CHAPTER 10
Economic and financial perspectives on intensive groundwater use

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ABSTRACT: This paper provides an economic perspective on intensive groundwater use. The chapter begins by exploring the economic reasons behind the growth in groundwater use. Subsequently, an economic framework for analyzing the efficiency and equity of alternative institutional arrangements for managing groundwater is outlined. Case studies are examined in order to observe both successes and failures in groundwater management and trends in innovation. Finally, recommendations are made about the characteristics of groundwater management policies that promote economic efficiency and equity.

1 INTRODUCTION

Around the world, use of groundwater is growing dramatically. A number of factors, such as cost, convenience, and supply security, make groundwater particularly attractive for water users. As intensive groundwater use has grown, so has social concern about the appropriate way to manage this resource. Typical social concerns include the impact of intensive use on the integrity of the aquifer itself and related ecosystems, as well as potential future users. Successful management of groundwater resources must incorporate the key geological, physical and chemical aspects that, together with the hydrological regime, determine the quality and sustenance of groundwater services through time.

This chapter looks at management of intensive groundwater use from the economic perspective. In a mature situation, management of groundwater usually requires regulation of access and individual extraction rates. Establishing an acceptable and legitimate regulatory regime is greatly complicated by the fact that typically, in the initial stages of use, aquifers are used by overlying land owners who are limited only by their own pumping capacity. The challenge, from an economic perspective, is to establish a management regime that is both efficient and equitable. This applies to changing institutional arrangements from an unmanaged to a managed system and to use within the particular managed regime.

This chapter aims to distill valid economic lessons about the role of economics in making the transition to efficient and equitable groundwater management. It begins by presenting key economic differences between groundwater and surface water. In the following section, we provide a brief overview of the main economic factors that explain the growth of groundwater demand and exploitation, and why the historical trend of some of these factors may hinder the institutional transition towards sustainable groundwater management. Section 3 reviews the extant economics literature applied to groundwater problems and identifies key concepts commonly used in the field. It also explores alternative institutional arrangements that can be used to manage groundwater. In Section 4, we review a number of cases in which existing or changing institutions governing groundwater resources may be illustrative of alternative approaches in developed countries. [Problems faced by developing countries are not addressed. See Burke, van Steenbergen & Shah, and Moench (all in this volume), for an analysis of the problems faced by developing countries]. Section 5 summarizes the major findings and distills lessons that may be valid for managers or legislators.

2 SURFACE WATER *VS*. GROUNDWATER ECONOMICS

2.1 *A brief historical background*

In order to understand the economic characteristics associated with the use of groundwater resources, it is instructive to compare the differences between groundwater and surface water exploitation, as they have historically evolved. Until very recently, groundwater use has been treated similarly to a mining problem. Entrepreneurs took the risk to invest in wells with little assurance of the final yield, but they could extract as much as they wished. No external intervention was justified because the activity involved high costs of entry and significant risks. Large fixed and variable extraction costs restrained intensive mining and the properties and limits of the aquifers were by and large unknown.

The notion of use externalities that was developed in the Roman legal texts for rivers and streams was first applied for common property aquifers by Burt (1964, 1967). Why might the sum of individual actions extracting groundwater resources lead to collective welfare losses? For aquifers relatively small or shallow, the individual user incurs a dual extraction cost: one is the energy cost and the other is the increasing cost associated with lowering the aquifer's level resulting from his/her own extraction. If s/he is a small user, this second cost is hardly relevant from his/her private perspective, but will affect the rest of the users, increasing marginally their individual costs. Unless each user internalizes the entire social cost resulting from his/her action, the sum of individual actions will lead to a sub-optimal rate of extraction. This implies that, in principle, there is an alternative extraction path, which will make some or all users better off making no one worse-off.

This simple description is only partially valid, and rather incomplete, as it only represents one type of the several problems identified in many cases of intensive groundwater use. As Section 3 will show, if cost externalities were of such nature, these problems would be much easier to tackle than simple inspection of numerous world cases indicates, for a number of reasons that Brown (2000) discussed in detail. Briefly, these are: 1) that individual actions have effects on spatial and temporal domains whose properties may be only partially known; 2) that in many cases collective actions cannot be clearly separated from the singular actions of early exploiters; 3) that costs of implementing optimal extraction rates are not spread equitably among those benefiting from it; and 4) that there are public goods associated with many aquifers that are commercially exploited by private individuals.

In contrast to groundwater, the type of market failure associated with the exploitation and development of surface waters is of entirely different nature. Since water infrastructure is lumpy and generally takes decades to produce benefits, the State has traditionally taken the steps needed to convert the final beneficiaries into water right-holders. It was often perceived that individuals could never agree to pool resources for such projects, some of whose benefits were also of public nature and in most the cases required decades to become operative. Even in cases where users became right-holders just showing evidence of their usage, the state recognised their rights and assumed the responsibility of river guardians to protect their interests.

In virtually all world's countries, legislative and governmental actions have always had to proceed the development of surface water infrastructure to gain public consensus about using this highly visible resource. In this sense, at least, use externalities were kept at lower levels, in part because water rights were granted with considerable conditions or at least subject to the mandates of the official agencies that granted the rights. The fact that surface water rights are attenuated explains why legislative examples such as the USA Reclamation Reform Act or the Spanish Water Law Reform (46/1999) can impose more stringent requirements on irrigation districts using surface water.

Thus, on the legal side, one main difference is that groundwater legislation has been palliative and corrective, rather than anticipatory, which may explain why it has failed to deliver the benefits it purported in many countries and circumstances. Another difficulty is that, in many cases, legislation requires that any aquifer subject to specific actions must be first declared overexploited (and this term is interpreted in various ways). Moreover, the evidence accumulated in most countries indicates that in addition to cost externalities, the most acute problems related to groundwater concern water pollution, subsidence and irreversible effects on the long term integrity of aquifers. These problems generate externalities of the nature that Brown (2000) judges as intractable by the economics profession and, to date, unsolved through resource pricing or exploitation charges.

One point to stress is that the development of surface sources, by means of large infrastructure, entails irreversible costs, whereas groundwater's costs may or may not be irreversible. The fact that these irreversible costs are uncertain makes the application of the precautionary principle difficult. Witness the controversial regulation of *overexploited aquifers*, in place in many water codes, including the Spanish one (Foster 1999, Custodio 2000). The fact that the trigger of public action (a declaration of aquifer *overexploitation*) is a concept widely challenged on scientific grounds adds a significant degree of institutional complexity.

2.2 *Costs' trends of surface and groundwater sources*

To grapple with the growing reliance on groundwater use, it is instructive to look at the trends of energy prices, and construction prices. The argument can be made that the difference in relative costs of surface and groundwater means that, *ceteris paribus*, groundwater will be preferred unless surface water is substantially subsidized. Figure 1 plots three indexes related to construction activities and energy costs. The construction index is referred to 1996 US$ and is based on the Construction Cost Index History (see http://www.enr.com/cost/costcci.asp), which includes labor costs and various materials and construction elements. The two energy cost indexes plotted in Figure 1 refer to the cost of pumping 1 m^3 up 40 m under two assumptions. Labeled as *Energy cost*, the first index is computed in 1996 US$ and based on the industrial retail price of electricity sold by electric utilities in the USA (see http://www.eia.doe.giv/pub/energy.overview).

Labeled as *Energy cost (60 m well lowering)*, the second index assumes that during the 30-year period the aquifer level is deepened 2 m/yr. Clearly, construction costs are investments costs and energy is a variable cost, which renders the comparison quite relative. Despite all *caveats*, Figure 1 shows that groundwater costs have been reduced in real terms by about 50%, whereas construction costs have increased by almost 60%. On the costs side, thus, it is not surprising that farmers, water utilities and industries, had larger incentives to rely on groundwater than on surface water, unless access to the latter source is at subsidized rates.

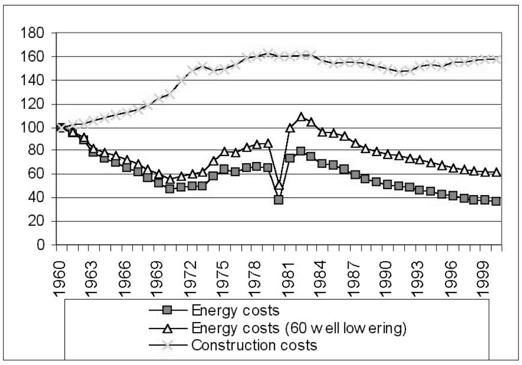

Figure 1. Construction and energy real costs indexes. (Index 100 in 1960).

2.3 *The different impact of subsidies on surface and groundwater use*

To see the differing impact of subsidies in groundwater and surface water exploitation, various costs referred to US$ per m^3 used have been computed for a wide range of situations. Per m^3 total cost has been computed using data provided by Hernández-Mora & Llamas (2001), who report actual project costs, including all investment costs required to pump water from the aquifer and bring it to the root zone. The last two rows refer to irrigation development using surface water, assuming two cost levels of off-farm investments: US$ 15,000 per ha and US$ 20,000 per ha (Sumpsi *et al.* 1998).

The impact of three subsidy levels (0%, 50% and 75%) on capital investment costs result in three water application costs reported in columns 5 and 6 of Table 1. In columns 7 and 8 we report total use costs in the case of energy subsidization at 50% and 75% levels. The results show unambiguously that subsidies are hardly relevant for a wide range of irrigated agriculture relying on groundwater, if the subsidy comes in the form of the capital grant. This is because during the 10-year life span of pumping and irrigation equipment, energy will be the main water application cost. However, if energy is subsidized, the application costs are reduced by about 50% and 75%, respectively.

In contrast to groundwater, surface irrigation (last two rows in Table 1) subsidies are often fundamental in ensuring the profitability of farming activities under a general range of circumstances. It is not surprising that irrigation districts projected to be developed in the next decade in Spain, Canada, Portugal or Turkey, will require a minimum capital grant of 50% of the investment costs, reaching 75% in Canada (Hoppe 2000).

If differing supply costs contribute towards explaining the strength of groundwater extraction rates worldwide, the demand side is no less significant. Recent work by García Mollá (2000) and Hernández-Mora & Llamas (2001) shows that farmers using groundwater are significantly more efficient and productive than those that rely on surface water. Factors such as supply flexibility and reliability, combined with a much larger degree of management decentralization at the farm level, explain the efficiency differences found in many studies.

In sum, cost differences, technological factors and better farming conditions underlie the worldwide observed trends in favor of the use of groundwater resources, particularly in the irrigation sector. From a social point of view, economic analysis should also incorporate benefits and costs that represent present and future welfare impacts, positive or negative. Thus, looked from a broader perspective, the economics of groundwater use become more complex, because externalities can grow to non-negligible levels, and non-regulated or unconstrained profit-maximizing agents may lead to exploitation regimes that are far from optimal.

3 FRAMEWORK FOR ANALYSIS: THE ECONOMICS OF GROUNDWATER

3.1 *The foundation of efficiency: property rights*

This section provides a basic overview of groundwater economics. That is, how do economists apply economic principles in order to understand groundwater problems and their solution? This is a relatively new field in economics. Natural resource and environmental economics has been recognized as a *bona fide* sub-field in economics for about thirty years. Groundwater resources remain a fairly novel area of study within the sub-field. For this reason, there is much to be gained from careful study and analysis.

The importance of institutions in determining the direction and pace of economic development is well known (North 1990). While the institutions governing surface water allocation and use have garnered substantial attention, the question of institutional design in relation to groundwater is relatively undeveloped.

Table 1. Irrigation water costs for various supply conditions.

			Total cost (US$/m^3)				
Depth (m)	Flow (L/s)	Water-Source	No subsidies	With a capital grant of		With a subsidy of energy cost of	
				50%	75%	50%	75%
50	50	groundwater	0.15	0.14	0.14	0.08	0.04
100	50	groundwater	0.22	0.21	0.20	0.11	0.06
150	20	groundwater	0.29	0.28	0.27	0.15	0.07
200	70	groundwater	0.35	0.34	0.33	0.18	0.09
14	10	groundwater	0.12	0.10	0.09	0.06	0.03
440	42	groundwater	0.67	0.65	0.64	0.33	0.17
560	33	groundwater	0.82	0.81	0.80	0.41	0.21
1	50	groundwater	0.09	0.08	0.07	0.04	0.02
0	50	surface water (1)	0.28	0.14	0.05	0.14	0.05
0	50	surface water (2)	0.36	0.18	0.07	0.18	0.07

(1) Assuming a per ha investment cost of US$ 15,000; (2) US$ 20,000. All figures are evaluated for a 10-year loan payable at 5% interest rate. Based on Hernández-Mora & Llamas (2001), and authors' calculations.

Traditionally, economists have studied surface water scarcity and supply side solutions (structural projects). More recently, attention has been focused on the demand side of water allocation, i.e. the institutions and policies that establish water use incentives and govern the reallocation of water between uses (Easter *et al.* 1998). However, most of the work on water institutions deals with surface water (Anderson 1983). Economic research on groundwater institutions is still relatively scarce.

The goal of this particular section, and indeed the objective of the entire chapter, is to provide an economic perspective on the policy debate concerning groundwater. Because we intend to approach the problem from an economic perspective, we build on the theoretical work of Brown (2000), which captures the state of the art in regard to the economics of natural resources. Brown's work is compelling because it is sophisticated in theoretical terms and yet it is focused directly on the problem of actual application. In order to make our contribution, we do not advance this theoretical work. Instead, we focus on applying the key elements of Brown's analysis specifically to groundwater resources.

Brown (2000) and others, clearly recognize that application of economic principles to groundwater management, to date, is very limited. Our hope is that by reviewing the basics of economic theory, and then examining typical cases of actual groundwater institutions, we can identify both where groundwater policy is sound and where substantial policy innovations must be made in order to promote efficient resource use.

Management of non-renewable groundwater aquifers can be viewed simplistically as a mining problem. For renewable groundwater, the analysis becomes more complex since it has to account for recharge, which is variable over time and essentially non-linear. In the broadest terms, achieving the goal of economically efficient resource use requires that we maximize social net benefits over time, subject to the dynamics of the resource (Brown 2000). This requires a delicate interplay between markets and regulation that may well need to vary between geographic regions and over time. Economists often emphasize the role of pricing in resource management. But in the case of groundwater (and in many other resources), the problem is considerably more complicated.

In order for individuals to use any natural resource in a way that is economically efficient and equitable, it is absolutely critical that they take into account all the benefits and costs associated with their decisions, regardless of to whom the benefits and costs accrue (including other water users and also non-users who may have a *stake* in the quantity or quality of the aquifer). Property rights provide the foundation for individual decisions, and determine who is responsible for various benefits and costs. Therefore, property rights deserve special attention.

Property rights (i.e. institutions) constitute the rules that govern resource use. Property rights specify who has access to groundwater, under what conditions it may be used, who has the right to claim income, and who must pay costs in regard to use (Bromley 1982). For an economist, property rights are lacking or deficient when the conditions guiding individual use of a resource do not require that all benefits and costs be accounted for (Baumol & Oates 1988, Hanley *et al.* 1997). As a result, perverse incentives exist, and individuals will use the resource in an inefficient way. The nature of property rights is also a key element in equity questions. In fact, efficiency and equity concerns overlap in almost every economic aspect of management.

Ciriacy-Wantrup (1956) was perhaps one of the first economists to recognize the importance of security and flexibility in fostering efficient resource use. Howe *et al.* (1986) have extended these principles to incorporate important equity considerations and the problem of institutional change. According to Howe *et al.* (1986), resource institutions must: 1) create security and relative certainty in resource use; 2) be flexible; 3) result in opportunity cost pricing; and 4) be perceived and equitable and reflect social values.

Water rights are secure if: 1) right holders are certain about the quantity, quality, location and timing of resource availability; 2) the right is guaranteed to be intact over a fairly long period of time; and 3) the user is protected against uncompensated damage to the right by other individuals and public agencies. This is fairly difficult to achieve given the nature of water, but the particular structure of water rights can be highly instrumental in approaching this ideal (Livingston 1995).

Water rights must be flexible in order to be efficient, because institutional arrangements must accommodate the need for reallocating water over time, in response to changing economic conditions. Reallocation of water within and between sectors is economically justified when transfers move water to the highest value uses thereby maximizing net economic returns (Howe *et al.* 1986). Institutions are critical in determining whether water transfers are in response to *bona fide* efficiency concern, whether they incorporate inappropriate or inaccurate considerations, or disallow reallocation altogether.

Resource prices emerge out of the property rights structures. To the extent that resource users integrate all social impacts into decision making, resource price will be economically correct. However if externalities exist, meaning users do not take into account the full beneficial and detrimental impacts of their decisions on others over time, resource prices will be biased, yielding incorrect signals in the market place (Randall 1983).

3.2 *The pervasiveness of externalities*

Unfortunately, externalities in groundwater use are extremely pervasive (National Research Council 1997). In addition, they occur in stunning variety. 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. The following paragraphs outline basic types of externalities and how they actually manifest in groundwater use.

The topic of externalities in groundwater use is a complicated one. The form of a particular externality depends on both the natural and economic features of a particular aquifer. It matters very much: 1) whether or not the aquifer is recharged, and if so, at what rate; 2) the extent to which ground and surface water supplies are connected, if at all; 3) the types of water use associated with the resource, e.g., irrigation, municipal, etc.; 4) the geographical scope of the aquifer, i.e. the range of users that affect, and are affected by, the resource; 5) the particular mix of quantity *vs.* water quality issues that are relevant; 6) the extent to which environmental uses are an issue; and 7) the exact nature of the environmental use, e.g. species preservation, recreation, aesthetics, etc. These elements are important because they determine the relationship between users (and often non-users) of groundwater that may create, or be subject to, external impacts. In Table 2, we offer a few examples of various externalities that have been valued in US$ terms.

Table 2. Examples of economic valuation of groundwater externalities.

Authors	Study location	Type of externality	Calculation method	US$ value
Collins & Steinbeck (1993)[1]	West Virginia	Contamination by bacteria, minerals, organics	Household Averting behavior	US$ 320–1,090 per household and year and contaminant
Jordan & Elnagheed (1993)[1]	Georgia	Contamination by nitrates	Contingent valuation studies (option price)	Public: US$ 65.9 per household and year Private: US$ 88.56
Sun (1990)[1], Sun & Dorfman (1992)[1]	Georgia	Contamination by nitrates and pesticides	Contingent valuation studies (option price)	US$ 961–998 per household and year
Tsur (1997)	California	Stock externality	Valuation of the stabilization value	58% of the total groundwater use value
Ministerio de Medio Ambiente (2000)	Com. Valenciana and Región de Murcia, Spain	Groundwater overexploitation.	Cost of water transfers to replace water taken from overdrafted aquifers	US$ 0.22– 0.50 per m^3
Mues & Kemp (2001)	Murray River (Australia)	Water salinization	Net present value of the reduction in agricultural returns from high saliized water tables	US$ 139 million
Barbier & Chia (2001)	Vittel (France)	Water contamination	Compensatory payments to contaminant farmers	US$ 197 per ha

[1]Cited in National Research Council (1997).

3.2.1 *Stock externalities*

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, and therefore increases the costs faced by other water users. In groundwater, the problem is usually one of lowering the groundwater table, thereby imposing added pumping costs not born by the private decision maker. The impact of the stock effect may be felt by other current water users, or by future generations of water users, depending on the physical characteristics of the aquifer. To complicate matters, aquifer recharge is generally non-linear so conventional stock arguments do not always apply.

Groundwater use is also fairly unique among renewable natural resources in that, unlike biological resources, changes in the stock of groundwater do not automatically, or generally, affect the growth rate (recharge) of the resource. The recharge rate of a particular aquifer is usually independent. (However, a lower stock of a particular aquifer can open the aquifer to higher rates of recharge and can improve, or worsen, water quality). On the assumption that recharge is independent, this is economically important because it can be demonstrated that when use does not affect growth rates, price changes in the resource will not affect privately optimal use rates (Brown 2000).

In order to account for stock externalities and promote efficient resource use, it is necessary to craft property rights (or put public conditions on private use) in a way that individual pumpers pay the full external cost, i.e. the *user cost* stemming from the stock effect. Brown (and the authors of this paper) are not aware of any precise externality charge in the real world; the efficiency notion is fairly sophisticated whereas actual groundwater policy is not. For instance, Helleger & Van Ierland (2001) report that only 2% of Dutch farmers pay the groundwater tax. The Groundwater Act (1985) foresees that it should be applicable for any unit exceeding 40,000 m^3/yr. This is one example of the combined use of quotas and prices that effectively keeps farmers' water use levels under control. Where surcharges on water withdrawals are imposed, they are usually very rough approximations of third party effects (see the Texas case, Section 4.2.4) or they are not motivated by economic efficiency at all (Brown 2000). Often, surcharges are employed to raise government revenue for other purposes.

3.2.2 *Spatial externalities*

Spatial externalities, as defined here, are impacts on other parties that arise due to their geographic location, rather than from the level of water under the ground *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 the user in question. In confined or superimposed aquifer systems, the impacts of extraction from flow and storage can be complex resulting in reduced pressure heads and changed leakage and boundary conditions that impact distant users. Environmental externalities may also be spatial as explained below.

3.2.3 *Environmental externalities*

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, which in turn provide habitat for waterfowl and other species. This exemplifies the import of ground-surface connections. In other cases, surface springs may be impacted by groundwater use (Iglesias 2001).

While the quantity of water is central to these examples, it is not difficult to imagine how water quality could be relevant. Typically (but not always), groundwater tends to be of higher quality than proximate surface supplies, so mixing results in positive externalities (Roseta Palma, in press).

The case of environmental externalities makes it clear that an individual must not necessarily be a water user to be impacted by water use decisions. Non-users may well have a stake in groundwater use decisions, through their external impacts on environmental or other (e.g. social or cultural) resources.

3.2.4 *Temporal externalities*

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 and other natural resources requires that future benefits and costs be integrated into the analysis. Unfortunately, in most cases, contingent futures markets are missing (Brown 2000). From a private point of view, this deficiency drives a wedge between the present market value of the resource and the true opportunity costs (foregone net benefits in the future). Under these conditions, because the individual is unable to capture the future value of the resource, he will face a perverse incentive to develop and use the resource sooner than is economically justified.

3.3 *Institutional approaches to groundwater management*

Institutional arrangements (meaning the formal laws, and policies governing water access and use) are central to groundwater management. There is a great variety in institutions governing groundwater around the world. From an economic perspective, it is critical to analyze how the particular physical and use characteristics of an aquifer interact with policy to yield the incentives that guide groundwater use. This section discusses basic approaches to governing groundwater and relates them to the principles developed by Howe *et al.* (1986).

3.3.1 *The interface between private and public control*

In order to characterize various institutional approaches to groundwater management, some broad categorizations may be useful in generating insight. One aspect to consider is the degree of private or public control over the resource. Ownership, allocation and reallocation of water may be controlled by private individuals, public officials or a combination of the two. It is overly simplistic to imagine that management of groundwater resources in a particular case is simply one or the other. Typically, private and public controls are interwoven, and are often specific to a region or culture.

In many places around the world, as the use of groundwater becomes more intense, public regulation increases (Caponera 1992). On the other hand, one can also observe cases of very private approaches to handling intensive groundwater use (e.g. see the case of the Canary Islands in Section 4.2). It is important to realize that either public and/or private control may generate efficiency problems, depending on the character of the specific groundwater source, relevant uses, and the specifics of the policy in question.

Despite the plethora of possibilities, it can be highly instructive to examine exactly how the public and private spheres interact in a particular situation or locale. The specific connection can create synergies that are extremely important in terms of promoting the security of supply, flexibility, the generation of externalities, and therefore, the balance between allocative efficiency and equitable distribution of access.

There are many vehicles through which private parties can own groundwater and make decisions about the allocation and/or reallocation of water. Groundwater can be held by private individuals with their own facilities, by private corporations, or by water organizations made up of private shareholders.

From an economic perspective, the factors that determine what quantity of water is available and the price that applies is particularly material. Typically, water held by private individuals carries a price equal to whatever annualized investment costs plus operating and maintenance costs are actually paid by the individual. Quantity may be unrestricted, limited by land holdings, or specified in permit conditions.

Institutions that establish the rules of access, ownership and quantity of water available for use are particularly important in terms of creating certainty in the system (rule one, according to Howe *et al.* 1986). The rules that apply to transfers of water between economic agents relates to flexibility (rule two). And pricing relates to rule number three.

When water is held privately through a water organization, there are, in turn, a variety of ways in which water can be allocated. It may be prorated according to a variety of criteria; for example, shares may be based on land holdings or financial contribution. The way in which private corporations decide the quantity and price paid by individual users can also vary.

To the degree water is controlled by a public agency, it is important to analyze what specific conditions are placed on resource use. In particular, one must examine what affects the quantity and price of the resource available for individual use. With respect to price, there are at least three aspects to think about. One basic consideration is whether individual users pay the full financial cost of water acquisition and delivery or alternatively, whether the price of water or the price of water access (e.g. subsidized energy in India, Pakistan and Yemen) is subsidized by the public agency. If water is not subsidized, one may ask whether users pay the marginal or average cost of the water.

Even when water users pay the full financial cost of water, typically some economic costs are not considered nor paid for. Externality costs imposed on other current users, and users in the future, are rarely included. When some environmental premium is attached, the real purpose is often to raise revenues rather than compensate for ill effects. In many cases, it is very difficult to define the boundaries beyond which no individual would be entitled to compensation.

Public agencies affect the quantity of groundwater available to individuals in myriad ways. In many regions of the world, access to water resources is limited to owners of overlying land, and yet these landowners may claim an unlimited quantity of water. On the other end of the spectrum, quantities may be limited to a specific permitted amount, which is also limited by periodic (yearly) approval and renewal. In other regimes, the quantity of water available for individual use is limited according to estimated crop requirements or prorated based on actual well yield or on estimates of total sustainable water supply.

The ability to transfer allotted groundwater is critical for flexibility in water allocation and economic efficiency. Yet very often, public rules and regulation prohibit or limit water transfers. Groundwater is often appurtenant to land and can be transferred to another users only via land acquisitions. Sometimes public policy requires that water be used directly on the land in question, while in other cases water can be transferred to other locations.

It may be useful to consider the extremes in the spectrum of possibilities introduced above, if only to demonstrate that neither extreme is ideal in economic terms. Both private and public extremes do exist but, fortunately, are fairly rare.

The private extreme would consist of an institutional void, i.e. lack of any public rules or regulations whatsoever. Under these conditions, individuals essentially gain rights through intrusion. There is no limit on quantity used, and the price of water is thoroughly un-subsidized. In an institutional void there is no accountability to other parties; most certainly there is no externality premium for impacts on other users, or environmental resources. On the other hand, there is no protection against other current users, or users in the future. Therefore, existing rights are extremely insecure. As a result, water resource use will be economically inefficient, since there is no incentive to invest in the future.

Another institutional extreme would be total public control over groundwater allocation and pricing. In all likelihood, this would amount to permits for a specific quantity of one time use. The right would not be held in perpetuity; rather it would be periodically renewed, with changes in conditions determined by the public agency. The price would be set by public agencies; it is likely that the criteria for setting price would not match a perfectly competitive market. Transfers would also be controlled, requiring public approval. The problem with the entirely public approach is that rights are both insecure and inflexible. With regard to the latter, the system is very rigid, and cannot respond to changing economic conditions.

3.3.2 *Common property in groundwater*

There is an alternative to purely private or public control of groundwater. Resources can be managed as common property. While common property management of surface water is quite typical, groundwater resources are rarely held in common. The work of Ostrom (1993) in analyzing common property sheds some insights into why common schemes are so unusual in groundwater management.

Ostrom cites the following factors as facilitating well managed common property schemes: 1) common property management is enhanced if the resource basin is small; 2) it is beneficial if the resource is renewable; 3) it should be possible to impose sanctions at low cost; 4) common property is more appropriate when individuals cannot impose major harm on others; 5) common property is more effective when users employ similar technology; 6) common property is more effective among stable populations where users share social norms (so that legal costs are minimized).

Common property may be used as a mechanism to pool risks and is seen more often among relatively poor groups (Ostrom 1993). As product prices increase, common property tends to become less attractive. Technological progress can also effect the degree to which property is held in common or privately. Technology can either increase or decrease the ability to effectively exclude individual users.

Clearly, the factors that facilitate well managed common property resources are often absent in groundwater. Many aquifers underlie large geographic areas. Some aquifers renew rapidly, but many others renew at rates much smaller than use rates. It is fairly plausible that in many cases, users share similar technology. However, the harm imposed on others (especially in the future) may be significant. Conflicts over groundwater are greatest where the population of users is in great transition, and where users are quite dissimilar. This fact bears out Ostrom's theory, but does not bode well for the prospect of common property management in groundwater.

3.4 *A policy recommendation for achieving efficiency and equity objectives*

Finding an economically ideal groundwater institution is very unlikely in the real world. Ideally, the institutions governing groundwater would create security, transmit perfect information, be thoroughly flexible and be perceived as equitable. In more practical terms, progress in groundwater management can be made by incremental improvements in efficiency and equity. The overall idea is to encourage private resourcefulness (efficiency) within broad, and reasonable (equitable), public guidelines.

Two common features abound in some of the most innovative institutions proposed in the literature. They are: 1) quotas on the total amount of water extracted in a certain time period; combined with 2) markets that allow trade. Both features have efficiency and equity implications. But in general, the first feature is linked critically with social equity whereas the second feature is connected more with economic efficiency. Simplistically, the idea is one of using efficient means to achieve equitable goals.

Quotas can be fixed or proportional to any other factor that differentiates users, but they must be set based on actual stock levels and on stock targets, presumably on the basis of known hydro-geological limits. Quotas are the means to shift to an equitable or environmentally sustainable extraction path. Within the overall quota, users are allowed to buy, sell or trade rights. This allows users to respond to market signals, and increase or decrease their extraction rates correspondingly with their relative productivity among the whole group of users. Flexibility is hardly possible without markets or institutions that allow one to trade water, extraction rights or shares.

Any combination of markets and quotas leads to the notion of Individual Transferable Quotas (ITQs), which have already being used in fisheries with success (Brown 2000). For instance, Provencher (1993) proposed a decentralized mechanism to ensure an aquifer's recovery to a given optimal steady-state. The system would involve issuing shares for all current water and recharge, and distributing them among all users. Shares would be freely traded, but at a given time in the future a number of shares would be withdrawn from the market to ensure aquifer's recovery to the optimal level. The anticipation of increasing share prices would provide users incentives to reduce their water demand and adapt to the new regime.

Other authors have proposed alternatives along similar lines, including option and lease contracts. For instance, Iglesias (2001) developed the notion of a water bank among rightholders to facilitate the transition to a groundwater table to ensure the preservation of a valuable wetland in Spain. Farmers would be allowed to bank extraction rights, use them or sell them in a market, but as in other proposed mechanisms the amount of extraction permits would need to be fixed before hand. The extraction path of such a water bank system would be less efficient than the optimal path evaluated by the perfect planner, but the divergence might be relatively small.

3.4.1 *Efficiency aspects*

Efficiency aspects of groundwater management revolve primarily around the policies determining the price and quantity of water available to users. To an economist, reasonable conditions on price and quantity are as follows: with regard to price, individual parties would pay the full marginal financial cost of water acquisition (Griffin 2001). In addition, water prices would carry a premium exactly equal to the sum of all marginal external costs so that true *opportunity cost pricing* is achieved. Economically, the volume quantity of water owned is not particularly important in terms of efficiency, but may be critical in terms of equity. It is important that the quantity is specified with certainty, and access to that specific quantity would be granted in perpetuity.

In an ideal system, water would be fully transferable and not attached to land or another resource. The only limit on transferability would be that transfers not precipitate any uncompensated (quantity or quality) externalities on other parties (water users and non-users alike).

3.4.2 *Equity aspects*

Equity aspects of groundwater institutions tend to revolve around the rules that determine: 1) how much water is open to development and how much is reserved for environmental or other uses; 2) how access to water is determined; and 3) the distributional issues associated with changing from an unregulated to regulated management. These aspects are explained below.

Beyond the basics of quantity and price, the question remains how initial rights to the resource should be allocated. Most economists would agree that, at some (early) point, a balance must be struck between monetary and non-monetary (usually environmental) uses of water. This is a key equity element that relates to the fourth principle developed by Howe *et al.* (1986). This allocation cannot be made in the market, due to the very nature of the problem. In the absence of market based valuation, typically, a judgement must be made based on expert, or public, assessments of environmental safety and prudence.

The total quantity of water devoted to economic development must then be allocated on an equitable basis. Common notions of equity rest on historical use or physical need. Once initial rights are allocated, transfers will result in a water allocation that maximizes social net benefits.

Even when reasonable rules for groundwater use are established, these questions remain: How do we get the correct incentives for individuals to obey established rules? How can we be assured that individuals will accept mandatory regulation on access, and on pumped volumes? What provisions are there for monitoring compliance and what sanctions apply when individuals or companies violate the rules? Water rights are secure only in name, not in fact, when monitoring and enforcement are absent or inadequate. This often forms the crux of the problem in water resource management, even where institutions are fairly sophisticated.

Another set of problems is posed when, in order to improve efficiency, groundwater policy and institutions must be changed. Institutional innovations certainly, and often intentionally, change the incidence of economic benefits and costs. Parties that are advantaged by existing policy very often stand to lose when policy changes are implemented. Typically, stakeholders in the established regime raise political oppositions to change. The problem becomes how to overcome this hurdle in order to effect efficient change. The solution is often compensation. It may be necessary to *pay off* groups who stand to experience short term losses as a result of changes in resource policy. Compensation may raise ethical questions, e.g. compensating polluters *vs.* using the polluter pays principle. Political acceptability usually requires compensation regardless of other considerations.

3.4.3 *Summary*

A lesson from this literature is that, in the interest of both efficiency and equity, there is an unavoidable need to have a supra-individual authority dictating, or at least sanctioning, the size of the quotas, the stock targets and other restrictions. This assumes that the agency is sufficiently expert to make resources assessments and assign levels of risk. Flexible mechanisms are suggested to approach optimal paths of use, in a manner that allows each individual user less costly adaptation (Colby 2000). The flexibility of ITQs is also thought to produce market prices that internalize stock and some other externalities, making private decisions less perturbing for the collective resource.

Most institutional arrangements designed for groundwater management are a mix of the public/private combinations described in this section and may or may not include elements of ITQs management. Both the particular mix of instruments and the context in which they are applied have important implications for economic efficiency. In the next section, five case examples of groundwater institutions in developed countries are presented, with particular emphasis on the private/public interface discussed above. In many cases, innovations in institutions are occurring. It is interesting to speculate as to whether these changes are in fact improvements in terms of economic efficiency.

4 REPRESENTATIVE CASES OF EXISTING GROUNDWATER INSTITUTIONS

4.1 *Introduction*

Management of water resources has, very naturally, commanded significant human attention throughout the course of human history. The ability of various societies to use the resource efficiently has had a significant impact on prosperity. With regard to surface water, in recent decades (and in general) attention has shifted from technical approaches to controlling water to institutional means of allocating water among individuals and uses in order to maximize efficiency (Easter *et al.* 1986).

While groundwater has always been important to humankind, both technical and institutional management of the resource tends to be fairly primitive relative to surface water. Perhaps this is due to the physical nature of groundwater. The fact that it is often invisible in its sources and movement poses some problems that complicate management. Even as technical understanding has grown, institutional arrangements have lagged behind.

There may be much to be gained from examining the social institutions that govern groundwater resources around the world. Institutions establish *the rules of the game*, thereby defining property rights. In turn, property rights shape relationships between people via their relationship to the physical resource.

Groundwater resources are under scrutiny around the world, and institutions are evolving quickly. There are many questions that arise for economists. Certainly, one is whether or not these changes are improvements in terms of efficient and equitable water use. There is certainly not a singular and consistent theme in institutional change. In many cases, institutional innovations constitute social experiments. The purpose of this section is to give the reader some indication of the general trends in institutional change that are occurring in the developed world and how they deal with common efficiency and equity issues.

4.2 *Case studies of changing groundwater institutions*

4.2.1 *Spain (Mainland): a complex and incomplete transition from private to public property*

Spanish Water Law dates back to 1985, and was amended in 1999 to incorporate, among other things, the option to interchange water rights. See also, the detailed coverage of the Spanish case (Hernández-Mora *et al.*, this volume), and the treatment by Burchi & Nanni (this volume). In regard to groundwater use, the 1985 Law offered those right holders, that before 1985 did not have rights catalogued in the registry, two options to comply with Law. One alternative was to keep the rights as private property for 75 years, enjoying unencumbered access similar to the situation they had before the 1985 entered into force. The other alternative was to file an application to convert their private rights into water use rights, similarly defined as surface water rights. The advantage of the first options was that right-holders kept past privileges, but that would last until year 2060. The advantage of the second option was that use rights would normally be renewed every 30 years, although they resemble a public concession and not a private property right.

Unexpectedly, few groundwater users opted to convert their rights into concessions, preferring to maintain their pre-1985 status. As a result of this outcome, public action in the groundwater area was limited to cases where severe overexploitation became apparent, and the Water Authority issued a specific declaration of aquifer overexploitation. This implied that a management plan to restore the aquifer's levels must be developed, which included caps on extraction rates by users irrespective of the nature of their groundwater rights. On the few occasions where these actions were promoted, users appealed to courts, refused to observe the rules or simply ignored the plans. Coercively implemented plans failed on all grounds. In contrast, in the well-known case of Tablas de Daimiel (a wetland located in the Southern Castillian plain), irrigators opted to reduce their extraction rates after being generously compensated with EU funds attached to the *Agri-Environmental Programme* (2078/92 EU Regulation) (Sumpsi *et al.* 2000).

Two very recent issues merit further comment. One is the approval in July 2001 of the Law of a National Hydrological Plan. Although largely devoted to a large inter-basin transfer, the Law includes an article which forces all groundwater users, either with or without rights, to file a declaration expressing their claims and laying down their pumping capacity. After the closing date of application, no user will have any chance of legalizing their wells and pumps except by means of a court appeal. This provision brings to a halt any further expansion of extraction capacity, and paves the way for the process of grandfathering water rights (legitimizing pre-existing uses and users) among all claimants.

One example of the type of response that this new Law has triggered is the uni-lateral proposal to grandfather water rights that was tabled by the Managing Board of the *Junta Central de Regantes de la Mancha Oriental,* and approved by the assembly of members in September 2001 (see Table 3).

Table 3. Proposed extraction rates for the irrigators in the Mancha Oriental.

Maximum per hectare volume (m^3/ha/yr)	Prerequisites
5,200	Those farmers that had irrigated crops prior to 1986 and had filed an application to opt for one of the alternatives laid down in the 1985 Law (see text).
3,500	For those farmers that had either initiated irrigated farming or filed a right application between Jan.1, 1986 and Jan.1, 1997.
To be set by the Water Authority	For those farmers operating under other conditions.

The proposal was accepted by 70% of the farmers. A simple inspection on the criteria tabled by the Board to be approved by the users shows that seniority is assigned to pre-1986 users, access is in principle not denied to the junior users, and farmers operating under non-legal status are referred to the Water Authority.

Another experience worth reviewing is in the Lower Llobregat (Catalonia, Spain). The intensive industrial development of the area near the Barcelona airport brought the alluvial aquifer of the Llobregat to a severe situation of overexploitation in the late 1970s. Prompted by record low aquifer levels, users formed an informal association in 1977 which became legal in 1982, including municipalities, irrigators, industrial users, and *Sociedad General de Aguas de Barcelona* (*Agbar*, the large water company that supplies water to the city of Barcelona and many other surrounding areas).

Users agreed on the need to develop recharge plans and limit the extractions. This took place before the 1985 Water Law entered into force, but had the support of the water administration. Presently, the Association, with 150 members, sets annual exploitation plans, enforces the rules, monitors extraction rates, collects water fees and carries out hydrological studies. According to Galofré (2001), the factors that seem to explain the successful Llobregat experience are: 1) the leadership of Agbar and its willingness to bear all the costs of the artificial recharge plans; 2) the risk perception among both small and large users; 3) the general awareness of the critical situation which the aquifer was leading to in the absence of control and management plans; and 4) the fact that both users and aquifer's limits were easily identified and rarely contested during the course of its early development stages.

4.2.2 *Canary Islands, Spain: an example of privately held water and common property*

The Canary Islands in Spain provide an interesting example of largely privatized groundwater allocation institutions. Groundwater management on the Canary Islands is quite unique among regions in Europe in that private companies and corporations have been involved in the development and allocation of groundwater resources for over a century (Tremolet 2001).

It is plausible that the natural resource endowments of the islands played an important role in influencing groundwater institutions. The region is water scarce, with about one fourth the water availability of the Iberian Peninsula, and the vast majority of water resources are beneath the surface of the earth.

According to Tremolet (2001): "the public sector water was not interested in this development and gave private investors a free hand". Private companies made substantial 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. Investment in water shares does carry some risk. A particular well can generate large or small flows, and the quality of water differs greatly between wells.

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 1980s concern over dwindling aquifers, and environmental effects, began to rise. Public control over all water was suggested, but soundly rejected. Existing infrastructure may remain private until 2065. Even so, public oversight of new groundwater developments and desalinization has been introduced. Private investors have also shown less interest in investing, as public involvement has grown. 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. More recently, State companies such as Balten (in the Tenerife Island) has stepped into the water supply business with commercial and regulatory purposes. Among the latter are the elimination of excessive price discriminatory practices caused by infrastructure bottlenecks, a more efficient water quality grading and flattening-out market price trends (Fernández Bethencourt 2001).

4.2.3 *Colorado, USA: the tie between ground and surface water*

Groundwater institutions in the state of Colorado have changed over time in response to changing economic conditions. For example, institutions have been innovated to deal with conjunctive water supplies, i.e. co-management of ground and surface water. See Sahuquillo & Lluria (this volume), for a detailed treatment of issues in conjunctive management. As in most places in the USA, management of groundwater resources has been largely separate from management of surface water supplies. However, between 1940 and 1970, great attention came to be paid to the connection between using groundwater supplies and the diminishment of related surface supplies.

In 1965, the Colorado legislature made a distinction between tributary and non-tributary groundwater. Lawmakers made groundwater that is tributary to surface water subject to the overall surface water law doctrine of prior appropriation (Hobbs 2000). The appropriation doctrine prioritizes water rights based on chronology: *first in time is first in right*. However, groundwater users must obtain an official permit rather than simply making beneficial use of un-appropriated water, as in the case of surface water.

Because use of groundwater lagged behind surface water, almost all groundwater rights in tributary systems are *junior* to surface water. However, the 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.

Colorado utilizes the public concept of groundwater districts to allocate water in the Ogallala aquifer (see Smith, this volume, for more information on the Ogallala aquifer). The state wide Ground Water Commission establishes water basins, within which there are many management districts. In order for private parties to use this source of groundwater, a permit from the public district must be obtained.

In the Northern High Plains Basin, which contains part of the Ogallala aquifer, the Colorado commission adopted (in 1967) a policy to allow 40% depletion in 25 years (Simpson 2000). In 1990, the policy was revised to only allow appropriations that contribute to a depletion of 40% in 100 years, which essentially cut off additional appropriations. At current use rates, it is estimated that nearly 20,000 ha of irrigated land will convert to dryland farming by 2015.

Management of the Ogallala is hugely complicated by the fact that it underlies several states (see the Texas case, Section 4.2.4) and is connected to surface water. Conjunctive water supplies are also important in inter-state conflicts concerning the Ogallala aquifer. There is current litigation in the USA 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. These conflicts parallel some of the issues found in international transboundary groundwater resources.

4.2.4 *Texas, USA: the changing private/public interface and the Ogallala*

The recent history of groundwater institutions in the state of Texas in the USA is instructive in terms of the co-existence of private and public control, as well as a general trend when groundwater supplies are stressed economically. (See also, the discussion by Burchi & Nanni, this volume).

Historically, groundwater policy in Texas has been based on the doctrine of absolute ownership (Griffin & Characklis 2002). Access to groundwater is based on private ownership of overlying land. Private parties are entitled to an unrestricted quantity of water. It is important that 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 landowners allowing the town to capture water on the rural property and then pipe it to town. The town pays for all infrastructure plus an annual minimum payment.

In terms of price, the financial cost of water is unsubsidized; private individuals pay the full cost of investment in equipment as well as operation and maintenance costs. This case is also typical in that the financial cost does not capture the external impacts on other parties now or in the future. As groundwater resources have been used more intensely, and as potential conflicts with environmental uses have grown, public groundwater *conservation districts* have been formed to address problems and amend policy. For example, in Texas, public policy targets depletion of the Ogallala aquifer by 50% in 100 years. This introduction of public restrictions is fairly typical in the USA, and around the world when groundwater resources become stressed.

Clearly, one of the most stressed aquifers in Texas is the Edwards Aquifer, which has been an important source of water supply for the growing needs of San Antonio, Texas. This aquifer is connected to surface water and heavy use diminishes surface springs. The problem is that several endangered species rely on the surface springs, which means the federal USA government environmental policy supercedes state water policy. The Endangered Species Act is perhaps the most definitive limit on economic uses of both surface and groundwater throughout the USA today. It constitutes the operating balance between monetary and environmental uses of water at the national level.

In order to reduce the impacts of groundwater use on surface springs to an acceptable level, the aquifer is currently being adjudicated. Adjudication will allow permits for specific quantities of water to be allocated based on actual historical use. When pumping data is lacking, irrigation rights are based on about 6,130 m^3/ha. Subsequently, the total number of permits will be reduced, probably through market purchase followed by retirement of those permits. This is a good example of public agents configuring, and then operating within, private markets.

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 district officials are concerned that these efforts will deplete the Ogallala in 25 years and are supporting legislation to charge fees on extractions to fund studies on the effects of pumping and the possibility for replenishment projects (The Economist 2001). This amounts to a rough attempt to charge an *externality premium*.

4.2.5 *The European International Directive: a narrow focus*

In the year 2000, the European Union (EU) issued the *Directive 2000 EC of the European Parliament and of the Council of establishing a framework for Community action in the field of water policy* (hereafter referred to as the Directive) (European Union 2000). The overall purpose of the Directive is to begin the process of developing an integrated Community policy on water that addresses the increasing demand for good quality water. The document is intended to provide the institutional guidelines for water management for years to come.

Under the Directive, countries must develop programs to achieve good ecological status of heavily modified bodies of water. In terms of vehicles to improve water management, the primary focus of the Directive is on pricing and on the development of programmes of measures to restore all EU water bodies to good quality status. Subsidization of surface water is very common throughout the Community. Typically, governments pay for the initial investment in surface water infrastructure with users responsible for only operation and maintenance costs. *Ceteris paribus*, surface water subsidies tend to produce overuse and undue decreases in water quality.

However, in contrast to surface water, use of groundwater resources are typically not subsidized by the state. Private users often incur both investment and operating costs. Nonetheless, groundwater is often used inefficiently. Groundwater use often imposes externalities on other parties now and/or in the future. Correcting these inefficiencies often requires more fundamental changes than simply freeing prices.

As explained in Section 3, fundamentally, institutional arrangement must provide: a) security, meaning users can be certain about the probability of getting water and be assured that all resources users have the incentive to obey the rules of access; and b) flexibility, meaning economic agents are able to negotiate changes in resource allocation as conditions changes. Problems in groundwater are more often a result of inappropriate rules of access, unspecified quantities or water, or restrictions in transferability. However, since each EU Member State has different constitutional and legal frameworks in regard to water resources, the Directive rightly focuses on ends, targets and numerous provisions to define the compliance timetable for each country.

In setting the objective to apply strict cost recovery rates for all water users, the apparent neutrality of the Directive is blurred because it obliges all Member States to estimate financial, environmental and resource costs. We know from many of the seminal works reviewed in this chapter that these costs are not independent of the ways water institutions are framed, and water codes are essential parts of them. Hence, by the time the European Commission starts to review each Member State's progress in implementing the Directive, it will need to examine thoroughly how costs are identified and quantified, and the extent to which water users' fees contribute to cover them in full. Eventually national water codes will have to be examined and perhaps redefined, at least in the manner they are enforced and applied. This is something that the Directive tried to avoid since it began to be drafted in the late 1990s.

5 CONCLUSIONS

Groundwater management issues are coming to the fore around the world. This chapter starts out with the recognition that the economic forces in place make groundwater a much more reliable and cheap source of water than surface sources. This explains the large expansion in groundwater use during the last decades, witnessed even in countries and regions where the further expansion of surface sources has been stopped. Not surprisingly, this growth has been accompanied by an increase in social concern about groundwater management.

Natural resource economics science applied to the questions of managing intensive groundwater use yields a number of prescriptions, disproportionately oriented towards finding optimum prices that could narrow the gap between private costs and social costs. With not much avail, legislators and managers either pay little attention to what economists say, or more likely, they do not find enough political support to charge water users tariffs or levies based on external costs.

Further knowledge about the physical aspects of aquifers renders mainstream economic prescriptions even less practical. Aquifer problems are not only related to stock externalities, but may be subject to even more dire difficulties as temporal and spatial externalities and groundwater pollution became apparent. Institutions must deal with real problems, and evolve subject to the resulting forces of individual incentives and collective behavior.

A challenge facing the economics profession is to formulate general propositions that explain why successful stories occur in countries and regions where failures are also common. The literature has borrowed from adjacent social sciences, and institutional analysis and governance studies have become common themes in resource economics. This chapter is an attempt to contribute to this particular policy debate.

Our analysis suggests that successful examples result from a multi-layered approach. These are defined by: 1) the definition and enforcement of property rights, but not the complete privatization of aquifers and the groundwater therein; 2) a skewed distribution of pumping rights –sometimes including one big user and a moderate number of smaller ones– and including water uses of different nature; 3) the recognition that vested water users should be given preferential access in legalizing pumping rights, although not to the extent of depriving more recent users of equal pumping access and the right to compete; and 4) that deadlocks may require external compensation or revenue transfers to facilitate the transition to implementing extraction controls and persuade users to yield part of their rights to a communal authority.

This observation and distillation of case examples is at odds with the approach developed in the European Union' Water Framework Directive (WFD). While WFD aims to improve the quality of the water services and of all water bodies across the EU, it takes the premise that poor and/or insufficient water pricing explains the current state of the EU waters, and emphasizes the need to (and forces Member States to) bring water tariffs closer to the water service costs, including financial, environmental and resource costs. This chapter shows that water pricing may not be the best emphasis, and certainly is not sufficient in itself, as an instrument to manage water demand on intensively used aquifers.

One important implication of this chapter is that the WFD does not establish a new and valid instrument for the European Member States. Water or resource prices are very often absent in many of the most successful experiences in groundwater management. This omission is justified on empirical as well as on theoretical grounds. As was shown in Section 2, private costs show a downward trend, reinforcing the lower relative cost of ground- *vs.* surface water. If water technologies are more easily applicable with groundwater, this implies that charges resulting from pricing policies must be set at increasingly higher levels, well above extraction cost.

For aquifers that are renewable (where recharges are substantial) pricing is not the primary key to successful management even in developed countries. Rather, the primary challenge is to establish secure property rights in groundwater that can be traded as economic circumstances evolve. That is, the key is to embed security and flexibility, even incrementally. For aquifers that are not renewable (where recharge is negligible) or subject to serious environmental externalities, successful management often relies on *cap and trade* policies. This means withdrawals are limited (capped) based on environmental targets (which entails grandfathering quotas, and perhaps compensation to those who lose pumping privileges) combined with the ability to trade remaining rights. Under this scenario, prices are not set; rather they emerge out of the trading scheme.

Establishing secure and flexible water rights in both private and public spheres is critical to successful management of groundwater. In order to accomplish this feat, the physical characteristics of the aquifer and the various types of use (both economic and environmental) associated with the resource must be taken into account. Economics can indeed contribute to the policy debate. The institutional challenge is a complicated one, but one that may be improved through consideration of the economic principles outlined here.

REFERENCES

Anderson, T. L. 1983. *Water rights: scarce resource allocation, bureaucracy and the environment*. San Francisco: Pacific Institute Public Policy Research.

Barbier, M. & Chia, E. 2001. Negotiated agreements on groundwater quality management: a case study of a private contractual framework for sustainable farming practices. In C. Dosi (ed.). *Agricultural use of Groundwater – Towards integration between agricultural policy and water resources management*: 195–212. Manchester: Kluwer Academic Publishers.

Baumol, W.J. & Oates, W.E. 1988. *The theory of environmental policy*. Cambridge: Cambridge University Press.

Bromley, D.W. 1982. Land and water problems: An institutional perspective. *American Journal of Agricultural Economic* 64(4): 834–844.

Brown, G.M. 2000. Renewable natural resource management and use without markets. *Journal of Economic Literature* 38: 875–914.

Burt, O. 1964. Optimal resource use over time with an application to groundwater. *Management Science* 11: 80–93.

Burt, O. 1967. Temporal allocation of groundwater. *Water Resources Research* 3: 45–56.

Caponera, D.A. 1992. *Principles of water law and administration: National and International*. Rotterdam: Balkema.

Ciriacy-Wantrup, S.V. 1956. Concepts used as economic criteria for a system of water rights. *Land Economics* 4: 295–312.

Colby, B.G. 2000. Cap and trade policy challenges. *Land Economics* 74: 638–658.

Custodio, E. 2000. *The complex concept of overexploited aquifer*. Papeles PAS. Serie A, no.2. Madrid: Fundación Marcelino Botín.

Easter, K. W. Dixon, J. A. & Hufschmidt, M. M. (eds.) 1986. *Watershed resources management*. Boulder: Westview Press.

Easter, K.W.; Dinar, A. & Rosegrant, M. (eds.). 1998. *Markets for water: Potential and performance*. London: Kluwer Academic Press.

European Union. 2000. *Directive of the European Commission of the European Parliament and of the Council of establishing a framework for Community action in the field of water policy*. Brussels, June 30.

Fernández Bethencourt, J.D. 2001. El papel económico de las aguas subterráneas en Canarias. In N. Hernández-Mora & M.R. Llamas (eds.), *La economía del agua subterránea y su gestión colectiva*; 251–266. Madrid: Eds. Fundación Marcelino Botín & Mundiprensa.

Foster, S. 1999. Essential Concepts for Groundwater Regulators. In M.A. Salman (ed.). *Groundwater. Legal and Policy Perspectives. Proceedings of a World Bank Seminar.* Washington D.C.: World Bank Technical Paper no. 456.

Galofré, A. 2001. Las comunidades de usuarios de aguas subterráneas en la Catalunya del 2000: desarrollo histórico y realidad actual. In N. Hernández-Mora & M.R. Llamas (eds.), *La economía del agua subterránea y su gestión colectiva*: 323–366. Madrid: Eds. Fundación Marcelino Botín & Mundiprensa.

García Mollá, M. 2000. *Análisis de la influencia de los costes en el consumo de agua en la agricultura valenciana. Caracterización de las entidades asociativas para riego*. Doctoral Dissertation, Universidad Politécnica de Valencia.

Griffin, R.C. 2001. Effective water pricing. *Journal of the American Water Resources Association* 37(5): 1335–47.

Griffin, R.C. & Characklis, G.W. 2002. Issues and trends in Texas water marketing. *Water Resources Update*. Issue 121 (January), pp. 29–33.

Hanley, N.; Shogren, J.F. & White, B. 1997. *Environmental economics in theory and practice*. Oxford: Oxford University Press.

Helleger, P. & Van Ierland, E. 2001. Policy instruments for groundwater management for agriculture and nature. Paper presented to the joint conference of the *International Water and Resource. Economics Consortium and the seminar on Environmental and Resource Economics*, Girona, Spain, June 30.

Hernández-Mora, N. & Llamas, R.M. (eds.). 2001. *La economía del agua subterránea y su gestión colectiva*. Madrid: Eds. Fundación Marcelino Botín & Mundi–Prensa.

Hobbs, G. 2000. Groundwater Law in Colorado. *Colorado Water*: April: 20–22.

Hoppe, T. 2000. Report on: *The Potential for irrigation expansion in Western Canada*. Prairie Farm Rehabilitation Administration Paper. Agriculture and Agri-food of Canada. (http://www.agr.ca/pfra/pub/irrexpan.htm#listtab).

Howe, C.W.; Schurmeier, D. R. & Douglas, W. 1986. Innovative approaches to water allocation: The potential for markets. *Water Resources Research* 22: 439–445.

Iglesias, E. 2001. *Economía y gestión sostenible de las aguas subterráneas: El acuífero Mancha Occidental.* Doctoral Dissertation, Madrid: Universidad Politécnica de Madrid.

Livingston, M.L. 1995. Designing water institutions: market failures and institutional response. *Water Resources Management* 9: 203–220.

Ministerio de Medio Ambiente 2000. *Proyecto de Plan Hidrológico Nacional*. Madrid.

Mues, C. & Kemp, A. 2001. Salinity management. Assessing priorities. *Managing Agricultural Resources* 1: 67–75

National Research Council 1997. *Valuing Ground Water. Economic concepts and approaches.* Washington, D.C.: National Academy Press.

North, D. 1990. *Institutions, institutional change, and economic performance.* Cambridge: Cambridge University Press.

Ostrom, E. 1993. Design principles in long enduring irrigation institutions. *Water Resources Research* 29: 1907–1912.

Provencher, B. 1993. A private property rights regime to replenish a groundwater aquifer. *Land Economics* 64(9): 325–340

Randall, A. 1983. The problem of market failure. *Natural Resources Journal* 23: 131–148.

Roseta Palma, C., in press. Groundwater management when water quality is endogenous. *Journal of Environmental Economics and Management.*

Simpson, H.D. 2000. Administration of Ground Water in Colorado. *Colorado Water*, April: 22–24.

Sumpsi, J.M.; Garrido, A.; Blanco, M.; Varela, C. & Iglesias, E. 1998. *Economía y políticas de gestión del agua en la agricultura*. Madrid: Mundi-Prensa.

Sumpsi, J.M.; Blanco, M. & Varela, C. 2000. Las Tablas de Daimiel: The case of a protected area in the Upper Guadiana Basin, Castilla-La Mancha, Spain. *Proceedings, Seminar 1: Water and agriculture*. WWF-European Commission. Brussels.

The Economist 2001. *Pay up or Dry Up*, May 26, 2001, p. 33.
Tremolet, S. 2001. Water Means Business in the Canaries. *Global Water Report* 122.
Tsur, Y. 1997. The economics of conjuctive ground and surface water irrigation systems: basic principles and empirical evidence from Southern California. In D. Parker & Y. Tsur (eds.), *Decentralization and Coordination of Water Resource Management:* 339–362. Norwell: Kluwer Academic Publishers.