

ENTERING THE GROUNDWATER POLICY DEBATE: AN ECONOMIC EVALUATION OF INSTRUMENT CHOICE

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Abstract

The demand for high quality groundwater is growing at unprecedented rates around the world. This unprecedented growth rates create considerable stress on groundwater resources in certain parts of the world, and considerable social controversy over how the resource should be managed. The policy problem is rooted in the fact that established groundwater institutions (policies) cannot handle the new resources realities. In response to emerging economic, environmental and social stress, there is pressure for change in groundwater policy in many developed countries. From an economic perspective, the question is whether groundwater policy can be designed to enhance wise groundwater management. The objective of this research is to examine the potential for developing efficient and equitable groundwater policy as a tool for groundwater management. An economic framework is presented for understanding externalities, market failures and the fundamental economics of institutional change. Several key aspects of corrective policy are explored in depth, including, 1) the economic impetus for policy change, 2) the challenges in quantifying and protecting existing rights, 3) implementing limits on aquifer use and 4) the role of water pricing and transfer flexibility. Case studies from Europe and the United States are examined to induce practical lessons concerning best practices in these areas. This research contributes to the policy debate by evaluating the economic impacts of alternative groundwater management policies and by making policy recommendation that have the potential to improve water management around the world.

1 INTRODUCTION

Groundwater is the subject of growing social concern around the globe. The ownership and control of underground aquifers, the intensive use of groundwater resources, potential changes in both groundwater quality and quantity and the related impacts on natural systems command the attention of scholars and public policy makers in many countries. Very few intensively exploited aquifers experience rising water tables. When agricultural, industrial or municipal interests use groundwater resources intensively, controversies arise over the rate of aquifer depletion, the fairness of allocation between users, and whether or not access and use should be limited. In addition, groundwater pollution is becoming a public health concern in many areas of the world. In the United States and Europe, environmental concerns are coming to the forefront of public debate. Many important habitats, especially wetlands, depend on the state of underlying aquifers.

In all these cases, the role of policy in managing groundwater resources is at issue. Public administrations around the world struggle to bring the negative impacts associated with groundwater use to a halt. However, groundwater resources are increasingly cost competitive

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relative to surface and non-conventional supplies. This means that existing incentives, coupled with poorly designed groundwater policies, pose serious obstacles to slowing groundwater use.

Despite these undesired trends, there are a number of positive experiences that illustrate policy solutions to social gridlock. We will argue that these examples of success have a few features in common that illustrate what economic theory has suggested for decades. Specifically, real world observations support the idea that property rights and cooperation among individuals are of critical importance. But property rights and cooperation do not occur naturally; they are institutionally driven processes. In order to deal with emerging groundwater problems, the institutions and policies that make up property rights regimes must change in a way that enables economic agents to resolve problems. Clearly, we are in an age of transition in groundwater policy. The objective of this article is to contribute to the policy debate, from an economic perspective.

What constitutes an improvement in groundwater policy? As economists, our central focus is efficiency in resource use, but we must also incorporate the notion of equity into evaluation of improvement. Equity can be thought of as a fair distribution of the risks, costs and benefits of all agents relying on groundwater unit. However, the rules themselves cannot be evaluated on efficiency grounds (Bromley, 1982) and must incorporate some broader notion of social welfare including equity.

The economic theory pertaining to natural resources is quite sophisticated. While theoretically efficient prices have been posed and defined under a wide arrange of assumptions, they are too complex to administer or information demanding. The approach taken here is to conduct an international comparison of groundwater policies in Spain and the United States, and to examine them for evidence of best practices in the context of change. This observational and inductive exercise is inherently difficult, but has the potential to yield real and relevant insights. Based on real observation, we will also suggest patterns in policy that contribute towards answering critical questions design and implement sound groundwater policies.

The following section outlines the economic concepts that lay the foundation for analyzing efficiency and equity in the context of groundwater policy. Subsequently, four case studies are presented where 1) fairly representative problems and social controversies surrounding groundwater use have emerged and where 2) groundwater policy innovations have been tried with more or less success. From a synthesis of the case studies, lessons for groundwater policy are derived and presented for consideration.

2 THE EQUITY AND EFFICIENCY GOALS OF POLICY INNOVATIONS: ESTABLISHING INITIAL RIGHTS AND CORRECTING FOR EXTERNALITIES

The social concern surrounding groundwater management usually involves a perception that an aquifer is undergoing unsustainable processes towards overexploitation or severe contamination. These problems can largely be framed as significant externality problems and/or fundamental rights problems. Both problems mean we must examine potential changes in groundwater policy for their impacts on efficiency and equity. In this case, equity questions revolve around the initial rights structure. In order to be socially acceptable, i.e., perceived as equitable, groundwater policy must structure access and limits to access, in a way that strikes a balance between economic, environmental and other social goals. Efficiency concerns the impacts of one rightful user on another.

2.1 The Essence of Equity: Initial Right Structures

In order to address the question of efficient and equitable management of groundwater resources, one must necessarily look at policies and institutions, as “ordered relationships among people which define their rights, exposure to rights of others, privileges and responsibilities” (Schmid, 1972 p.893). They determine who has the right to claim the benefits from resource use and who must bear the costs (Bromley, 1982). Ideally, water institutions create order and relative certainty for water users which facilitates achievement of economic and social goals. Unfortunately, in many cases, groundwater policy (or the lack thereof) creates obstacles to efficient use and/or serious inequities. Typically, resource policy lags behind evolving technology and social values (North, 1990; Ruttan and Hayami, 1984).

2.2 Efficiency and Externalities

Neoclassical economic theory asserts that under specific conditions (those that define perfect competition), markets will yield incentives that produce efficient resource use. However, in most cases, markets either cannot exist, or when they do, they produce perverse incentives that lead, systematically, to inefficient resource use (Randall, 1983), creating “market failures”.

Perhaps the most significant condition, in the case of groundwater, is the requirement for “independent production and consumption functions”. This assumption implies that water use should not effect, nor be affected by, use of the resource by another party. If groundwater use impacts other stakeholders that are not party to resource use decisions, “externalities” are created that lead to inefficient use. As we discuss below, externalities are pervasive in the case of groundwater resources and they occur in stunning variety (National Research Council, 1997). The existence of external effects makes it unlikely that individual groundwater extractions will match what is economically efficient. This means property rights must be modified or regulated in order to achieve optimal outcomes (Livingston, 1995). We argue that externalities often generate the pressure for institutional innovation.

Perhaps the most basic type of externality in groundwater use is the stock externality. Stock externalities occur when use by an individual affects the stock of the groundwater resource, increasing the costs faced by other water users. In groundwater, the problem is usually one of lowering the groundwater table. The impact of the stock effect may be felt by other current water users, or by future generations of water users.

To complicate matters, aquifer recharge is generally non-linear so conventional stock arguments do not always apply. As Hernández-Mora and Llamas (2001) contend, in many cases the improvements of pumping technologies offset the effects of stocks externalities. Stock effects may be quite irrelevant for water tables lowering up to 100 meters. In addition, under specific circumstances, intensively exploited aquifers can yield larger sustainable rates than others maintained with strict and low pumping rates.

Spatial externalities, as defined here, are impacts on other parties that arise due to their geographic location, rather than from the groundwater level per se. Groundwater extraction in unconfined aquifers is taken out of storage (not flow) and can create local “cones of depression” that impact users within the direct vicinity of a particular user.

Environmental externalities may also be spatial. Increasingly, the socially important externalities associated with groundwater use are environmental in nature. In particular, the impacts of groundwater use on various plant and animal habitats are of central concern in contemporary water conflicts. It is relatively common for groundwater to be connected with surface wetlands (Iglesias, 2001).

Water quality, rather than water quantity, may be central to a particular externality. Typically (but not always), groundwater tends to be of higher quality than proximate surface supplies. Often, mixing results in positive externalities (Roseta-Palma, 2001). The case of environmental externalities makes it clear that an individual must not necessarily be a water user to be impacted by groundwater use decisions.

The temporal aspect of external impacts cuts across all of the aforementioned categories of externalities and deserves to be emphasized. Economically efficient management of groundwater requires that future benefits and costs be integrated into the analysis. Unfortunately, in most cases, contingent futures markets are missing (Brown, 2000). In many others uncertainties regarding hydrological and water chemistry processes unfold over very long time frames. Under these conditions, individuals will face a perverse incentive to develop and use the resource sooner than in economically justified (Baumol and Oates, 1988).

3 THE PROCESS OF POLICY INNOVATION: CONCEPTS AND INDICATORS

Economists have a fairly well developed idea of the ideal institutional framework that “should” govern natural resource (including groundwater) use. In this case, the ideal set of laws and policies would deal with both equity and efficiency issues. In terms of equity, the groundwater institution would define the total limit on groundwater use in a particular aquifer, based on an equitable balance between economic and environmental goals and an overall rate of extraction spanned for a “just” social time horizon. In terms of efficiency, the institutions would define what groups and individuals have access (property rights) to the resource and those rights would be both certain and flexible. Users would bear the full cost of their use (including external impacts) and groundwater available in any year would be allocated to the “highest valued uses” which would occur through trades and transfers (Howe, Schurmeier and Douglas, 1986). These are often referred to as “cap and trade” policies (Colby, 2000).

The actual use of such an ideal groundwater institutions is based on very challenging requirements that abstract from actual economic, political and social realities. However, some groundwater institutions are certainly more successful in meeting efficiency and equity goals. In order to better understand changing institutions and their impact on efficiency and equity goals, it is useful, to look at the actual process of institutional change. Institutional change must actually occur before it can have any impact on efficiency and equity goals! Some notion of the structure and sequencing of actual change is critical in analyzing the factors that make changes in groundwater institutions successful in some regions, and not in others. Actual innovations in groundwater (and most natural resource) institutions occur in a stage-based process including at least three fundamental stages: 1) changes in the perception of needed institutional change, 2) political articulation of needed changes and 3) operational changes to actually implement changes (Dinar and Maria-Saleth, 2002).

The perception of a needed change in institutions can result from subjective, rooted in ideology or political power, or objective elements. Often, changes in objective resource realities (e.g. drought, environmental crisis, etc.) can also alter the perception of needed change (Giansante et al. 2002).

Once the need for institutional change is recognized, the interaction between political and economic elements becomes even more complex. Two concepts that are particularly important and useful in understanding the process are *path dependency* and *institutional transactions costs*. Analytically, it is important to understand that potential changes in institutions are both constrained and enabled by past institutional configurations. The role of the state, and public agents, are critical in overcoming institutional inertia and providing political leadership. Institutional transactions costs are especially relevant in stages two and three and affect the

ability of political entrepreneurs to effect actual change. Institutional transactions costs refer to all costs (e.g. time, resources, information, and bargaining costs) incurred in the process of enacting new laws, changing policies or altering operation rules.

In Table 1, we propose a number of physical, economic and institutional indicators that have a direct relationship to pressure for change in groundwater institutions due to externalities and the potential for actual institutional innovation to occur, given the structure of economic incentives and institutional precedents.

Table 1. Physical, economic and institutional indicators relevant to groundwater policy.

Indicator	Type of harmful effect	Units of measurement
Physical		
▪ Shallowness	Cost and stock externalities	<ul style="list-style-type: none"> • Total sustainable use volume (million m³)/Aquifer surface • Total sustainable use volume (mil. m³/aquifer's thickness)
▪ Water pollution	Environmental externalities	<ul style="list-style-type: none"> • Presence of specific polluting agents • Downward trends of aquifer's water quality key indicators
▪ Hydrological connection to surface water bodies	Space externalities	<ul style="list-style-type: none"> • Percentage of total sustainable use over outflows to or inflows from surface sources • Aquifer's downstream or upstream situation
▪ Hydrological resilience	Irreversible effects	▪ Aquifer's geological structure
Economic		
▪ Relative and absolute Pumping costs	Cost externalities and sensitiveness to financial distress	<ul style="list-style-type: none"> • \$ per m³ • % of \$ per m³ over commercial benefit.
▪ Economic costs of aquifer recovering	Opposition to incurring recovery costs and incentives to delay action	<ul style="list-style-type: none"> • Number of years of needed to approach sustainability • Effort demanded from users (% of use reduction needed to achieve sustainable levels)
▪ Distribution of costs	Uncoordinated interests, if relative costs differ widely among users	• Combination of Gini's coefficient and total recovery costs.
▪ Number of users	Difficulty of coordination	<ul style="list-style-type: none"> • Number of users • Number of pumping facilities
▪ Types users	Uncoordinated interests and incentives	• Types and number of users
▪ Asymmetry of users	Uncoordinated interests but facility to encourage leadership	• Gini's coefficient of access to water rights
Institutional		
▪ Presence of a legitimate Users' Association	A forerunner for a true Water authority	<ul style="list-style-type: none"> • Does it exist? • Is it legal or developed under statute mandates? • Does it command authority?
▪ Source of the WAU statutes	Whether rules have been imposed externally	<ul style="list-style-type: none"> • Are they accepted by the users? • With which majority?
▪ Presence of a higher water authority	Whether a water body can exert power to impose use changes	<ul style="list-style-type: none"> • Does it exist? • Is it legally empowered to impose use pattern changes? • Does it have carrots, in addition to sticks?

4 OBSERVATIONS FROM THE CASE STUDIES

In an effort to better understand the actual experience with changing groundwater institutions, and the factors that influence the degree to which particular cases meet with failure or success, we chose to examine a set of actual, recent changes in groundwater policies in the U.S. and Spain. There is no doubt that in response to growing pressures in terms of both perception and resource reality, groundwater institutions are in flux all around the world. The regions examined were selected based on our own country expertise in Spain and the United States. We looked at recent, and substantial, changes in groundwater policy in 1) mainland Spain, 2) the Canary Islands in Spain, 3) Colorado, in the U.S. and 4) Texas, in the U.S.

4.1 Mainland Spain

Groundwater institutions in Spain have undergone substantial reform in the past two decades (Hernandez-Mora and Llamas, 2001). While water in Spain is used for many purposes, agriculture is a particularly important user group in groundwater policy issues. In both 1985 and 1999 legislation, reforms were introduced that attempted to address both equity and efficiency issues. Importantly, the right to trade in water rights was formalized, which embodies significant potential efficiency gains.

In response to the perception that significant externalities may be imposed on both current and future users, the legislation also authorized the transition from largely unregulated private groundwater use to public oversight of groundwater rights. This necessarily involves a formal process of establishing exactly who access to specific quantities of groundwater (“grandfathering” rights). Those claiming rights had a choice between 1) keeping the right as private property for 75 years, enjoying unencumbered access, until the right expired or 2) filing an application to convert their private rights into water use rights, which could be renewed every 30 years. Unexpectedly, few groundwater users opted to convert their rights into concessions, and the intended transition failed. The 1985 legislation gave the state clear and specific provisions to undertake actions in cases of overexploited aquifers, but the management plans developed under these provisions were ignored, violated or appealed in legal courts. Only in cases where generous European Union’s subsidies under the form of Agri-environmental programmes were present did irrigators halt their unsustainable use patterns.

Subsequently, legislators in Spain introduced another, more successful attempt to grandfather groundwater rights, thereby establishing the starting point for limiting access and use. In 2001, the Law of a National Hydrologic plan (largely devoted to a large inter-basin water transfer) included an article which forces all groundwater users to file a declaration expressing their claims and laying down their pumping capacity. After the closing date of application, no user has any chance of legalizing their wells and pumps except by means of a court appeal. The 2001 Law introduced another crucial element that helped basin agencies tackle their most intractable problems. By allocating the total basin’s resources to groups of users and regions, the Law effectively introduced caps to many overexploited and uncontrolled hydrogeologic units and transferred to water users associations the responsibility to set up water distribution enforceable criteria.

Another important innovation concerns the Tablas de Daimiel is a well-known wetland located in the Southern Castilian plain of Spain. The European Union deemed these wetlands as an important environmental resource. This is an example of a spatial, environmental externality related to the connection between groundwater and surface water. Funds attached to the Agri-Environmental Programme (2078/92 EU Regulation) were used to generously compensate irrigators in order to reduce extraction rates (Iglesias, 2001).

Essentially, mainland Spain’s groundwater policy is now based on use caps, with sound hydrological planning. Allocation criteria are defined from the bottom-up by users’ association

at the regional levels. These criteria are translated into enforcement rules that the State is willing and capable to apply.

4.2 The Canary Islands

The Spanish Canary Islands (100 miles off the Sahara's Atlantic coast) provide an interesting example of a largely privatized groundwater allocation institution, which is also undergoing significant change. The main islands are water scarce, with about one fourth of the water availability of the Iberian Peninsula, and the vast majority of the water resources are beneath the surface of the Earth. This case is quite unique within Europe in that private companies and corporation have been involved in the development and allocation of groundwater resources for over a century (Tremolet, 2001). According to Tremolet, early in the development of groundwater "the public sector was not interested in this development and gave private investors a free hand" (p.1, 2001). Private companies made substantial and risky investments in wells and established "water communities" owning "shares". Each shareholder is entitled to a percentage of water flow and in turn is partially responsible for financing costs. Water is fully transferable between shareholders. Brokers serve as intermediaries in a bi-annual tendering process, and fees are charged based on capacity utilization. There is also a short term rental market, where water prices tend to be triple the annual rate (Tremolet, 2001). Water markets have been instrumental in transferring water from the agricultural sector into the tourist sector as the economic structure of the Canaries has changed.

In the 1980's concern over dwindling aquifers (stock externalities) and environmental effects began to rise. Public control over all water was suggested, but was soundly rejected. Existing infrastructure may remain private until 2065. Even so, public oversight of new groundwater developments and desalinization has been introduced. As in most parts of the world, the particular form of the public/private interface in future groundwater allocation in the Canaries remains to be seen. Currently, the public sector is concerned most with excessive price discrimination (due to bottlenecks), more efficient water quality differentiation, and stabilization of market prices (Fernandez Bethencourt, 2001).

In addition, as Aguilera Klink (2002) shows, water markets in Tenerife (with the most active water markets, among the seven main islands) are far from efficient. Markets are thin, not competitive, and reach equilibrium prices that do not reflect neither scarcity situations nor water quality differentials. As a response to these widely known facts, the state has set up public water companies that retail water at regulated prices, accomplishing more sectoral efficiency and fairness than decades of public attempts to renationalize all water resources and revoke water private property. It is remarkable that in the water economy in the Canaries there is no record of water service cuts or shortages for any sector during the last two centuries.

4.3 The State of Texas in the U.S.

Historically, groundwater policy in Texas has been based on the doctrine of absolute ownership (Griffin and Characklis, 2002). Access to groundwater is based on private ownership of overlying land. Private parties are entitled to an unrestricted quantity of water. Even though access is tied to land, groundwater is fully transferable to other locations and uses, once it is "captured". Typically, in order to transfer water, towns sign a lease contract with land owners (typically ranchers) allowing the town to capture water on the rural property and then pipe it to town. The town usually pays for all infrastructure plus an annual payment. As groundwater resources have been used more intensely, and as both stock and environmental externalities have grown, public groundwater "conservation districts" have been formed to address problems and amend policy. Clearly, one of the most stressed aquifers in Texas is the Edwards Aquifer, an important source of water supply for San Antonio, a growing urban area. Heavy use of the aquifer diminishes surface springs, which are relied upon by several "endangered species". The

Endangered Species Act in the U.S. gives the federal U.S. government the authority to over ride state water policy and has generated major changes in groundwater policy for that region.

In order to reduce the impact of groundwater use on endangered species, the aquifer is currently being adjudicated. Adjudication will allow permits for specific quantities of water based on historical use. When pumping data is lacking, irrigation rights are based on about 6,130 cubic meters per hectare. Subsequently, some of the permits will be purchased by public authorities and then retired to reduce overall extraction. In a related development, recently, entrepreneurial efforts have been initiated to form water corporations that would transfer large quantities of groundwater to thirsty municipalities in distant locations (including San Antonio). Cities would be charged based on distance, which is a rough indicator of pumping costs. Groundwater officials are concerned that these efforts will deplete the Ogallala too rapidly and are supporting legislation to charge fees on extractions (The Economist, 2001).

4.4 The State of Colorado in the U.S.

In Colorado, the tie between ground and surface water has produced significant innovation in the past and promises to stimulate additional changes in groundwater policy in the near future. As in most places, management of groundwater resources has been largely separate from management of surface supplies. However, over time, the connection between using groundwater supplies, and the related reduction of surface supplies in alluvial aquifers attached to the South Platte, for example, have gained attention. (In this case, farmers are the primary user of both interconnected ground and surface water supplies.)

In 1965, the Colorado legislature made a distinction between tributary and non- tributary groundwater. Groundwater that is tributary to surface water became subject to the surface water law of “prior appropriation” (first in time is first in right) (Hobbs, 2000). Because, in general, surface water rights were developed before groundwater use, almost all groundwater rights in tributary systems may technically be used only after surface rights are satisfied. In recent decades, the Colorado legislature made innovative provisions for “augmentation”, whereby groundwater users can pump “out of priority” if they buy additional surface water that augments the stream. Augmentation has become a very popular way to utilize groundwater without diminishing surface flows. The connection of ground and surface water has another set of policy changes looming in Colorado and other Western U.S. states under which the Ogallala aquifer lies. Conjunctive water supplies have become important in inter-state conflicts concerning this aquifer. There is current litigation in the U.S. Supreme Court, where the state of Kansas claims that the state of Nebraska’s use of the Ogallala affects surface water in the Republican River in a way that violates interstate compacts. If Kansas is successful in this litigation, it is very likely that Colorado will also be taken to court over the same conjunctive use issue. Interstate compact law is federal and provides the legal authority to over-ride state policy, forcing state to make changes in groundwater policy

5 LESSONS AND POLICY IMPLICATIONS

This section outlines some of the lessons that are suggested by the case studies. The lessons suggested here, relate to the institutional foundations that might be used to initiate change, the transactions costs that must be overcome, and the vehicles that have the potential to be effective.

5.1 Lesson One: The Legal Authority for Changes in Groundwater Institutions

When studying cases of actual change in water institutions, it is important to recognize the reality of path dependency. This means that the potential for future institutional change is dependent on the preceding configuration of related policies and interests governing resource use.

In the case of both Spain and the U.S., it appears that the public authority to initiate groundwater policy innovations often results from the tie between ground and surface water, and the legal connection between the two. The recognition of the interrelationships within the hydrologic cycle at the legal and institutional level should be considered as a primary prerequisite to successful reforms.

5.2 Lesson Two: Creating Sufficient Incentive to Quantify Existing Rights

When groundwater aquifers come under stress, it is important to quantify the specific rights held by specific parties. This need attests to the fact that groundwater institutions are very primitive, often allowing un-quantified and unrestricted use. The case studies seem to suggest that voluntary techniques are rarely effective. It is quite common for groundwater users to resist establishing a formal quantity of water attached to their claim, probably because it entails (explicitly or implicitly) a limit on total use. Moreover, the experience of Spain suggests that users would rather have uncertain private rights, than relative certain rights under the scrutiny of public officials. However, in overexploited aquifers private right holders were forced to accept caps to their pumping capacity, which confirms their legal standing.

5.3 Lesson Three: Alternative Vehicles for Compensation in Total Use Limits

When groundwater resources are under stress, the most common innovations in institutions involve setting a limit (cap) on total extractions. A limit on total extraction may derive from either equity or efficiency concerns. In either case, some form of compensation is typically necessary in order to eliminate some existing uses. The case studies of the Edwards aquifer in Texas and the Tablas de Daimiel in Spain are similar in that reductions are necessary to meet environmental goals. However the vehicles proposed for compensation are quite different: one-time purchase in the former and continual compensation, in the latter.

5.4 Lesson Four: The Role of Pricing

It is fairly typical for resource economists to focus on pricing issues. Inefficiency in resource use is often the result of subsidization, and efficiency, we say, hinges on “getting the prices right”. In the case of groundwater, and the particular case studies examined, this characterization is largely off the mark.

The pricing problem for groundwater resources is not a matter of subsidization. In developed countries, groundwater is largely unsubsidized. Typically, users pay both investment and operating costs, unlike the case for many surface water supplies. In the case of the Canary Islands, we see very sophisticated pricing, which takes into account capacity utilization, quality differentials, and the like. Yet, in this case complexity does not imply efficiency, as intermediaries may be taking advantage of dominance positions created by water transportation bottlenecks and markets locally thin and uncompetitive. The pricing problem for groundwater is tied to the pervasiveness of externalities, both for other groundwater users and other (e.g.) environmental stakeholders. This seems to be a problem that, to date, is better handled through means other than pricing (perhaps due to the information costs) and problems are most often tackled through extraction limits.

5.5 Policy Implications

Emerging stresses on groundwater resources, the need for institutional innovation, and the difficulty of change provide the focus of this study. The study suggests that a dichotomy between public vs. private control over water resources is both false and misleading. Certainly changing groundwater policy requires a balance between private and public control. In general broad public guidelines must be instituted to provide overall equity and legal security, and

private resourcefulness is necessary and useful for efficient implementation of these overall rules of the game. Not surprisingly, none of the institutional innovations incorporate all of the principles for efficient and equitable resource use. Institutional innovations in groundwater are experimental and accumulative, based in a great extent on a trial-and-error process. Our goal was to look for patterns that pertain to the relative success or failure of groundwater policy. The case studies examined here suggest the following: 1) legal authority to change groundwater policy may be drawn from institutions governing surface water, 2) claims to groundwater will not be quantified voluntarily; however, the threat of future costs, or the presence of technology to determine actual use, may be sufficient to induce quantification; 3) implementing reductions in total extractions will require compensation of those who cut use; 4) pricing should not be the sole focus of innovation in groundwater institutions; rules governing access and total extraction have greater potential to address equity and efficiency issues; and 5) agents may be willing to accept pumping limits in return for increasing rights' security and assurance about decisive and credible commitment to manage aquifers sustainably.

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