WATER MARKETS AND THE PRIOR APPROPRIATION DOCTRINE

Micha Gisser
The University of New Mexico

Economics deals with the allocation of scarce resources among many consumer goals. Water is a scarce resource in the southwestern states and a plentiful resource in the humid eastern states. Scarcity, however, is a relative term. For example, in Arizona, ground water was available in vast amounts during the first half of the 20th century. Nevertheless, with the growth of cities, industries, and mines in the second half of the 20th century demand for water intensified, thus rendering ground water in Arizona a scarce resource. As demand for water intensified, markets for water rights evolved in the Southwest United States. Yoram Barzel (1989) offers the following hypothesis about why and when people may invest efforts in obtaining rights:

> People acquire, maintain, and relinquish rights as a matter of choice. Individuals take such actions directly in the private sector. Indirectly through the state, in the public sector. People choose to exercise rights when they believe the gains from such actions will exceed their costs. Conversely, people fail to exercise rights when the gains from owning properties are deemed insufficient, thus placing (or leaving) such properties in the public domain. What is found in the public domain, therefore, is what people have chosen not to claim (1989, Chapter 5, p. 65).

Water rights in the arid Southwest were created by American settlers who moved west in the middle of the nineteenth century and brought with them the *riparian system*, which is governed by the *English common law*. As demand for water intensified, the common law became incongruous with the arid southwest, and over the years, the most arid states abandoned the riparian doctrine and instead adopted the *prior appropriation doctrine*. The origins of the prior appropriation doctrine are traced to miners who initially swept into the California gold fields in 1849. They established *de facto* rules for protecting rights to use water. The first user was protected against a later arrival-the law of first in use, first in right. Later, the appropriative doctrine was adopted to ground water, and it became known as the *Colorado doctrine*. The mountain states (New Mexico, Arizona, Nevada, Utah, Colorado, Idaho, Wyoming and Montana) completely rejected the riparian doctrine and basically adopted the Colorado doctrine. The humid eastern states have the riparian doctrine. The *California doctrine* is a system that relies on both the riparian and the appropriative rules. The Pacific Coast states (California, Oregon, and Washington), the Great Plains states (Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota) adopted the California doctrine. These states have great heterogeneity in natural water supplies. However, over the years the California-doctrine states have been slowly converging to the Colorado doctrine. For example, in 1967 Texas upgraded its surface water from the English to the prior appropriation doctrine. In California, the public reclamation districts authorized by federal and state legislation, own most of the irrigation water. The rapidly increasing value of water since 1980 led to legislation that started the decentralization of the process of water transfers by empowering the reclamation districts to serve as brokers between individual users. The aim of this legislation has been to encourage water transfer from low to high value uses. The implication of the Barzel rule is that with intensification of the demand for water in the southwestern states, the prior appropriation doctrine will replace the remnants of the riparian doctrine. In particular, California water users will desert their scramble water law and accept the appropriative market system. I believe that in the future, facing a growing demand for water, following the Barzel rule, water users will continue to take steps leading eventually to a water market based on the prior appropriation doctrine. The rest of this paper is devoted to an informal discussion of the doctrine.

SURFACE WATER

Surface-water rights evolved earlier than ground water rights. The most arid states in the Southwest adopted the prior appropriation doctrine to surface water either at the end of the 19th century or at the start of 20th century. The adoption of the prior appropriation doctrine to ground water occurred later in the 20th century. For example, New Mexico enacted its appropriative Surface-Water Code in 1907. Later, in 1931, New Mexico enacted the Underground Water Law that adapted the state's surface law to ground water. To understand why surface-water rights predated ground water rights, consider a fully used stream. The threat from upstream surface-water capture is immediate. An upstream river user can increase his or her level of irrigation only by depriving downstream users of sufficient flows. The appropriative system protects users from capture by assigning water rights based on consumptive use.

Irrigation water diverted from the stream moves into canals and from there onto farm fields. Water not consumed by crops or evaporated moves off the fields or through the root zone into drains and back to the stream. This process is repeated downstream of each user. Water is "recycled" in the sense that some of it is used and reused. Thus, if the *ith* agricultural user diverts S_i acre feet of water per year, the consumptive use of this user is $(1 - R_i) S_i$, where R_i is the return-flow coefficient of this user. Suppose the return-flow coefficient for irrigation is estimated at 1/5. A farmer who diverts 100 acre feet consumes only 80 acre feet. Put differently, if this farmer owns 80 acre feet of consumptive use rights, he or she is allowed to divert a maximu m of 100 acre feet. The typical return-flow coefficient of a non farm user, e.g., a city, could be as high as 0.5.

Following Johnson, Gisser, and Werner (1981), consider a stream in which the flow at the source is $\hat{S}$ acre feet, and there is a compact agreement, or a treaty calling for $\bar{S}$ acre feet per year. Assuming no evaporation and no augmentation to the flow below the headwater, the property rights of the *n* users along the stream would be protected from capture if the following equation is satisfied:

$$\hat{S} - \sum_{i=1}^{n} (1 - R_i)(S_i) \geq \bar{S}.$$

As a simple illustration, consider a hypothetical stream with only two users in which the flow at the source is 100 acre feet of water, with a legal obligation to leave an annual flow of 60 acre feet at some point downstream. A user located near the source diverts 40 acre feet and returns to the stream 10 acre feet. His consumptive use rights amount to 30 acre feet, leaving a flow of 70 acre feet in the stream. At a point downstream, another user who owns 10 acre feet of consumptive use rights, diverts 30 acre feet and returns to the stream 20 acre feet, thus leaving 60 acre feet of water as called for by the compact.

Johnson, Gisser, and Werner (1981) also provided analysis showing that a market for water rights that is based on consumptive use is economically efficient. They discussed an additional constraint that requires that at any point of diversion the stream flow is greater than the diversion. In rare occasions, this flow constraint could be violated if a user upstream were to purchase large quantities of water rights from a user downstream, thus leaving a user in the middle of the stream with insufficient flows. The New Mexico water law recognizes the issue of flow constraints. To protect third parties-users in the middle-from flow deficiencies, any application to transfer water along the stream is examined by the state engineer. If the application is in proper form, it appears for three weeks in a newspaper of general circulation in the stream vicinity in which the transfer is proposed.

Finally, if user i with a return-flow coefficient of R_i sells his/her water rights to user *j* with a return-flow coefficient of R_j, user *j* may increase his diversion by

$$S_j = \frac{S_i (1 - R_i)}{(1 - R_j)}.$$

User i should decrease his/her water diversion by S_i acre feet. Indeed, during most of the 20th century cities, farmers, manufacturers, and miners in New Mexico have traded water rights in a lively and active markets. All water transfers in New Mexico were governed by Equation (2).

INSTREAM WATER RIGHTS

The demand for instream flows is derived from recreation activities and our desire to preserve wildlife and aesthetic enjoyments-the *non-traditional* water uses. The problem of instream flows has become acute during the recent decades because the demand for the non-traditional water uses has intensified with the population growth and rising standard of living. To illustrate the instream problem, consider the hypothetical illustration in the previous section. Suppose, one day, a group of environmentalists decides that a flow of 70 acre feet between the two points of diversion is insufficient to support wildlife and fish in the stream. For instance, if free and indiscriminate claiming of instream inflow rights were permitted, the environmentalists could claim rights to 75 acre feet of flow, attempting to force the user upstream to reduce his consumptive use from 30 to 25 acre feet. This is an opportunistic behavior that must result in heavy legal costs and eventual political struggles. An efficient solution that relies on the market would require individuals, groups, or governmental agencies interested in augmenting instream flows, to purchase water rights on the open market from users upstream and sell these rights to users downstream. Such "pro-environment" transactions would be approved by the state engineer provided they are not detrimental to a third party. In our hypothetical example, the environmentalists should purchase 5 acre feet of consumptive use from the user near the source of the stream, and sell these rights to the user downstream. The user upstream would not be allowed to purchase water from the downstream user because this would violate the rights of the environmentalists and recreationists to 75 acre feet of instream flows.

GROUND WATER

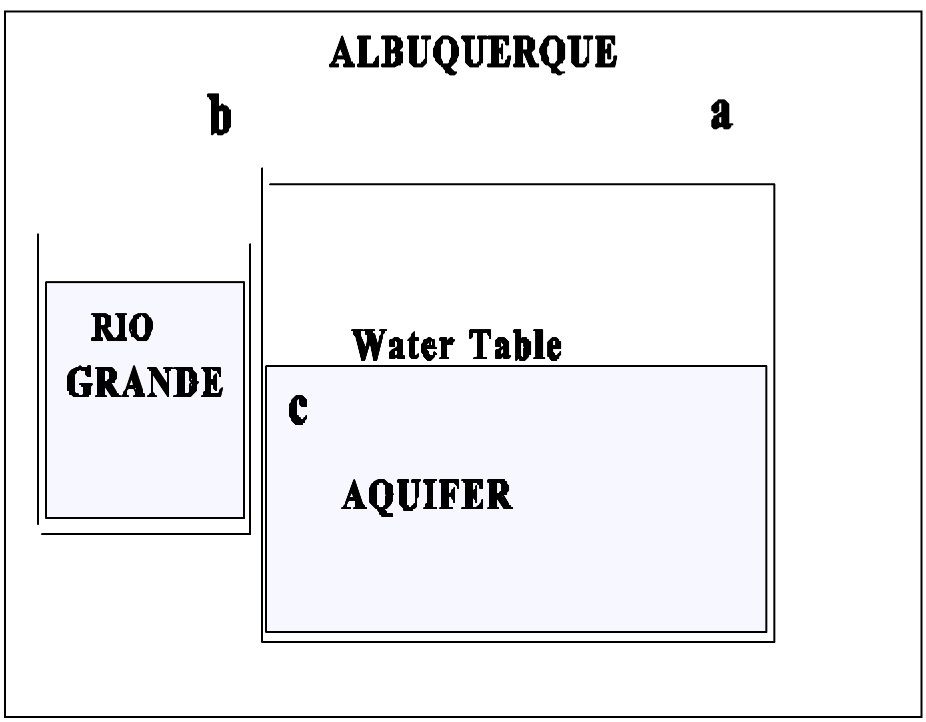
In the early stages of mining an aquifer, the threat of ground water capture from any group of users is not immediate. Historically, given the enormous size of most aquifers compared with water depletion, if some users were to increase today their ground water pumping, the impact tomorrow on other users would be an infinitesimal lowering of the water table. Consequently, before embarking on expensive demarcation of ground water rights, farmers would simply be content with inexpensive well spacing regulation. Furthermore, since most aquifers had been only infinitesimally affected by droughts, there has been no sense of urgency among users. Growing demand for water by cities, mines, and industries, coupled to falling water tables, would eventually pose a serious threat of ground water capture and consequently induce farmers to seek a more protective system of ground water rights. In Arizona, some copper-mining companies attempted to capture ground water rights from farmers by exploiting the ambiguity of the English Doctrine. This resulted in a political earthquake that gave birth to 1980 Ground water Management Act (GMA). The GMA contains some elements of the appropriative doctrine, but it is regulatory in nature.

Let net natural recharge, return-flow coefficient and water pumped be denoted by, *N*, *R* and *S*, respectively. Consider the following simplified expression for *n* ground water users overlying a certain aquifer

$$\sum_{i=1}^{n}(1 - R_i)(S_i) \geq N.$$

The left side of the inequality is the sum of the water pumped by all users less what is returned to the aquifer. The right side is the net natural recharge. If the left side pumpage minus return flows exceeds the right side natural recharge mining of ground water occurs. If the two sides are equal, the aquifer has achieved a steady state, also known as self yield. Obviously, if ground water is mined, the water table falls and the marginal cost of pumping water increases. As the marginal cost of pumping rises, individual users economize in water consumption. To explain what must happen in the future, we need graphic illustration. In Figure 1 time is measured along the horizontal axis, and the depth of the water table, *H*, along the vertical axis. If the aquifer is not sufficiently deep, say it has a bottom at H_m feet below the surface, the water table trajectory reaches the bottom of the aquifer at point *A*. Clearly, at point *A* some junior ground water rights must be retired to bring the net pumping, $\sum_{i=1}^{n}(1 - R_i)(S_i)$, into line with the net natural recharge, *N*. The water table trajectory is $H_0 A \ H_m$. At this point it should be stressed that the bottom of the aquifer is defined in engineering and economic terms, not physical terms. The reason for this is that pumping is inefficient in the bottom portion of the aquifer.

[Figure 1]



If the aquifer is sufficiently deep, say it is $H_{m'}$ feet below the surface, a steady state will eventually be reached when water pumping will be reduced such that the left side of Inequality (3) is equal to its right side. The water table trajectory would be $H_0 AB$, approaching the level H_s asymptotically.

For three decades natural-resources economists focused on the issue of optimal mining of water, and designed optimal control schemes for ground water management for commonly used aquifers. David Sanchez and I (1980) could show, that under the assumption of exclusiveness and a stable demand-for-water, "temporal optimal control of ground water would not enhance the welfare of farmers compared with a strategy of free markets (1980)." Meanwhile, wise policy makers designed reasonable systems that assigned property rights to ground water mining. As I detailed in a later paper (1983), in New Mexico ground water rights were assigned to farmers who overlie the Ogallala Aquifer based on acreage and crops. For example, in the late 1940s and early 1950s, water rights were determined at 2.5 acre feet of consumptive use per irrigated acre. Ground water rights were assigned to non farm users based on average use over a certain period. To estimate the future date of reaching the bottom of the aquifer (point *A* in Figure 1) the New Mexico state engineer took the following two steps: First, he calculated the remaining stock of ground water by multiplying the average thickness of the aquifer by its area and then by its storativity coefficient. The state engineer reserved the bottom one third of the aquifer for reasons mentioned above. Second, he divided the remaining stock by the total annual consumptive water rights to obtain the time to exhaustion. Because the falling water table must lead to rising marginal cost of pumping, this estimate was an understatement. Nevertheless, in New Mexico the State Engineer demonstrated that property rights can be assigned to mining ground water.

Once either the bottom of the aquifer, or the steady-state level is reached, the prior appropriation doctrine governing surface water allocation is easily adapted to ground water: Total consumptive use, pumping minus return flows is the same as diversion minus return flows, [$\sum_{i=1}^{n}(1 - R_i)(S_i)$]. In surface water total consumptive use along the stream is limited to the water flow at the source less the legally required flow at some point downstream ($\hat{S} - \bar{S}$). In pumping ground water from the aquifer, total consumptive use is limited by the natural recharge (*N*). Also, transactions between any two users are governed by Equation (2).

A transfer of ground water from one aquifer to another, or surface water from one stream to another, requires exporting water via pipe, or a similar conveyance system. For example, consider user i with a return-flow coefficient of 0.5, pumping from aquifer *A*, selling 50 acre feet of consumptive use to user *j* with a return-flow coefficient of 1/3, pumping from aquifer B. User i should reduce his/her water pumping by 100 acre feet; user *j* should increase his pumping by 75 acre feet; to protect the rights of third parties who overlie aquifer *B*, user i should export 50 acre feet via pipe to user *j*.

MEASUREMENT

Under the prior appropriation doctrine, water rights are not appurtenant to the land. Nevertheless, measurement of surface water use is costly. Assume that farm land has no alternative use yet its marginal product is positive; to maximize his profit, if measurement is costless, a farmer selling some of his water rights should "spread" his remaining water over his entire lot. Nevertheless, because of high measurement costs of surface water, the most prevalent form of transfer is a transaction in which one farmer sells his water rights and permanently retires the acreage with appurtenant duty and another farmer purchases the water rights and enlarges his/her farm lot proportionately to the amount being transferred. In contrast, ground water pumps can be metered and, moreover, the State Engineer can prevent cheating by monitoring the electric or gas bills for energy used at the pump.

The measurement of return-flow coefficients is also very important. For example, the Alliance for the Rio Grade Heritage, an environmental group in New Mexico, recently accused the Middle Rio Grande Conservancy District, that mainly supplies Rio Grande water to farmers, of diverting about three times more water than it is entitled to. While the Alliance for the Rio Grade Heritage is not aware of return flows, the Middle Rio Grande Conservancy District cannot effectively defend itself in the courts because it does not posses reliable measurements of the return-flow coefficients of the users under its jurisdiction. As predicted by the Barzel rule (1989), facing the attempt of the Alliance for the Rio Grande Heritage to capture some of its water, The Middle Rio Grande Conservancy District is actively seeking funds for the installation of measurement devices to monitor return flows back to the river.

CONCLUSION

Water markets are ruled by self-interest groups always comparing the additional benefit with the additional cost of taking another step aimed at perfecting their water rights. There is a fair amount of determinism in the process of evolving water rights; in the future, as demand for water continues to intensify, self interest groups will take steps, small and large, moving in a track, leading eventually to the prior appropriation doctrine. What I attempted to show in this paper is that we already have in place an economic theory that shows that if water rights are assigned according to the prior appropriation doctrine, and are based on consumptive use, and if markets are permitted to allocate water among users, then water rights are traded freely and allocated efficiently in the marketplace. A century of experience in New Mexico confirms that water markets governed by the prior appropriation doctrine function smoothly. I believe that because of the intensification of the demand for water in the west coast, self-interest groups in California and other states will take the necessary steps leading to water markets governed by the prior appropriation doctrine.

AUTHOR

Micha Gisser. Department of Economics, The University of New Mexico. Albuquerque, New Mexico 87131. gijsser@unm.edu. Professor Gissar received his bachelor's degree from school of Law and Economics, Tel Aviv, Israel. He received his master's degree and doctorate from University of Chicago before joining the Department of Economics at the University of New Mexico. Professor Micha Gisser published many articles in the fields of Industrial Organization and Agricultural and Natural Resources Economics. In particular he published articles in the field of private water rights and efficient markets for water.

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