' needed to engage in rule making and confidence that they will be able to capture the benefits of their institutional investments. While Ostrom (2001) separates the two sets of attributes for the sake of clarity, the attributes interact to support or discourage collective action. Resource users may have a relatively complete and accurate understanding of the resource; however, they may still be unwilling to invest in new sets of rules if the resource is of low salience to them.

Comparing surface water and groundwater irrigation

The emerging theory of CPR governance provides a consistent set of concepts and analytical tools to diagnose problems, provide a deeper understanding of the conditions under which local governance of CPRs is likely to occur, identify promising policy alternatives and shed light on the shape and form of productive relations between local-level governance arrangements and regional and national governments. One valuable use of the theory is to systematically compare surface water irrigation with groundwater irrigation. In so doing, the very real, but very different, challenges facing both types of irrigators are clarified. Local-level self-governance is possible in both settings, but it will probably exhibit different structural features and require different types of linkages with higher levels of government because of the diverse challenges presented by two contrasting physical settings: surface irrigation systems that are human-constructed CPRs, and groundwater basins that are naturally occurring CPRs.

Surface water irrigation

The governance challenges groundwater irrigators commonly face differ considerably from those faced by surface water irrigators. The differences result from the distinct physical structures of surface irrigation systems compared with groundwater basins and, consequently, the different water development paths that unfold between the two types of water systems.

To construct and operate a surface irrigation system requires considerable upfront production and transactions costs. Using the terminology discussed above, irrigators immediately confront provision problems. At a minimum, production costs entail building a diversion structure, a distribution system and field outlets and channels. A single person or family generally cannot meet such production costs; rather a collective effort is necessary, involving many people, their resources and their participation. The transaction costs of organizing people, developing information about the physical setting, negotiating over the location and design of the irrigation system, organizing labour as well as monitoring and enforcing agreements concerning contributions and work are significant. Providing an irrigation system requires upfront organization and collective action.[3]

Marshalling the participation and resources needed to provide an irrigation system is closely tied to anticipating and addressing the inevitable appropriation dilemmas that will emerge. In many instances, water will be insufficient to meet all irrigators' needs all the time. Water allocation rules must be established, at least in a rudimentary form before the system is built, to provide assurance to farmers about the benefits they will likely receive from participating in the collective undertaking. Once the system is built, it must be maintained, requiring the creation of rules governing irrigators' contributions to system upkeep (Tang, 1992, 1994). Farmers will be more likely to abide by their maintenance requirements if the water allocation rules are functioning well. In turn, water allocation rules are likely to be more productive if the system is well maintained. In other words, provision and appropriation dilemmas are closely tied together in surface irrigation systems. Adequately addressing one set of dilemmas often requires adequately addressing the other. If that is accomplished, positive feedback between the two processes acts to support and sustain the system. Of course, the opposite is true as well. If appropriation dilemmas are not adequately addressed, provision is likely to falter, which will further exacerbate the appropriation dilemmas (Tang, 1994; Lam, 1998).

Rose (2002) notes the unique character of surface irrigation systems that may make them particularly amenable to farmer-based governance. She argues, echoing Ostrom's attributes of the resource, that unlike many other CPRs,

> [r]esource-related activities involved in irrigating – taking water from ditches, laboring on infrastructure development and upkeep – are especially open to mutual monitoring. Not only can one farmer observe another farmer along the same ditch, but upstream and downstream communities can observe what other communities are doing with respect to water use and infrastructure maintenance.
> (Rose, 2002, p. 239)

Farmers can more readily determine and define the boundaries of their irrigation systems. They can monitor water flows and the variation in volume over time. They can experiment with different water allocation rules and determine which allocation methods better fit their particular physical setting. They can also readily monitor and observe one another's behaviour and determine whether water allocation or labour contribution rules are generally being followed.

While the physical setting of surface irrigation systems is more conducive to the emergence and persistence of farmer-based management compared with groundwater irrigation settings, as will be discussed below, scholars have noted the challenges that farmers face in maintaining their governing systems over time. In particular, scholars have begun to explore the effects of heterogeneity on the performance of farmer-governed surface irrigation systems (Bardhan and Dayton-Johnson, 2002; Ruttan, 2004). Bardhan and Dayton-Johnson (2002) reviewed the findings of several large *n* studies of farmer-managed irrigation systems that devoted attention to heterogeneity. Across all of the studies, the effects of heterogeneity were consistently negative (Bardhan and Dayton-Johnson, 2002, pp. 104–105). Income inequality and asymmetries between head-enders and tail-enders was associated with rule breaking, poor system maintenance and poor water delivery performance. Landholding inequalities were associated with poor canal maintenance. Differential earning opportunities among irrigators were associated with lower rule conformance and system maintenance.

Ruttan (2004) carefully reanalysed the data collected by Tang (1989, 1992) to explicitly examine the effects of different forms of heterogeneity on the performance of irrigation systems. In addition to the findings reported by Bardhan and Dayton-Johnson (2002), she found that variation in income had a negative effect on the likelihood that sanctions for rule breaking would be applied (Ruttan, 2004, p. 28). Ruttan (2004, p. 35) also found that sociocultural heterogeneity had a negative effect on rule conformance and system maintenance.

Causal mechanisms have not been identified. However, a number of attributes of appropriators could be at work. For instance, differential earning opportunities could affect the salience (appropriator attribute 1) of irrigation systems for farmers. If irrigated agriculture becomes a secondary income source for some farmers, they may be unwilling to devote resources to the irrigation system. Sociocultural heterogeneity could impact trust and reciprocity (appropriator attribute 4). If irrigators speak different languages, or if they come from different ethnic traditions, communicating and developing cooperative norms may be very difficult.

Groundwater irrigation

One of the most striking aspects of groundwater development is how rapidly it unfolds once a minimum level of technology and energy becomes widely available. Entry to groundwater basins is minimally restricted, with land ownership or leasing the only requirement for access. Depending on the setting, such as water table levels, even relatively poor farmers may access groundwater through inexpensive technologies. Even if farmers do not invest in their own wells, either because they do not have the necessary capital or their landholdings are too fragmented to justify a well, they may gain access to groundwater through markets (Shah, 1993; Dubash, 2002).

Groundwater is widely adopted because of its high value. For some farmers it may be the only source of irrigation water, either because they do not have access to surface water irrigation, or even if they are within the command area of a canal system they may not receive water. For many farmers, groundwater is more reliable, timely and adequate than the water they receive from canal systems. For other farmers, groundwater may be more 'convenient' than canal water, even if canal water is reliable and timely. A farmer who owns a well that provides enough water for irrigation needs may opt out of a communal system and its various requirements and responsibilities, such as contributing labour and materials for canal maintenance.

Compared to surface irrigation, developing groundwater entails substantially lower upfront production and transaction costs. Nature has provided a reservoir that is, at least initially, and in many cases, very easily accessed through a well. Consequently, production costs may be borne by a single individual or family. Transaction costs are also low. Farmers need not organize, bargain and negotiate over the development of an irrigation system and system design, or monitor and enforce commitments. Some farmers may form partnerships to raise the capital necessary to build a well; however, the transaction costs they face are substantially lower than those faced by farmers attempting to develop and build a surface irrigation system.

The physical setting of groundwater basins acts as a two-edged sword. Groundwater basins are a source of relatively inexpensive, reliable irrigation water that may be developed by individual families, once technology and energy are readily accessible. However, at the same time, the physical setting presents extraordinarily difficult challenges that may confound irrigators' attempts to address appropriation and provision problems. Unlike surface irrigation systems in which, through experience, observation and experimentation, the boundaries, capacity and variability of the system may be determined by irrigators, groundwater pumpers may never grasp the boundaries, structure or capacity of the 'invisible resource' they tap into without considerable assistance from engineers and hydrologists. Furthermore, unlike surface irrigation systems, in which irrigators may readily observe one another as they go about their daily farming activities, groundwater pumpers cannot easily determine the number of other pumpers, the capacities of their wells, how much water they are taking, the effects of their pumping on the overall productivity of the groundwater basin, etc. Thus, surface irrigators are more likely to develop norms of CPR management because of the information-rich environment within which they interact. Groundwater irrigators face an information-poor environment that makes it more difficult to develop self-governance norms (Rose, 2002).

Easy accessibility and limited information about the CPR combine to create significant barriers to the emergence of local-level governance of groundwater basins. Easy accessibility allows hundreds, if not thousands, of farmers across a groundwater basin to farm more intensively and to raise more high-valued crops. Only after farmers have invested heavily in wells and in productive activities and have come to appreciate and enjoy improved living standards do appropriation and provision problems emerge. As Bastasch (1998, p. 102) notes concerning groundwater development in the state of Oregon, located in northwest USA:

> Judgments about general groundwater availability, whether or not water tables are declining, impacts of new uses on nearby wells or streams and ultimately the public welfare itself, all hinge on good data. . . . When data are sufficient

to trigger groundwater controls, the damage has usually already been done and communities are heavily invested in the customary level of (over-)use.

Tackling appropriation and provision problems is not easy (i) because of information problems; (ii) because solutions often require farmers to limit well building and to adopt limits on the amount of water they may pump, which they may perceive as threatening their livelihoods; and (iii) because monitoring the use of an easily accessed, but invisible, resource is costly and difficult. Assuring thousands of farmers that their conservation actions will benefit them and will not be siphoned off by others is not likely to be easy.

The water development path in groundwater irrigation is very different than that in surface water irrigation. Farmers using groundwater do not have to organize, build and manage an irrigation system. They individually invest in wells that are used for irrigation. Farmers using groundwater are not confronted by appropriation or provision problems until long after they have become accustomed to the benefits of irrigation. When they do face dilemmas, they are more likely to face appropriation problems initially and provision problems later. Recalling Ostrom's resource and appropriator attributes, the following subsection argues that farmers are much more likely to organize to address appropriation problems than they are to address provision problems.[4] Farmers are likely to address provision problems only with considerable assistance from higher-level governments.

Appropriation problems

Appropriation problems are highly local compared to provision problems. They stem from actions and choices of appropriators whose effects become apparent within a short time frame, such as during an irrigation season.[5] Assignment problems, for instance, occur because people compete to use the most productive patches of a CPR and in the process they interfere with one another's harvesting activities. People may place wells too closely together, reducing the productive capacity of each of the wells. Technological externalities occur because the different harvesting techniques that people use interfere with one another. A high-capacity well may create a cone of depression that dries up surrounding shallow tube wells (Dubash, 2002).

Effectively and equitably addressing assignment problems and technological externalities requires considerable time and place information. Working knowledge of the types of technologies used, location of wells, uses made of the water, landholding patterns, actions causing the harvesting conflicts and so forth are necessary if rules that match a specific setting are to be devised. Such local knowledge resides with water users and not regulators. Shah (1993, pp. 129–132) notes the numerous difficulties regulators external to local communities have in devising effective rules. A common approach to address assignment problems is to impose well spacing rules. The rules only apply to more modern technologies, such as electric and diesel pumps, thus failing to afford any protection for more traditional technologies. Also, well spacing rules are enforced through banks that will not provide capital for the purchase of pumps unless well spacing rules are followed.[6] Farmers who can raise sufficient capital without relying on a bank can avoid well spacing rules.

Groundwater users can determine the causes and effects of spacing wells too close together or of allowing high-capacity wells to be situated among traditional water-lifting devices. Well owners and others who are dependent on those wells for water face incentives to problem-solve in order to protect their water sources. Depending on the social ties among groundwater users and experiences that they have had in engaging in other collective efforts, they may pursue strategies or undertake collective efforts to address assignment problems and technological externalities. For instance, Shah cites several examples of groundwater users effectively addressing such problems among themselves:

> The owners of grape orchards in Karnataka and Andhra Pradesh, for instance, are known to buy up neighbouring lots at premium prices to solve the problem of interference . . . in many parts of Gujarat, where localized water markets have assumed highly sophisticated forms, it is common for a well owner to lay underground pipelines through neighbours' fields at his own cost, and dissuade them from establishing their own wells by informal long-term contracts for the supply of water at mutually agreed prices.
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> (Shah, 1993, p. 7)

Appropriation externalities result from overuse of CPRs in the short term. Appropriation externalities in groundwater may often be spatially and temporally confined, allowing closely situated groundwater users to learn about the effects of pumping on water tables and on one another's pumping activities. That learning can form the basis for developing locally devised solutions to appropriation externalities.[7] For instance, Sadeque (2000) examines the development of water access and allocation rules to address appropriation externalities that emerge during the dry season in Bangladesh. Domestic water uses are provided for through shallow hand pumps. During the dry season, when groundwater demand is quite high, especially to irrigate the winter rice crop, the hand pumps dry up, leaving many households without a reliable and convenient source of water. As Sadeque (2000, p. 277) notes: 'In the competition for groundwater, simple, low-cost technologies like hand tube wells, used mostly for drinking and other domestic users, lose out. The perception of affected people of the low water table areas as victims of water deprivation is becoming marked, with acrimony towards irrigation'.

In a study of two villages in northwestern Bangladesh, Sadeque (2000) found conflict between domestic users and irrigators to be widespread during the dry season. However, he also found instances of cooperation and coordination emerging to address such conflicts. For instance, a series of shallow wells installed by an international non-profit development agency for domestic water uses are carefully governed by the households who participated in their development and who are responsible for their maintenance. During the dry season, the households impose restrictions on water use to tide families over. These restrictions also affect households who did not participate in the well project. While during the wet season non-participating families are not restricted in their access to the wells, during the dry season their access and use is strictly limited. They are allowed water after the households who govern the wells have their needs met. In addition, cooperation is emerging between villagers and owners of irrigation wells. Irrigation well owners allow villagers to take water from wells to meet basic consumption and cooking needs. Also, some well owners operate wells during early morning hours for the express use of villagers' domestic water needs. Sadeque (2000, p. 286) argues that such cooperation has emerged as a means of avoiding government regulation: 'People realized that negotiation was better than having controls imposed by central and distant authorities which might not be in the interest of either party. Additionally, regulations would result in bureaucratic control and therefore encourage corruption'.

In general, appropriation problems tend to be local in nature. Furthermore, the specific types of problems that emerge and their causes tend to be highly dependent on configurations of factors unique to each situation. Consequently, workable solutions are usually those grounded in specific time and place information – information that is readily available to groundwater users, but not to regulators. In addition, groundwater users often face incentives to invest in collaborative attempts to resolve such problems. Coordination may yield substantial benefits. Thus, compared with provision problems, which will be discussed later, communities are more likely to address appropriation problems.

It is not uncommon in the emerging literature on groundwater and irrigation to find instances of groundwater users addressing appropriation problems or having the capacity to address such problems. For instance, Shah (1993) describes a village in Junagadh district, Gujarat, in which numerous irrigation wells dry up during the dry season. Shah (1993) notes that farmers have a good understanding of how their wells function, and pursue a variety of strategies to ensure water availability throughout the dry period, but with mixed success. Some farmers are more innovative than others and appear to have developed approaches that are relatively successful. Shah (1993, pp. 164–165) argues that with a little assistance, primarily in the form of information, such as location and productivity of wells over time and various successful strategies that some farmers pursue, farmers could develop collective strategies to address appropriation problems and thereby increase agriculture productivity.

Appropriation problems that emerge in groundwater aquifers may be more manageable for irrigators because they exhibit some of the resource attributes identified by Ostrom (2001). Owners of closely situated wells, for instance, may readily realize the effect that their pumping has on one another as water levels in their wells decline under heavy pumping and begin to recover as they reduce their abstractions (attribute 2 – indicators; attribute 3 – predictability). In other words, it is possible through experience and careful observation to determine the onset and causes of appropriation problems.

Provision problems

Provision problems center on maintaining, recovering or enhancing the productive capacity of a CPR. Provision problems are the undesirable effects of intensive groundwater use (Llamas and Custido, 2003). As increasing volumes of water are pumped and water tables decline, a host of problems may emerge – pumping costs may increase, and wells may need to be replaced. Soil compaction and subsidence occur as water is withdrawn and the sand and gravel that compose the basin compact. If a groundwater basin is hydrologically connected to surface streams and rivers, surface water sources may dry up as water tables decline. As surface water sources are depleted, aquatic life, riparian vegetation and the birds and animals dependent on it die off (Blomquist, 1992).

Provision problems also include water quality. Basins may be polluted by industrial and municipal wastes, agricultural runoff and inadequate or improper disposal and treatment of human and animal waste. Declining water tables and water quality problems combine in the form of salt water intrusion. Coastal basins are highly susceptible to salt water intrusion. As water tables decline, the hydrologic pressure that the fresh water of the basin exerts against the salt water declines and salt water invades the fresh water. Although it is possible to halt the spread of salt water, it is very difficult and costly to reclaim portions of basins that have been polluted by salt water (Blomquist, 1992).

Provision problems do not only centre on undesirable effects of intensive resource use; they may also include the failure to take advantage of opportunities to enhance the productive capacities of CPRs. In the case of groundwater basins this typically takes the form of failing to use their full storage capacity. The unfilled storage space may be taken advantage of and surface water may be captured and placed underground for use at a later time. Of course, enhancement, if not carefully managed or attended to, can result in degradation of surface soils in the form of waterlogging, a common problem among some canal irrigation systems.

Provision problems are especially challenging to address, both for local communities of resource users and regional and national governments. Provision problems tend to be extensive – they are caused by, and affect, many groundwater users across an entire basin. It may take well owners years to detect longer-term declines of water tables, as water tables may vary from year to year. Even if well owners suspect long-term declines, their magnitudes and causes may be difficult to determine without considerable effort and investment in hydrogeologic studies. Such studies may take years to complete as the boundaries and structure of the basin must be determined, storage capacity identified, rates of natural recharge and pumping volumes computed, and identification of different water uses and their consumptive use of water measured (Kendy, 2003). No single well owner, or community of well owners, is likely to have the expertise or sufficient resources to invest in such studies.

Even if a community undertook such a study, and developed information about a basin, it is unlikely the community, acting alone, could resolve the problem of mining. Mining affects the multiple communities or clusters of groundwater users scattered across a basin and would require widespread participation to resolve. A similar argument may be made for the other types of provision problems. Developing reliable information about groundwater basins requires considerable time and investment in technical studies; it is not information that water users can develop by monitoring their wells and speaking with their neighbours.

Even if adequate models and data have been developed for a groundwater basin, sufficient uncertainty and a weak legal system may provide groundwater pumpers the opportunity to avoid making difficult choices. For instance, the Umatilla River basin, located in northeastern Oregon, has experienced water conflicts and controversies for several decades (Oregon Water Resources Department, 2003). The Umatilla River, a tributary of the Columbia River, is hydrologically connected to alluvial and hard-rock (basalt) aquifers. The basin also includes a number of closed, or contained, deep hard-rock aquifers. Most surface and groundwater diversions are devoted to agricultural enterprises – irrigated crops and dairies. As surface water supplies became fully appropriated and rights in surface water difficult to obtain, farmers turned to groundwater, which was not heavily regulated. By the 1960s, however, a variety of groundwater problems began to emerge in different parts of the basin such as sharp water table declines, unstable water levels and interference among water appropriators. Under Oregon law, the Oregon Water Resources Commission can impose various types of control measures to address groundwater problems. Since the mid-1970s, the Commission has created four critical groundwater areas and one classified groundwater area within portions of the basin (Oregon Water Resources Department, 2003). The primary effect of designating critical and classified areas is to stop or substantially reduce the number of new well permits issued. In other words, new water rights cannot be developed in critical groundwater areas. If an individual or business wants to obtain additional water supplies, they have to acquire existing water rights.

Currently, groundwater problems persist and in some instances are becoming more acute in the Umatilla basin. In some critical groundwater areas, water levels have stabilized; in many, the rate of water level declines has slowed; and in others, declines continue unabated (Oregon Department of Water Resources, 2003). Outside of the designated critical groundwater areas, groundwater problems are emerging. These results are not surprising. Restricting or closing areas experiencing groundwater problems to new groundwater development may work to slow the intensity of groundwater use. Adequately addressing groundwater problems will likely require careful management of existing uses as well.

The Oregon Water Resources Commission finds itself in a difficult spot. Through its ongoing groundwater monitoring program in the Umatilla basin, and through a variety of hydrogeologic studies that it has carried out, it has developed a working understanding of the basin and the location as well as likely causes of groundwater problems. However, it cannot readily act on that knowledge. Designating critical groundwater areas is very unpopular among water users and is actively resisted. For instance, it took the Commission almost 14 years to designate the Butter Creek critical groundwater area in the Umatilla basin and impose pumping controls, in part because groundwater users repeatedly challenged the Commission's actions in court (Bastasch, 1998). Administratively imposed controls are unlikely to lead to the sustainable use of the Umatilla basin. Currently, Umatilla county, which is home to the four critical groundwater areas in the Umatilla basin, is attempting to create a collaborative effort involving a wide variety of stakeholders to develop and implement alternative management actions (Umatilla County Groundwater Solutions Taskforce, 2005).

As the Umatilla River basin case illustrates, addressing provision problems requires that users limit their pumping of groundwater, forego some of the income and other valued activities that pumping made possible and switch to economic activities in which the consumptive uses of water are lower (Kendy, 2003). In addition to limiting groundwater pumping, groundwater users may also have to invest in public goods to recover or maintain the groundwater basin, such as recharge projects to increase the amount of water stored in the basin, or different sources of surface water to supplement groundwater. Given the very difficult physical, social and economic challenges surrounding provision problems and their solutions, groundwater users and governments, in general, will not be able to address such problems without assistance from each other.

Shah (1993) describes the situation of a coastal village of Mangrol *taluka*, Gujarat (a taluka is an administrative division in India below a district). The wells closest to the sea are saline and unfit for irrigation and the fields watered from those wells are barely productive. A middle belt of fields and wells are just beginning to experience salinity; however, it is expected that they too will succumb to the migrating sea water within a few years. A belt of fields and wells further inland have not yet experienced salinity. While the farmers know what is happening, they are reluctant to address the problem. For those whose fields have been rendered unproductive, limiting pumping is unlikely to be effective unless it is matched with active recharge programmes. They view their situation as hopeless; the resource has been so degraded that there is little that they can do that would make a difference. For those who are just beginning to experience salinity, they are unwilling to limit their pumping. They believe that limiting pumping would not protect them from salinity, unless everyone limited pumping. That would only occur if additional sources of water were developed, so that no one would have to cut back on water use. Those further inland are not experiencing problems and are not interested in developing solutions (Shah, 1993, pp. 168–169).[8]

Relations between irrigators and governments

Surface and groundwater irrigators need the assistance of higher levels of government if they are to adequately address provision problems. The form of that assistance is not entirely clear; however, accumulated evidence suggests the form such assistance should not take. The empirical evidence from studies of surface water irrigation systems is clear and consistent. Farmer-managed irrigation systems perform better than government-managed irrigation systems. Tang (1989, 1992, 1994) studied 47 irrigation systems located around the world and Lam (1998) studied more than 100 irrigation systems in Nepal. Both studies included farmer-managed and government-managed systems. In both studies, farmer-managed irrigation systems performed significantly better than did government-managed irrigation systems. Compared with government-managed systems, irrigators in farmer-managed systems paid close attention to boundaries and to exclusion, attempting to more closely match water supply with demand. Furthermore, irrigators in farmer-managed systems devised more rich and complex sets of rules to govern access, water allocation and contributions to maintenance that better matched the physical and social settings. In addition, irrigators in farmer-managed systems had a better understanding of their systems, and were more likely to engage in attempts to revise the rules. Also, irrigators in farmer-managed systems have devised active monitoring systems, and were therefore more likely to be sanctioned if caught violating the rules. In general, the work of Tang and Lam suggests that farmer-managed systems outperform government-managed systems in terms of system maintenance, adequacy of water supply and rule-following behaviour.

Evidence from groundwater irrigation is suggestive, but few systematic comparative institutional studies of different forms of well-governing arrangements have been conducted. Shah (1993) cites a study conducted by Lowdermilk *et al*. (1978) in Pakistan of crop yields under different levels of control of water sources. Among groundwater users, crop yields were highest among farmers who owned their own wells and lowest among farmers who depended on public tube wells (Shah, 1993, p. 29). Shah (1993, p. 29) states that a number of studies have been conducted in India that suggest that farmers prefer water from privately owned tube wells over publicly owned tube wells. This is so, Shah (1993, p. 29) argues, because water service from state tube wells is inferior to that of private tube wells. State tube wells suffer from poor maintenance, long shutdown periods, erratic power supplies and so forth. The root of the problem lies in management. Shah (1993, p. 30) concludes: 'A state tubewell operator is in reality accountable to no one, for he can neither be punished nor rewarded by the community he is meant to serve'.

A case study, developed by Singh (1991), of the construction, operation and maintenance of a public tube well used for irrigation in Uttar Pradesh, India, clearly illustrates Shah's arguments. The well and its associated infrastructure were designed and built by the government irrigation department. The department is supposed to operate and maintain the well. Water allocation and distribution was turned over to farmers' committees formed by the government irrigation department. The well and its infrastructure are not well matched to the patterns of landownership. According to Singh (1991), government officials face few incentives to operate and maintain the well appropriately, water service is erratic and the farmers' organizations have slowly fallen apart.[9] The evidence from studies of well ownership and operation appears to coincide with the evidence from canal irrigation systems. Government-operated canal systems and wells perform poorly relative to farmer-operated canal systems and wells. What is not well understood in relation to wells, and consequently needs more study, is the relative performance of different types of farmer-based ownership and management structures.[10]

If governments perform poorly in the direct production and management of surface irrigation systems and wells, what should the roles of governments be? As Stern *et al*. (2002) note, one of the most understudied areas in the field of CPR governance is the linkages and relations among local communities and higher-level governments and organizations. Young (2002) argues that developing productive, complementary relations is challenging because local communities and regional and national governments often have conflicting and competing interests in how CPRs should be governed and used. For instance, national governments tend to view CPRs as valuable for producing national revenues, either through granting concessions to multinational corporations to harvest timber, or to encouraging farmers to raise multiple cash crops. Local resource users tend to view CPRs as the foundation for their livelihood and are not as interested in generating foreign exchange, or other revenue generating activities for their national governments or government officials. Young (2002) urges giving greater weight to local interests and greater decision-making authority to local resource users rather than external government officials. Local resource users are more likely to attempt to address their most pressing needs, which are directly related to the productivity of CPRs.

Generally, productive relations among different levels of government tap into the strengths of local communities and higher-level organizations and match them to the particular CPR dilemma facing the resource users. Appropriation problems, as argued earlier, tend to be localized, with both causes and solutions hinging on time and place information. Since resource users have ready access to, and familiarity with, time and place information, they are likely to be in a better position to address such problems. Consequently, government roles should be more limited, such as assisting resource users in developing information about activities and practices contributing to appropriation problems, providing users with access to conflict resolution mechanisms, and recognizing as legitimate the rules that resource users devise. Supportive roles for governments may also involve redesigning or repealing rules that adversely affect the ability of resource users to address appropriation problems. As Shah (1993; see also Shah, Chapter 2, this volume) so forcefully argued, electric board pricing policies have a powerful effect on the actions of owners of electric wells. Pricing policies may need to be redesigned to provide more appropriate incentives for well owners to address appropriation problems.

Provision problems call for the development of different types of productive and complementary relations. The causes of provision problems tend to extend across a basin, affecting many communities of groundwater users and not single communities, as appropriation problems do. Solutions, too, will often require the active participation of many of the groundwater users scattered across the basin. Consequently, communities of groundwater users will likely need the active assistance of higher levels of government in order to adequately address provision problems.

As Moench (2004) has convincingly argued, one of the most critical roles for governments to play in addressing provision problems is developing appropriate and reliable sources of groundwater information. For instance, many national governments develop and rely on 'crudely estimated extraction and recharge balances'. Such estimates are often based on outdated information and educated guesses about well numbers and extraction rates. Furthermore, water balance estimates are made at too general a level to be useful to support local management actions. Moench (2004) suggests providing direct measures of groundwater conditions, such as trends in water table levels, which groundwater users are most interested in and most affected by. Kendy (2003) too rejects the widespread practice of estimating and using water balance estimates. Instead, governments should focus on measuring the amounts of water consumed, not extracted. Water consumption is a more accurate and useful measure of water use.

Given the public goods nature of solutions to provision problems, such as developing accurate and timely data about groundwater basins and groundwater use, or developing alternative sources of water, the temptation may be to assign primary responsibility for provision problems to governments. That, however, would be a mistake, if for no other reason than the solutions and the information on which the solutions will be based, to be workable, require the active participation of groundwater users. For instance, effective solutions that slow or eliminate declines in water tables, or that stop the intrusion of salt water into a basin, require that groundwater users accept limits on wells and pumping, and explore and adopt activities that reduce water consumption. Furthermore, developing alternative sources of water will only have the desired effect of reducing or eliminating the undesirable effects of intensive groundwater use if groundwater users switch to the alternative sources and reduce their groundwater pumping.

Provision problems are difficult to resolve. In many instances in western USA, states and water users have, at best, managed to slow the progression of provision problems (Schlager, 2005). In many fewer instances, states and water users have managed to resolve provision problems and restore groundwater basins to a very productive level of functioning. Blomquist (1992) details several case studies of groundwater basins in southern California in a handful of which groundwater users, city and county governments as well as the state of California were able to arrest groundwater mining and salt water intrusion. For instance, West Basin underlies much of the coastal portion of Los Angeles county. West Basin is relatively vulnerable. It adjoins the Pacific Ocean on one side and, because the basin is covered with impermeable clays, recharge occurs almost entirely through water discharges from Central basin, the groundwater basin directly upstream of it (Blomquist, 1992, p. 33). West Basin began to experience degradation problems in 1912. By the end of the 1950s, 'with water levels down 200 feet in some places, an accumulated over-draft of more than 800,000 acre-feet, and a half-million acre-feet of salt-water underlying thousands of acres of land and advancing on two fronts, the groundwater supply in West Basin was threatened with destruction' (Blomquist, 1992, p. 102). Over the course of 50 years, groundwater users, local and regional governments, California courts and the legislature were able to craft a series of solutions that arrested groundwater mining and halted salt water intrusion. The solutions involved limiting pumping, although not to the level of natural recharge; building surface water projects to import water from other areas of the state; building and operating recharge basins in the Central basin; and investing in a series of injection wells in which a barrier of fresh water was built to halt the spread of salt water. Through a combination of pumping limits, which were developed by groundwater users bargaining with one another in the shadow of a state court, and the development of a series of public goods that required the close coordination of state and local agencies and groundwater users, some southern California basins have been protected.

Work by Lopez-Gunn (2003) illustrates, however, the delicate relations between groundwater users and regional and national government agencies. Lopez-Gunn explored three adjoining groundwater basins in Spain, only one of which is actively governed in such a way that in the long term it is likely to halt water table declines, even though pumpers and government officials in all three basins have access to similar types of groundwater management tools (Lopez-Gunn, 2003, p. 370).

The three groundwater basins are located in the interior region known as Castilla La Mancha. The region is home to three of the largest aquifers in Spain, two of which have been declared overused under the Spanish Water Act (Lopez-Gunn, 2003, p. 369). A declaration of overuse triggers a variety of actions, including the mandatory formation of a water user association and the adoption and implementation of strict pumping regulations. Thus, the relations between well owners and government agencies differ. In eastern La Mancha, one basin that has not been declared over used, well owners voluntarily formed their own water user association, which was recognized by the state regional water authority. The water user association includes all well owners in the basin and has developed its own set of pumping regulations, which have been recognized by the state. Furthermore, the water user association and the regional water authority are working together to define and allocate water rights, and they work together to actively monitor and sanction use to rule violators (Lopez-Gunn, 2003, p. 372).

Relations between well owners and government agencies are markedly different in the other two basins – western Mancha and Campo de Montiel. Water user associations were imposed in both basins and their membership does not encompass all well owners. Strict management plans were also imposed. In the case of western Mancha, rules are regularly violated and thousands of unsanctioned wells have been built. Monitoring and sanctioning are exercised entirely by the regional water authority, with the water user association turning a blind eye to rule violations (Lopez-Gunn, 2003, pp. 371–372). Surprisingly, however, water tables have stabilized in both basins. Lopez-Gunn (2003, p. 377) attributes this to a rich subsidy programme that pays farmers to limit pumping. Once the subsidy programme ends, Lopez-Gunn (2003, p. 377) expects water tables to decline once again.

The form that productive and complementary relations among communities of groundwater users and higher levels of government are likely to take will vary depending on the nature of the CPR dilemma to be addressed. In many instances, appropriation problems can be addressed by groundwater users with more limited support from governments. In general, governments can be most helpful by encouraging resource users to solve their appropriation problems and by reducing any regulatory or legal barriers standing in the way of self-governing solutions. Provision problems are much more difficult and costly to address and require close coordination between resource users and governments. Effective solutions require the expertise, resources and authority of higher-level governments to supply public goods, and the expertise,resources and authority of resource users to change how and how much they use groundwater and to help shape the type, form and location of public goods provided by governments.

Conclusion

A growing body of groundwater case studies demonstrates that groundwater users are capable of devising solutions to CPR dilemmas that are local in nature. More complex and extensive CPR dilemmas, however, often require more collaborative efforts between resource users and regional and national governments.

The shape and form of productive and complementary relations among resource users and different organizations and governments is not well understood and requires substantial investigation. Groundwater basins and large-scale canal irrigation systems present challenging governance issues that are often avoided, ignored or made to disappear within the black box of integrated management (Chambers, 1988; Ostrom, 1992; Blomquist and Schlager, 2005). Even if a workable set of arrangements are devised that adequately address appropriation and provision problems, governance challenges do not end. As Ostrom (1992, p. 63) argues:

> It is necessary to stress the ongoing nature of the process of crafting institutions, since it is so frequently described (if discussed at all) as a one-shot effort to organize farmers. . . . Without the continuing capacity to match new rules to new circumstances, successful irrigation systems face considerable difficulties in coping with the diverse environmental and strategic threats that arise in dynamic systems.

Notes

1 See Kendy (2003) for a discussion of confusion surrounding the concept of sustainability in relation to groundwater aquifers.

2 The attributes are an initial effort to identify proximate factors that directly affect self-organizing efforts among resource users. The factors require greater conceptual development and empirical testing before they may be strictly relied upon (Ostrom, 2001; Agrawal, 2002). Conceptually, the physical characteristics implicitly assume that appropriation externalities, or specific forms of provision problems, are the central problem to be addressed. For instance, feasibility of improvement centres on degradation of the resource, and predictability centres on resource flows. However, the attributes of the physical system may be interpreted more broadly to include the components and structure of resource systems and not just flows. This would allow for a wider range of problems to be captured by the characteristics.

3 Among the many criticisms of government-built and -operated surface irrigation systems is that little attention is paid to provision or appropriation dilemmas and their linkages. Once a system is built, few resources are devoted to maintaining it, and in many systems irrigators are not asked to contribute to upkeep. Also, appropriation dilemmas often emerge as the system is being built. Those at the head of the command area are often allowed to take as much water as they please, as the rest of the

system is being built. Later, they are reluctant to limit their water use. A vicious circle readily emerges: as appropriation dilemmas intensify, farmers face few incentives to contribute to system maintenance; as the system continues to decay, farmers face few incentives to take water in an orderly manner.

4 As one reviewer noted, irrigators are more likely to develop rules that address appropriation problems in alluvial aquifer settings and not hard-rock aquifer settings. In alluvial aquifers, pumpers can more readily identify the effects of their pumping on others and on the aquifer. I am grateful for the reviewer's insight.

5 As Shah (1993, p. 135) explains: 'Externalities associated with private development and exploitation of groundwater resources – and the environmental ill effects they normally produce – are generally considered and analysed from a macro perspective. The source of the problem, however, is micro and can be traced to characteristic behavioural patterns of farmers as economic agents'.

6 As a reviewer noted, well spacing rules may also be enforced through limiting electricity connections.

7 Findings from studies of CPRs such as fisheries suggest that resource users find appropriation externalities more challenging to address than assignment problems and technological externalities. In the case of fisheries, fish populations fluctuate unpredictably and fishermen find it difficult to relate their harvesting activities with fish abundance or scarcity (Schlager, 1990, 1994). The 'noise' of fish population dynamics drowns out the effects of harvesting on fish stocks. While local fishing communities do a relatively good job of addressing assignment problems and technological externalities, they rarely attempt to directly address production externalities (Schlager, 1994). Groundwater users may find appropriation externalities less challenging to address than fishermen because the interaction between pumping and water tables is more direct and observable than is the interaction between fishing and fish populations.

8 The exception to the claim that in general communities will not organize to address provision problems appears to provide support for it. Sakthivadivel (Chapter 10, this volume) notes the emergence of a people's groundwater recharge movement in India. Communities in a few states are actively investing in small-scale recharge facilities, or they are using existing canal irrigation infrastructure, such as canals, tanks and reservoirs, to percolate water underground. The purpose of such activities is to maintain the productivity of shallow wells. The water from the wells is used to ensure a reliable source of drinking water or to ensure irrigation water over the course of a season. The communities are able to capture most of the water that they recharge for their own uses. They are not engaged in attempts to restore, maintain or enhance the productivity of the groundwater aquifer as a whole. Rather, they are engaged in annual storage projects.

9 A number of other studies have noted the poor performance of government-owned tube wells (see e.g. Johnson, 1986; Meinzen-Dick, 2000).

10 Dubash (2002) provides a careful comparative institutional analysis of varying and changing groundwater exchange relations across two villages.

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