9 When the Well Runs Dry but Livelihood Continues: Adaptive Responses to Groundwater Depletion and Strategies for Mitigating the Associated Impacts

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Core Arguments

Groundwater level decline, pollution and quality degradation are widely recognized as major emerging problems in many parts of the world. This recognition has not, however, translated into equally wide management responses. The reverse has, in fact, often proved true. In parts of India, groundwater overextraction and quality decline have been recognized since the 1970s (United Nations Development Program, 1976; Bandara, 1977). With a few possible exceptions, little has been done to regulate groundwater extraction or control degradation of the resource base. This is also the case across Latin America and Africa and in countries as diverse as China, Spain and the western USA (Ballester *et al*., Chapter 6; Masiyandima and Giordano, Chapter 5; Wang *et al*., Chapter 3; Llamas and Garrido, Chapter 13; and Schlager, Chapter 7, this volume, respectively). This situation is, in fact, mirrored across much of the globe.

This chapter argues that the lack of progress in implementing conventional management responses to groundwater problems reflects a combination of technical, social, behavioural and organizational limitations that are inherent features in most contexts. Such limitations are often compounded by the growth of competing demands and social 'conflict' over access to the resource and the manner in which it is used. In some cases, such conflicts are fundamental, i.e. one set of objectives or uses cannot be satisfied unless other sets of objectives and uses are modified in fundamental ways. Recognizing the importance of an emerging problem or the 'need' for management does not change the fundamental nature of the limitations or reduce the inherent nature of some conflicts. As a result, whatever the 'need' for management, alternative

 The Agricultural Groundwater Revolution: Opportunities and Threats to Development (M. Giordano and K.G. Villholth)

or complementary approaches that are adapted to the inherent limitations present in a given context are often essential. In many cases, such adaptive approaches will involve courses of action that fall outside the limits of conventional groundwater management. Furthermore, at least in some cases, adaptive approaches may be more effective in addressing the societal impacts of groundwater problems than even the best-implemented forms of conventional 'water-focused' management.

What is an adaptive approach? Research conducted by the Institute for Social and Environmental Transition (ISET) and our partners in India and other locations (Moench, 1994; Moench *et al.*, 1999, 2003) suggests that adaptation is a continuous process and adaptive approaches need to be designed in ways that:

- Encourage evolution of strategies as conditions change over time or, to put it another way, have in-built mechanisms to respond to ongoing change processes;
- Reflect the social, political, economic and technical context in which groundwater problems are occurring and the types of response – including or excluding conventional management – that are likely viable within that context;
- Respond to inherent limitations on scientific knowledge;
- Build off the incentives and courses of action households, communities and regions are already undertaking or have a strong incentive to undertake in response to a given problem;
- Are strategic in that they focus on core objectives (livelihood and environmental values as opposed to specific groundwater parameters) and respond to the spatial and temporal factors that influence the probable effectiveness of response strategies rather than attempting to be 'comprehensive' or 'fully integrated'.

The above criteria indicate that adaptive responses do not exclude conventional water management techniques. Instead, they identify such conventional techniques as one among many avenues for responding to groundwater problems. Conventional 'water-focused' techniques are, in essence, one subset of a much larger set of techniques, each of which may be more or less effective in any given context for addressing core social objectives that are threatened by groundwater problems. Strategic 'adaptive' approaches can be viewed as including the full array of conventional water-focused management techniques while also moving beyond them to encompass a potentially very wide range of interventions designed to reduce or eliminate the negative impact of groundwater conditions on livelihoods and environmental values. This can involve fundamental shifts in livelihoods (e.g. changing from agricultural to non-farm systems) or it can involve shifts within livelihoods (e.g. crop choice or technology shifting within agriculture). Furthermore, the element of change or 'process' is central. Strategies need to recognize and be able to respond as economic, social, hydrological and other conditions change over time. The core difference between the approaches suggested here and most conventional management is the explicit focus on: (i) core livelihood and environmental objectives rather than groundwater per se; (ii) the inclusion of response strategies that do not attempt to influence groundwater resource conditions directly; (iii) the 'strategic' element – tailoring water- and non-water-related responses to a given moment and socio-ecological context rather than attempting to develop 'comprehensive' 'integrated' strategies; and (iv) the concept and role of adaptation – the manner in which strategies can continuously be shaped to reflect ongoing change processes. This last element – a tautology at present (adaptive approaches are defined as approaches that focus on adaptation) – is explored in detail later.

This chapter begins with a section that briefly outlines a series of key factors that limit the viability of conventional approaches to groundwater management in many, if not most, contexts. Following this, the conceptual foundations for alternative, more adaptive approaches to groundwater management and the mitigation of impacts from emerging groundwater problems are discussed. Illustrative examples of adaptation drawn from specific field areas in India, Mexico and western USA are presented next. A diverse selection of examples has been utilized to highlight both the similarity of many key issues and the fact that solutions appropriate in one region usually cannot be generalized to other areas. The final section outlines strategic implications for organizations seeking to catalyse effective responses to groundwater problems.

The Limits of Management

Conventional approaches to the sustainable management of groundwater supply generally consist – at least on the conceptual level – of techniques designed to balance extraction within any given aquifer to levels that do not exceed long-term recharge rates, i.e. on the 'sustained yield'. Extraction levels that exceed recharge rates over the short term – e.g. during a 3- to 4-year drought period – should ideally be balanced by other periods when high levels of precipitation or artificial recharge activities ensure that recharge exceeds extraction. This approach is often enshrined in law. According to Llamas and Garrido (Chapter 13, this volume), for example, the Spanish Water Act of 1985 'basically considers an aquifer to be overexploited when the pumpage is close or larger than the natural recharge'. This is also the case with estimation procedures in India (World Bank and Ministry of Water Resources – Government of India, 1998). While the validity of the sustained yield concept is widely debated (Llamas and Garrido, Chapter 13, this volume), in practice it generally forms the basis for most legislation and management attempts designed to regulate groundwater supply.

The above ideal is rarely met. In some cases this is an inherent characteristic of the resource: natural recharge rates can be extremely low and extraction is, in essence, an inherently unsustainable activity that involves mining a finite supply. Such situations are common in many arid parts of the world. Where they exist, the technically 'ideal' goal of groundwater supply management would consist of a planned depletion schedule along with longer-term strategies for replacing supplies or shifting demand as the aquifer is depleted. More importantly from the perspective of this chapter, however, are the much more common situations in which substantial natural and/or induced recharge *does occur* but extraction rates are well above sustainable levels. In these situations the ideal image of managing aquifers to achieve long-term sustained yields may be technically feasible but is in fact rarely achieved. Even where aquifer recharge rates are known to be extremely low, effective attempts to develop depletion schedules and manage extraction to achieve them are extremely rare.

The reasons why management rarely reflects technical ideals are important to understand. They may reflect a fundamental disjuncture between management concepts and social, economic and scientific ground realities (Moench, 1994, 2002, 2004; Burke and Moench, 2000 COMMAN, 2004). While a detailed discussion of the reasons that management concepts often fail is beyond the scope of this chapter, key elements include:

1. *Timescales and the rapid process of social and economic change*. Conventional approaches to groundwater management necessitate an inherently long-term perspective. Precipitation and recharge fluctuate greatly over periods of time that often involve decades. Groundwater systems are lagged, and the effectiveness of conventional management approaches depends on the ability to take action on a sustained and consistent basis. The factors driving demand for groundwater and, more importantly, the incentives local populations have to participate in management and the vulnerability of livelihood to groundwater conditions are generally influenced by factors that operate on much shorter timescales. In many parts of the world, rapid processes of economic, social and political change have a major impact on the nature of local livelihood systems and, through those systems, on groundwater dependence and the incentives individuals, communities and regions have to invest in longer-term groundwater management initiatives. The short-term nature of incentives conflicts with long-term management ideals.
2. *Inherent scientific limitations on the ability to quantify water availability and hydrologic dynamics within aquifers*. These include: (i) the absence of data, particularly the long-term monitoring information required to define basic hydrological and water use parameters; (ii) ongoing climatic and other change processes; and (iii) the hydrogeological complexity of aquifer systems. As a result, the dynamics of even the best-monitored systems in wealthy locations such as western USA are often poorly understood. Where monitoring systems are weak, as they are throughout much of the less industrialized world, the scientific understanding of aquifer systems necessary for conventional management is even less sound. As Llamas and Garrido (Chapter 13, this volume) note, 'uncertainty is an integral part of water management'. As a result, response strategies need to be developed in ways that incorporate, rather than attempt to eliminate, such uncertainties.
3. *Mismatches between the scale and boundaries of aquifer systems and the scale and boundaries of human institutions*. The fact that human institutions rarely match with the boundaries of hydrologic systems has been widely recognized for decades as a critical factor constraining water management and underlies the emphasis on developing watershed institutions as the criti-

cal unit for management that runs throughout the integrated water resources management (IWRM) literature. This constraint is particularly severe in the case of groundwater where boundaries may not have any surface representation and rarely, if ever, match with existing human institutions. Furthermore, in many cases the core 'human unit' determining groundwater use lies at an extremely micro-level – the individual well owner. As a result, groundwater conditions are affected by the aggregate demand coming from thousands of individual disconnected decision makers.

4. *Disjuncture between the factors that have been shown through recent research on common property as important for the formation of effective management institutions and the nature of groundwater occurrence and use*. A substantial literature has developed over the last two decades that documents the conditions common to successful management of common pool resources (see e.g. BOSTID, 1986; Ostrom, 1990, 1993; Bromley, 1998; Schlager and Blomquist, 2000; and Schlager, Chapter 7, this volume) such as groundwater. Some of the most important factors that emerge regularly in this literature include: (i) a high level of – and broadly felt – need for management; (ii) clear systems of rights or rules-in-use governing access and resource utilization; (iii) clear boundaries on the resource and the user group; (iv) mechanisms to control free riders (including ways to restrict access for non-members or those not holding resource use rights); (v) clear systems for monitoring resource conditions and use including documentation of the benefits from management; (vi) relative economic and cultural homogeneity among group members; (vii) a proportional equivalence between the costs and benefits from management; (viii) effective mechanisms for enforcement; and (ix) small primary management group size often accompanied by the nesting of institutions where some management functions need to occur at regional or system scales rather than local scales. These conditions are generally violated in groundwater management contexts.

The above issues may be conceptually clear, but the practical constraints they impose on management are rarely recognized. These constraints are illustrated below using examples from India, Mexico and western USA.

In India, debates over the need for groundwater regulation and management have been ongoing since the mid-1970s. While these have led to numerous proposals for augmentation, regulation, rights reform and the implementation of economic incentives for efficient use, with the exception of extensive efforts to harvest and recharge rainwater, relatively few reforms have actually been implemented (World Bank and Ministry of Water Resources – Government of India, 1998; Shah *et al*., 2003a; COMMAN, 2004). Even reduction of electricity subsidies to agriculture – which are widely recognized as a major incentive encouraging groundwater overdraft – and/or reforming tariff structures to reduce such incentives has proved difficult (World Bank, 1999; Kumar and Singh, 2001; Shah *et al*., 2003b). Why has the initiation of management been so difficult? While a very wide variety of factors play a role, key elements include:

1. The extremely large number of wells. Recent estimates suggest that the number of wells exceeds 20 million (World Bank and Ministry of Water Resources – Government of India, 1998). As a consequence, tens of thousands of individuals often use any given aquifer, and the ability of the government to register wells or move beyond this to establish and enforce volumetric rights systems is extremely limited (Dhawan, 1990; Moench, 1991, 1994; Moench *et al*., 1997). Similarly, the large number of users complicates virtually all of the factors known to contribute to management through common property approaches.

2. The rapid pace of economic and demographic change affecting much of the country. India is undergoing a process of 'peri-urbanization' involving, in many areas, diversification in the nature of rural livelihoods to include many non-agricultural elements (Moench and Dixit, 2004). Nevertheless, at present many rural livelihoods are heavily dependent on groundwater-irrigated agriculture. This appears to have two effects. First, because people depend on agriculture to meet current needs, management activities that would require reductions in groundwater use are seen as having an immediate impact on current income. Second, despite current dependency, growing aspirations and the vision of opportunities beyond agriculture limit user concerns over the longer-term impact groundwater depletion may have. In combination, these factors reduce the incentive to manage groundwater resources in order to protect livelihood in the future while increasing the incentive to exploit the resource base to support current needs.

3. Limited scientific information on groundwater conditions. Although groundwater monitoring networks were established in parts of India during the 1970s and have been substantially expanded since then under programmes such as the 'Hydrology Project', basic scientific information on aquifer conditions is often extremely limited (World Bank and Ministry of Water Resources – Government of India, 1998). The problem is compounded because key elements in any water balance equation – such as evapotranspiration by native vegetation – are not estimated. Furthermore much of India is underlain by hard-rock systems that can make the identification and modelling of groundwater flow systems extremely complex – a factor noted more than a decade ago (Narasimhan, 1990).

Overall, conditions in India clearly illustrate many of the factors constraining conventional management approaches.

The difficulties inherent in establishing the information base required for conventional management approaches are also clearly illustrated in the case of Mexico. There, despite substantial support from the World Bank, even the precursor activities required for management have not proceeded rapidly or smoothly. Although Mexico has invested more than a decade of effort on well registration, it has so far proved impossible to develop a systematic register of operational wells (Garduno, 1999; Foster *et al*., 2004). Registration of wells is an essential first step required to enable the state (or any other organization) to monitor any water rights or regulatory system. A recent review summarizes the situation well:

> In the 1990s major efforts were made by federal government (the CNA) to register and administer the groundwater abstraction and use rights system. However, lack

> of local operational resources and failure to mobilize user cooperation has eroded the system. Lack of consistent enforcement has meant that those who decide not to follow the rules are usually not sanctioned, thus deterring the rest of the user community to cooperate or comply with the regulation processes.
>
> Attempts to constrain groundwater exploitation in Guanajuato included three periods of nominal 'waterwell drilling bans', but the number of deep wells appears to have more or less doubled during each of these periods.
>
> (Foster *et al*., 2004)

This note also highlights scientific uncertainties and voices concern that attempts to develop local management institutions (called COTAS) may 'flounder because of lack of action on complementary "top-down" legal procedures and policy decisions'(Foster *et al*., 2004, p. 8). Different pieces of the information and institutional environment are moving at different rates and are, in fact, being driven by different social forces. This disjuncture, one that is often inherent in social processes operating at local and national levels, undermines the development of the consistent information and institutional framework required for groundwater management. Overall, major difficulties in developing a systematic register and the institutions for groundwater management have emerged despite the fact that the number of wells in Mexico is much smaller and typical well capacities are much larger than in India – factors that should, at least conceptually, make the task of registration and institutional development substantially more straightforward (Shah *et al*., 2000).

The problems in India and Mexico are similar to those found in the USA and Europe. In Spain, Llamas and Garrido (Chapter 13, this volume) point out that only 2 out of 17 'groundwater user communities' that are supposed to manage groundwater in areas identified as 'overexploited' are operative. In western USA, while some systems for groundwater management that are at least partially effective have evolved in locations such as the Central Valley of California, these systems involve a very limited number of actors – in the Central Valley case between 100 and 200 large utilities, corporate and agricultural entities – that pump most of the water (Blomquist, 1992). Groundwater resources in the Central Valley remain, however, under stress. As T.N. Narasimhan, a noted groundwater expert in California, comments: 'Major regions of California such as the San Joaquin, Salinas, Owens, and Santa Clara Valleys have supported extensive groundwater use by agriculture, industry and municipalities. These resources are also presently over-developed' (Narasimhan and Kretsinger, 2003). Thus, despite some success in organizing a management system, sustainability of the groundwater resource base remains far from assured. In other regions, management is even less effective. In Arizona, for example, strong regulatory agencies were established in the 1980s to address overdraft in what were termed 'active management areas' (AMAs). This was done as part of a quid pro quo for federal investment in the Central Arizona Project, a major diversion to supply water to Arizona from the Colorado River. Despite this, groundwater levels continue to fall under many major cities in Arizona and overdraft concerns have not been resolved. The situation is of particular concern in the context of climatic variability and change where 'safe yield' policies are intended to provide a solid water-supply buffer that could reduce drought impacts. According to the US Global Change Research Program:

> A team from the University of Arizona analyzed the water budgets of several Arizona cities to determine how severe the drought impacts would be from the deepest one-year (1900), five-year (1900–19), and ten-year (1946–1955) droughts on record. Case study sites included two of the fastest growing areas in the U.S. – the Phoenix and Tuscon Active Management Areas (AMAs). In these AMAs, stringent groundwater management is mandated under the 1980 Arizona Groundwater Management Act. The study showed that, even under assumptions of continuing 'average' climate conditions, the possibility of achieving 'safe yield,' as articulated in the Act (i.e., supply and demand are in balance), remains uncertain.[1]

More to the point, in many areas information that is fundamental for effective management remains unavailable. Climatic variability and change predictions are widely recognized as involving high levels of uncertainty. As a result, defining 'safe yield' in locations such as the example from Arizona is, at best, a complex effort that will not resolve uncertainties in the information needed for management. This is, however, equally often the case even when climate change is not a central concern. Take, for example, the case of the city of Albuquerque and the Middle Rio Grande. Despite the relatively strong institutional capacity of the US Geological Survey (USGS) and the New Mexico State Engineer's office – which are responsible for groundwater monitoring – a recent report on the region states:

> Until the locations and pumping characteristics of the major supply wells in the Middle Rio Grande Basin are known with more certainty, estimates of these important parameters will introduce error into simulations and estimations of ground-water behavior. However, it may be impossible to know exactly the locations of all domestic-supply wells in the basin and the volumes of water pumped from each.
>
> (Bartolino and Cole, 2003, p. 128)

The report goes on to highlight uncertainties related to the quantity and quality of water available deeper in the basin and, probably more importantly, difficulties in measuring evapotranspiration from the *bosque* riparian vegetation a habitat that has recently been recognized as having an important environmental value. According to the report: '[E]stimates of evapotranspiration in the Middle Rio Grande Basin vary because it is a difficult parameter to measure directly. Because maintenance of the *bosque* has become a priority for esthetic and wildlife purposes, the measurement of actual evapotranspiration is of critical importance' (Bartolino and Cole, 2003). This quote illustrates two points: (i) the inherent uncertainty (despite ongoing efforts to improve estimates) in the ability to measure and monitor key parameters (domestic pumping and evapotranspiration); and (ii) the fact that new values emerge over time – historically the *bosque* was not widely recognized as having a key environmental value.

How important are such factors in the overall water balance equation and how might they affect management institutions? According to the USGS: 'The Middle Rio Grande water budget of the Action Committee of the Middle Rio

Grande Water Assembly (1999) estimated that between 75,000 and 195,000 acre-feet of water is lost annually to evapotranspiration by the *bosque* in the river reach between Otowi (north of the basin) and San Acacia' (Bartolino and Cole, 2003, p. 84). This is equivalent to 24–63% of the total groundwater withdrawals of 309,890 acre-feet reported in 1995 for the region (Bartolino and Cole, 2003, p. 61). Overall, despite intensive research on groundwater in the Middle Rio Grande that dates back at least to the 1950s, new issues are continuously emerging and fundamental scientific uncertainties regarding key parameters in the water balance equation remain high. The science is weak, and the institutions even weaker. It is, for example, extremely difficult to allocate 'secure' water rights when uncertainties regarding the quantity available account for almost 40% of current extraction.

This uncertainty has huge economic and political implications. As with many cities, Albuquerque is growing rapidly and is facing a situation in which urban and industrial demands are competing heavily with established agricultural users for access to water. As part of this general dynamic, Albuquerque has encouraged the development of new high-tech industries – including an Intel factory to produce next-generation computer chips. This new industry, the cutting edge of technological development, also happens to require substantial amounts of pure water. Steve Reynolds, who was the New Mexico state engineer for 30 years, wrote in 1980: 'Albuquerque is probably better situated with respect to water than any large city in the Southwest'.[2] With substantial water available, rapid expansion of water-intensive high-tech industries appeared to be a logical step. In 1993, following substantial investment in plant facilities, Intel requested a permit to extract 4500 acre-feet of groundwater to support its operations. This request happened to arrive at the same time that a new USGS report was released, showing that the city was pumping groundwater at nearly three times the natural replenishment rate.[3] The economic and political consequences continue to reverberate. Scientific uncertainty had, in essence, allowed (or perhaps been used) as a mechanism to enable forms of development that were ultimately unsustainable.

The above situation is common in many other parts of western USA and has a major impact on the technical ability to manage groundwater resources in an effective manner. Furthermore, limitations of technical understanding often contribute substantively to political limitations on the ability to make management decisions – it is politically difficult to argue that users should make major cutbacks in extraction unless the need is clear. When the understanding of underlying groundwater system dynamics contains huge uncertainties, defining the 'need' for management in a way that is convincing to key actors (from politicians to individual farmers) is difficult. This lag between identification of a potential problem and the gradual growth of information necessary to 'prove' makes timely responses difficult and allows use patterns to become deeply embedded. In Colorado, for example, difficulties in defining the degree to which groundwater resources are hydrologically linked to specific surface sources have been a major point of contention within many major river basins since the 1950s. Although the links between surface flows and groundwater extraction in the basins are increasingly well understood, well owners have been using groundwater for decades and it is politically difficult to reverse established use patterns. As a result, legal 'wars' between groundwater users and surface water right holders are an increasingly common part of the institutional landscape of water in Colorado. These have become 'battles of the experts' in which competing models and competing analyses seek to gain legal ground in the context of substantial scientific uncertainty. Issues may be resolved – but often only incrementally and with huge investments in legal and technical resources.

Overall, conventional approaches to groundwater management are commonly constrained by the large number of wells, the rapid pace of social and economic change as well as scientific knowledge and data limitations. It is important to emphasize that many of these limitations are *inherent* rather than situational. The challenges reflect scientific uncertainties that cannot be eliminated, political dynamics that reflect basic human nature and scale issues that emerge due to the number of users and the fundamental mismatch between patterns of human organization and patterns within the physical groundwater system. While such challenges may be narrowed by advances in knowledge or organizational systems, they are unlikely to be eliminated. As a result, the ability of society to manage groundwater resources effectively has clear limitations. Adaptation to emerging problems – rather than attempts to 'solve' them directly – thus appears essential.

Concepts of Adaptation

What does adaptation mean? In relation to natural resource issues, at least two core concepts are common. The first involves the growing field of 'adaptive' management. This term is generally used to describe management systems that focus on the resource base itself but are intended to work in a flexible manner and that respond to changes as they occur over time. The management system is 'adaptive' in that it has inbuilt mechanisms whereby the tools and objectives of management can be adjusted as new information becomes available or other conditions change. In many situations, adaptive management approaches provide for review processes at specific intervals so that such adjustments can occur.

The second concept, which I am primarily dealing with in this chapter, involves tailoring responses to the larger context in which they fit – i.e. adapting to the context rather than defining response strategies based on a relatively narrow predefined set of hydrologically focused management objectives and techniques. From this perspective, adaptation emphasizes approaches that focus on adjusting livelihood, economic and other systems in ways that mitigate the impact of groundwater problems – i.e. the core goal is to adjust society to groundwater conditions rather than attempting to 'manage' the resource base itself. This is, however, simply a matter of emphasis and does not exclude direct attempts to manage the resource base. In some contexts, direct management may be viable and adaptation in the larger sense would include both conventional and water-focused iterative 'adaptive' groundwater management strategies. Except where explicitly noted, the term 'adaptation' in the remainder of this chapter refers to the second larger concept rather than the more narrowly defined adaptive management processes.

Substantive work related to the conceptual foundations of adaptation processes has been undertaken by a number of authors loosely grouped into the Resilience Alliance.[4] Many of the concepts underlying adaptation in social systems have emerged from research on systems dynamics and the application of insights on adaptation gained from ecosystems research (Holling, 2001; Gunderson and Holling, 2002; Holling *et al.*, 2002). This research emphasizes core phases in the ongoing processes by which natural systems evolve. These phases can be seen as a loop, outlined in Fig. 9.1 from the Resilience Alliance, that consists of: 'entrepreneurial exploitation (r), organizational consolidation (K), creative destruction (Ω), and re- or destructuring (α)' (Holling, 2004). The core insight here is that systems – whether in the natural environment or, as many members of the Resilience Alliance would argue, in the social and institutional environment, progress through very clear phases. These phases start with initial expansion under conditions in which core resources (nutrients, energy, finances, etc.) are readily available and the system is relatively unstructured, followed by a phase of consolidation or restructuring.

In the case of groundwater, these two phases would be represented by the initial spread of energized irrigation when expansion led to rapid increases in productivity and has now transited into highly efficient, but much less diversified (more structured), forms of intensive agricultural production. The process of increasing structure as resources are captured leads to efficient systems that are also increasingly rigid in that the available resources tend to be evermore fully captured and utilized. Rigidity, in turn, creates the conditions for creative destruction when surprises or extreme events shake the system. Again, in the groundwater case, this might be a drought hitting when aquifers have been fully exploited. When intensification captures all recharge, the groundwater buffer that provided resilience against drought is no longer reliable and intensive agriculture cannot continue in locations where access to groundwater fails. The disruption caused by this phase breaks system rigidity and frees resources (in

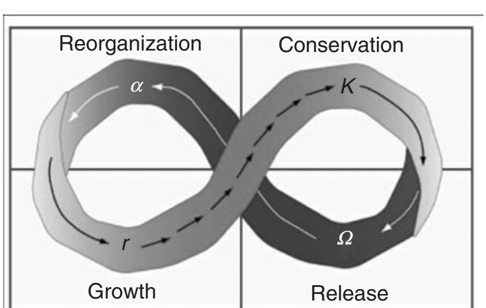

Fig. 9.1. System dynamics. (From the Resilience Alliance.)[5]

the groundwater case, an example would be the human and financial capital that had been fully invested in intensive agriculture), and leads, in turn, to a phase of reorganization.

Studies on system resilience indicate that the process of growth, conservation, release and reorganization occurs at all levels in a system and is interlinked across such levels, as the household, livelihood system, village and regional economic levels within any given agricultural economy. The studies also indicate that the nature of creative destruction is heavily dependent on the degree to which the *r–K* growth to conservation phase has resulted in the creation of a highly structured system. Basically, the more structured a system becomes, the greater is the destruction when it fails. When systems are constantly responding to small destructive events across several levels, the degree to which they become rigidly structured is limited by continuous processes of release and reorganization – that is adaptation. Such systems tend to be much more resilient, and much less subject to fundamental reorganization, when surprise events occur. However, when disruption is limited, efficiency and rigidity both grow. Again, to relate this to groundwater, by eliminating the constant need to adjust to variations in precipitation and water supply, access to groundwater has enabled the development of efficient and intensive, but also rigid, agricultural livelihood systems. When drought and groundwater overdraft in conjunction eliminate access to secure water supplies, livelihood systems based primarily on intensive irrigated agriculture have low resilience and lack capacity to adapt without first undergoing significant reorganization.

The conceptual frameworks described are closely related to concepts of risk. As the risk management literature clearly documents, exposure to, and familiarity with, risk is a key factor underlying the incentive to develop coping and avoidance strategies (Wisner *et al*., 2004).

What does this imply for responses to emerging groundwater problems? While exploration of all the implications is well beyond the scope of this chapter, a few observations appear central:

1. It indicates that disruption, change and adaptation are inherently interlinked processes and that periods of disruption should be recognized as opportunities as well as times of crisis. Probably the most ‘natural’ time of change in an agricultural economy based on intensive groundwater use is during drought or similar times of ‘crisis’. This is the time when creative destruction is likely to occur and livelihood, economic and political systems will be forced to adapt. In contrast, periods of stability are likely to be periods when change is resisted.

2. It implies that activities designed to buffer livelihood or agricultural systems against variability are likely to increase rigidity and reduce adaptive capacity. The shift away from rain-fed systems into systems based on groundwater irrigation that has occurred in India over the last 50 years – while it has allowed tremendous increases in productivity and been a major factor for reducing poverty (Moench, 2003) – has also encouraged the development of systems that are much more dependent on secure water supplies and much less resilient when water supply reliability declines. While it is important to avoid large-scale disruption of agricultural systems, exposure to risk and variability is essential in order to maintain resilience of the system as a whole. In the case of groundwater overdraft, actions that protect people against immediate loss also reduce the incentive to undertake structural changes that would, in a larger sense, reduce vulnerability.

3. It suggests that principles central to resilience in ecological systems (such as diversification) are also central to the development of resilient livelihood systems. Livelihood founded primarily on groundwater-dependent agricultural systems is likely to be much less resilient when the resource fails than that based on a diversified portfolio of agricultural and non-agricultural activities. Similarly, within agricultural livelihood systems resilience is likely to be enhanced when those systems involve a mix of crops, crop varieties and agriculturally related activities (e.g. animal husbandry). Diversification both between and within livelihood systems is important.

Insights from the Field

Detailed field research on what households and communities actually do to 'adapt' or respond to groundwater problems was recently undertaken as part of a larger programme on adaptation by a consortium of organizations across India and Nepal (Moench and Dixit, 2004). Aspects of this research in Gujarat, India, are discussed by Mudrakartha (Chapter 12, this volume) from the Vikram Sarabhai Centre for Development Interaction (VIKSAT), one of the partner organizations (Mudrakartha, 2005). As a result, only the broad insights generated by the project are discussed here.

The project focused on areas in which long-term groundwater overdraft conditions were compounded by drought. In these areas, people responded to both the creeping process of increasing water scarcity and the immediate impact of drought primarily by:

1. Attempting to diversify income sources away from water-dependent, agricultural forms of livelihood;

2. Attempting to increase access to water, particularly secure sources of water for domestic and livestock use, through water-harvesting activities, by drilling ever-deeper wells and by purchasing water through informal markets supplied by water tankers (commonly known as 'tanker markets');

3. When all else failed, by coping through reduced consumption.

Those who successfully 'adapted' – i.e. those who were able to maintain living standards and avoid the coping strategies that involved reductions in consumption and other indicators of living standards – were the ones who succeeded in diversifying their livelihood and obtaining secure sources of domestic water supply. The story is not, however, simply one of economic diversification and domestic water security. To be effective, these core strategies depended upon sets of linkages with higher-level economic, information and social systems. In addition, while some of the linkages occurred due to the immediate pressure of drought, many of them evolved over much longer periods of time. To be more specific, in most areas, successful diversification into non-farm activities was enabled by a combination of factors including:

1. Proactive migration and commuting: Migration and commuting were core strategies that enabled families and communities to obtain access to outside labour markets and sources of non-farm income. In some cases, this occurred over a generational basis. Families invested in efforts to find non-agricultural work for at least one key member in an urban area. In other cases, the strategy involved long-term investments in education. When drought hit, the income generated by family members working in urban areas served as a critical buffer for livelihood or as the source of capital for recovery or investment for those still living in rural areas. In yet other cases, migration involved short-term travel to work in regional labour markets – or even commuting to access specific local work opportunities. The core points here, however, are that (i) mobility was a core factor enabling diversification and (ii) in many cases it was a *proactive* strategy that occurred over long periods of time and not a short-term *reactive* response to immediate drought impacts.
2. Access to transport and markets: The ability to diversify depended heavily on the presence of transport systems and access to regional markets. In the Gujarat drought case, many farmers increased dairy production by using fodder grown in distant locations and transported it into their area. Similarly, access to secure domestic water supplies – which are in effect the single most essential requirement for people to remain in any given region – was often enabled by access to regional tanker markets for water. This was also the case for many other non-farm activities such as woodworking, diamond polishing and developing other small businesses. Transport and market access were, as a result, core prerequisites, enabling diversification both within the agricultural economy and between agriculture and non-farm activities.
3. Access to social networks: Familiarity with regional labour markets and access to key individuals already working within them were commonly mentioned as important factors enabling diversification. This was also the case for other resources such as credit.
4. Access to credit and financial institutions: Without credit, the investments required for diversification – including the costs associated with migration to distant labour markets – are often impossible to make. Similarly, without financial institutions (whether formal or informal), the ability to send remittances earned through migration and commuting for investment in local livelihood systems is greatly limited.
5. Access to education: Key skills, such as basic literacy and any higher levels of education, played an important role in the ability to diversify. In many cases, the least educated only had access to jobs as wage labourers in agriculture or the construction industry, whereas those with higher levels of education had access to a more diversified portfolio of job opportunities.
6. Presence of local institutions: Self-help groups and other community organizations along with access to higher-level non-governmental organizations (NGOs), government organizations and private businesses played a critical role. To take another example from the Gujarat drought case, cooperatives played a major role in

organizing fodder transport, enabling bulk purchase and providing credit. This was a critical input that enabled farmers to shift out of irrigated agriculture and diversify into dairy production as groundwater levels declined and the drought increased.

In most of the areas studied, the ability to adapt was not uniform across the communities. As with many other studies in the development literature, existing patterns of vulnerability created by gender, income and social position played a critical role. Women, for example, had far less access to many of the opportunities for income diversification than men, and this was often the case for other economic or socially constrained groups also. The poor were not, however, always the most vulnerable or the least adaptable. In many areas marginal farmers had much greater familiarity than larger farmers with regional labour markets as well as the established social networks required to access them. As a result, when the wells of the larger farmers failed, they lacked the experience and contacts necessary to diversify. In some cases, these larger farmers invested virtually all their capital and acquired substantial debt in unsuccessful attempts to obtain access to groundwater by deepening their wells. As a result, they suffered a far greater decline in income than smaller farmers who already had contacts and familiarity with regional labour markets. When the wells were successful, however, the larger farmers were able to maintain existing livelihood systems and experienced little, if any, decline in living standards. They, however, remained vulnerable to the next drought and the potential failure of the new wells in which most of their wealth was now invested. Instead of reducing vulnerability, the ability to maintain access to groundwater may have, in fact, reduced the incentive to adapt, and therefore increased vulnerability over the longer term.

Overall, the ability to adapt to the combination of drought and long-term groundwater overdraft was heavily influenced by a combination of location-specific factors and wider regional conditions. Where access to groundwater remained secure, the incentive to adapt to any specific drought event was low, but farmers were often aware of longer-term threats to the resource base and were taking proactive measures (e.g. investing in education and economic diversification) that would increase the ability of their family to adapt if secure water supplies were lost. Other local courses of action, such as investments in water harvesting, were a way of increasing local water security. Critical points of transition occurred when wells failed and the ability to continue intensive irrigated agriculture failed with them. At this point, the impact on livelihood depended on the degree to which diversification out of vulnerable activities had already occurred and the immediate ability of livelihood units to shift on relatively short notice. This ability depended, in turn, on social position and the ability of information, goods, services and people to flow into , and out of, affected areas.

Strategic Implications

Our recent research on responses to the combination of drought and groundwater overdraft provides a series of initial insights that raise as many questions as they answer. As a result, the implications of research on adaptation for proactive responses to emerging groundwater problems can only be identified in a preliminary manner. However, at least some implications appear to be clear.

1. Adaptation at the household livelihood level can form a central part of a proactive strategy for responding to groundwater problems. Farmers are in most cases fully aware that water level declines in their wells and changes in water quality represent a fundamental threat to agricultural livelihood. They often take proactive steps to reduce their vulnerability by investing in education and taking other long-term actions to diversify income sources. Action by governments and development agencies to support existing adaptive responses of this type are as important and may be more effective in reducing the social, livelihood and economic impacts of groundwater problems than attempts to manage the groundwater resource base directly.
2. From a hydrological point of view, it should be relatively straightforward to identify vulnerable regions in which support for adaptation in livelihood and economic systems is likely to be particularly critical. Regions where water levels (or water quality) are declining rapidly and where hydrological conditions suggest that additional groundwater resources are insufficient to sustain intensive agriculture in zones in which adaptive change is required. In such areas, interventions to assist economic transition and secure domestic water supplies are particularly critical.
3. Response strategies need to combine activities that are 'water-focused' with others that may have little direct relationship to groundwater. Particularly in areas where groundwater resources are under threat and conventional management strategies appear unfeasible, responses focused on developing the physical and social infrastructure for diversification into non-agricultural activities (roads, communications networks, financial and other institutions) are as important and need to be combined with steps to protect domestic water supplies.
4. The central role of mobility – migration and commuting – in adaptation needs to be recognized and appreciated. Globally, urban populations are growing and rural areas are taking on urban economic characteristics. This trend towards social and economic integration is a major factor contributing to the ability of populations to adapt to location-specific constraints such as groundwater overdraft. Rather than seeing migration as a signal of distress to be resisted, strategies to support it and mitigate the negative effects need to be an integral part of both long-term responses to groundwater problems and short-term responses to drought.
5. Far more attention needs to be paid to the linkages between long-term groundwater management issues and issues such as drought that are often treated as completely separate short-term crises. Droughts represent times of crisis and opportunity. They are the points of time when groundwater problems come to a head, when livelihood must shift and when the foundations for adaptation are tested. They are also times of political and social opportunity when governments, communities and households are most aware of the need for effective responses. While attempts to manage the groundwater resource base and protect domestic water supplies are inherently long-term, droughts

can represent a window of opportunity for the establishment of management systems. They are also windows of opportunity when resources (drought relief) are often available that could be used to support longer-term economic diversification and other adaptive responses. In sum, it appears particularly important to develop links between the traditionally quite separate water management, disaster relief and long-term economic development communities.

6. Explicit frameworks and approaches need to be developed that reflect the *process nature* of both conventional 'water-focused' and the wider strategies emphasized here. The adaptive management paradigm that is now emerging in a number of natural resource management fields generally incorporates explicit opportunities for revisiting decisions and strategies within management plans. This represents a starting point. The ability to adapt depends, however, on the flexibility of institutions and management concepts as much as it depends on explicit mechanisms for iteration within a management programme. Where institutions are concerned, for example, water rights that are granted in perpetuity and that relate to specific quantities (or even proportions) of the resource base are likely to be much less flexible than systems that are conditional depending on (changing) social interests, climatic conditions and a host of other factors affecting water use and availability. The same can be said for management concepts. Education and training systems that define water management in terms of 'engineering hydrology' are unlikely to produce managers capable of understanding or utilizing approaches that rely heavily on social change processes or indirect management tools. Approaches that define effective units for management based only on hydrological characteristics (aquifers and basins) are unlikely to be effective when water use within those units depends on virtual flows of water (grain, jobs, etc.) that are driven by regional or global factors. Building temporal and geographic flexibility in, and emphasizing the process nature of, management is central to the development of more adaptive approaches.

7. Although many of the issues related to the development of effective responses to emerging groundwater problems in different areas are similar, responses need to emerge from processes tailored to the specific local context. Much can be learned through comparisons between regions, and underlying response strategies (emphasizing, for example, processes and a mix of conventional, indirect and adaptive techniques) may be similar, but the details of specific management interventions and tools need to reflect location-specific conditions. In many regions, globally accepted 'best practices' are used with little evaluation of whether or not they will work. Adaptation requires learning from other areas but 'adapting' the approach to suit local conditions.

8. It is important to emphasize that adaptation and conventional approaches to groundwater management are not mutually exclusive approaches. Economic transition for populations that currently depend on intensive irrigated agriculture could be used to reduce pressure on groundwater resources and create the political space for direct management of the resource base. Strategically, approaches that focus technical resources on the protection of key groundwater resources that are of particular importance for domestic water supply would directly complement indirect actions to encourage economic transition.

Such points of synergy between conventional groundwater management and more adaptive approaches appear particularly important to explore.

Capturing benefits from the above potential synergies requires strategy. Those actors concerned with emerging groundwater problems need to move beyond the linear step-by-step attempts to develop integrated water management programmes and institutions that characterize current global water debates. As Schlager (Chapter 7, this volume) comments: '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'. As a result, instead of attempting to formulate comprehensive approaches, more incremental 'clumsy' solutions tuned to specific times, physical contexts and institutional settings are needed. As any commercial organization interested in building a dam knows, ideas need to be developed and multiple plans formulated so that they can be put into action when a drought or other crisis creates a window of opportunity. Similarly, instead of advocating a single 'best practice' model for groundwater management, multiple models tuned to time and place are needed. It may be possible to mobilize the technical, scientific, institutional and political resources necessary to protect a key strategic aquifer supplying water to an urban area using conventional management techniques. In such cases, the aggregate political weight of urban domestic users is often articulated through a single well-organized water utility. This is far less likely to be the case in rural India or China where the social structure of resource use revolves around the livelihood of numerous individual farmers. As a result, the strategy for responding to groundwater problems in each situation needs to be different in fundamental ways.

Notes

1 Available at: http://www.usgcrp.gov/usgcrp/images/ocp2003/ocpfy2003-fig8-3.htm
2 Quote from Albuquerque Tribune in High Country News. Feature article for 26 December 1994 . Available at: http://www.hcn.org/servlets/hcn.Article?article_id=728
3 High Country News. Feature article for 26 December 1994. Available at: http://www.hcn.org/servlets/hcn.Article?article_id=728
4 Available at: www.resalliance.org

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