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The Marginal Economic Value of Streamflow From National Forests

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Abstract

Changes in forest overstory lead to changes in runoff. This report estimates what such changes in runoff are worth to society using two sources of information: economic valuation studies and, most importantly, water market transactions. Evidence from over 2,000 transactions that occurred in the western U.S. over the past 14 years (1990 through 2003) was examined to learn who is selling to whom and for what purpose, how much water is involved, and how much it is selling for. Roughly half of the transactions were sales of water rights; the rest were water leases. The transactions show that the price of water is highly variable both within and between western states, reflecting the localized nature of the factors that affect water prices. Ideally, if water market prices or valuation studies are to be used to help determine the marginal value of water from specific areas, such as national forests, information from local markets or local studies should be used. Lacking site-specific value information, only rough estimates are possible.

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Introduction

Water is both essential and versatile. It is critical to human and ecosystem health, necessary in many industrial processes, indispensable in food and energy production, an important vehicle for disposing of wastes, and integral to many forms of recreation. Because a substantial portion of the nation's water supply, especially in the West, originates on national forests, a good understanding of its economic importance is necessary when making decisions affecting the national forests.

The economic importance of water originating on national forests manifests itself in two ways: (1) as jobs or income that would not exist without that water (known in economic parlance as the economic "impacts" of water), and (2) as economic value. This report focuses on economic value.

Economic value is indicated by a willingness to sacrifice other goods and services in order to obtain or retain something (or by the willingness to accept compensation in exchange for giving something up). That "something" can be anything—a good such as tap water, a service such as a fishing opportunity, or simply the knowledge that a healthy riparian environment exists.

Economic value is typically measured in money terms, usually as willingness to pay (WTP). Prices indicate marginal WTP for market goods, but the lack of a market is not a sign of a lack of economic value. Competitive markets cannot develop for goods that cannot be owned, and for which access cannot be controlled. Where competitive markets do not exist, economists have strived to develop methods for estimating economic value. They have had much success for quasi-market goods such as water and recreation, the consumption of which involves direct use of or access to environmental assets. Economists have been less successful in estimating so-called "nonuse" or "passive use" values, which are said to consist of the knowledge that something exists ("existence" value) and that it will be there for others to use ("bequest" value). Although studies indicate that nonuse values can be substantial (Brown, 1993), their magnitudes are difficult to accurately measure, and no estimates from the literature on nonuse value are reported herein.

WTP may exist for changes in the *quantity*, *quality*, or *timing* of streamflow. The distinction between water quantity, quality, and timing is somewhat artificial, because all three combine to define the value of water for most water uses. For example, the value of water to a municipality depends on the amount of water available, when it is available, and how clean it is.[1] Essentially, a value for a change in water quantity assumes a given water quality and timing, and a value for a change in water quality assumes a given quantity and timing.

This report focuses on water quantity, but the emphasis on water quantity should not be taken to suggest that water yield is the most important water issue for public land management agencies like the Forest Service. To the contrary, water quality is probably

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[1] As another example, consider recreation. The effects of streamflow on recreation depend on immediate quantity and quality concerns as well as long-term impacts of flow quantity and timing on maintenance of gravel bars for camping, maintenance of channel form and function for fish habitat, and control of encroaching vegetation to ensure scenic visibility (Brown et al., 1991).

the key water concern, especially via the effect of land management on stream sediments, which in turn affect aquatic habitat as well as downstream water management facilities and water treatment costs.[2] And the effects of land management on streamflow timing affect flooding as well as the ability of downstream water users to benefit from the streamflow.[3] Much remains to be learned about the economic value of water, especially its water quality and timing aspects.

Two measures of the economic value of water quantity from national forests are: (1) the *marginal* value of water originating on a national forest, and (2) the *total* value of water originating on a national forest. The former amount answers the question, "What is the value of a small increase or decrease in streamflow originating on a given national forest area at a given time?" This value is policy-relevant because forest management can cause small changes in flow amount or timing. The latter amount answers the question, "What is the value of stopping all water flow from a national forest?" This question is nonsensical from a land management standpoint, because the bulk of the water will flow in any case. There is in fact no plausible land management decision that is enlightened by an estimate of the total value of water leaving a forest area. Nevertheless, it can be argued that knowing the total value of the water originating on a national forest would be useful if it could be compared with similar values for other resources originating on the same forests. A comparison of those values would provide a general idea of the relative importance to society of the various resources. The total value of streamflow from national forests is addressed in Appendix B.

Whether we are discussing marginal or total values, let us be clear that we are concerned with the value of streamflow—of raw water in the stream. Transporting such water from the stream to points of use, storing it for later use, and purifying it are services performed by water users or water management entities that add to the value of water. For example, a farmer may be willing to pay $30 for an additional acre-foot of irrigation water at his field. Pumping the water up from the river may cost $10 per acre-foot, leaving only $20 as the residual value to the farmer of the water in the stream. Similarly, city dwellers may be willing to pay $300 for an additional acre-foot of treated water delivered to their houses. The costs of transporting the raw water to the water treatment plant, treating the water to potable standards, and pressurizing and piping the potable water to customers may sum to $250 per acre-foot, leaving only $50 as the residual value to the domestic user of the raw water in the stream. The value of raw water in the stream

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[2] Two WTP amounts applying to water quality that might be of interest are: (1) the marginal value of the quality of water originating on a national forest, and (2) the total value of the water quality protection provided by public ownership and management of a national forest. The former amount is the answer to the question, "what is the value of a small increase or decrease in the quality of streamflow originating on a given national forest area?" This is policy-relevant because watershed management affects water quality. The latter amount answers the question, "what value would be lost if land currently in national forests were converted to private ownership?" This question is irrelevant to public forest managers charged with carrying out current laws, but might be of general interest.

[3] Typically, storage of water in forest soils allows for a more gradual runoff, with lower flow peaks and therefore less soil movement and fewer downstream floods. Forest management affects runoff timing by altering the infiltration rate of the soils and the rapidity with which snow melts. Infiltration rate can be altered by activities such as severe fire, road construction and use, and timber harvest. Forest management affects the timing of snow melt largely by altering the overstory, and thus snow deposition.

is analogous to the value of timber stumpage, the delivered water to lumber at the construction site.

The objective of reporting on the value of raw water in the stream is, however, not always met because it is often difficult to extract the value of raw water from the value of water that is reported in a valuation study or the price that is observed in a water market transaction. Many studies in the literature report values of offstream water at the point of use (e.g., the farm or the house), called "onsite" values, rather than values for water at its source, or "net" values.[4] Similarly, as will be explained in more detail below, many if not most water market transactions are of water that is able to be stored for delivery when the water is most useful, and thus most valuable. Therefore, the values reported herein sometimes include consideration for the value of storage and delivery facilities.

The focus here is on the marginal value of streamflow, so as to provide estimates of the value of small changes (increases or decreases) in streamflow, such as changes originating on national forests. Such estimates would, for example, be useful in analyzing policies that affect flow volume. For this purpose, we take the existing assignment of property rights, and the existing laws and agreements that support them, as given. Thus, our aim is not to address the issue of whether or not the existing assignment of rights or the existing levels of diversion are efficient (whether, for example, it would be more efficient for a small increase in flow from a certain national forest to be used offstream or instream). However, the information provided here about the marginal value of streamflow would also be useful in addressing such efficiency issues.

Estimating the Marginal Value of Streamflow

The aggregate marginal value of streamflow from a national forest is equal to the sum of the marginal values in the different instream and offstream uses to which the water is put during its journey to the sea in the one or more rivers that leave the forest. For example, on a given river an acre-foot of streamflow increase may first be used by recreationists, next pass through a hydroelectric plant, then be diverted to a farm, and finally be diverted to a city. The first two uses consume no water, so, except for evaporation losses, the full acre-foot is available to the farmer. If the acre-foot arrives when it is useful to farmers, irrigation will consume (via evapotranspiration) some of the diverted flow, but return a portion that becomes available to the city downstream. In addition to these four uses there may be value attributable to ecosystem functions served by water, such as dilution of wastes, channel maintenance, and enhancement of fish habitat. And there may be some nonuse value attributable to the knowledge that the river has sufficient flow; this value could reflect, among other things, concerns for the ecological integrity of the aquatic environment.

Of course, a basin may not be configured as described in the previous paragraph. Because of evaporation, upstream diversions, reservoir storage capacities, and other concerns, any use may be deprived of some or all of the marginal acre-foot. For the

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[4] One study that reported both, for irrigation in Texas by Lacewell et al. (1974) as reported by Gibbons (1986, Table 2-3), listed onsite and net 1980 marginal values for grain sorghum of $32 and $19, respectively. Similarly, for domestic water Martin and Thomas (1986) reported that the demand for raw water in Tucson comprised only about 12 percent of the demand for delivered water.

general case, the aggregate marginal value of water from a national forest with only one river is given by:

$$\begin{aligned} V* = &\sum_k \alpha_k^o \beta_k^o V_k^o + \sum_i \alpha_i^h \beta_i^h V_i^h + \sum_j \alpha_j^s \beta_j^r V_j^r + \sum_j \alpha_j^s \beta_j^w V_j^w \\ &+ \sum_j \alpha_j^s \beta_j^e V_j^e + \sum_j \alpha_j^s \beta_j^f V_j^f + \sum_j \alpha_j^s \beta_j^n V_j^n + N \end{aligned} \qquad \textbf{(1)}$$

where

$V*$ = aggregate marginal value of water in a river

″ = proportion of the marginal acre-foot that reaches a point of use, whether the diversion point of an offstream user (α_k^o), a hydroelectric plant (α_i^h) or a river reach (α_j^s) (″ ≤ 1)

\$ = proportion of the marginal acre-foot reaching a point of use that actually affects the specified use (\$ ≤ 1)

V_k^o = value of the marginal acre-foot in offstream uses diverted at diversion point k ($V^o \geq 0$)

V_i^h = value of the marginal acre-foot at hydroelectric plant i ($V^h \geq 0$)

V_j^r = value of marginal acre-foot in instream recreation in river recreation reach j (V^r is generally ≥ 0, but may be < 0)

V_l^w = value of the marginal acre-foot in waste dilution in river reach l ($V^w \geq 0$)

V_l^e = value of the marginal acre-foot to ecosystem functions in river reach l ($V^e \geq 0$)

V_l^f = value of the marginal acre-foot in flooding in river reach l ($V^f \leq 0$)

V_l^n = value of the marginal acre-foot in commercial navigation in river reach l ($V^n \geq 0$)

N = nonuse value of the marginal acre-foot ($N \geq 0$).

Ignoring nonuse value because it is very difficult to estimate, the task of estimating the marginal value of streamflow from the national forest consists of estimating the *V*s and their respective ″s and \$s.

Is a Water User Affected by a Streamflow Change?

The likelihood that a given water user is able to use an addition to streamflow, or is affected by a flow decrease, depends on two major considerations, which for simplicity we will discuss here in terms of a flow increase. First, ability to use the flow increase depends on whether the increase reaches the stretch of river or diversion point of the user. There may be numerous hydroelectric plants, instream recreation reaches, and offstream users affected by the marginal acre-foot of streamflow. The portion of the flow increase that flows through a reach or past a diversion point (″ in equation 1) depends on whether upstream users or evaporation have already consumed any of it. Some users may receive the entire flow increase, whereas others further downstream may receive only a portion.

The second consideration is that the ability to use the flow increase also depends on whether the additional water can be delivered and used when needed (\$ in equation 1). This is a matter of timing—the timing of the streamflow increase versus the timing of the needs of the use or user. A flow increase caused by harvest of forest overstory, for example, occurs disproportionately in wet years and, in snow dominated regions of the West, during the spring snow melt (Troendle, 1983). However, junior right holders need more water during dry years, and during the late summer and fall when flows are low. Thus, the flow changes occur when they least matter to offstream users and some instream users—when flow is already ample. Only if vacant water storage is present and if the reservoir is in priority can a flow increase be saved for later use.[5] If reservoir storage is lacking on the river, overstory-dependent flow changes are unlikely to have much effect on offstream water use or even some instream uses.

Timing varies by region. In the Southeast, where snowmelt is less of a factor and rainfall is rather evenly distributed over the year, flows tend to be relatively evenly distributed throughout the year, but in the West much of the flow from national forests occurs during the spring snow melt (largely during April, May, and June). Because the peak offstream withdrawal months are July through October, the snowmelt must be stored to be available for downstream users. Ability to store water and deliver it to offstream users or to downstream recreationists when needed varies greatly among rivers. For example, the Colorado River has reservoir capacity equal to over four times mean annual flow, but the Poudre River near Fort Collins and the South Platte, Missouri, and Mississippi Rivers further downstream have little reservoir capacity relative to flow. In this latter case, most of the year's snowmelt from the national forest at the Poudre River's headwaters flows on to the sea, such that additional snowmelt is almost certain to remain instream.

Even in rivers with ample reservoir storage, however, some of the marginal acre-foot of flow may not be diverted. The sensitivity of the reservoir system to adapt to changes in flow depends on reservoir operating rules, which may have developed in response to complicated legal requirements. Some systems do not appear to be particularly sensitive. For example, Brown et al. (1990) found that less than one-third of a flow increase due to overstory management at the headwaters of the Colorado River was likely to be delivered to offstream users, despite substantial downstream storage. Simulations showed that much of the flow increase would remain in storage until times of flooding, when it would be released to the sea.

The ″s and \$s must be estimated on a case-by-case basis, for distinct points along individual rivers. However, a rough idea of the magnitude of \$ can be obtained by comparing storage capacity and withdrawal to streamflow for large watersheds, as developed in a later section. This analysis indicates that \$ is greater in the West, where water is often lacking.

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[5] Similarly, a flow decrease has little impact on offstream use unless the lost flow was previously being stored for later use.

If Accessible, What Is the Water Worth?

The marginal value of streamflow (*V* in equation 1) is obtained from application of economic valuation techniques or from observation of water market prices. Unless values are estimated anew for each location involved in an analysis of flow changes, or unless prices can be observed in the location of interest, *V* is estimated by benefit transfer. That is, estimated values or prices are adapted from other locations. Because new studies are time-consuming and expensive, and because markets are often lacking, benefit transfer is commonly used.

Water valuation studies are typically performed in locations where the marginal value is expected to be positive, because those are the locations of most interest. And clearly prices are observed only where price is positive. However, in some locations and for some water uses the marginal value of streamflow is zero, even if the user is physically and legally in a position to divert or otherwise use the marginal acre-foot. Consider the case of offstream uses depicted in Figure 1. Water supply (*S*) is constrained at Q_1, as indicated by the vertical supply curve at that quantity. If demand for water at the point of use is indicated by D_1, Q_1 is the quantity of streamflow available for diversion, and P_1 is the cost of transporting (e.g., pumping) the diverted water to the point of use, then quantity Q_2 will be diverted. P_1 is the marginal value of the delivered water because users divert up to the point where the marginal benefit of the water equals the delivery cost. In this case, the marginal value of the raw water that is diverted from the stream (V^o) is marginal onsite WTP (P_1) minus delivery cost (P_1), or \$0. In this case, transfer of estimated marginal values or prices from other locations would overstate marginal value.

Now assume that, perhaps because of economic growth, onsite demand has increased to D_2 but the cost of transporting the water to users is still P_1. Given D_2, users desire to divert Q_3 acre-feet, but only Q_1 are available. At a diversion of Q_1, the marginal value of delivered water is P_3, and the marginal value of the raw water (V^o) is $P_3 - P_1$. Thus we see that raw water has value at the margin for offstream use only when there is not enough of it to meet all demands. This is more likely to be the case in dry areas, where minimum instream flow constraints sufficiently restrict diversions, or where institutional constraints preclude an efficient water allocation.[6]

A more realistic characterization of the supply of water is presented in Figure 2, which shows the same demand curves as does Figure 1 but includes three supply curves, Sav for the average year, Swet for a wet year, and Sdry for a dry year.[7] Given a diversion cost of P_1 and demand at D_1, users will desire to divert quantity Q_2, which is possible in the average and wet years. However, if the year is dry enough, users are left without as much water as they are accustomed to divert. If demand increased to D_2, resulting in a desired diversion of Q_3, shortage would become more frequent.

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[6] Even in wet areas, institutional constraints may cause water shortages. For example, Chicago suburbs were forced to pump from ever-dropping water tables, despite their proximity to Lake Michigan, because of concerns for and rights associated with the lake level.

[7] The characterization would become even more realistic if the demand curve also shifted with the weather, to the right in dry years and to the left in wet years.

Municipal Supply

Studies of municipal supply often focus on the elasticity of demand (i.e., on the slope of the demand curve) at current use quantities—see summaries by Espey et al. (1997) or Diaz and Brown (1997)—but these studies alone do not indicate the marginal value of raw water. To estimate the raw water value, we must examine how that water is acquired by the water provider. As Gibbons (1986) describes, municipal water is typically supplied by public utilities or regulated water companies. Although some utilities must purchase raw water, many others merely appropriate water, paying only the cost of transporting it to their treatment plants. This water is typically sold to customers at prices that just cover costs, following an average cost pricing structure. The charges of such water utilities may offer little information about the marginal value of raw water.

Where water supplies are not limited and the utility pays nothing for the raw water, customers are charged a price to cover the utility's costs (of diversion, treatment, delivery, removal, and waste treatment) and will consume up to the point where their marginal WTP equals that cost. Here the marginal value of the raw water (V^o) is \$0, as depicted in Figure 1 where D_1 indicates consumers' WTP for delivered water and P_1 indicates average cost. However, where raw water is limited, $V^o > 0$ and will depend on the degree to which supply is limited versus demand, as indicated by demand D_2 as limited by quantity Q_1 in Figure 1.

Because municipal uses are relatively high-valued, municipal suppliers may purchase the water they need from lower-valued uses if a market is present.[8] Where raw water can be purchased, the purchase price is a good estimate of V^o. Because water for municipal uses is actually purchased in many locations of the Wet, observation of market price is a useful approach.

Industry

The cost of raw water is a small part of total production costs in most industries (Gibbons, 1986). Thus, industries are often able to pay considerable sums for water (as indicated by prices paid by the mining industry reported in the "Evidence from Water Markets" section below). However, industrial water users that have the option of recycling water in their production processes are not willing to pay more for additional water withdrawals than the cost to them of recycling their water.[9] Thus, the value of marginal withdrawals is no greater than the marginal cost of recycling. Few studies have estimated such costs. Gibbons, citing Young and Gray (1972) and others, reports marginal cost estimates of \$5 to \$11 per acre-foot for cooling water, and \$51 to \$75 per acre-foot for industrial process water (1980 dollars). However, these estimates come from studies performed before recent technological advances.

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[8] In some municipalities, developers are required to turn over water rights to the water utility when a new property is added to the system. Here the value of the raw water is expressed in the price the developer pays for the water rights.

[9] Over the past century, industrial withdrawals per unit of output have fallen dramatically, which has done much to contain the rise in total industrial withdrawals (Brown, 2000). This increase in efficiency of water use is a response to a combination of technological advance and environmental pollution legislation (most importantly the Clean Water Act of 1972 and its amendments). The pollution legislation regulated discharges and thereby encouraged recycling or a change to more water-efficient production methods.

For situations where recycling is not an option, or for new enterprises that must acquire water, observation of market transactions, if any exist, should be a good source of value information.

Irrigated Agriculture

The principles described for municipal use apply here as well. Where raw water is not limited in supply and is available at no cost, its marginal value is 0. Only where raw water is limited in supply does it have a positive marginal value. Assume that water is in short supply, that demand is shown by D_2 in Figure 1, and that P_1 is the cost of applying water.[10] If raw water is limited to quantity Q_3, the marginal value of the raw water is $P_2 - P_1$.[11]

Because most of the water diverted to offstream uses in the West is used for irrigation (Solley et al., 1998), and because much of irrigated agriculture has been partially subsidized by public funds, there has been considerable study of the marginal value of irrigation water; see Young (1996) for a description of the valuation methods and Gibbons (1986) for a summary of the resulting value estimates. A common method, sometimes called residual imputation, estimates the value of irrigation water as the difference between revenues and non-raw water costs of production.[12] When the method is applied to multi-crop farming areas, the result is typically to derive a series of water values, varying from quite high values for crops such as vegetables to much lower values for feed grains and forage crops. For example, observe Figure 4, taken from Kelso et al. (1973), showing a stair-step demand curve for irrigation water, with the top steps reflecting the marginal value of irrigation water in relatively high-value crops and the bottom steps reflecting the marginal value of irrigation water in low-valued crops. Because farmers will protect their most valuable and sensitive crops, taking water from the lower-valued and less sensitive crops when necessary, the marginal onsite value of water in farming areas with multiple crops, as estimated using this residual method, will be determined by the revenues and costs of lower-valued crops, such as feed grains and forage crops.[13]

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[10] An irrigation district's assessment fee for water shares is sometimes set to cover the costs of storing and delivering the water when needed.

[11] In areas served by unregulated ground water pumping, where the only constraint on water applications is the cost of pumping, water will typically be pumped to the point where its marginal benefit is equal to the pumping cost. If new raw surface water could somehow be delivered to the farm, its marginal value would be equal to the cost of pumping ground water minus the delivery cost. If water from the national forest of interest cannot be delivered to such farms, observation of pumping costs in such areas of ground water pumping is not helpful.

[12] A methodological issue for valuation is the difference between short run and long run values. This issue arises when the value of water is estimated as the difference between the value of the end product (e.g., irrigated wheat) and the non-water costs of producing that product. To compute the short run value, only the variable costs are subtracted; for the long run value, fixed costs are also subtracted. Short run values are appropriate for use in decisions about whether to apply more water during the current season. Because fixed costs represent real commitments of resources, just as variable costs do, long run values are appropriate for long run planning such as land management planning.

[13] In areas with a climate favorable to fruits and vegetables, such as the Central Valley of California, the marginal crops may return more to water than do feed grains and forage crops, and the marginal value of water correspondingly will be higher. However, even in such areas farms may diversify by also growing feed grains or forage.

Although irrigated agriculture is not expanding in the West, and farmers are more often the sellers of water than the buyers, where water markets it is common to find at least some purchases of water for irrigation, indicating marginal willingness to pay in agriculture.

Hydroelectric Power

Most customers receive their electricity from large power grids that are fed by a mix of power plants, typically including both hydroelectric and thermoelectric plants. Because electricity from hydroelectric plants is, at a given time of day, a perfect (but less expensively produced) substitute for electricity from thermoelectric plants, the marginal value of water at hydroelectric plants (V^h) can be estimated as the cost savings allowed by a small increase in hydropower production, in that the increase allows an equal decrease in production at thermoelectric plants. The cost savings from a small increase in hydroelectric production is equal to the marginal cost at the thermoelectric plant minus the marginal cost at the hydroelectric plant (similarly, a small decrease in hydroelectric production is met by comparable cost increase). This cost savings (or cost increase in the case of a decrease in flow) is multiplied by the amount of electricity produced with the quantity of water at issue.

If, as is typical, the hydroelectric plant is a relatively small contributor to a large power grid, a change in production level at the plant is unlikely to affect electric or fuel prices, such that the cost savings per unit is constant across production levels, as indicated by the horizontal demand curve in Figure 3 (in this case, the marginal and average values are identical). Ignoring the complications introduced by distinctions between base load and peaking power, the demand curve for additional streamflow at a hydroelectric plant is horizontal at one level of net cost savings (P_1) to the point of the capacity of the turbines or the intakes or reservoir that feed the turbines, indicated by Q_1 in Figure 3. Up to this point, the marginal value of flow to the hydroelectric plant (V^h) is P_1; beyond this point $V^h = 0$.

Market purchases of water by hydroelectric plants are rare, but the cost savings allowed by the substitution of hydroelectric power for thermoelectric power is relatively easy to estimate with available data. Some examples are included in a later section.

Recreation

Several factors make the estimation of the aggregate marginal value of a flow change to recreation problematic. First, the marginal value of flow (V^r) for fishing or floating recreation rises with flow to a point and then drops as flow rises further, reaching zero at some point and then becoming negative as additional flow causes accidents or impairs fish habitat (Figure 5). Because flow levels typically change markedly over the year, the marginal value of flow in recreation also varies. Second, the points of maximum and zero marginal value will differ by recreation type, even on the same river (Brown et al., 1991). Third, because recreational use of water is nonconsumptive, the various uses along a river are fully additive (except where congestion limits use) and estimates of all of them are needed.

Market purchases of water for recreation are rare, so nonmarket valuation methods must usually be used. Results of nonmarket valuation estimates are summarized in a later section.

Habitat

The value of instream flow in maintaining habitat for aquatic organisms is undoubtedly large, but is difficult to estimate in economic terms. Except for the contribution of aquatic habitat to fishing quality and thus to recreation, mentioned above, these values are a matter of so-called nonuse value, the estimation of which remains controversial among economists, and of ecosystem service value, which is also a complex area. Marginal values may be substantial where diversions have significantly lowered instream flow.

Channel Maintenance

To date there have been no attempts to estimate the economic value of instream flow in maintaining stream channels, partly because geomorphologists are still gaining a full understanding of the physical processes involved and the relation of periodic channel maintenance flows to services of more immediate utility, and also because of the complexity of the relation of stream channel morphology to flooding damage.

Navigation

Few studies have estimated the value of water in commercial navigation. Gibbons (1986) provides the most comprehensive generally available treatment of the topic—a set of six estimates of the short-run average value of water in navigation. Except for some eastern rivers or waterways, she reported low values per acre-foot; values on the Mississippi, Columbia, and Missouri Rivers were \$6, \$3 and \$1 per acre-foot, respectively. And these are average values. Marginal values on free-flowing rivers would be \$0 unless the marginal water just happened to bring a river up to the level where it becomes navigable. Different and more complicated conditions apply to slack water rivers with locks.

Flooding

Small streamflow increases will exacerbate a flooding event. Flooding losses are highly site-specific. The flow increases from overstory management, even though they are concentrated in the wet years, are unlikely to have a large impact on downstream flooding unless they occur over vast acreages.

Water Rights and Market Prices

There are two basic approaches to estimating the marginal value of water (the *V*s): employing economic valuation methods and observing water market prices. The suite of valuation methods (for summaries see Gibbons, 1986; Lew et al., 2001; U.S. Water Resources Council, 1983; Wollman, 1962; Young, 1996; Young & Gray, 1972) was developed because markets for goods like water were uncommon and, when present, rarely competitive. However, new water markets have appeared in recent years, raising hopes that they can offer useful estimates of water value. Evidence from water market transactions in the West is reviewed in the next section. Here we examine some issues regarding water markets and how accurately their prices indicate the value of a change in streamflow.

If water in a water short area were freely traded in an efficient market, including the key condition that all units of water traded in this market were identical both legally and physically, water would be reallocated via trades to the point where each user was consuming at the point where the marginal value in all uses was identical (e.g., the marginal value in irrigation would be equal to the marginal value in municipal use). In this ideal world, a single market price would emerge that would indicate the marginal value of raw water in that market area. However, in the real world, even in those locations where water markets exist, water rarely trades so easily or completely, for a host of reasons. In this section we explore three important reasons: lack of a homogeneous produce because of a prioritized system of water rights, lack of market competitiveness, and inclusion of water management services in the product being traded.

Priority

Eheart and Lyon (1983) describe two types of water rights, each using a distinct approach for dealing with variability in streamflow amount. *Prioritized* rights allow prioritized diversion of a fixed amount of water during each time period. Here shortage is accommodated by temporarily canceling permission to divert, beginning with the most junior right and moving as far up the list of priorities as needed to assure delivery to more senior rights. *Fractional flow* rights entitle users to a fraction of the available flow. Here all users have equal priority, and shortage is accommodated in a given time period by lowering the allowable diversion for all users.

The prior appropriation system of water rights, which prevails in most of the West, is a prioritized system of rights. Users are ranked from the most senior (who have first priority) to most junior (who have last priority). During each time period, typically a year, rights are satisfied in order of priority. Junior right holders are latecomers who have not managed to purchase or otherwise acquire more senior rights. Many of the senior rights in the West were originally claimed by irrigators. As municipalities and industries grew, if unappropriated water was scarce they purchased what they needed from farmers or developed new water sources, perhaps by importing water from another basin where water was more plentiful. But where purchase or development was difficult, because of institutional or physical constraints, junior right holders may include the relatively high-valued municipal and industrial users. And because not all farms were established early, some farms will also be served by junior rights. Certainly the latecomers will include instream flow uses, which only recently, in most areas subject to prior appropriation, have been legally allowed to acquire water rights (Gillilan and Brown 1997).

Senior rights are worth more than junior rights because senior rights face less risk of shortage. On heavily appropriated streams the difference in value can be considerable, since the most senior rights nearly always receive their water, whereas the most junior rights may seldom receive their water. In an appropriative rights system, it is the relatively junior right holders that benefit from a flow increase or are first to be hurt by a flow decrease, all else equal.

A prioritized system of water rights is not without its problems. In times of shortage, such a system distributes the pain very unevenly, raising concerns about fairness and requiring vigilant oversight in administration. Perhaps not surprisingly, the use of fractional rights became common where its adoption was feasible, as in mutual ditch companies and some water conservancy districts, wherein water is owned as shares of the total amount available (Hartman & Seastone, 1970). Within such an organization all members essentially have the same priority, and the effect of a flow increase—if the increase becomes available to the organization—is distributed to the members in proportion to the number of shares each owns. In many such organizations the transaction costs of water transfers are small (Howe et al., 1990). The low transaction costs along with the homogeneity of the product allow for a common share price and a relatively competitive market. Here share price is usually a good indication of marginal value (V^o). As seen later, many of the more active water markets deal in shares of such a company or district.

Another exception to differentiation of rights by priority occurs when the priorities of numerous individual rights become lumped by court or legislative decision. For example, when the territory of New Mexico passed in 1907 its Water Code, existing surface water appropriations were given a priority date of 1907. Priority dates of subsequent appropriations reflected their actual date of appropriation, but a good many rights share the 1907 date.

Demand curves such as depicted in Figures 1 and 2 accurately depict demand for water in a market of proportional shares because all shares of water are identical in priority. However, in an area of unaffiliated water rights, say the set of individual rights for water along a river, each right is unique because of its different priority date. Strictly speaking, demand for water along such a river cannot be depicted by a single demand curve, because the product is not homogeneous. Although areas where such unique rights are traded are sometimes called a water "market", the prices observed in such a market will not all indicate marginal value because the users forced to curtail diversion in times of shortage are typically only those with the most junior rights.[14] In these areas, because market prices reflect a mixture of rights, from senior to junior, and because the primary effects of a flow change are felt by the junior right holders, the typical (or median) market price will tend to overestimate the price of the junior rights that are most likely to be affected by a change in streamflow.

Market Competitiveness

A fundamental tenant of neoclassical economic theory is that competitive markets yield prices that reflect the true marginal economic value of the good being traded. Lack of competitiveness of a water market can affect the accuracy with which market price indicates the true marginal value of water. Competitive markets have many buyers and

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[14] If transfers of unique but related (i.e., on the same river) water rights were easy to accomplish (if transaction costs were low), it would be reasonable to assume that water users with the greatest WTP would hold the most senior rights and users with the lowest WTP would hold the most junior rights. High transaction costs interfere with such a rearrangement, allowing a situation where users with lower WTP may still own the senior rights, and vice-versa. Because transaction costs are typically high for transfer of unique rights subject to the prior appropriation doctrine, it cannot be assumed that junior right holders have relatively low willingness to pay for water on the stream.

sellers, do not artificially restrict price or ability to trade, have low transaction costs, allow an easy flow of information about prices and potential trades, and internalize all relevant costs and benefits of the transaction. These conditions may or may not be met in a given water market. Many markets areas are so small that sellers and buyers are few. In others, laws, regulations, or customs limit price. In many water markets transaction costs are substantial, involving administrative and hydrologic requirements. In many markets information is not readily available. And externalities commonly exist, especially in the form of changes in water quality and instream flow (Howe et al., 1986; Saliba, 1987). Some of these restrictions on the competitiveness of the market (e.g., a limited number of sellers) may elevate the price relative to the price that would be established in a purely competitive market, whereas others depress the price (e.g., government subsidies, transaction costs, regulations or customs). Many of the restrictions, such as transaction costs, will tend to limit the number of trades.

Even where markets are active, the marginal values of different water uses may differ because owners of water may be slow to enter into what on the face of it may appear to be an attractive transaction. Population growth in the West has greatly increased municipal water demand. Because farmers own most of the water, and because irrigation typically returns less to the water than developers are willing to pay, many farmers have been presented with offers for their water. Yet, farming is more than simply a job, and selling one's irrigation water is a huge step—one usually avoided unless the farmer is strapped for cash or going out of business. Thus, even where markets are active, the marginal value of water in agriculture may lag below the willingness to pay of developers.

This circumstance is depicted in Figure 6, which shows aggregate water demand schedules made up of agricultural and municipal demands. Initially, agricultural demand (Da) and municipal demand (Dm_1) result in aggregate demand curve D_1. Given water availability of at least Q_1 and diversion costs of P_1, Q_2 is demanded by farmers, Q_3 is demanded by cities ($Q_2 + Q_3 = Q_1$), and the marginal value of raw water to both uses is $P_1 - P_1 = 0$. Assume that water availability is exactly Q_1 (for simplicity, we are ignoring inter-annual changes depicted in Figure 2), so that the farms and cities are using all available water. Now if municipal demand rises to Dm_2, causing aggregate demand to shift to D_2, the cities, in the absence of the supply constraint, would increase their diversion, bringing aggregate diversion to Q_6. However, in the face of the supply constraint at Q_1, the marginal value of raw water to cities will rise to $P_3 - P_1$, inducing cities to offer to by water from farmers, where the marginal value remains at 0. In a perfectly competitive market, trades will occur until the marginal values of the two uses are equalized at $P_2 - P_1$, leaving farmers diverting quantity Q_5 and cities diverting quantity Q_4 ($Q_4 + Q_5 = Q_1$). However, if farmers are slow to sell their water—or if buyers have difficulty overcoming impediments to trade, such as transaction costs—the marginal values in the two uses may remain unequal.[15]

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[15] If the urban expansion occurs on agricultural land, the agricultural demand curve will shift to the left, and farmers selling their land to developers are likely to also sell their water.

Value of Services

Another reason that observed price may exceed the marginal value of raw water is that the good traded in a water market often includes not only raw water but also related services, such as water storage and delivery. Storage can greatly increase the value of raw water unless the water right at issue is so senior that the owner can divert even when flows are low. Much of the water traded in the West, including most of the water managed by ditch companies and water conservancy districts, has storage attached. Assessments fees of these organizations may cover some of the management costs, but usually do not capture all of the value of the management facilities.[16]

Summary

It is difficult to say what, in general, is the effect of lack of competition on the ability of price to estimate *V*. To summarize, let γ be the ratio of the price for the junior right that is affected by the flow change to the price of the typical right that is traded and about which we have price data ($\gamma \leq 1$), let θ be the ratio of the true (purely competitive market) marginal value of water to the estimated market price ($\theta \leq \geq 1$), and let δ be the ratio of marginal value of raw water to observed price, where observed price includes a consideration for the value of related services ($\delta \leq 1$). Then the relation of the marginal economic value of a flow change for offstream uses (V^o) to market price (P) is as follows:

$$V^o = P \bullet \gamma \bullet \theta \bullet \delta \qquad \textbf{(2)}$$

Thus, taking all three factors into consideration, we are, in general, left ambivalent about whether market prices tend to over- or under-estimate the marginal economic value of water.[17] Of course, a thorough examination of an individual market can settle the issue for that one market, but based on these considerations a general statement about over- or under-estimation of marginal value is not possible.

Evidence from Water Markets

Scarcity begets trade, which begets markets. Water has become scarcer as population and economic growth in the West have increased demand for water. Where institutions allowed it and transaction costs were not excessive, that growing scarcity often brought willing buyers and sellers together in what is called a water market. The term “water market” lacks a precise definition, but once a few voluntary trades of water of common physical and legal characteristics occur, it is said that a water market has developed. For example, when shares of an irrigation company—which all carry the same physical and legal descriptions (such as amount of water per share, timing of availability, and water quality)—are actively and voluntarily exchanged, a water market is said to exist.

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[16] It can be argued that where the facilities needed to provide the service, such as reservoirs and ditches, have excess capacity, and where the labor costs for managing an increase in flow are small, a moderate flow increase does not impose significant additional water management costs, so that the full price may be assigned to the flow increase.

[17] An additional consideration is that the price may be affected by expected future increases in the demand for that water (i.e., speculation). Opinions differ on whether speculation interferes with the establishment of a market price that indicates social value.

In many dry parts of the West water scarcity is not a recent development, but water markets nevertheless often failed to, or were slow to, materialize because of institutional constraints or a lack of experience with market trades. The dearth of water market data led economists to develop or adapt several methods for estimating the marginal value of water. Those methods have been applied in a large number of published studies (see the summary by Gibbons, 1986). While the methods are still useful, and indeed are essential where water markets have failed to develop, the appearance of water markets in other locations has lessened the need to rely on the valuation methods because, ideally, such markets yield the very prices that the methods were designed to estimate. Thus, with the existence of markets, the complicated and time consuming application of valuation methods has been replaced by mere observation of prices. The voluntary actions of buyers and sellers naturally yield prices that indicate the marginal value of water.

This of course sounds too good to be true, and it is. Market imperfections and government subsidies commonly affect the price of water and therefore its accuracy in indicating marginal value. And in many areas where water trades occur they occur so seldom that it is difficult to assess the reliability of the prices that result. Indeed, many gradations of water market are found, from the most rudimentary of markets to the very well functioning. Nevertheless, water markets offer a wealth of information about the value of water, and a great many trades have occurred across the West.

Three things are essential for a water market to exist. First, there must be a well-administered system of transferable water rights. As is well known, the doctrine of prior appropriation that underlies water law across the West allows for clearly defined and transferable water rights,[18] and state agencies or the courts administer and enforce those rights—although the states differ in how they implement the doctrine and administer the water rights systems (National Research Council, 1992).[19] Second, the water must be mobile, both legally and physically. Legal mobility follows from the prior appropriation doctrine, which specifies that water is separable from the land where the water might be used. Physical mobility is generally facilitated by a system of diversion structures, canals and pipes, plus perhaps storage reservoirs, for moving the water to the buyer's use location. Third, the transaction costs of transfers must be low enough to make entering into a transaction sensible. Transaction costs are the costs incurred to bring about the transaction, such as legal and broker fees.[20] Markets of course differ in the degree of physical mobility that they offer and in the transaction costs of transfers.

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[18] An early but still very good discussion of water marketing in the context of the prior appropriation doctrine is found in chapter 9 of the book by Hirshleifer et al. (1960).

[19] A water right under the prior appropriation doctrine specifies an amount of water that may be diverted (or otherwise used) and a priority for the diversion relative to the priorities of other rights on the river. A junior's use may be curtailed if it would interfere with the senior right receiving its full allotment. However, as described above, in some cases—such as where water users have banded together in a mutual water company (commonly called a ditch company)—each owner has a certain fraction of the group's total water supply, and no distinction is made among owners regarding priority. In this case, as the total supply changes with the weather from one year to the next, the amount going to each user also changes—all users share the burden of dry times and the bounty of wet times.

[20] From the standpoint of buyers and sellers, transaction costs include those involved in learning about available supplies or potential demands and finding a willing seller or buyer (which may involve a broker fee), establishing the precise nature of the water right or lease at hand and resolving return flow issues

Water markets are facilitated by conditions such as: (1) readily available information about quantities, prices, and trading opportunities, (2) the presence of many buyers and sellers,[21] (3) a homogeneous water product, and (4) a lack of return flow issues.[22] Markets differ greatly in the extent to which these conditions are present. We will return in more detail to these issues, but for now we focus on what water markets have to offer.

Studies of water markets have typically consisted of a detailed examination of one or a few specific markets (e.g., Hartman & Seastone, 1970; Howe & Goemans, 2003; Michelsen, 1994; Saliba et al., 1987). Only with a detailed examination can the numerous characteristics of the individual markets be given their due consideration. This study, to the contrary, takes a broad look across the western U.S., emphasizing geographical scope rather than in-depth focus. This "big picture" approach offers a look at how prices in general have changed over the past few years and at how they differ across locations or across the purposes for which the water was purchased.

When water is sold in the West, either a water right changes hands or use of the right is essentially leased for a defined period of time. Ownership of a water right conveys access to a specified quantity of water in perpetuity, subject to particulars such as priority, timing, and location. With a water "lease" as used herein, the holder of the right agrees to deliver, or allow the buyer access to, a certain quantity of water over a stated time period, subject to conditions such as timing of access and location. The time period or periods specified may be carefully prescribed (say a certain day or set of separate days) or a longer period or set of periods (perhaps years) over which diversions may be made.[23] For example, the lease might state that the buyer may divert up to a certain number of acre-feet any time during the current irrigation season. This report focuses on both of these types of transactions.

(which may involve legal, engineering, and hydrologist fees plus the cost of title searches), negotiating a deal (which may again involve the services of experts), obtaining approval from the relevant state agency or court (which may involve filing or court fees plus the services of experts), and the cost of moving the water to the buyer's location, if any. For large transfers that might raise environmental concerns or legal challenges (such as those pursuant to the Endangered Species Act), transaction costs can be substantial (Carey et al., 2002; Colby, 1990; Howe et al., 1990). Clearly, transaction costs keep market price from accurately indicating the true marginal value of water.

[21] The number of buyers and sellers is likely to increase the larger is the area connected by the water distribution infrastructure and the greater is the amount of water available to that infrastructure.

[22] Under the prior appropriation doctrine, a water transfer may not injure other water right holders, even if their rights are junior to the right being transferred. Thus, a water transfer may not alter the return flow of the subject right if that return flow was used by other right holders downstream. So, for example, if a transfer would move the water to another drainage basin, that transfer must be restricted to the consumptive use portion, leaving the return flow portion in the original stream. Quantifying the return flow portion can be complex and costly. Importantly, some water transfers are not subject to return flow concerns. For example, the rules for CBT (Colorado-Big Thompson project) shares specify that the full water allotment may be transferred (Hartman & Seastone, 1970; Howe et al., 1986; Michelsen, 1994). Adoption of this rule was possible because the CBT project apportions water from another basin—water that was new to the South Platte basin when it was first introduced and the rules for transfers were set.

[23] One-time transfers of water (essentially short-term leases) are sometimes characterized as "spot market" trades or "rental" transactions.

Methods

The broad-scale examination of water prices reported here is made possible by the *Water Strategist* and the *Water Intelligence Monthly*, published by Stratecon, Inc., which have summarized many of the available western water market transactions in reports released on a monthly or quarterly basis.[24] Fourteen years of transactions reported by these publications (1990-2003) were tabulated to provide the estimates of the price of water described herein. It is important to note that these publications did not report on all the transactions that occurred. Especially in the case of water leases, large numbers of trades were not summarized.[25] Neither are the included transactions a random sample. Thus, the current report indicates the nature, but not the breadth or precise character of western water trades.

Each water transaction entry in the *Water Strategist* or *Water Intelligence Monthly* briefly summarizes one or more actual trades.[26] The entries do not allow a full

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[24] Stratecon, Inc., is located at P.O. Box 963, Claremont, California 91711. The transactions summarized here were taken from the *Water Intelligence Monthly* for 1990-1994 and from the *Water Strategist* for 1995-2003. The *Water Strategist* reports used here were published more or less quarterly in 1995-1998, and monthly beginning in 1999. A different publication, the *Water Market Update*, published by Shupe and Associates, Inc., summarized transactions for three years prior to 1990.

[25] Five examples should suffice to demonstrate that these publications did not report on all western water market transfers. The first deals with water rights, the others with leases. First, Howe and Goemans (2003) report, based on their examination of water court records for Colorado Division 1, that in 1992 about 230,000 acre-feet of non-CBT water rights changed hands in the South Platte Basin. The *Water Intelligence Monthly* lists non-CBT water rights trades for that year and basin totaling fewer than 4500 acre-feet. Second, cities along the Colorado Front Range regularly sell surplus water to farmers and others on a temporary basis. The city of Fort Collins, for instance, leased rights to 24,561 acre-feet in 2002 (at an average of $18.85 per acre-foot) and similar quantities in other years (Fort Collins Utilities, 2000). These leases were not reported in the Stratecon publications. Third, Yoskowitz (2002) reports that 1330 lease transactions occurred along the Rio Grande in Texas between 1993 and 2000, compared with only 101 listed by the Stratecon publications. Fourth, Loomis (1992) reports that the California Water Bank leased a total of 830,000 acre-feet from 351 sellers in 1991, whereas the Water Intelligence Monthly included no CVP entries in 1991. Fifth, Carey et al. (2002) report that, between 1993 and 1997, an average of 2153 lease transactions occurred each year (involving an average of 368,112 acre-feet) in the Westlands Water District. The Stratecon publications did not track these trades. Located in California's Central Valley, Westlands is the state's largest water district, covering nearly 600,000 acres. Of course, Stratecon does not purport to summarize all Western water transactions, and it would be unrealistic to expect that all transactions could be captured by the firm; water trades are rarely publicized and are thus difficult to learn about, and Stratecon gathers information on trades throughout the West. Also, these examples may not be representative of the typical degree to which transactions were not summarized.

The fourth example mentions a water bank. A water bank is an institution that serves as an intermediary for water leases, accepting water from willing sellers and making it available to buyers. Water supply organizations, such as ditch companies, that facilitate short term transfers among share holders have essentially acted as water banks for many years, but the term came into being when new institutions were created specifically to facilitate leases among water right or share holders. The price at which water changes hands may be fixed by the bank or allowed to fluctuate with demand and supply. See Howitt (1994) for discussion of a California water bank and Green and O'Connor (2001) for a description of an Idaho water bank.

[26] An "entry" as used here is a single write-up in the *Water Strategist* or *Water Intelligence Monthly*, which may report on one or more transactions. A "case" indicates a case of analysis for the current study, which originated as all or part of an entry. "Trade" and "transaction" are used interchangeably herein to indicate any exchange involving water, whether an exchange of water for water or of water for money. "Purchase" and "sale" are used interchangeably to indicate the exchange of water for money.

understanding of what influenced the price, and thus do not aid greatly in understanding why prices differ from one location to another. Further, the entries are not always consistent in how the transactions are described (perhaps because some information was not available or because the diligence of the personnel compiling the entries varied). Nevertheless, most of the entries do provide sufficient information for a rudimentary analysis of the factors influencing water market prices, and together they form the most comprehensive set available of water market trades in the U.S.

The entries typically included buyer, seller, purpose for which the water was purchased, type of transaction (whether purchase or lease of a water right), and the source of the water (surface water, ground water, effluent, or treated water). Buyers and sellers were categorized herein as one of the following: (1) municipality, (2) farmer or rancher (irrigator), (3) private environmental protection entity (e.g., public trust concern, private entity such as the Nature Conservancy), (4) private entity providing water to many users, such as a water "district," "association," or "company," herein labeled a "water district," (5) public agency (federal or state government agency, conservancy district, or other water "authority"), (6) power company (thermoelectric energy), (7) mining company, (8) real estate developer, (9) other entity (e.g., investor, country club, business such as feedlot, individual homeowner), or (10) several entities (several buyers or sellers of different types, such that the transaction could not be neatly assigned to one of the other categories[27]).

The purpose of the transaction was characterized herein as one of the following: (1) municipal or domestic (including commercial and industrial if serviced by a municipality, and golf courses and other landscape irrigation), (2) agricultural irrigation, (3) environmental (e.g., instream flow augmentation), (4) thermoelectric cooling, (5) recreation, (6) mining, (7) aquifer recharge, (8) other (e.g., augmentation of flows leaving the state per court order, supply to individual businesses such as feedlot or manufacturing plant, an investment of undefined characteristics, unspecified), or (9) several (several purposes, such that the transaction could not be neatly assigned to one of the other categories).

Some entries covered several related transactions. For example, several sellers or several buyers, or both, may have been included in the entry. Or several transactions within the same market may have been listed together in the same entry.[28] Such entries were broken down into separate cases for analysis if the following two conditions were met: distinct prices were listed, and different categories of buyers, sellers, or purposes were involved.[29] After this disaggregation process, a total of 2447 transactions were available for the 1990-2003 period.

The Colorado Big Thompson (CBT) market is the most active market for water rights in the West, with up to 30 or more purchases per quarter by municipalities alone.[30]

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[27] For example, the entry may report that "a corporation and a municipality have acquired …".

[28] For example, a February 1990 entry reported that "thirty-nine entities, including cities, counties, water districts and other users, have contracted for a total of" 948,150 acre-feet of CAP water.

[29] Often in such cases the number of units of water for each separate trade was not listed. In such cases, it was assumed that the total number of units was distributed equally among the different trades.

[30] The CBT project is managed by the Northern Colorado Water Conservancy District. Its delivery area is located north of Denver, along the Cache la Poudre River including the cities of Fort Collins and Greeley,

It is also a market about which market information is readily available. The entries listed 949 CBT trades over the 14 years.[31] Because the sale price for CBT shares differed little among trades completed during a given month, and because the volumes traded were typically small (averaging 40 acre-feet), all CBT transactions of a single purpose within a given month were tabulated as one case for analysis in order to avoid having CBT transactions overwhelm the summary statistics. This aggregation process left a total of 228 CBT cases for the 14-year period, and thus a total of 1726 cases (2447–721) for analysis.

Of these 1726 cases, 349 were omitted from further analysis because key information was missing (such as price or amount of water transferred), something other than raw water (i.e., effluent or treated water) was involved, or the price listed did not appear to be a good indication of the value of raw water.[32] Thus, 1377 qualifying cases (1726–349) were left for analysis. Figure 7 shows the number of qualifying cases versus the full set of cases (1726) by climate division of the buyer for the 14 western states;[33] two additional states (Nebraska and North Dakota) had entries without useable price data.[34] Table 1 lists by state the total number of cases and the number of qualifying cases. Table A.1 of Appendix A lists the number of cases by geographical area or water project with in the state where the transactions occurred, as best we could determine from the information available, along with the number of acre-feet of water involved for the qualifying cases. A total of 262 separate sale locations (rivers, ditches, projects, or areas) were identified. Numbers of cases per location vary from one for many locations to 228 for the CBT project.

Prices, expressed on a per acre-foot basis, were adjusted to year 2003 dollars using the consumer price index. Prices for water rights were converted to an annual basis using a 3 percent interest rate, which is approximately the mean annual growth rate in real gross domestic product over the past 20 years in the U.S. Although mean prices are also reported, this analysis emphasizes median prices, which more accurately indicate the price of a typical water sale when the price distributions are skewed. As will be seen, the

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along the Big Thompson River including the cities of Estes Park and Loveland, along the St. Vrain River and its tributaries including the cities of Boulder and Longmont, and along the South Platte River from a few miles downstream of Denver to the Nebraska state line.

[31] Thirteen of the 949 were leases; all others were rights. Leases and rights were tabulated separately.

[32] Eighty-five transactions were omitted because goods of substantial value besides raw water—such as land or water distribution systems—were included in the transaction and captured in the price. In addition, 32 transactions were omitted because they involved water exchanges (trades of water for water, some of which also included a cash component). Another 79 were omitted because they were of effluent, and six were omitted because they involved water treated to potable standards. Finally, an additional 26 cases were omitted because a water volume was not listed and an additional 121 transactions were omitted because a price was not listed or the price listed (usually at or very near $0) did not appear to represent a market transaction.

[33] Climate divisions are available at: www.cdc.noaa.gov. Climate divisions are only one of numerous sub-state geographical breakdowns that could have been used to show a spatial breakdown of the water market activity. Counties or watersheds, for example, could have been used. We used climate divisions because we were interested is determining whether climate was a factor that influenced sale price, as presented further on.

[34] In Texas, 29 transactions along the Rio Grande, based on the information provided, could not accurately be assigned to a climate division. These transactions were assigned to division 6, which otherwise would have received no entries.

price distributions are highly skewed, causing the means to be heavily influenced by a few highly priced transactions.

Prices paid for untreated water often include reimbursement for water management—including, as described above, such services as storage, conveyance, and general administration—in addition to the cost of the raw water. Because our primary interest is in water value, costs of water management were not included when such costs were reported separately. However, many of the prices reported in the entries undoubtedly include some consideration for the value of water management services. In fact, storage and delivery services are so commonly part of water transactions that such services were rarely even mentioned in the entries. Most prices reported here probably include the value of some services. From an economic standpoint, the full price does not over-estimate the marginal value of the raw water if the service facilities (such as the reservoirs) have excess capacity and management costs are very small at the margin.

Results

Fourteen states have qualifying cases (all states in Figure 7 except North Dakota, South Dakota, and Nebraska). Three climatic divisions within these states have over 75 qualifying cases (Figure 7). Division 4 in northeast Colorado, including Denver, Fort Collins, and other cities along the northern Front Range, has 360 cases, 224 of which are CBT cases.[35] Division 5 in California, capturing the southern (San Joaquin River) portion of the Central Valley and on down to the Bakersfield area, has 123 cases, 44 of which involve Central Valley Project water and another 37 of which involve State Water Project water.[36] Division 10 at the southern tip of Texas, along the Rio Grande as it enters the Gulf near Brownsville, has 106 cases, nearly all of which involve water from the Rio Grande. Nine climatic divisions had between 26 and 75 cases—three in California, two in Texas, and one each in Arizona, Colorado, Idaho, and Nevada (Figure 7). Thirteen climatic divisions had between 11 and 25 cases, and 43 had from 1 to 10 cases. Another 44 climatic divisions in the 14 states had no cases.

As we begin this extensive summary of western water market transactions, it bears repeating that we are dealing only with those transactions reported by the two aforementioned publications. Although we have much data—data sufficient, for example, to plot trends in median price for specific kinds of water use—these results are not necessarily definitive because some transactions were missed and we have no way to know whether the missed transactions are randomly distributed across the population of transactions. This analysis is most valuable for characterizing the general nature of western water market trades, not the full extent of those trades.

Quantity of Water Sold

The median amount of water transferred per case is 1000 acre-feet for the full set of 1684 cases for which volume of water was listed and 804 acre-feet for the 1377 cases meeting the criteria for further analysis (the means are 16,961 and 17,234, respectively).

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[35] The next most common markets in Colorado Division 4 are North Poudre Irrigation Company with 24 cases and Windsor Reservoir and Canal Company with 11 cases.

[36] Moore and Howitt (1988) provide a good discussion of water management in the Central Valley.

Table 1 lists the number of acre-feet transferred by state. Three states (Arizona, California, and Idaho) account for 75% of the water transferred via the qualifying cases.

Figure 8 shows the trend in total water volume transferred for these two sets of cases. The water volume traded has varied widely over the past 14 years and shows no consistent trend.[37] Most interesting is the difference in amount of water transferred in leases versus rights (Figure 9). At least three findings of interest are apparent in the figure. First, in all years much more water has been transferred via leases than via rights, which probably reflects that fact that large amounts of water are easier to agree about on a temporary than on a permanent basis. The median lease size over the 14 years is 6000 acre-feet per case, compared with a median size of water rights transactions of 110 acre-feet per case.[38] This dramatic difference has been maintained during each of the 14 years, as suggested by the fact that the median lease size in any individual year has never dropped below about 3300 acre-feet per case, whereas the median water right sale size has always been below 250 acre-feet per case. Second, there is considerable annual variation for both types of transactions in amount of water transferred, and no apparent relation between the two types of transactions. Third, there is no obvious trend in volume transferred for either type of transaction.

Ten percent (141) of the qualifying cases involve ground water, with the remainder (1236) being of surface water. However, only 4% of the water transferred in these trades has been ground water, as suggested by the fact that the average water volumes per qualifying case are 6679 acre-feet for ground water and 18,438 for surface water. Eighty-three percent of the ground water volume and 96% of the surface water volume traded via leases (with the remainder trading via sales of water rights).

Occurrence and Price of Qualifying Cases Aggregated Over All 14 Years

Table 2 summarizes cases by state for the 14 western states with qualifying cases. A quick look at the table reveals at least four findings of interest. First, mean prices exceed median prices, indicating a skewed distribution. This holds true for the complete set of qualifying cases (a mean of $96 per acre-foot per year, versus a median of $56, Figure 10) and for all but two states. Second, the range of prices per acre-foot is substantial for each state, with minimums close to $0 and maximums typically in the $100s. Clearly, water changes hands at a variety of prices (depending, as seen below, on various site-specific characteristics). Third, water trades are much more common in some states (e.g., California and Colorado) than others (e.g., Montana and Oklahoma). Water scarcity no doubt plays some role in determining the number of trades that occur in a state, but institutional and legal differences are probably the most important factors affecting sale frequency among the western states. Fourth, the median prices vary substantially among the states, ranging from below $10 in Idaho and Oregon to over $80 in Colorado and

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[37] The larger than usual difference in 2002 between the volume transferred for all cases and the volume for qualifying cases is due mainly to a 579,200 acre-foot donation in Oregon from an electric power firm following the decommissioning of its hydroelectric dam. The donation was dedicated to maintaining instream flows.

[38] The aggregation of CBT transactions, described above, elevated this median size of water rights sales. Sales of CBT shares have averaged 40 acre-feet, such that if all the individual CBT sales were included in the computation of the median, it would be much below 110 acre-feet.

Nevada.[39] States are rather evenly distributed over the price range. Further, there is no apparent relation between number of trades and median price.

To begin to understand the reasons for the range of median prices, consider Table 3, which summarizes the sales by type of transaction, either a lease or a perpetual right. As seen in the table, the median price for leases ($47 per acre-foot per year) is about two-thirds that of rights ($72) given the 3% interest rate for annualizing prices of rights.[40] Fifty-two percent (715) of the sales were leases (though the percentage depends on how CBT sales were summarized, as mentioned above).

Table 4 shows the state breakdown in median price by type of transaction. Of interest here is that, contrary to the overall picture of Table 3, the median price of leases exceeds that of rights in most states. The superiority of median water rights prices in Table 3 results largely from the fact that 56% of the water rights cases (369) are for Colorado, a state where the median price of water rights far exceeded the median price of leases. Fully 216 (59%) of the 369 water rights cases for Colorado are of CBT shares, and another 129 (35%) are for other water rights along the northern Front Range within or near the area of the Northern Colorado Water Conservancy District where CBT shares trade (i.e., in climate division 4, Figure 7). Also of interest is that for 10 of the 14 states the number sales of leases exceeded the number of sales of rights. The exceptionally high number of water rights transactions in Colorado reflects the relative ease with which such transactions can be consummated and the strong demand for secure water supplies by the fast-growing Front Range cities.

Table 5 summarizes the cases by the purpose for which the water was purchased. Over half (739) of the purchases were for municipal purposes, another 23% (321) were for irrigation, and 11% (150) were for environmental purposes. The highest prices (a median of $171) were paid for mining; all 28 of these transactions were leases, 25 of which occurred in Texas. The median price paid for municipal uses ($77) was nearly three times that paid for irrigation water ($28) and nearly twice that paid for environmental purposes ($40). The lowest prices were paid for recreation and thermoelectric cooling. As Table 6 shows, purchases for municipal purposes tended to be of water rights, suggesting that municipalities desire—and are able to pay for—dependability of supply. Purchases for environmental or mining purposes tended to be of leases. Purchases for irrigation purposes were divided 62/38 between leases and rights.

Figures 11-13 show the very skewed distributions of municipal, irrigation, and environmental water prices. The distributions for municipal and irrigation uses are bimodal. The upper mode of the municipal distribution centers on the $80 to $120 per acre-foot category, which includes 136 cases, 54 of which are from Colorado (most of these are CBT sales) and another 35 of which are from Nevada (largely in the Truckee River area near the city of Reno).

Among the qualifying cases, transfers for municipal purposes occurred in all but two states (Table 7). The median price of the 739 cases for municipal purposes of $77 per

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[39] Medians for Montana and Oklahoma are based on so few observations as to be unreliable. Data on these two states are included in the tables and general summaries but are not given specific attention in the text.

[40] An interest rate of 1.9% is necessary to reduce the median water price of water rights to that for leases of $46 per acre-foot per year.

acre-foot per year is heavily influenced by sales in Colorado, where the median price of the 250 cases is $88. All but 28 of these 250 cases occurred in climate division 4, largely along the northern Front Range. Other states with both high median prices for municipal purposes and a substantial number of cases are California (median of $96), Nevada ($110), and Wyoming ($77). Excepting Colorado, the median price of the remaining 489 sales for municipal purposes was $57.

Transfers for irrigation occurred in all but two states (Table 7). The median price of the 321 cases for irrigation water, of $28 per acre-foot per year, is heavily influenced by Colorado, which had over one-third of these cases and a median price of $72. Other states with a substantial number of cases include California (median of $45), Idaho ($4), and Texas ($24), indicating a great range across states. Excepting Colorado, the median price of the remaining 211 cases for irrigation purposes was $16.

Transfers for environmental purposes occurred in ten states (Table 7). The median price of the 150 cases is $40 per acre-foot per year. States with the highest median prices and with at least ten cases are California (median of $64), Colorado ($20), Idaho ($8), Oregon ($26), and Washington ($32).

Who Sold to Whom, and for What Purpose?

Farmers are the sellers in 38% (531) of the qualifying cases (Table 8), not counting when they might appear among the 222 cases involving several sellers.[41] Public agencies are the sellers for another 16% (224) of the cases. In California, the state with the most public agency sales (68 cases), such trades are nearly all leases and typically involve State Water Project or Central Valley Project water. In Arizona, the public agency sales (24 cases) typically involve Central Arizona Project water managed by the Arizona State Land Department, the Central Arizona Water Conservancy District, and other agencies. In Colorado (27 cases), nearly all public agency sales are leases of water from reservoirs managed by the U.S. Bureau of Reclamation. In Oregon (20 cases), most public agency sales are leases to irrigators by the Bureau of Reclamation, with some also by the U.S. Army Corps of Engineers. In Wyoming (34 cases), all public agency sales are from reservoirs managed by the U.S. Bureau of Reclamation.

Ignoring seller types with less than 10 cases and the unusually high median price paid to developers ($114), median price varies from $40 for sales by public agencies to $71 for sales by farmers (Table 8).

Municipalities were the most common buyers of water, accounting for 27% (375) of the cases (Table 8), not counting when they might appear among the 206 cases involving several buyers. Other active buyers were public agencies with 17% (234) of the cases, farmers with 15% (204) of the cases, and water districts with 13% (183) of the cases. Developers and mining companies paid the most for water, whereas farmers and environmental interests paid the least (Table 8). Prices paid by water districts and public entities tended to be lower than prices paid by municipalities.

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[41] See Michelsen (1994) for a summary of transfer history (1970-1993) for the CBT project. He reports that agriculture accounted for 83% of the sales and 28% of the purchases, and that municipalities (not including industry) accounted for 52% of the purchases.

Farmers tended to sell to municipalities, public agencies, or other farmers (Table 9). Public agencies and water districts sold to a mixture of buyers, most importantly municipalities, farmers, water districts, and public agencies. Developers usually sold to municipalities. Table 10 is similar to Table 9, but reports on sales of water rights only.

Fifty-three percent of the public agency purchases were for environmental purposes, with most of the rest for municipal or irrigation purposes (Table 11). Sixty-five percent of water district purchases were for municipal purposes, with another 31% for irrigation.

In terms of water volume, and looking only at qualifying cases, 23% of the water leased was leased for municipal purposes (Table 12), whereas 65% of the water transferred via water rights was purchased for municipal purposes (Table 13). For agricultural irrigation these percentages were 21% and 7%, respectively, and for environmental purposes the percentages were 17% and 16%, respectively. Also of note is that 85% of the water purchased for municipal purposes (and ignoring cases where municipal buyers were part of the "several" category) was transferred via leases.

Trends in Occurrence and Price

The number of cases per year (across all states and purposes) ranges from a minimum of 77 in 1995 to a maximum of 142 in 1999 (Figure 14).[42] Recent years show an increase in the number of cases (over the 14 year period, the four highest numbers of cases occurred in 1999, 2001, 2002, and 2004); the overall increasing trend is statistically significant at the 0.05 probability level based on the Mann-Kendall test for time trends (test statistic = $k = 2.56$). Looking separately at sales of leases and rights (Figure 15) we see that the number of leases has increased substantially over the past 14 years; this increase is significant ($k = 3.60$). The increase in the number of leases is evident in most states. The numbers of sales of rights show no trend ($k = -0.49$).

The median price per year (across all states and purposes) ranges from \$34 in 1998 to \$76 in 1991 (Figure 14).[43] No overall trend is evident ($k = 0.24$). However, looking separately at sales of leases and rights (Figure 16) we see that the median price of rights has increased significantly ($k = 2.07$), whereas the price of leases has not ($k = 0.00$). Looking at the three states with the most water rights cases (and with sufficient cases each year to compute meaningful annual estimates of median price), we see that Colorado is largely responsible for the recent increase (Figure 17). The dramatic increase in prices

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[42] Some variation during 1995-1998 may be an artifact of the assignment to individual years of transactions listed in quarterly reports. In particular, the fall 1997/winter 1998 report spanned two years.

[43] In Figure 14, the unusually high median prices in 1991 and 1992 occurred largely because of a three-fold increase in the number of lease entries in California (mainly for municipal and irrigation purposes), where lease prices were relatively high in the early 1990s, spurred by a five-year drought. The sales took place in various basins throughout California. 1991 was the first year of operation of the California Water Bank, under which the state purchased water at \$125 per acre-foot and sold it at \$175 per acre-foot plus delivery costs. In 1991, 351 sellers (all, or nearly all, farmers) sold 830.000 acre-feet, most of which was purchased by 13 buyers (Loomis, 1992). The unusually high number of entries in 1999 occurred largely because of increases in leases in California, Kansas, and Texas and increases in sales of rights in Nevada and Utah. The reason for the increased number of entries is not clear; 1999 was drier than the previous year in all of these states, but 1999 was not an exceptionally dry year (for example, 2002 was drier than 1999 in all but one of the states). There remains the possibility that Stratecon Inc. increased efforts in 1999 to capture available trades.

in Colorado is associated with growth along the Front Range, especially in the residential housing market. Most Front Range cities and towns require developers/builders to provide either water rights or the money to purchase such rights. The necessary amount of money is determined by the cities and towns and is updated as market conditions change. The prices charged by some cities closely track the price of CBT shares.

Figures 18-21 show trends in price and in number of cases for the three water uses with the most cases. No distinct trend is apparent in sales for municipal purposes (Figure 18). For irrigation, however, both price and number of trades have been dropping since 1992 (Figure 19). For environmental purposes, the number of trades has risen dramatically but the price shows no trend (Figure 20). The erratic behavior of median price of water sold for environmental purposes may simply reflect the low number of trades per year. Figure 21 restricts data points to at least nine cases and shows a more coherent environmental price trend.

Environmental Trades

Trades for environmental purposes were reported in ten states (Table 14). In most states there was a large range in price. The highest median price, $64, was found in California. Median prices in four states (Arizona, New Mexico, Nevada, and Utah) were in the $40 to $47 range. Two states, Idaho and Montana, had median prices below $10. Loomis et al. (2003) report based on 84 environmental trades from 1995 through 1999 (most of which were summarized by Stratecon) that the most frequently stated purpose for environmental purchases was increasing instream flows. The most frequent reasons stated for increasing instream flows were enhancing fisheries and protecting threatened species.

Price Differences across Markets

For most markets the number of qualifying cases is small, usually below five, but for a few there are enough cases to examine market-specific trends. Two sets of examples are provided here, one for water leases and the other for water rights.

A Sample of Markets for Water Leases from Five States. Figure 22 shows median prices for leases of water in five water market areas, one each in New Mexico, Wyoming, Arizona, Texas, and Idaho.[44] These are all areas where leases were much more common than sales of rights.[45] The figure is presented to show the range and relative variability across market areas—not to offer a detailed understanding of any of the individual market areas. Indeed, although 230 trades are summarized in the figure, many of the individual data points are represented by only a few trades. For example, 10 data points are represented by only 1 trade, and only one market has any data points with more than 5 trades (Table 15). It bears repeating that this database includes only a fraction of the total number of trades that occurred (see footnote 25).

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[44] Without further investigation it is risky to classify some of these five market areas as single markets. Trades that occurred in some locations within a given market area may in fact have little or no effect on trades elsewhere in the same market area. Further research is needed before these market areas can confidently be characterized as individual markets.

[45] Across the five markets, 230 lease transactions (shown in the figure) and 40 sales of water rights were reported.

Three of the markets, considered first, show little annual price fluctuation. Median price for Upper Snake River water varied from $3 to $14. Half of the 30 purchases were for environmental purposes, with most of the rest for irrigation. Many of the trades were handled by Idaho water banks. Green and O'Connor (2001) report that the banks set prices based on administrative costs plus the cost of owning reservoir space, and suggest that the relatively low level at which the prices were set may have limited the amount of water available for sale in dry years. Median price for Rio Grande water in Texas varied from $20 to $37. Half of the 126 purchases were for municipal purposes, 30% were for irrigation, and 20% were for mining.[46] The market is active and competitive, with the price being determined by negotiation between buyer and seller. The Rio Grande Watermaster's office facilitates the market by bringing buyers and sellers together (Yoskowitz, 1999). Median prices for the North Platte River in Wyoming water varied from $41 to $50. Ten of the 21 purchases were for irrigation and 9 were for municipal use. In all cases, the Bureau of Reclamation supplied the water, which was stored in Glendo Reservoir, at nominal prices of $5 per acre-foot for irrigators and $75 per acre-foot for M&I uses. These administratively set fees remained constant over the ten-year period (1994-2003) for which leases were recorded. The median prices of Figure 22 reflect the updated (year 2003 dollars) midpoint between these two set prices.

The Central Arizona Project brings up to 1.2 million acre-feet of water per year from the Colorado River to the Phoenix and Tucson areas, using 336 miles of canal and 14 pumping plants that raise the water 3000 feet by the time it reaches Tucson. Median prices for leases of CAP water varied from $34 to $88 in year 2003 dollars (Table 15, Figure 22). Most of the 36 purchases were for municipal use and irrigation, but five were for environmental purposes. Most of the sales were by the Central Arizona Water Conservation District, which administered CAP water. Almost all of the trades occurred at administered prices (typically made up of two components, a pumping (energy) fee and an operations and maintenance fee). Annual fluctuations in the median prices of Figure 22 were primarily dependent on the purposes for which water was leased in a given year, with most agricultural customers paying significantly less than municipal and industrial customers. For example, the dip in median price in 1994, when compared with 1993 and 1995, occurs because the 1994 median mainly reflects sales to irrigators, whereas the medians of the other two years mainly reflect sales to municipal suppliers. M&I customers were charged about $40 per acre-foot in 1990 (in nominal dollars), but this charge gradually increased to about $110 per acre-foot by 2003, whereas agricultural customers were charged in the range of $15 to $45 per acre-foot over the 14-year period.

The San Juan-Chama project brings water from the San Juan River in southern Colorado (the San Juan flows into the Colorado River) by tunnel to the Chama River in northern New Mexico. This water is stored in Heron or El Vado reservoirs (managed by the Bureau of Reclamation) along the upper Chama, for release to users along the Chama river or along the Rio Grande into which the Chama flows. Fourteen leases were reported in a total of eight different years (Table 15). The six recorded leases of San Juan-Chama water in the early years (1991-1994) were from the city of Albuquerque to

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[46] Yoskowitz (2002), reports that of 1330 lease transactions that occurred along the Rio Grande in Texas between 1993 and 2000, 83% were for irrigation, 8% were to municipalities, and 8% were for mining. Mean prices paid were $22, $22, and $432, respectively, in nominal dollars.

either (1) a mixture of entities (municipal, industrial, and agricultural) at about $43 per acre-foot (this charge covers the city's payment to the Bureau of Reclamation for the city's San Juan-Chama water, which is related to repayment for the project plus the Bureau's operation and maintenance costs), or (2) to the New Mexico Interstate Stream Commission at $10 per acre-foot.[47] The eight leases in later years (1999-2003) were from various entities to the Bureau of Reclamation for the purpose of maintaining instream flows for the silvery minnow in the Rio Grande. Most of these leases were for either about $45 or $100 per acre-foot. In all cases the prices appear to have been administratively set. The fluctuation in median price appears to mainly reflect changes from year to year in what administrative prices were used. Seven of the 14 purchases were for environmental purposes; the others were for a mixture of several uses.

Comparison of prices in these five market areas suggests the following two conclusions: median prices differ substantially across areas, and the prices of many leases are heavily influenced by administrative criteria, not competitive market exchange (the Texas Rio Grande market being a marked exception).

A Sample of Markets for Water Rights from Two States. Figure 23 shows median prices for water rights from four water markets along the Colorado Front Range and in eastern Colorado, plus one market from northwestern Nevada.[48] All of the Colorado trades and most of the Nevada trades of Figure 23 are for shares of water supply organizations.

For the CBT market, the data allowed computation of a median price for each of the 14 years, based on 213 CBT water rights cases. The annual medians were based on from 13 to 19 cases each. Much less data were available for the other four markets, none of which provided a measure for every year. For the North Poudre Irrigation Company there were 17 reported sales that occurred during 9 years. For the Windsor Reservoir and Canal Company there were 11 reported sales during six years. For Twin Lakes Reservoir there were 14 sales in 9 years. For the Truckee River market there were 54 sales reported in 11 years. Of course, only the trades recorded by the *Water Intelligence Monthly* and *Water Strategist* are included here; other trades may have occurred.

The CBT market reflects sales of water managed by the Northern Colorado Water Conservancy District and diverted from the Colorado River drainage to 30 cities and towns and about 600,000 acres of farmland in the South Platte drainage. Water in the CBT project is managed using 12 reservoirs, 35 miles of tunnels, and 95 miles of canals. The project is designed to deliver up to 310,000 acre-feet per year and typically delivers about 230,000 acre-feet. As seen in the figure, the price began increasing in 1995 and rose dramatically in 2000, largely in response to urban expansion.[49] Over half of the CBT shares are now owned by cities (Howe & Goemans, 2003; Howe et al., 1986; Michelsen, 1994).

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[47] When medians were computed for an even number of values, the midpoint of the two central values was computed. For example, the value for the San Juan-Chama project for 1993 in Figure 22, of $34, is the midpoint between the two data points, $13 ($10 updated to year 2003) and $55 ($43 updated to 2003).

[48] Leases of water are also common along the Colorado Front Range, but most such leases have not been recorded by Stratecon, Inc.

[49] Michelsen et al. (2000) present an analysis of 30 years of CBT rights transactions showing that speculation also probably plays a role in market price.

Shares of the North Poudre Irrigation Company consist of a combination of CBT shares and native water from the Cache la Poudre River, which flows from the mountains along the Continental Divide through Fort Collins and on to its confluence with the South Platte River at Greeley. The company operates several small reservoirs, such as Fossil Creek (11,100 acre-feet of capacity) and Halligan (6,400 acre-feet of capacity). About one-third of the shares are owned by the City of Fort Collins; most of the other shares are owned by farmers north of Fort Collins. The price of North Poudre shares tends to track that of CBT shares—in part because North Poudre shares each include some CBT water—but is lower on an acre-foot basis, largely because of the market area for North Poudre shares (the area over which the water can be delivered) is much smaller than that for CBT shares, and perhaps also because the non-CBT portion of the shares cannot be used for municipal purposes without a formal change of use which must be approved by the water court.

The Windsor Reservoir and Canal Company operates Windsor Dam (20,400 acre-feet of capacity) near the city of Windsor, in Weld County on a canalized tributary of Cache la Poudre River. The median price has remained relatively stable, ranging from $30 to $60 per acre-foot on an annual basis. The reservoir and its delivery area are relatively small, which in part accounts for the relatively low price.

Water from Twin Lakes Reservoir (141,000 acre-feet of capacity), located along the Arkansas River a few miles south of Leadville, serves users in a variety of locations, including south Denver metro areas such as Aurora, the Colorado Springs area, locations along the Arkansas River including Leadville in the headwaters, Pueblo along the Front Range, and farming areas further downstream. Twin Lakes water is diverted from the Colorado River drainage, and thus was new to the eastern side of the continental divide when the diversion was created. Prices have been relatively high—typically above $200 per acre-foot per year—both because of the economic and population growth and the dwindling ground water supplies along parts of the Front Range, and because of increased demand pursuant to the 1995 Supreme Court decision in *Kansas v. Colorado* that required the Upper Arkansas Water Conservancy District to augment streamflow to make up for reduced flows due to pumping along the Arkansas River in Colorado.

Purchases of water rights from irrigators in the Truckee River basin have been common for many years (Colby, McGinnis et al., 1991; National Research Council, 1992). Most of the purchases among the 61 qualifying trades represented in Figure 23 (see Table 15) were for municipal development, especially near the cities of Reno and Sparks, where developers must supply water rights for properties that they wish to add to the water utility service area. Since at least the early 1990s, however, purchases for environmental purposes have also been common (Lovell et al., 2000). The environmental purchases have been largely either for maintaining wetlands in the Lahontan Valley (including the Stillwater National Wildlife Refuge) or for improving water quality in the Truckee River and Pyramid Lake into which the river flows.[50] These environmental efforts are the result of lawsuits and multi-party negotiations, with the

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[50] The Lahontan Valley is located along the lower Carson River. Truckee River water reaches the Valley via the Truckee Canal connecting the two rivers.

water purchases funded largely by public entities.[51] Some of the purchases appear to have occurred at prices set by the purchaser,[52] whereas others appear to have been negotiated on a case-by-case basis. In any case, most of the median prices in Figure 23 are the result of a wide range of prices paid at various locations along the Truckee River, suggesting that the rather constant median (of about $100 per acre-foot per year, which is equivalent to a one-time price of about $3300 per acre-foot in 2003 dollars) is more a reflection of the large amount of irrigation water available than of price controls.

Three main points are evident from this comparison. First, from the Colorado markets we see that prices vary considerably even among markets located quite close to each other. Such markets are distinguished by local economic conditions, availability of alternative supplies (such as ground water as a supplement for surface water), extent of water distribution infrastructure, and past decisions to obtain secure surface water rights. Second, within a given market prices can change considerably over time as demand changes, although price change is not a certainty. Third, although in most cases the prices of water rights reported in Figure 23 were determined by individual negotiations between buyer and seller, in one case (Truckee River) the price was sometimes posted by the buyer or the seller.

Price Dispersion within Markets

Tables 5 and 6 showed wide price dispersion across water uses. For example, municipalities paid a median price of $77 per acre-foot per year but farmers paid a median of only $28. Such a large discrepancy begs the question: Are differences in price across water uses found in individual markets, or only when combining across trades from many different market areas?

To answer this question, consider evidence from three market areas where sales for irrigation and M&I uses (and in one case mining) were common. First, the median prices of North Poudre Irrigation Company shares, in 2003 dollars on a per-acre-foot per-year basis, were $37 for irrigation and $36 for M&I uses. Second, as seen in Figure 24, prices of CBT shares sold to farmers and for M&I uses were nearly identical for each year from 1990 to 1998 (for subsequent years, there were insufficient cases of water sold for irrigation to compute a meaningful median price).

The third example comes from the market for water leases along the Rio Grande in Texas. Yoskowitz (2002) reports that over the time period from 1993 to 2000 the average price of the 110 sales for municipal use, of $22, was identical to the average price of the 1109 sales for irrigation. However, the average price of the 111 sales for mining was $432 (this discrepancy was also found among the lower Rio Grande trades

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[51] Congress authorized the U.S. Fish and Wildlife Service to purchase agricultural water rights to support wetlands in the Lahontan Valley in the 1990 Fallon Paiute-Shoshone and Truckee-Carson Pyramid Lake Water Rights Settlement Act. The Truckee River Water Quality Agreement of 1996 specifies that $24 million, provided by the U.S. Department of the Interior, Washoe County, and the cities of Reno and Sparks, will be used to purchase water rights (Lovell et al., 2000). NGO organizations facilitating the purchases include The Nature Conservancy and Great Basin Land and Water.

[52] For example, in the early 1990s the Sierra Pacific Power Company, which provides municipal water to the Reno and Sparks area, tended to purchase water at a standard price (of about $2600 per acre-foot), and the Department of the Interior purchased water at a set price based on a general analysis of fair market value (Lovell et al., 2000).

reported by Stratecon). Yoskowitz concludes that the price discrepancy reflects search costs and differing levels of information.[53]

Effect of Low-priced Trades

Without a detailed examination of the markets where individual trades occur, it is difficult to assess the competitiveness of the market. Lacking such a detailed examination, all sales with a positive price were included in the analysis unless it was obvious from the description provided by Stratecon that the price was intentionally held very low. Nevertheless, it can be argued that water that sold at a very low price—such as a price of $1 or even $10 per acre-foot—was not sold in a competitive market. Conventional wisdom suggests that water is worth at least $10 per acre-foot. Lacking the resources to fully assess the market characteristics of all the trades included in this assessment, we perform a simple sensitivity analysis of the effect of removing low-priced sales. An arbitrary cutoff of $10 per acre-foot was used.

One hundred seventy-eight entries with a nominal price below $10 were removed, reducing the total number of qualifying sales to 1199 (a 13% reduction). Of the 178 entries, 125 were leases and 53 were of water rights. The median price of remaining leases rose from $47 to $60 (the mean rose from $85 to $102), and the median price of rights rose from $72 to $77 (the mean rose from $108 to $117). Over all entries, the median price rose from $56 to $68 (the mean rose from $96 to $110).

Table 16 is similar to Table 2, but reports on the 1199 qualifying sales. Comparing the two tables shows that four states (Idaho, Oregon, Montana, and Wyoming) were especially affected by removal of low-priced entries, in that about 50% or more of their entries were removed. These states account for over half of the removed entries (97 of the 178). The case of Idaho is most notable: 52 of the 64 cases were removed, raising the median sale price from $6 to $19. For the states with the most cases—Arizona, California, Colorado, and Texas—the effect was modest, raising the median sale price by $3, $2, $2, and $0, respectively.

Among the purposes for which water was traded, the effect of removing low-prices sales was most noticeable for irrigation, were 93 cases (29% of the full set of irrigation cases) were removed and the median sale price rose from $28 to $45. Among trades for environmental purposes, 26 cases (17%) were removed, raising the median sale price from $40 to $47. The restriction had little effect on trades for municipal purposes, where 38 cases (5%) were removed and the median sale price rose from $77 to $80.

The concentration of the low-priced trades in certain states and among purchases for irrigation raises the possibility that irrigation prices in some states are controlled, perhaps via government pricing arrangements tied to rules such as those established by the Bureau of Reclamation (see Wahl, 1989).

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[53] Colby et al. (1991) present an example for the Gila basin in southwestern New Mexico of price dispersion for water rights that occurs across buyer type for a single use. High profile land developers paid more than small developers or individual homeowners for water rights in order, the authors suggest, to maintain good will in an area where some people objected to the rapid growth that was occurring.

Analysis of Spatial and Temporal Variability

Perhaps the primary observation one can make based on these price data is that the price of water varies considerably from one market to the next. This is true for nearly all categories listed in the tables. For example, as seen in Table 2, the ranges in price are substantial for most states, with most minimum prices below $10 and most maximums above $100. Similarly, as seen in Table 5, prices for irrigation water varied from $1 to $490 and prices for municipal water varied from near $0 to $1607. The large price ranges reflect both temporal and spatial variability. Regarding spatial variability, water markets are, as explained above, each characterized by a series of factors that may vary across locations.

Next we examine two factors that may influence water prices, population and climate.[54] Then we examine possible factors influencing water prices within a multivariate framework.

It bears repeating that the data on water market trades used herein constitute neither a random sample nor a complete census of trades. Thus, any results we may obtain from the analysis are tentative, and must be considered only hypotheses for testing with a proper sample (once that becomes available). Furthermore, it should be mentioned that the distributions of most variables are not normal, in possible violation of the assumptions upon which use of parametric statistics is based.

Population. Urban or residential development is a primary force behind water trades, as evidenced by the large proportion of purchases that occurred for municipal purposes. From census records we obtained county population data for 1990 and 2000 for the counties where the qualifying water trades occurred. The counties of the buyer and the seller of each transaction were determined as closely as possible given the information provided in the transaction summaries. The results presented here are based on the county of the buyer except in cases where we could not determine the county of the buy but could determine the county of the seller; in these cases we used the county of the seller. A county was specified for 1372 of the 1377 transactions with market prices.

Table A2 lists the 162 counties with qualifying transactions and reports the number of transactions, the median sale price, and the total number of acre-feet involved. Figure 25 plots county data for year 2000 population versus median sale price, exhibiting no obvious relationship ($R^2 = 0.02$).[55] Figure 26 plots county data for population growth (from 1990 to 2000) versus median price, again exhibiting no linear relationship ($R^2 = 0.00$). Most of the counties have very few transactions. When the analysis is restricted to the counties with at least ten transactions, these R^2s change to 0.01 and 0.15, respectively.[56]

Climate. Dry weather tends to stress water supply systems, which may engender water trades. The relation between drought and trades was examined by obtaining the

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[54] A careful look at institutions affecting water trades would also be very useful, but data are not available for the full set of market areas, so that analysis must wait for a future time.

[55] This graph and correlation, and those for Figure 20, are based on 160 counties, two outliers with exceptionally high population or price having been removed.

[56] Thirty-two counties have at least 10 transactions. This analysis was restricted to 30 counties, the two outliers mentioned in note 32 having been removed.

Palmer Drought Severity Index (PDSI) number for every month during the period 1990-2003 for each climatic division with qualifying market trades (see Figure 7 for locations of the divisions). It was assumed that weather during the six months prior to the trade would have an effect on the probability of sale. Thus, for each entry a mean PDSI was computed, the mean being of the PDSI numbers for the six months prior to the sale for the climatic division where the sale occurred.

Table A3 lists the 68 climatic divisions with qualifying transactions and reports the number of transactions, the median sale price, and the total number of acre-feet involved. Figure 27 plots median monthly PDSI (over the 14 years of study) versus median price by climatic division, exhibiting no linear relationship ($R^2 = 0.01$). Figure 28 compares total volume of water traded versus median PDSI, again exhibiting no linear relationship ($R^2 = 0.00$). When the analysis is restricted to the 26 climatic divisions with at least ten transactions, these R^2s are 0.09 and 0.00, respectively.

Multivariate analysis. In a multivariate analysis, explanatory variables are assessed independent of (i.e., adjusted for) the effect of other explanatory variables, allowing for a more telling assessment of the independent influence of the various predictor variables. To provide adequate degrees of freedom, this analysis is restricted to use classes for which we have ample cases classes (municipal, irrigation, mining, and environmental) and to the states for which we have at least 20 cases (thereby excluding Kansas, Montana, and Oklahoma). Further, we excluded two use classes (other and several) because neither characterizes a distinct use category. Through these eliminations our sample size is reduced from 1377 to 1184.

Table 17 lists results of a regression of Price on the following eight explanatory variables ($R^2 = 0.12$, overall significance < 0.001):

- YEAR, the year of the trade (from 1990 to 2003).
- TYPEd, a dummy variable (1 = right, 0 = lease).
- SOURCEd, a dummy variable (1 = ground, 0 = surface).
- USEdm, a dummy variable (1 = municipal, 0 otherwise).
- USEdi, a dummy variable (1 = irrigation, 0 otherwise)
- POP2000, year 2000 population of the county of the buyer, or if the buyer’s location could not be identified, of the seller.
- PDSI6m, the mean monthly PDSI for the six months prior to the sale for the climatic division where the sale occurred. PDSIs vary from about 4.0 for extremely wet conditions to about −4.0 for extreme drought (Alley, 1984).
- AF, the volume of the trade in number of acre-feet per year.

YEAR is significant (at the 0.05 significance level) and positive, indicating that real price increased over time. TYPEd is significant and positive, indicating that the price of rights was greater than the price of leases. SOURCEd is significant and negative, indicating that the price of surface water exceeded the price of ground water. USEdm is significant and positive, indicating that the price of water purchased for municipal purposes is greater than that of water purchased for environmental purposes. USEdi is not significant, indicating that the price of water purchased for irrigation is not significantly different from the price of water purchased for environmental purposes. Population is significant and positive, indicating that price increases with the population of the county.

Table 18 lists results of an analysis of variance of Price, with the following independent variables ($R^2 = 0.42$):

- TYPE (right or lease)
- USE (municipal, irrigation, or environmental)
- STATE (AZ, CA, CO, ID, NM, NV, OR, TX, UT, WA, or WY)
- YEAR, as above
- SOURCE (ground or surface water)
- POP2000, as above
- PDSI6m, as above
- AF, as above

Two-way interaction terms were included for the categorical variables. Cases were restricted as they were for the regression described above. POP2000, PDSI6m, and AF were entered as covariates.

None of the effects are significant at the 95% confidence level, but the following four two-way interactions are significant: TYPE * USE, TYPE * STATE, TYPE * YEAR, and STATE * YEAR. Figure 29 shows the TYPE * USE interaction. For municipal and agricultural uses the prices of rights tends to exceed the price of leases, whereas for environmental purposes the opposite is true. Figure 30 shows the TYPE * STATE interaction. For some states (especially Nevada, Colorado, and New Mexico) the mean price of water rights is greater than the mean price of leases, whereas for other states (especially California, Texas, and Washington) the opposite is true. Figure 31 shows the TYPE * YEAR interaction. During some of the early years the prices of leases tended to exceed the prices of rights, whereas in recent years the opposite is true. The STATE * YEAR interaction is not as easily depicted graphically because each variable has numerous levels. Most states show either little change or erratic changes from year to year, which partly reflects the small sample sizes in many cases. The exception is Colorado, where average prices have risen dramatically, driven by price rises for water rights along the Front Range, as shown in Figure 17. Two of the covariates are significant, POP2000 and PDSI6m. As shown in Table 16, price increases with POP2002 and decreases with PDSI6m (thus price increases are associated with larger county populations and drier climates).

Eta^2 gives the proportion of the total variability in the dependent variable that can be accounted for by knowing the values of the independent variable. As indicted in Table 18, the TYPE * STATE and STATE * YEAR interactions are most effective in explaining variability in market price. Population, PSDI6m, and volume in acre-feet account in sum for less than 2% of the variance in price.

The analysis of variance was also run on the restricted set of 1038 cases with a price of at least $10. Although there were minor changes in the significance of some of the main and interaction terms, there was very little change in the significant or importance of the covariates.

The analysis of variance explains nearly one-half of the variance in price. Remaining variance is likely to be explained in part by such factors as (1) the size of the market, (2) priority of the affected water right, (3) the presence and magnitude of reservoir storage, (4) transaction costs, including the cost of moving the water from the location of the seller to the location of the buyer, and (5) the quality of the water.

In addition to these considerations, it must be remembered that active water markets exist in relatively few locations, and transferring a value from one location to another is risky because water market prices reflect the particular physical and legal characteristics of the market in which they occur. These characteristics include: (1) the timing of the availability of the water (e.g., a right that allows delivery anytime during the year will be more valuable than a right restricting delivery to only a few months), (2) the security with which the water can be delivered, which is related to the average and minimum (firm) annual yield of the right, which is in turn affected by the priority of the raw water relative to other rights on the river, (3) the extent of the market (i.e., the number of buyers and sellers in the market, which reflects the size of the geographic area over which the water can be transferred), (4) the quality of the water, (5) the type of use to which the water may be put (e.g., municipal users can typically afford to pay more than farmers), and (6) costs of moving the water to the new location. Because these factors differ from one market to the next, water market prices are typically not directly comparable (thus complicating the process of benefit transfer).

Key Findings from Analysis of Market Trades

Analysis of the trades reported by Stratecon allows the following general statements (which may not represent the full population of western trades):

1. The incidence of water market trades is geographically variable. Markets are very active in a few areas of the West, but most areas have had few trades over the past 14 years. Although three states (California, Colorado, and Texas) account for three-fourths of the qualifying sales, even in these states some areas have had very few trades.
2. In a given year, at least ten times as much water changes hands via leases as changes hands via sales of water rights. The median size of leases is over 50 times that of water rights sales.
3. Using a 3% interest rate to annualize the prices of water rights and looking across the West as a whole, the median price of leases is about two-thirds that for water rights.
4. The price of water is highly variable within every state, reflecting the very localized nature of water markets.
5. Across the western states, the median price of water is highly variable, with Colorado and Nevada having the highest medians when sales of leases and rights are combined. The median price of leases is greatest in Arizona,

California, Kansas, and New Mexico. The median price of water rights is greatest in Colorado and Nevada.

6. Purchases for the purpose of mining garnered the highest median price, but the number of sales (all leases) is small. Purchases for municipal uses have the next highest median price ($77) and account for over half of all trades. Purchases for agricultural irrigation, environmental protection, and recreation have lower median prices (roughly $35).
7. Purchases for municipal purposes have tended to be of water rights, whereas purchases for irrigation, environmental, recreational, thermoelectric, or mining purposes have tended to be of leases.
8. Median prices for municipal, irrigation, and environmental purposes all varied considerably across the states. For municipal purposes the highest medians (above $85) were for California, Colorado, and Nevada and the lowest medians (below $30) were for Texas and Utah. For irrigation purposes the highest median ($72) was for Colorado and the lowest medians (near $10) are for Idaho, Oregon, Utah and Wyoming. For environmental purposes the highest median ($64) was for California and the lowest median (below $10) was for Idaho. Note that because some of the sample sizes are small, these statewide medians may have been heavily affected by characteristics of the water markets where these transactions occurred, and therefore may not give an accurate picture of the relative values across the states.
9. Farmers were the sellers in about 40% of the transactions. Public agencies, such as federal agencies managing large water storage and delivery projects, were the sellers in another 16% or so of the transactions. Municipalities were the most common buyers, accounting for about 30% of the transactions. Other common buyers were farmers, public agencies, and water districts.
10. The number of leases has grown, whereas the number of sales of water rights shows no trend. The number of purchases for environmental purposes has been increasing, whereas the number for irrigation has been decreasing.
11. Across all cases, the median price of leases in real terms showed no consistent trend over the past 14 years, whereas the median price of water rights showed an upward trend. The median price of water purchased for municipal purposes showed no trend, but the median price of water purchased for irrigation tended to decrease.
12. When the effects of type, state, year, and use are controlled for, analysis shows that higher prices are associated with locations of greater population and drier conditions, although population and climate account for very little of the variance in price. Volume of water traded apparently has no effect on unit price.

Hydroelectric Power

Electricity production at hydropower plants depends on the volume of water that is run through the turbines, the head of the water, and the efficiency of the hydroelectric plant. Tables 19 and 20, adapted from Brown et al. (1990), list the head (set at 90% of maximum), cumulative head, and cumulative kilowatt hours (kWh) of production for the Colorado River and the Green River, which empties into the Colorado, assuming an 87%

conversion from feet of head to kWhs of electricity (Gibbons, 1986). Water entering the Colorado River from the Arapaho National Forest, for example, has the potential of flowing through the seven hydroelectric plants found at the seven reservoirs listed in Table 19. If the water were not consumed in route or spilled during floods, it would produce 1866 kWhs of electricity per acre-foot, assuming the reservoirs were each at 90% of maximum head. Similarly, water from the headwaters of the Green River would have the potential of producing 1503 kWhs of electricity per acre-foot (Table 20). Water entering the river below any of the reservoirs listed in the two tables would of course produce less electricity. For example, water entering the Colorado River below Blue Mesa reservoir would bypass the initial 282 kWh per acre-foot, leaving a cumulative production of 1584 kWh per acre-foot.

The value of the water in producing this electricity depends, as mentioned above, on the cost savings. Typically in the West, coal fired plants produce base load power and natural gas and hydroelectric plants are relied upon for peaking power (although natural gas and hydroelectric plants are also called upon to produce some base load power). Recent fuel prices for coal and natural gas have been about 16 mills per kWh for coal and 32 mills per kWh for natural gas.[57] Although hydroelectric plants replace a mixture of base load and peaking power, streamflow at the margin is likely to affect only peaking power (and even if it affected base load power, the more expensive, natural gas-produced base load power would most likely be replaced first). Assuming additional variable (operation and maintenance) costs of 5 mills per kWh at thermoelectric plants and 9 mills per kWh at hydroelectric plants yields a net cost savings by producing at hydroelectric plants of 28 mills per kWh. Using this cost savings gives the water values listed in Tables 19 and 20. As seen, water entering the Colorado River above Blue Mesa Reservoir is worth $52 per acre-foot at the margin, and water from the headwaters of the Green River is worth $42 per acre-foot.

Gibbons (1986) lists the typical head at hydroelectric plants on the Snake, Columbia, and Tennessee Rivers. Water from the headwaters of the Snake River in southern Idaho passes through 16 plants on the Snake and an additional four plants on the Columbia before reaching the delta. These 20 plants supply a cumulative head of 2480 feet. Using the conversion factor and cost savings listed above, the marginal value of this water in producing hydroelectricity is $60 per acre-foot (year 2003 dollars). Similarly, the nine plants on the Tennessee River supply a total of 484 feet of head; water flowing through all nine is worth $12 per acre-foot. The Snake/Columbia and the Colorado are perhaps the nation's most highly developed rivers for electricity, and the Tennessee is also relatively highly developed, but there are thousands of other hydroelectric plants in the U.S. The marginal value of flow from the national forests in producing electricity is likely to be substantial. Indeed, the marginal value of streamflow in hydropower may account for a large percentage of its aggregate marginal value; a study of the Colorado River Basin (Brown et al., 1990) found, for example, that hydroelectric production accounted for over half of the aggregate marginal value of flows from a headwaters national forest.

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[57] These estimates and those for O&M costs are from the Energy Information Agency of the Department of Energy for year 2002. Coal prices have been quite stable over many years, but natural gas prices are volatile, making firm estimates risky.

Given a list of the hydroelectric plants and their relevant characteristics, the remaining hurdles in estimating the hydropower portion of the marginal values of water from the national forests would stem from (1) specifying which plants are downstream from each national forest and (2) estimating the proportion of the forest's flow that reaches each plant. The former of these two tasks is simple, though time-consuming. The latter task is more complex, and no less important. The proportion of a national forest's flow that reaches hydroelectric plants is related to the value of that water in offstream uses, because any water diverted to an offstream consumptive use will diminish, by the consumptive use portion, the amount of water reaching downstream hydropower plants.

Short of this plant-by-plant approach, a rough approximation of the marginal value of streamflow in hydroelectric power can be obtained for major water basins by computing the average hydroelectric kWh of production per acre-foot of flow and multiplying the result by the standard cost savings per kWh. This approach relies on the assumption that the marginal and average values of flows in hydropower are equivalent, which, as explained above, is approximate but reasonable. The approach essentially provides the hydropower value of a randomly selected acre-foot of streamflow in a basin and is only useful for large-scale assessment, where plant-specific or river-specific information is not needed. The approach under-estimates the value for streamflow from national forests to the extent that the forests are located disproportionately at the headwaters of the watersheds.

The approach was followed for the water resource regions (Figure 32), combining the Upper and Lower Colorado regions. Hydroelectricity production for 1995 (Solley et al., 1998) was divided by the average annual available water supply (Foxworthy & Moody, 1986) to get average annual kWh produced per acre-foot.[58] This ratio was multiplied by the cost savings of 28 mills per kWh to yield the cost savings for the average acre-foot by region (Table 21). These values range from less than $1 for several regions to $26 for the Colorado basin. The average values for the East (regions 1-9) and West (regions 10-18) are $2.44 and $10.05 per acre-foot, respectively.

Evidence from the Literature

Recreation

Brown (1991) lists nine studies of the value of instream flow for recreation.[59] Recreation activities studied include fishing, boating, and general shoreline activities (camping, picnicking). One of the nine studies used cross-sectional analysis across the 48 contiguous states (Hansen & Hallam, 1991), but the others focused on specific rivers and used either the contingent valuation method (CVM) or the travel cost method (TCM).

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[58] Average annual water supply was computed from information in Foxworthy and Moody (1986), based on data for 1951-1980, as: basin outflow & ground water depletion + consumptive use + reservoir evaporation + exports & imports.

[59] Other papers that have summarized studies of the value of water in recreation include Loomis (1987), Brown et al. (1991), Frederick et al. (1996), and Diaz and Brown (1997, chapter 2). Note that many studies have been completed of the value of water-based recreation (see Rosenberger & Loomis, 2000 for a list of many of them), but most of these studies do not value the contribution of water flow to recreation.

Most studies showed the total value of flow reaching a peak at a relatively low flow and then decreasing as the flow level increased, as depicted in Figure 4. On an acre-foot basis, the CVM and TCM studies found that the marginal value of flow at times of low flow varied from less than $1 to $25. That is, recreationists were apparently willing to pay from $1 to $25 for an additional acre-foot of water to augment relatively low flows during periods of recreation use. Duffield et al. (1992) estimated WTP for a range of flows at two sites. They found a marginal willingness to pay per acre-foot in the Bitterroot River of Montana ranging from $10 at times of low flows to $0 at high flows, and on Montana's Big Hole river ranging from $25 at low flows to $1 at high flows (in 1988 dollars).

In addition to being time-specific, the values, on a per-acre-foot basis, are likely to be highly site-specific (Brown, 1991; Frederick et al., 1996). Frederick et al., in their summary of water-related recreation studies in the U.S., concluded that the range of estimated recreation values per acre-foot is "very wide, both within and among [water resource] regions" (p. 19). Thus, a value that applies to a stretch of a particular river in or below one national forest may not transfer to another national forest, or even to another stretch along the same river.

Hansen and Hallam's cross-sectional analysis perhaps offers the most promising values for use in large-scale assessment because they estimated marginal values per acre-foot for the entire contiguous U.S. that can be taken to apply to the average unit of flow, thus ignoring the timing issue. Their values, which are only for fishing, are below $10 per acre foot in most regions of the country, but considerably above that in some areas, especially the drier, southwestern states. Although some of the values they reported seem excessive, most appear reasonable given what we have learned from other studies.[60]

Frederick et al.'s Summary of Studies of the Economic Value of Water

Frederick et al. (1996) summarized the values estimated or reported in 41 U.S. water value studies, from which they tallied 474 separate estimates across eight water uses. Forty-three percent of the values were for recreation, and another 36% were for irrigation, many of which were crop-specific (e.g., in a given location, the value of water in growing lettuce was listed along with its value in growing alfalfa). Twelve percent of the estimates were for hydroelectricity, 5% were for waste disposal, and about 1% each was for industrial processing, thermoelectric power, domestic use, and navigation. The values included are a mix of marginal and average values, although an average value in this case applies to a specific user such as a farm or industry, not to an entire river basin. As the authors indicate, it is sometimes difficult to tell which value, marginal or average, a study is reporting. Frederick et al.'s results have been updated to 2003 dollars per acre-foot herein.

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[60] Hansen and Hallam (1991) present values for each of the 99 aggregated subarea basins in the U. S. (U.S. Water Resources Council, 1978) based on (1) characterizing fishing quality as a function of (a) the ratio of actual flow to virgin flow and (b) surface area of streams, (2) an estimate of days fished from a national survey, and (3) estimates of WTP for fishing recreation from an unpublished study. Median marginal values per acre-foot across the aggregated sub-areas within each water resource region, in 1980 dollars, were below $5 in regions 1–9, from $5–$10 in regions 10–12 and 16, and above $10 in regions 13–15 and 18.

Three cautions are in order. First, any summary of these values is dependent on the uses for which, and the locations where, studies happen to have been performed. Site-specific studies are more likely to have been performed where the value is substantial than where it is trivial. For example, studies of hydroelectric power value were not presented for basins with little hydropower capacity. Second, any average of these values will be highly dependent on the extremes of the distributions. Thus, the authors advise that the medians, rather than the means, of the estimates "may provide a better indication of the relative values of water in various uses under relatively normal hydrologic conditions" (p. 9). Third, the offstream values are for water that is delivered and put to use, not for raw water in the stream that could be delivered and put to use.

Table 22 summarizes the values by water use category for the U.S. as a whole, listing the medians and the number of values and studies that each median represents. Note that all waste disposal values come from just one study (Gray & Young, 1974) and all navigation values come from one study and are average values (Gibbons, 1986). Three-fourths of the recreation/habitat values come from a single study (Hansen & Hallam, 1991) and most of the rest are from one other study (Cooper & Loomis, 1993). Seventy-five percent of the recreation/habitat values are for fishing.

Table 23 shows offstream and instream recreation medians for the East and West.[61] The East was composed of the 9 eastern-most water resource regions (numbers 1-9) and West by the remaining water resource regions in the conterminous U.S. (numbers 10-18). By far the least reliable of these four estimates is that for offstream use in the East, which is based on only 17 estimates taken from only two studies (15 of the estimates are for irrigation and two are for domestic use). Because 88% of the eastern offstream values and 97% of the western offstream values are for irrigation, these medians are essentially irrigation values. The values for the West exceed those for the East, which is in agreement with the general trend suggested by the ranks of ratios in Table B3.

Also shown in Table 23 are hydropower values for the four water resource regions that the Frederick et al. summary covers. These values are roughly similar to those reported in the previous section.

The estimates presented in Table 23 may provide a reasonable summary of water value study results. Because the values include estimates of average value along with estimates of marginal value, the medians in the two tables may tend to over-estimate the marginal value. But the computation of medians, rather than means, should ameliorate this problem.

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[61] Frederick et al. (1996) also report medians at the water resource region level. These medians combine estimates across all water uses that happen to be represented by estimates within the region. The nine median values for the East range from $1 (for the Upper and Lower Mississippi regions) to $9 (for the Tennessee region), with seven of the nine at or below $5. And the nine median values for the West range from $4 (for the Arkansas region) to $65 (for the Texas-Gulf region), with five of the medians above $20. Some of the Western medians are surprising. For example, the very dry Great Basin region received a median of only $5, and the water-hungry and hydroelectric power-rich California region received a median of only $10, but the Texas Gulf region received a median of $65. These anomalies probably result from variations among regions in the mix of uses represented by the respective medians, and suggest that the medians cannot be trusted for such small geographic breakdowns.

The Marginal Value of Water from National Forests

As characterized in equation 1, the marginal value of water originating on an area of national forest depends on a substantial set of variables describing for each potential water user or river reach the likelihood that the marginal quantity of streamflow could physically arrive at the reach river reach, hydroelectric plant, or offstream user's diversion point (α), which depends on whether some of the water was consumptively used upstream; the likelihood that the water can be delivered to the user or will arrive in the river reach *when* it is needed (β), which depends partly on upstream storage capacity; and the economic value of the water if it is indeed put to use (V). Accurately computing such a value for an area of national forest would require a flow routing model to simulate (given the applicable laws and operating rules) the flow, storage, and delivery of water. The model would be applied over a sufficient number of years of actual or simulated flows to estimate reliable average annual values. Also, a substantial effort would be needed to estimate water values for the uses and locations at issue. For an example of such a study, see Brown et al. (1990).

Clearly, such involved studies will not be performed for every location where estimates of the marginal value of streamflow might be desired. As a fallback position, rough estimates of the marginal value of streamflow are computed here for each of the 18 water resource regions (WRRs) in the contiguous 48 states (Figure 32).[62] These estimates are best characterized as educated guesses of large-scale averages. They rely on data where available and assumptions where necessary, and use the conceptual model of equation 1, which was simplified in light of available data as follows:

$$\begin{aligned} V^* = &\left(\sum_k \alpha_k^o\right)\left(\beta^o V^o\right) + \left(\alpha^h \beta^h\right)\left(\sum_i V_i^h\right) + \\ &+ \left(\sum_j \alpha_j^s\right)\left(\beta^r V^r + \beta^w V^w + \beta^e V^e + \beta^f V^f + \beta^n V^n\right) + N \end{aligned} \qquad (3)$$

Thus, we are holding β_k^o and V_k^o constant for all k offstream users within a WRR, α_i^h and β_i^h constant for all i hydroelectric plants within a WRR, and the respective β_js and V_js of the different instream uses constant for all j river reaches within a WRR.

Specification of the parameters of equation 3 uses the following two new variables, which were computed for each WRR using information from Foxworthy and Moody (1986) and Solley et al. (1998):

η	is the ratio of mean annual offstream withdrawal to mean annual available water supply.
λ	is the ratio of total storage capacity to mean annual available water supply.

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[62] There are 18 water resource regions (WRR) of the contiguous 48 states. A WRR is a major watershed, such as the Missouri River basin, or large area of contiguous coastal watersheds, such as the California region (U.S. Water Resources Council, 1978).

For both variables, mean annual available water supply takes into account trans-basin (i.e., trans-WRR) imports and exports. Further, for the Lower Mississippi and Lower Colorado basins, available water supply includes flow from upstream basins.[63]

The parameters of equation 3 were then set as follows:

$\Sigma\alpha_k^o$ assumes two offstream users along the river ($k = 1, 2$). The first offstream user is assumed to have access to the entire marginal acre-foot (i.e., $\alpha_1^o = 1$). The amount of the marginal acre-foot available to the second offstream user is reduced by upstream consumptive use, which is assumed here to be proportional to η. To wit, the chance of upstream withdrawal of the marginal acre-foot is specified as $\eta/3$. Dividing by 3 reflects the fact that the likelihood of withdrawal is considerably less at the margin than on average (Brown et al., 1990). Further, we assume a 60% return flow. Thus $\alpha_1^o = 1 - 0.4(\eta/3)$.

α^h is the proportion of marginal flow that reaches the average hydroelectric plant on the river. It is assumed to vary inversely and linearly with η, from x in the basin with the largest η (i.e., with the greatest likelihood of diversion upstream to offstream users) to 1.0 for the basin with the lowest η. The value of x was set at 0.75 to reflect the fact that most hydropower facilities are located upstream of most diversions to offstream users.

$\Sigma\alpha_j^s$ assumes one river reach where instream recreation uses are pertinent ($j = 1$). This reach is assumed to be upstream of the offstream diversion, such that $\alpha_1^s = 1$.

β^o is the proportion of what reaches an offstream user that actually will be used. It is assumed to be equal to $\eta/3$; thus it is larger the greater is the amount of flow that typically is withdrawn. Dividing by 3, as above, reflects the fact that the likelihood of withdrawal is much lower at the margin than it is on average.

β^h is the proportion of what reaches the average hydroelectric plant that will be run through the turbines. It is set constant across WRRs at 0.8 based on the assumption that 20% of the flow will spill (mostly in high runoff years) or arrive when the plant is not operating.

β^r is the proportion of what reaches the average instream reach that contributes to improved recreation quality or quantity of use. It is assumed to increase with storage capacity because ability to store runoff increases the likelihood of delivering water when it is most needed. Specifically, β^r increases from a minimum of 0.25 for WRRs with no storage capacity to a maximum of 0.75 for the WRR with the most storage capacity, varying between the minimum and maximum in proportion to λ (i.e., β^r is a linear scaling of λ that ranges from 0.25 for lowest λ to 0.75 for highest λ). Restricting the maximum to 0.75 reflects the fact that some of the marginal flow will arrive in the winter

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[63] Supply for region 8 includes outflow from regions 5, 6, 7, 10, and 11. Supply for region 15 includes outflow from region 14. Storage capacities for regions 8 and 15 are for those individual basins, not the sums for all contributing basins.

	when recreation is minimal or during high flow times when additional flow is not helpful.
β^e	is set equal to β^r, reflecting the judgment that at the margin environmental benefits are greatest when timed to satisfy flow shortages.
β^w	is set equal to β^r, reflecting the judgment that flow timing is important for dilution.
V^o	is the value of offstream diversion. It is set for western WRRs except WRR 17 at the median market price value for offstream uses, as indicated by the qualifying water market trades summarized earlier, and for eastern WRRs and WRR 17 at the value determined by Frederick et al. (1996) for the East based on a literature review (Table 23). The median market price of offstream uses in WRR 17, of $8 per acre-foot, was considered to be an unrepresentative artifact of the sales that happened to be reported by Stratecom.
ΣV_j^h	is the cost savings at hydroelectric power plants in the WRR listed in Table 21.
V^r	is taken from the literature review by Frederick et al. (1996) summarized in Table 23.
V^w	is taken from the literature review by Frederick et al. (1996) summarized in Table 22.
V^e	is set for Western WRRs except WRR 12 at the median water market price value for environmental purposes, and for the remaining WRRs at the arbitrary value of $10.
V^f	is assumed to be $0.
V^n	is assumed to be $0.
N	is assumed to be $0.

β^f and β^r are not needed because V^f and V^n = \$0.

Table 24 contains the estimates of α and β for the respective water uses, and Table 25 contains the Vs for the respective uses.

Table 26 lists the results of the approach for offstream uses, hydroelectric power production, and the set of instream uses, in terms of year 2003 dollars per acre-foot per year. These three values sum to V^*, the total marginal value of streamflow. Offstream marginal values range from less than \$1 in several WRRs to \$36 in the Great Basin WRR. Hydroelectric marginal values range from less than \$1 in several WRRs to about \$17 in the Colorado River basins. Instream marginal values range from about \$5in several basins to \$42 in the Lower Colorado Basin. Totals range from \$5 to \$84. The portion contributed by offstream uses ranges from 4% in the Souris-Red-Rainy basin to 67% in the Great Basin.

It bears repeating that these values are large-scale averages based on numerous assumptions and sketchy valuation data.

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Tables

Table 1. Number of Western water market cases by state, 1990-2003

	All cases	Qualifying cases	
	N	N	Acre-feet (1000s)
Arizona	124	86	7910
California	423	294	8104
Colorado	475	427	443
Idaho	83	64	2802
Kansas	17	16	11
Montana	11	5	15
Nebraska	7	0	0
New Mexico	75	59	525
Nevada	90	69	1299
North Dakota	1	0	0
Oklahoma	5	3	81
Oregon	57	43	261
Texas	232	207	1376
Utah	49	43	122
Washington	35	25	563
Wyoming	42	36	219
All	1726	1377	23731

Table 2. Western water market prices by state, 1990-2003 (both leases and rights, year 2003 dollars per acre-foot per year*)

	Mean ($)	Median ($)	N	Min ($)#	Max ($)
Arizona	51	48	86	0	115
California	96	66	294	0	1000
Colorado	133	81	427	1	630
Idaho	15	6	64	0	251
Kansas	40	48	16	13	54
Montana	20	6	5	2	56
New Mexico	77	55	59	1	607
Nevada	125	106	69	6	375
Oklahoma	246	118	3	46	575
Oregon	31	9	43	1	302
Texas	104	28	207	7	2258
Utah	34	16	43	5	165
Washington	70	32	25	3	343
Wyoming	37	40	36	3	93
All	96	56	1377	0	2258

* Water rights prices were annualized using a 3% interest rate.

\# Cases with a $0 price were not included. $0 indicates rounding of a very low price.

Table 3. Western water market prices by type of transaction, 1990-2003 (year 2003 dollars per acre-foot per year)

	Mean ($)	Median ($)	N	Min ($)#	Max ($)
Lease	85	47	715	0	2258
Right*	108	72	662	1	630
All	96	56	1377	0	2258

* Annualized using a 3% interest rate.

\# Cases with a $0 price were not included. $0 indicates rounding of a very low price.

Table 4. Western water market prices by state and type of transaction, 1990-2003 (year 2003 dollars per acre-foot per year)

	Leases		Rights*	
	Median ($)	N	Median ($)	N
Arizona	58	48	40	38
California	68	250	37	44
Colorado	18	58	84	369
Idaho	8	49	3	15
Kansas	50	11	16	5
Montana	6	5		0
New Mexico	55	29	76	30
Nevada	83	4	109	65
Oklahoma	347	2	46	1
Oregon	9	34	7	9
Texas	29	159	24	48
Utah	7	11	17	32
Washington	37	21	13	4
Wyoming	40	34	43	2
All	47	715	72	662

* Annualized using a 3% interest rate.

Table 5. Western water market prices by purpose of buyer, 1990-2003 (both leases and rights, year 2003 dollars per acre-foot per year)

Purpose	Mean ($)	Median ($)	N	Min ($)#	Max ($)
Municipal	118	77	739	0	1607
Irrigation	46	28	321	1	490
Environment	56	40	150	0	450
Thermoelectric	167	26	9	0	1000
Recreation	44	33	8	5	155
Mining	409	171	28	34	2258
Recharge	47	56	5	27	61
Other	98	55	55	2	607
Several	51	56	62	2	190
All	96	56	1377	0	2258

* Water rights prices were annualized using a 3% interest rate.

Cases with a $0 price were not included. $0 indicates rounding of a very low price.

Table 6. Western water market prices by purpose of buyer and type of transaction, 1990-2003 (year 2003 dollars per acre-foot per year)

Purpose	Leases		Rights*	
	Median ($)	N	Median ($)	N
Municipal	69	286	78	453
Irrigation	15	198	71	123
Environment	47	113	26	37
Thermoelectric	19	8	44	1
Recreation	23	6	106	2
Mining	171	28		0
Recharge	38	3	56	2
Other	56	24	44	31
Several	55	49	62	13
All	47	715	72	662

* Water rights prices were annualized using a 3% interest rate.

Table 7. Western water market prices by state and purpose of buyer, 1990-2003 (both leases and rights, year 2003 dollars per acre-foot per year)

	Municipal		Irrigation		Environmental	
	Median ($)	N	Median ($)	N	Median ($)	N
Arizona	48	47	45	12	45	5
California	96	149	45	66	64	51
Colorado	88	250	72	110	20	19
Idaho	6	5	4	31	8	19
Kansas	48	14	51	2		0
Montana		0	6	1	2	3
New Mexico	77	26	50	4	47	10
Nevada	110	59		0	43	7
Oklahoma	118	3		0		0
Oregon		0	8	20	26	19
Texas	26	141	24	40		0
Utah	20	28	7	13	40	2
Washington	40	3	17	5	32	15
Wyoming	77	14	5	17		0
All	77	739	28	321	40	150

* Water rights prices were annualized using a 3% interest rate.

Table 8. Western water market prices by type of buyer and seller, 1990-2003 (both leases and rights, year 2003 dollars per acre-foot per year)*

Type	Seller		Buyer	
	Median ($)	N	Median ($)	N
Municipality	48	69	66	375
Farmer	71	531	23	204
Environmental entity	61	3	18	14
Water district	41	135	66	183
Public agency	40	224	49	234
Power company	101	5	50	11
Mining company	601	2	171	28
Developer	114	27	114	29
Other	67	159	54	93
Several	61	222	71	206
All	56	1377	56	1377

* Water rights prices were annualized using a 3% interest rate.

Table 9. Number of western water market trades from seller to buyer, 1990-2003 (both leases and rights)

Seller	Buyer										Total
	Mun	Farm	Env	Dist	Pub	Pow	Min	Dev	Other	Several	
Municipality	26	8	0	7	18	0	0	0	6	4	69
Farmer	175	96	10	60	95	4	6	9	21	55	531
Environmental	1	0	1	0	1	0	0	0	0	0	3
Water district	21	19	1	38	32	1	0	1	6	16	135
Public agency	39	48	1	32	46	2	3	0	13	40	224
Power plant	3	0	0	0	1	0	0	1	0	0	5
Mining	1	0	0	0	0	0	1	0	0	0	2
Developer	18	0	0	2	6	0	0	0	1	0	27
Other	38	12	1	24	15	1	1	18	45	4	159
Several	53	21	0	20	20	3	17	0	1	87	222
Total	375	204	14	183	234	11	28	29	93	206	1377

Table 10. Number of western water rights trades from seller to buyer, 1990-2003

Seller	Buyer										Total
	Mun	Farm	Env	Dist	Pub	Pow	Min	Dev	Other	Several	
Municipality	5	1	0	1	1	0	0	0	3	0	11
Farmer	139	75	8	33	28	0	0	9	19	52	363
Environmental	1	0	1	0	0	0	0	0	0	0	2
Water district	12	3	1	4	16	1	0	1	1	3	42
Public agency	5	0	0	1	2	0	0	0	0	1	9
Power plant	2	0	0	0	1	0	0	1	0	0	4
Mining	0	0	0	0	0	0	0	0	0	0	0
Developer	18	0	0	2	6	0	0	0	1	0	27
Other	36	10	1	20	11	0	0	18	34	3	133
Several	28	1	0	11	2	0	0	0	1	28	71
Total	246	90	11	72	67	1	0	29	59	87	662

Table 11. Number of western water market trades by purpose of buyer, 1990-2003 (includes both leases and rights)

Buyer	Purpose								
	Munic.	Irrig.	Envir.	Elect.	Recre.	Mining	Recha.	Other	Several
Municipality	360	5	5	0	2	0	0	0	3
Farmer	1	197	0	0	0	0	1	2	3
Environmental	0	0	14	0	0	0	0	0	0
District	119	56	0	1	0	0	1	2	4
Public agency	45	17	125	0	5	0	1	25	16
Power plant	3	0	1	7	0	0	0	0	0
Mining	0	0	0	0	0	27	0	0	1
Developer	27	1	0	0	0	0	0	1	0
Other	44	18	3	0	1	0	1	25	1
Several	140	27	2	1	0	1	1	0	34

Table 12. Volume of water purchased via leases by purpose of buyer, 1990-2003 (acre-feet per year)

Buyer	Purpose									Total
	Munic.	Irrig.	Envir.	Elect.	Recre.	Mining	Recha.	Other	Several	
Municipality	125176	308	0	0	471	0	0	0	65	126020
Farmer	0	220658	0	0	0	0	231	23	16916	237828
Environmental	0	0	1054	0	0	0	0	0	0	1054
District	127366	73565	0	462	0	0	2308	231	1553	205485
Public agency	41684	14217	281527	0	2252	0	0	18240	124054	481974
Power plant	1086	0	1231	39997	0	0	0	0	0	42314
Mining	0	0	0	0	0	3110	0	0	132	3241
Developer	0	0	0	0	0	0	0	0	0	0
Other	3024	18803	11462	0	31	0	6891	7242	10	47461
Several	103959	45617	3110	2643	0	0	0	0	435180	590508
Total	402295	373167	298383	43102	2754	3110	9429	25735	577909	1735886

Table 13. Volume of water purchased via water rights by purpose of buyer, 1990-2003 (acre-feet per year)

Buyer	Purpose									Total
	Munic.	Irrig.	Envir.	Elect.	Recre.	Mining	Recha.	Other	Several	
Municipality	22563	48	73	0	0	0	0	0	385	23069
Farmer	13	2665	0	0	0	0	0	12	0	2690
Environmental	0	0	800	0	0	0	0	0	0	800
District	9747	523	0	0	0	0	0	0	0	10270
Public agency	19081	2760	13689	0	142	0	1202	1539	361	38775
Power plant	0	0	0	498	0	0	0	0	0	498
Mining	0	0	0	0	0	0	0	0	0	0
Developer	631	5	0	0	0	0	0	0	0	637
Other	2625	197	35	0	0	0	0	113	0	2971
Several	3851	492	0	0	0	0	1	0	5540	9884
Total	58511	6690	14598	498	142	0	1203	1665	6287	89595

Table 14. Western water market prices by state for water purchased for environmental purposes, 1990-2003 (both leases and rights, year 2003 dollars per acre-foot per year)

	Mean ($)	Median ($)	N	Min ($)	Max ($)
Arizona	45	45	5	42	47
California	70	64	51	1	312
Colorado	48	20	19	2	450
Idaho	34	8	19	0	251
Montana	20	2	3	2	56
New Mexico	55	47	10	7	102
Nevada	55	43	7	19	114
Oregon	55	26	19	2	302
Utah	40	40	2	33	46
Washington	61	32	15	3	260
All	56	40	150	0	450

* Water rights prices were annualized using a 3% interest rate.

Table 15. Number of trades represented in Figures 22 and 23

	Figure 22 (leases)					Figure 23 (rights)				
Year	San Juan-Chama	North Platte	CAP	Rio Grande	Upper Snake	CBT	North Poudre	Windsor Reser.	Twin Lakes	Truckee River
1990	0	0	3	1	1	14	3	0	3	6
1991	2	0	2	9	4	17	0	1	2	2
1992	0	0	1	3	2	19	3	0	2	3
1993	2	0	1	4	1	16	1	2	1	0
1994	2	2	3	13	1	15	2	3	0	0
1995	0	2	4	6	4	19	1	0	1	1
1996	0	0	5	8	2	14	3	1	2	1
1997	0	3	0	11	2	17	0	0	1	1
1998	0	2	3	13	0	16	1	0	1	2
1999	1	2	4	11	0	13	0	0	1	16
2000	1	4	5	11	3	13	0	0	0	7
2001	1	2	1	14	0	13	2	1	0	7
2002	2	2	4	12	8	14	0	3	0	6
2003	3	2	0	10	2	13	1	0	0	9
Total	14	21	36	126	30	213	17	11	14	61

Table 16. Western water market prices by state, 1990-2003, restricted to sales with a price of at least $10 (both leases and rights, year 2003 dollars per acre-foot per year*)

	Mean ($)	Median ($)	N	Min ($)	Max ($)
Arizona	56	51	79	13	115
California	102	68	274	10	1000
Colorado	142	83	399	10	630
Idaho	58	19	12	11	251
Kansas	40	48	16	13	54
Montana	45	45	2	34	56
New Mexico	84	56	54	10	607
Nevada	127	107	68	11	375
Oklahoma	246	118	3	46	575
Oregon	65	37	18	11	302
Texas	107	28	201	10	2258
Utah	46	25	30	11	165
Washington	73	33	24	11	343
Wyoming	66	77	19	40	93
All	110	68	1199	10	2258

* Water rights prices were annualized using a 3% interest rate.

Table 17. Regression

Variable	B	St Error	Beta	t	Sig.
(Constant)	-11074.0	1684.0		-6.576	0.000
YEAR	5.6	.8	0.189	6.605	0.000
TYPEd	33.2	7.5	0.136	4.413	0.000
SOURCEd	-26.9	11.5	-0.068	-2.330	0.020
USEdm	57.7	11.1	0.231	5.188	0.000
USEdi	-0.3	11.7	-0.001	-0.026	0.980
POP2000	0.0	.0	0.078	2.632	0.009
PDSI6m	-1.7	1.3	-0.038	-1.326	0.185
AF	-0.0	.0	-0.012	-0.436	0.663

Adjusted $R^2 = 0.12$, total df = 1184, F = 21.38, Sign. < .001

Table 18. Analysis of variance

Source	Sum of squares	df	Mean square	F	Sig.	Partial Eta Squared
Corrected Model	9401093	231	40697	4.733	0.000	0.534
Intercept	23304	1	23304	2.710	0.100	0.003
TYPE	31890	1	31890	3.708	0.054	0.004
USE	22890	2	11445	1.331	0.265	0.003
STATE	148290	10	14829	1.724	0.071	0.018
YEAR	53599	13	4123	.479	0.937	0.006
SOURCE	463	1	463	.054	0.817	0.000
TYPE * USE	55377	2	27688	3.220	0.040	0.007
TYPE * STATE	1029719	9	114413	13.305	0.000	0.112
TYPE * YEAR	216420	13	16648	1.936	0.023	0.026
TYPE * SOURCE	10182	1	10182	1.184	0.277	0.001
USE * STATE	10976	16	6862	.798	0.689	0.013
USE * YEAR	292203	26	11239	1.307	0.140	0.034
USE * SOURCE	6983	2	3492	.406	0.666	0.001
STATE * YEAR	1800001	112	16071	1.869	0.000	0.180
STATE * SOURCE	108802	7	15543	1.808	0.082	0.013
YEAR * SOURCE	69496	12	5791	.673	0.778	0.008
POP2000	41876	1	41876	4.870	0.028	0.005
PDSI	94358	1	94358	10.973	0.001	0.011
AF	2782	1	2782	.324	0.570	0.000
Error	8195035	953	8599			
Total	27626853	1185				
Corrected Total	17596128	1184				

Adjusted R^2 = 0.42

Table 19. Marginal value of water for electricity generation on the Colorado River (year 2003 dollars)

Reservoir	Head (feet)	Cumulative head (feet)	Cumulative kWh per acre-foot	Cumulative water value ($/a-f)
Blue Mesa	324	324	282	8
Morrow Point	387	711	619	17
Crystal	202	913	794	22
Powell	511	1424	1239	35
Mead	527	1950	1697	48
Mojave	122	2073	1803	50
Havasu	72	2145	1866	52

Table 20. Marginal value of water for electricity generation on the Green and Colorado Rivers (year 2003 dollars)

Reservoir	Head (feet)	Cumulative head (feet)	Cumulative kWh per acre-foot	Cumulative water value ($/a-f)
Fontenelle	99	99	86	2
Flaming Gorge	396	495	431	12
Powell	511	1006	875	25
Mead	527	1533	1333	37
Mojave	122	1655	1440	40
Havasu	72	1727	1503	42

Table 21. Average annual hydropower water values (year 2003 dollars)

Water resource region	Supply (maf)	KWh (millions)	KWh /a-f	Cost savings ($/a-f)
1. New England	87	6720	78	2.17
2. Mid-Atlantic	109	5260	48	1.35
3. South-Atlantic-Gulf	238	17100	72	2.01
4. Great Lakes	88	24200	276	7.73
5. Ohio	157	5250	33	0.94
6. Tennessee	49	16000	330	9.23
7. Upper Mississippi	87	2990	34	0.96
8. Lower Mississippi	85	1320	16	0.44
9. Souris-Red-Rainy	9	100	12	0.32
10. Missouri	75	16000	213	5.97
11. Arkansas-White-Red	71	6740	95	2.65
12. Texas-Gulf	40	1050	26	0.73
13. Rio Grande	5	464	84	2.37
14+15. Colorado Basin	18	16960	940	26.31
16. Great Basin	9	633	68	1.90
17. Pacific Northwest	326	140000	430	12.03
18. California	93	47000	507	14.20

Table 22. National water values by use category from Frederick et al. (1996) (year 2003 dollars per acre-foot per year)

Water use	Median value ($/a-f)	Number of estimates	Number of studies
Instream			
Waste disposal	1	23	1
Recreation/habitat	6	211	11
Navigation	12	7	1
Hydropower	26	57	5
Offstream			
Irrigation	50	177	19
Industrial processing	164	7	4
Thermoelectric power	36	6	3
Domestic	120	6	3

Table 23. Water values for East and West from Frederick et al. (1996) (year 2003 dollars per acre-foot per year)

Water use	Median value ($/a-f)	Number of estimates
Offstream		
East	24	17
West	52	167
Instream—recreation		
East	5	89
West	10	203
Instream—hydropower		
WRR6	12	1
WRR14	29	3
WRR15	34	1
WRR17	44	2

Table 24. Values for parameters α and β by WRR

Water resource region	η	γ	$\Sigma\alpha_k^o$	α^h	$\Sigma\alpha_j^s$	β^o	β^h	β^r	β^w	β^e
1. New England	0.04	0.15	1.99	0.99	1.0	0.01	0.8	0.27	1.0	0.27
2. Mid-Atlantic	0.20	0.10	1.97	0.95	1.0	0.07	0.8	0.26	1.0	0.26
3. South-Atlantic-Gulf	0.12	0.16	1.98	0.97	1.0	0.04	0.8	0.27	1.0	0.27
4. Great Lakes	0.40	0.08	1.95	0.90	1.0	0.13	0.8	0.26	1.0	0.26
5. Ohio	0.20	0.12	1.97	0.95	1.0	0.07	0.8	0.26	1.0	0.26
6. Tennessee	0.20	0.23	1.97	0.95	1.0	0.07	0.8	0.28	1.0	0.28
7. Upper Mississippi	0.26	0.14	1.97	0.94	1.0	0.09	0.8	0.27	1.0	0.27
8. Lower Mississippi	0.02	0.01	2.00	1.00	1.0	0.01	0.8	0.25	1.0	0.25
9. Souris-Red-Rainy	0.02	0.93	2.00	1.00	1.0	0.01	0.8	0.36	1.0	0.36
10. Missouri	0.40	1.12	1.95	0.90	1.0	0.13	0.8	0.39	1.0	0.39
11. Arkansas-White-Red	0.13	0.45	1.98	0.97	1.0	0.04	0.8	0.30	1.0	0.30
12. Texas-Gulf	0.33	0.61	1.96	0.92	1.0	0.11	0.8	0.32	1.0	0.32
13. Rio Grande	0.95	1.86	1.87	0.75	1.0	0.32	0.8	0.48	1.0	0.48
14. Upper Colorado	0.59	2.73	1.92	0.85	1.0	0.20	0.8	0.59	1.0	0.59
15. Lower Colorado	0.88	4.05	1.88	0.77	1.0	0.29	0.8	0.75	1.0	0.75
16. Great Basin	0.53	0.35	1.93	0.86	1.0	0.18	0.8	0.29	1.0	0.29
17. Pacific Northwest	0.09	0.19	1.99	0.98	1.0	0.03	0.8	0.27	1.0	0.27
18. California	0.25	0.40	1.97	0.94	1.0	0.08	0.8	0.30	1.0	0.30

Table 25. Values for water uses by WRR (year 2003 dollars per acre-foot per year)

Water resource region	V^o	ΣV_i^h	V^r	V^w	V^e	V^n	V^f	N
1. New England	24	2.17	5	1	10	0	0	0
2. Mid-Atlantic	24	1.35	5	1	10	0	0	0
3. South-Atlantic-Gulf	24	2.01	5	1	10	0	0	0
4. Great Lakes	24	7.73	5	1	10	0	0	0
5. Ohio	24	0.94	5	1	10	0	0	0
6. Tennessee	24	9.23	5	1	10	0	0	0
7. Upper Mississippi	24	0.96	5	1	10	0	0	0
8. Lower Mississippi	24	0.44	5	1	10	0	0	0
9. Souris-Red-Rainy	24	0.32	5	1	10	0	0	0
10. Missouri	81	5.97	10	1	31	0	0	0
11. Arkansas-White-Red	46	2.65	10	1	12	0	0	0
12. Texas-Gulf	62	0.73	10	1	10	0	0	0
13. Rio Grande	28	2.37	10	1	47	0	0	0
14. Upper Colorado	35	26.31	10	1	33	0	0	0
15. Lower Colorado	46	26.31	10	1	45	0	0	0
16. Great Basin	105	1.90	10	1	43	0	0	0
17. Pacific Northwest	24	12.03	10	1	21	0	0	0
18. California	66	14.20	10	1	64	0	0	0

Table 26. Marginal value of instream flow by WRR (year 2003 dollars per acre-foot per year)

Water resource region	Offstream	Hydro-electric	Instream	*V**
1. New England	0.62	1.73	5.01	7
2. Mid-Atlantic	3.09	1.03	4.91	9
3. South-Atlantic-Gulf	1.87	1.56	5.03	8
4. Great Lakes	6.30	5.54	4.88	17
5. Ohio	3.17	0.71	4.96	9
6. Tennessee	3.18	7.02	5.16	15
7. Upper Mississippi	4.08	0.72	4.98	10
8. Lower Mississippi	0.40	0.35	4.75	5
9. Souris-Red-Rainy	0.29	0.26	6.45	7
10. Missouri	20.99	4.29	16.82	42
11. Arkansas-White-Red	4.08	2.05	7.70	14
12. Texas-Gulf	13.25	0.54	7.49	21
13. Rio Grande	16.54	1.42	28.26	46
14. Upper Colorado	13.32	17.79	26.32	57
15. Lower Colorado	25.56	16.19	42.46	84
16. Great Basin	36.08	1.31	16.52	54
17. Pacific Northwest	1.45	9.44	9.34	20
18. California	10.95	10.64	23.07	45

Figures

Figure 1. A demand increase with supply constraint

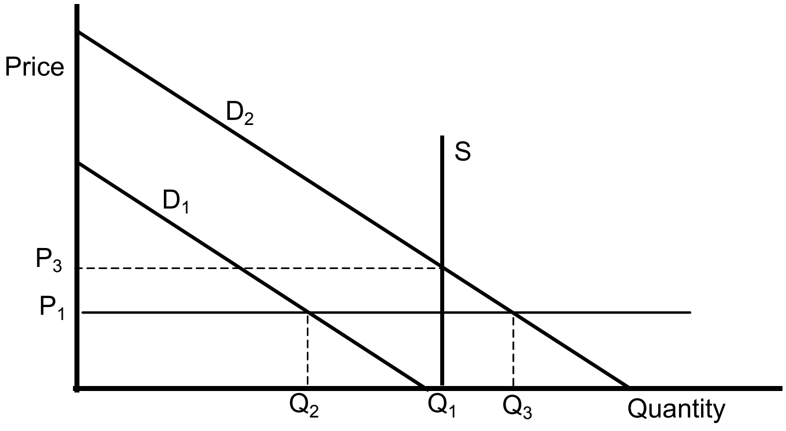


Figure 2. Supply of water varying by year

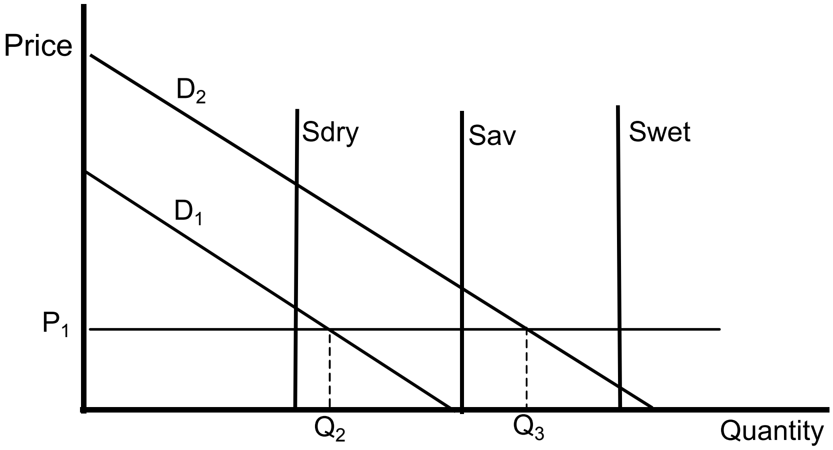


Figure 3. Demand for water at a hydroelectric plant with capacity constraint

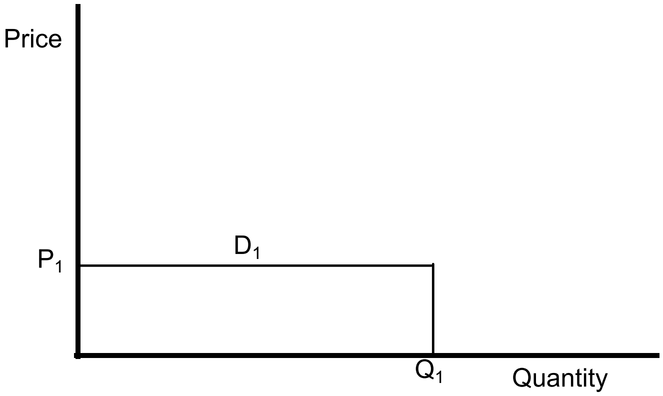


Figure 4. Estimated demand for irrigation water in a multi-crop farming area of central Arizona, from Kelso et al. (1973)

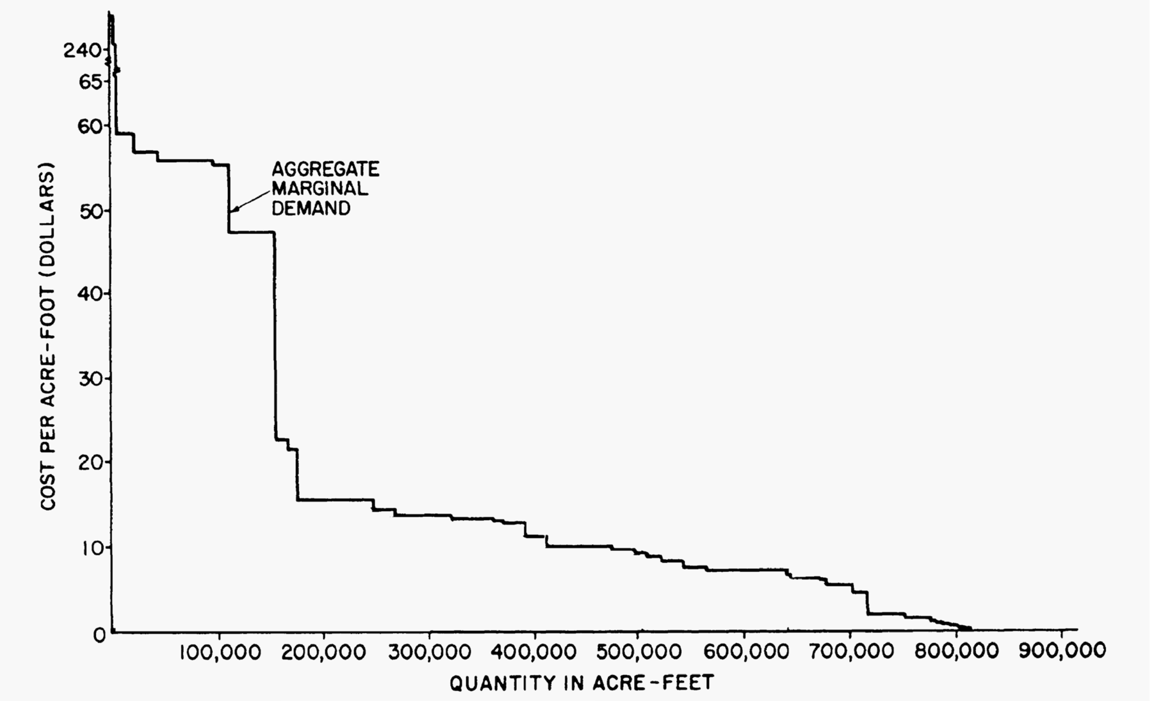


Figure 5. Recreation demand for instream flow

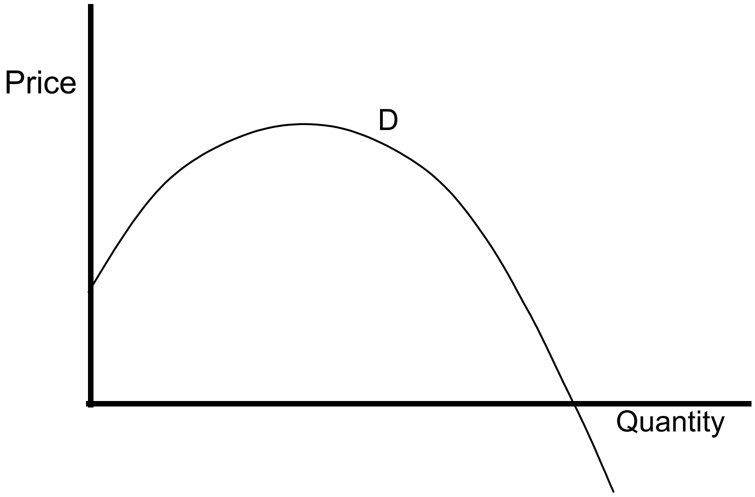


Figure 6. Effect of a change in municipal water demand

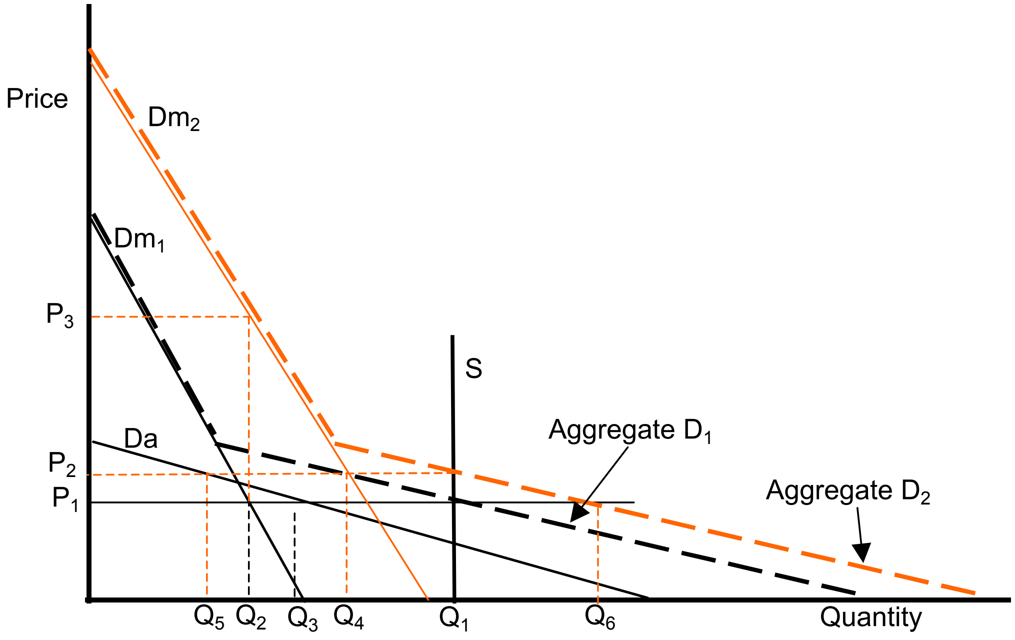


Figure 7. Number of cases meeting criteria for analysis of market prices, 1990-2003, by climatic division (divisions are numbered independently within each state)

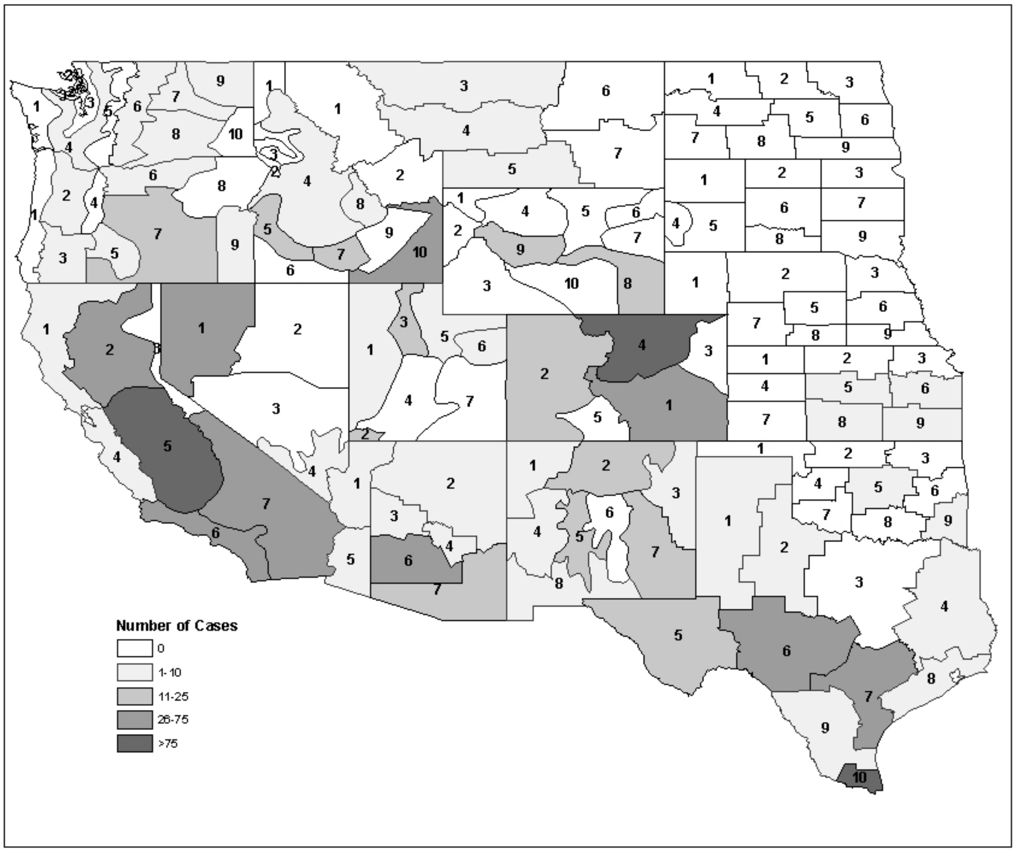


Figure 8. Trends in total number of acre-feet transferred

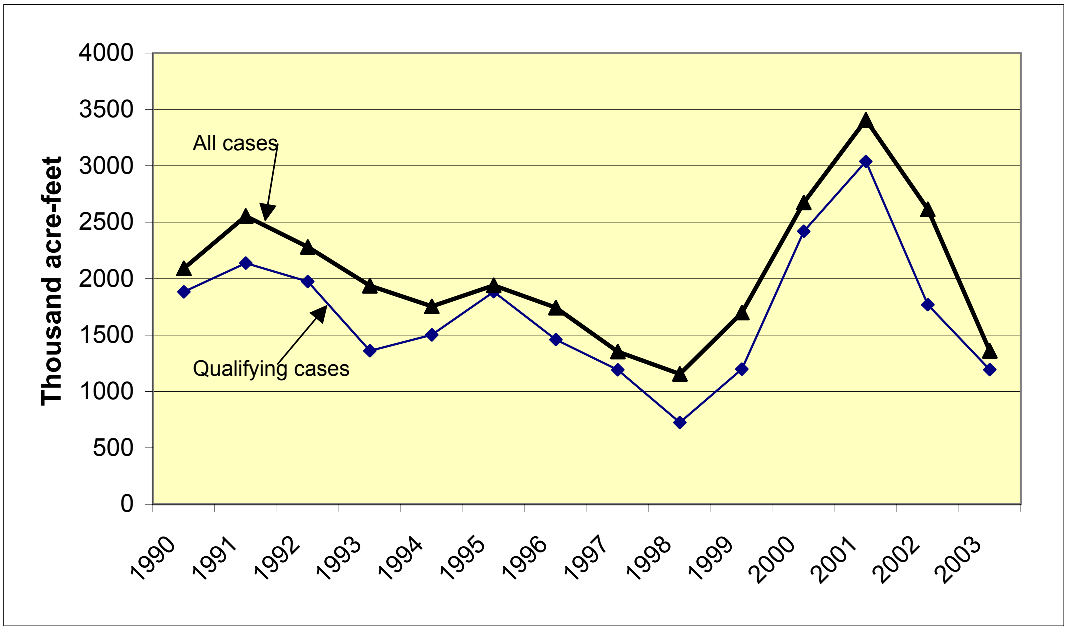


Figure 9. Trends in total quantity of water transferred (qualifying cases only)

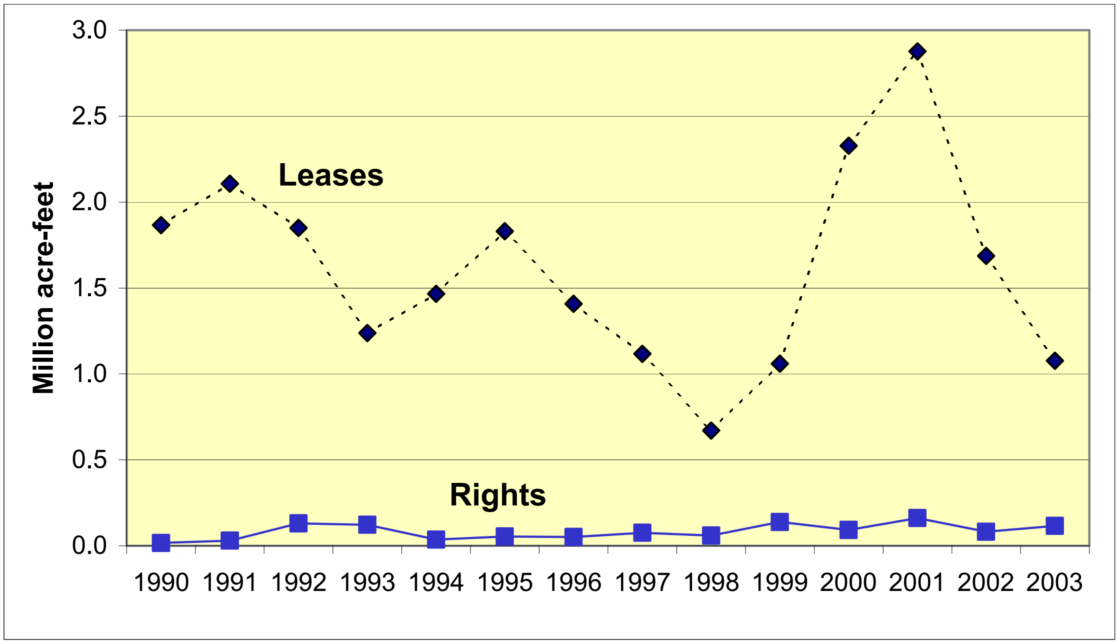


Figure 10. Distribution of prices paid for water, all water uses, 1990-2003 (including both leases and rights, year 2003 dollars)

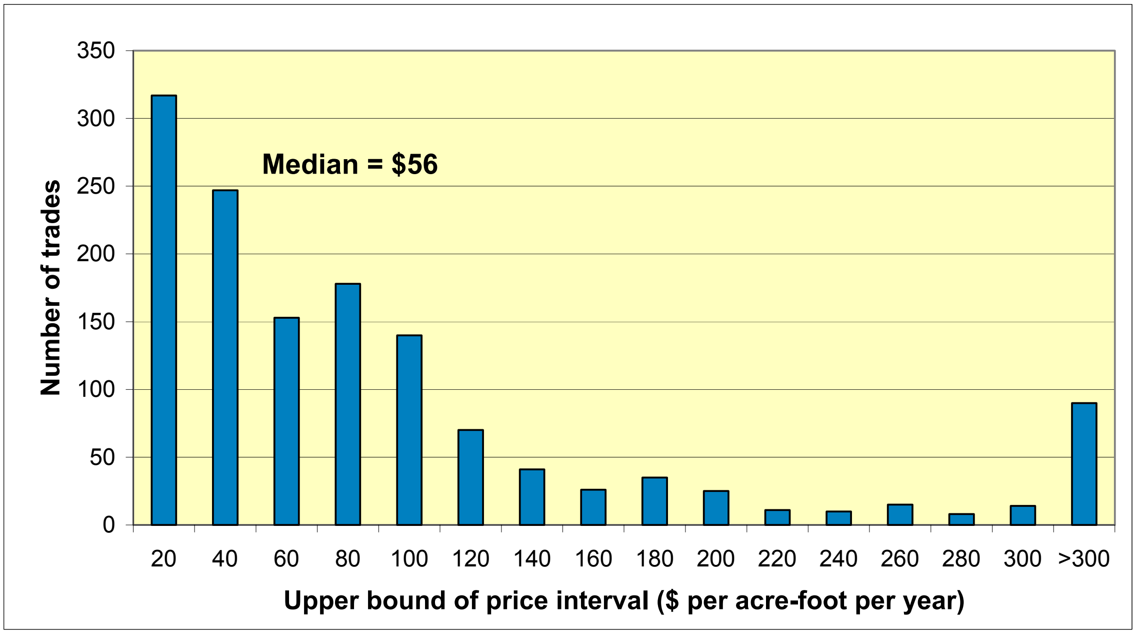


Figure 11. Distribution of prices paid for water for municipal purposes, 1990-2003 (including both leases and rights, year 2003 dollars)

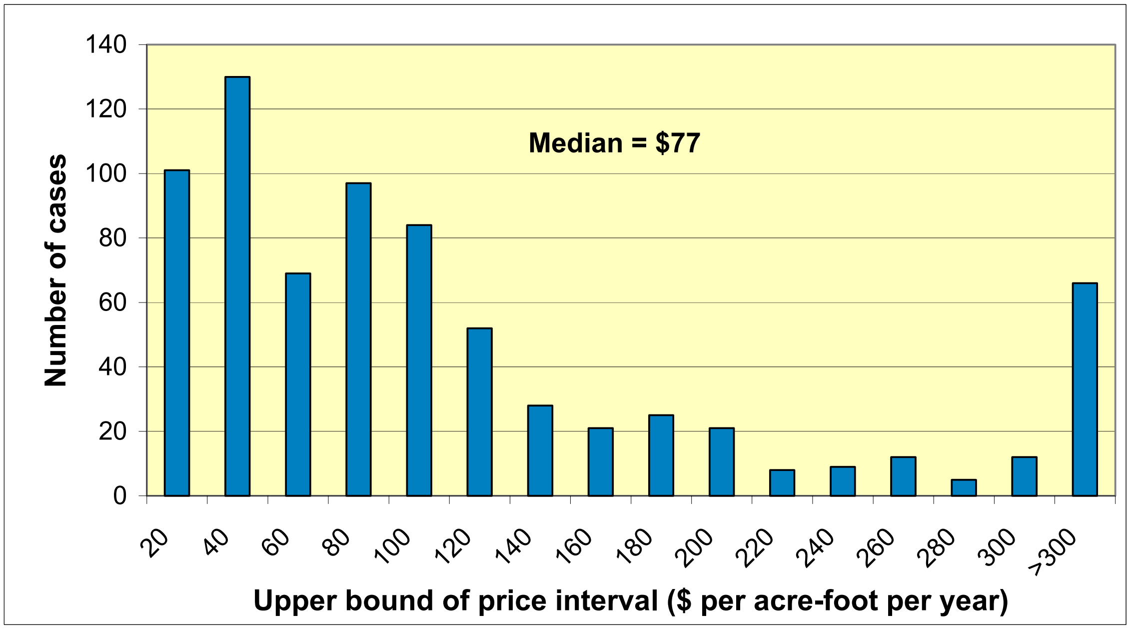


Figure 12. Distribution of prices paid for irrigation water, 1990-2003 (including both leases and rights, year 2003 dollars)

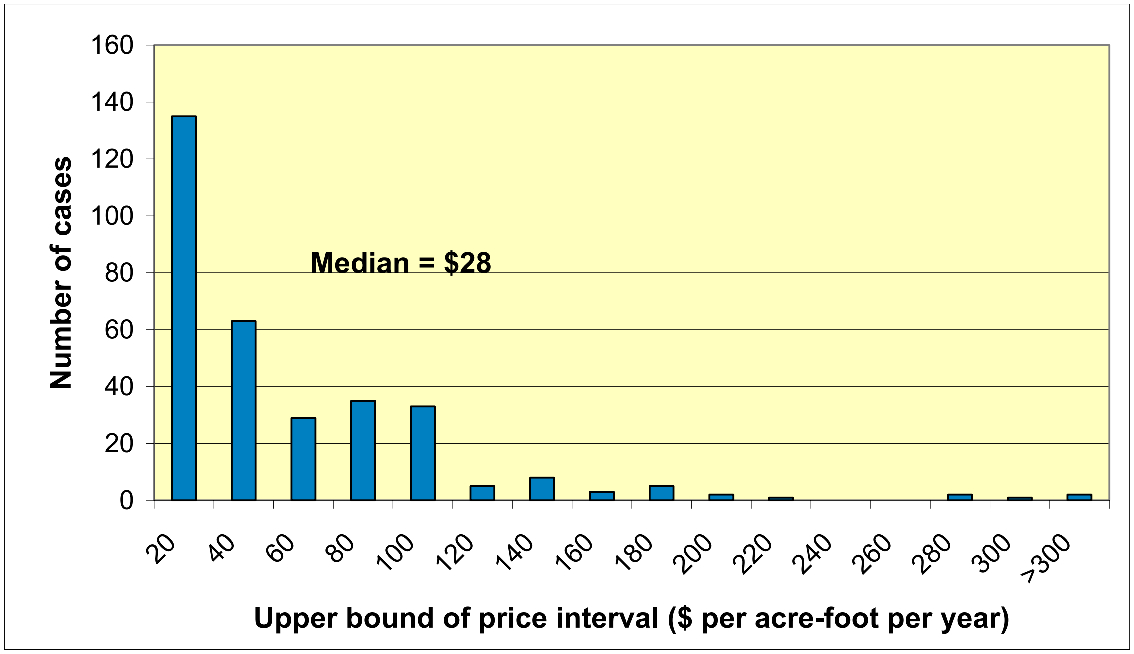


Figure 13. Distribution of prices paid for water for environmental purposes, 1990-2003 (including both leases and rights, year 2003 dollars)

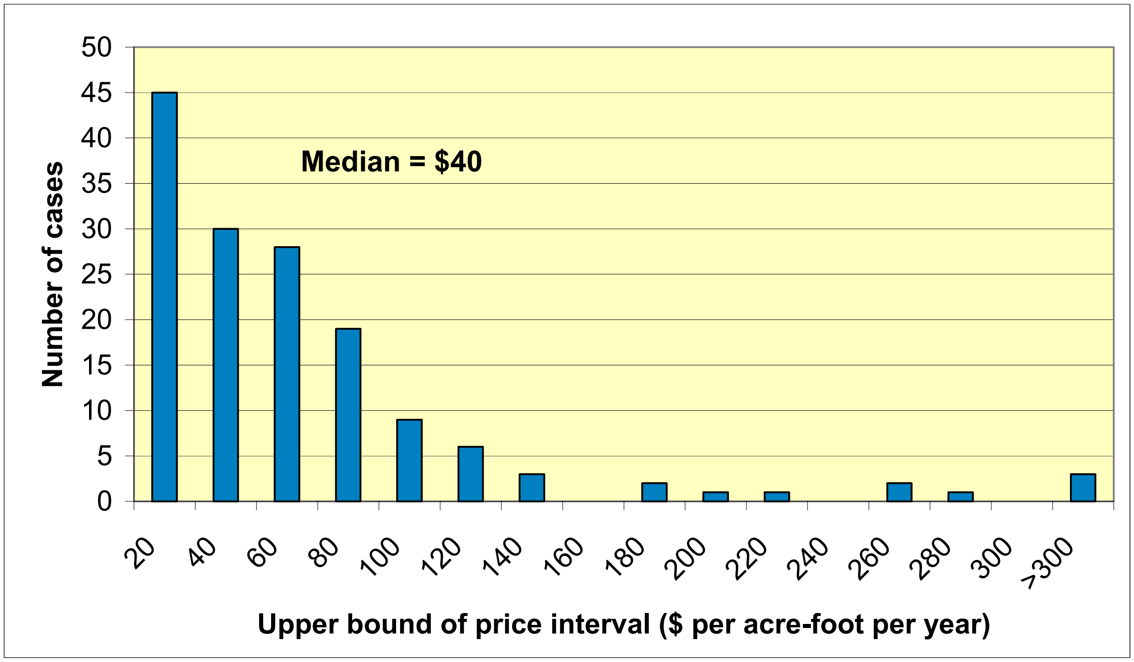


Figure 14. Trend in median price of water, all water uses (includes both leases and rights, year 2003 dollars)

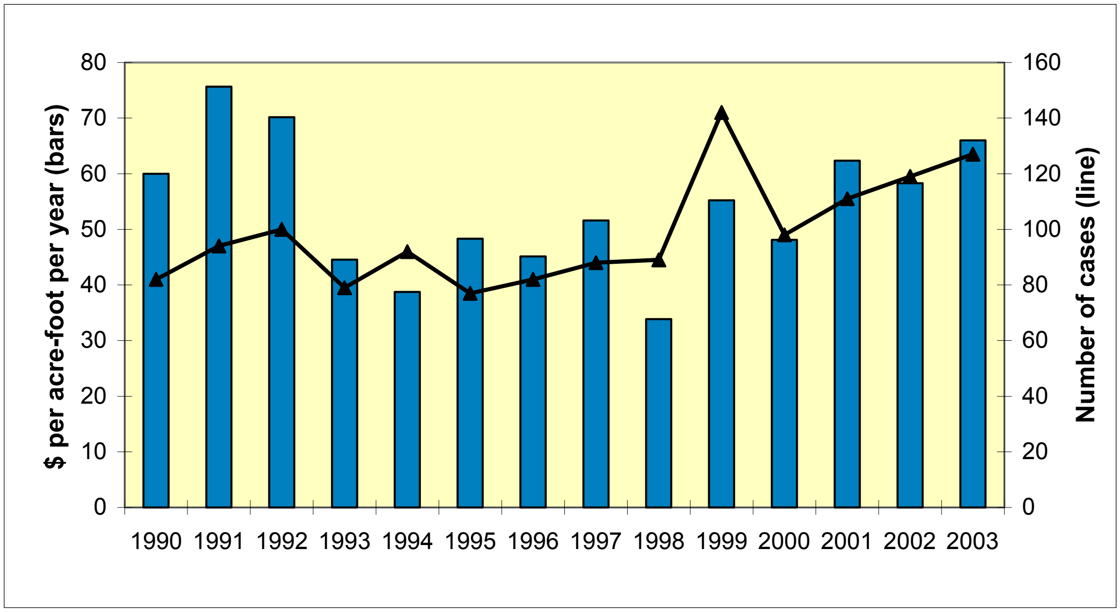


Figure 15. Trends in number of cases by type of transaction, all water uses, 1990-2003

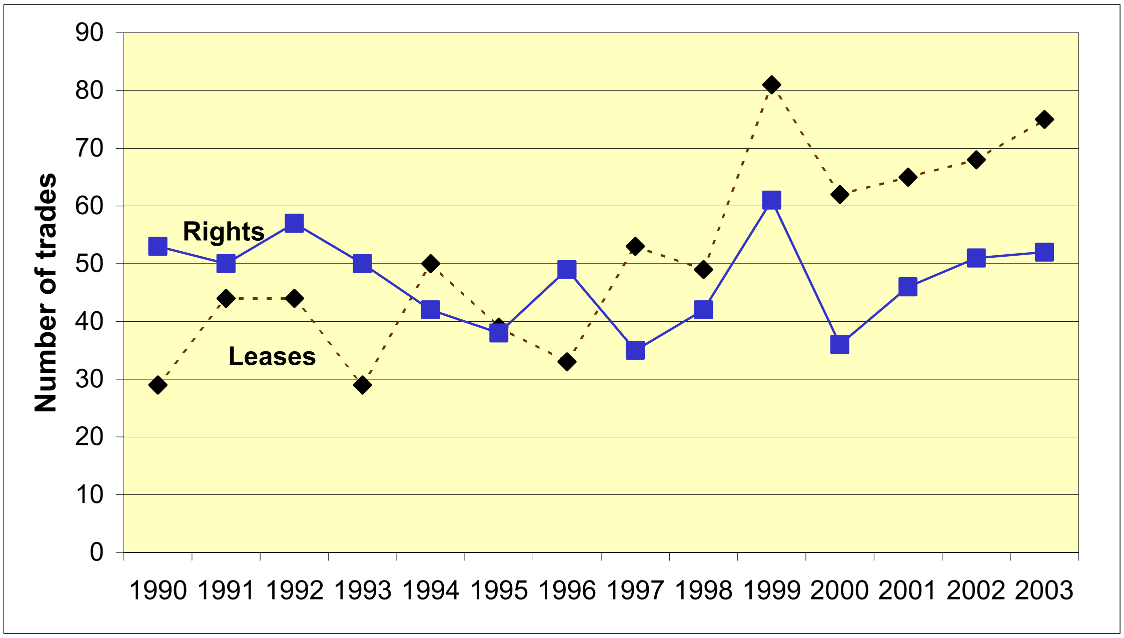


Figure 16. Trends in median water price by type of transaction, all water uses (year 2003 dollars)

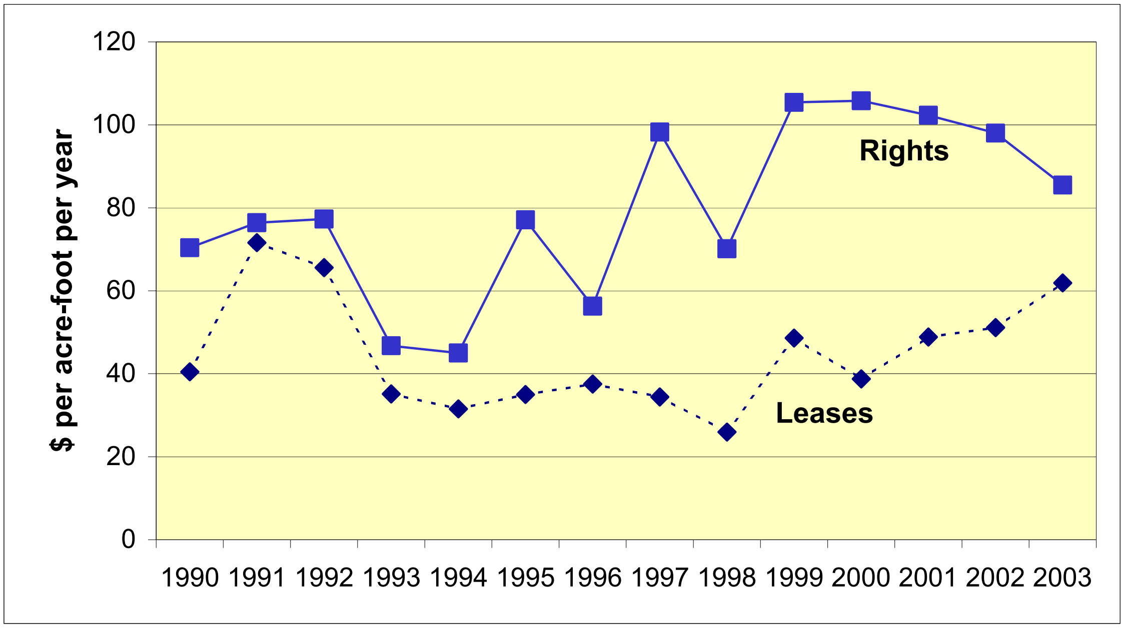


Figure 17. Trends in median price of water rights for three states, all water uses (year 2003 dollars)

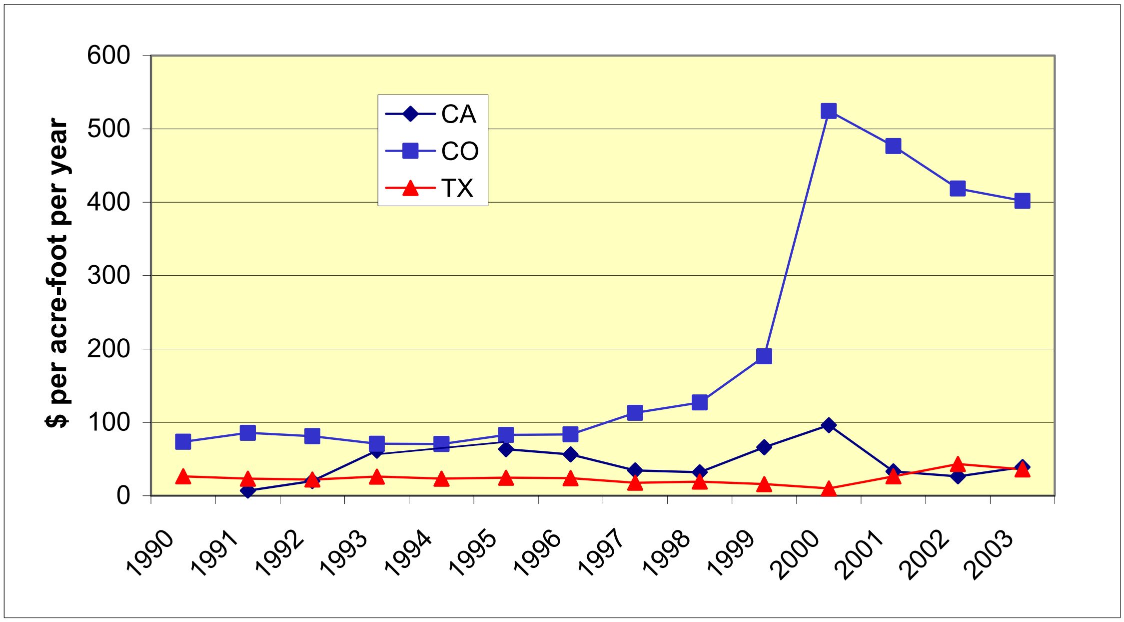


Figure 18. Trend in median price of water purchased for municipal purposes (includes both leases and rights, year 2003 dollars)

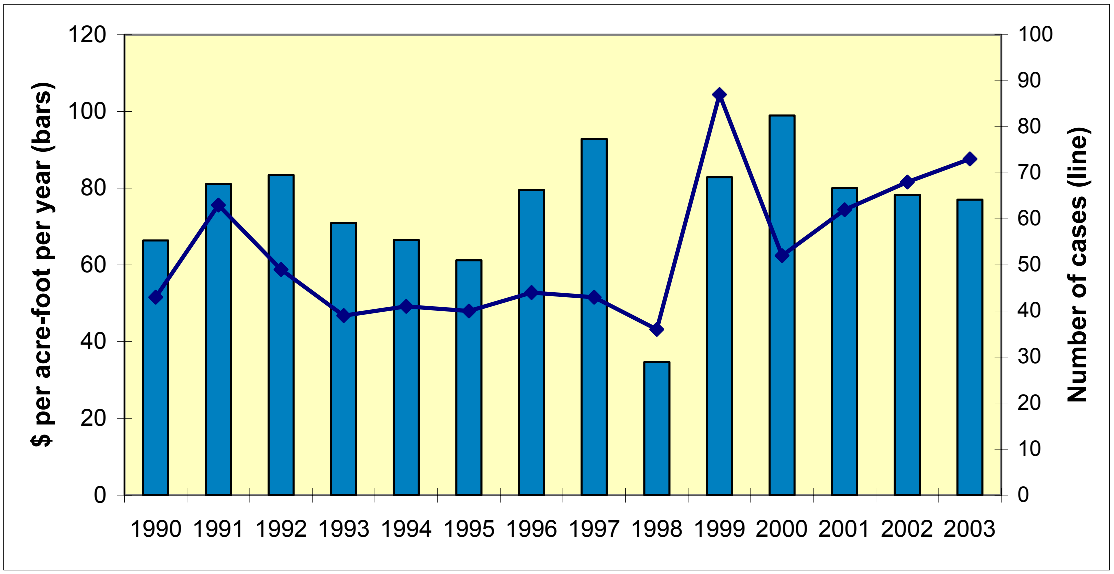


Figure 19. Trend in median price of water purchased for irrigation use (includes both leases and rights, year 2003 dollars)

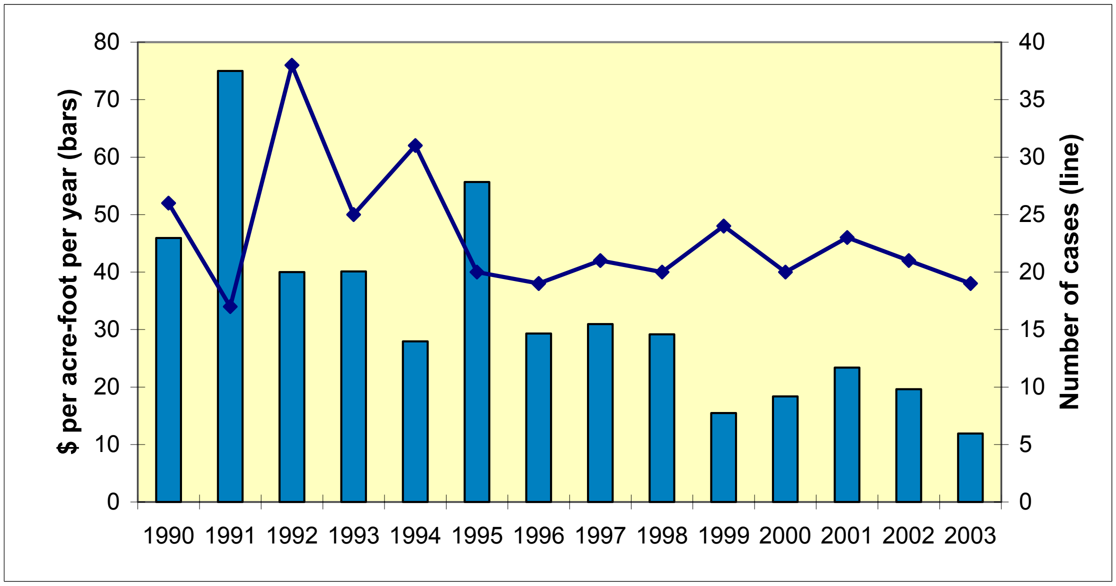


Figure 20. Trend in median price of water purchased for environmental purposes (includes both leases and rights, year 2003 dollars)

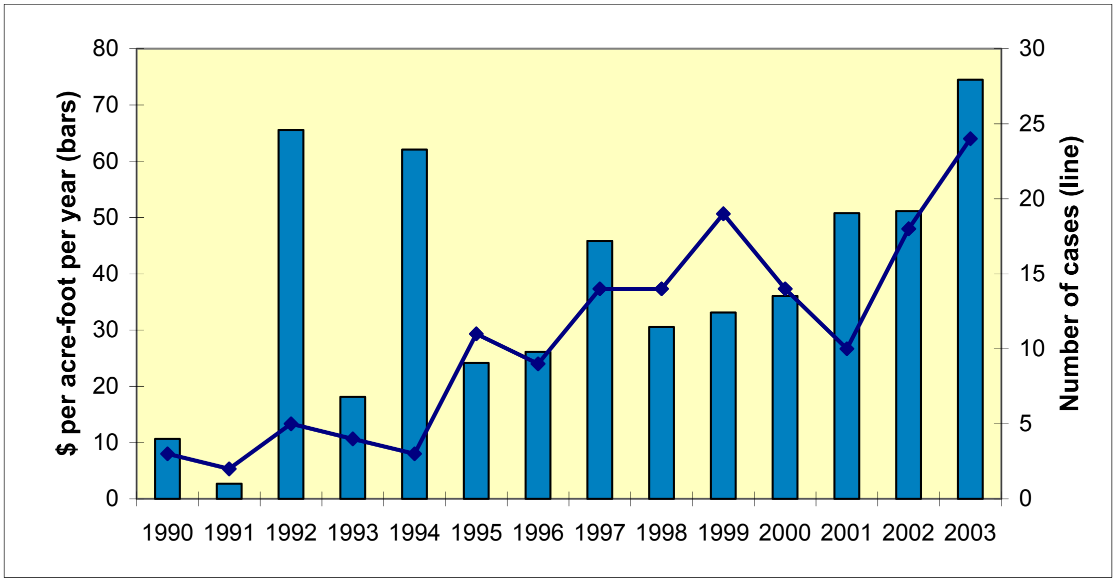


Figure 21. Trends in median price of water purchased for municipal, irrigation and environmental purposes (year 2003 dollars)

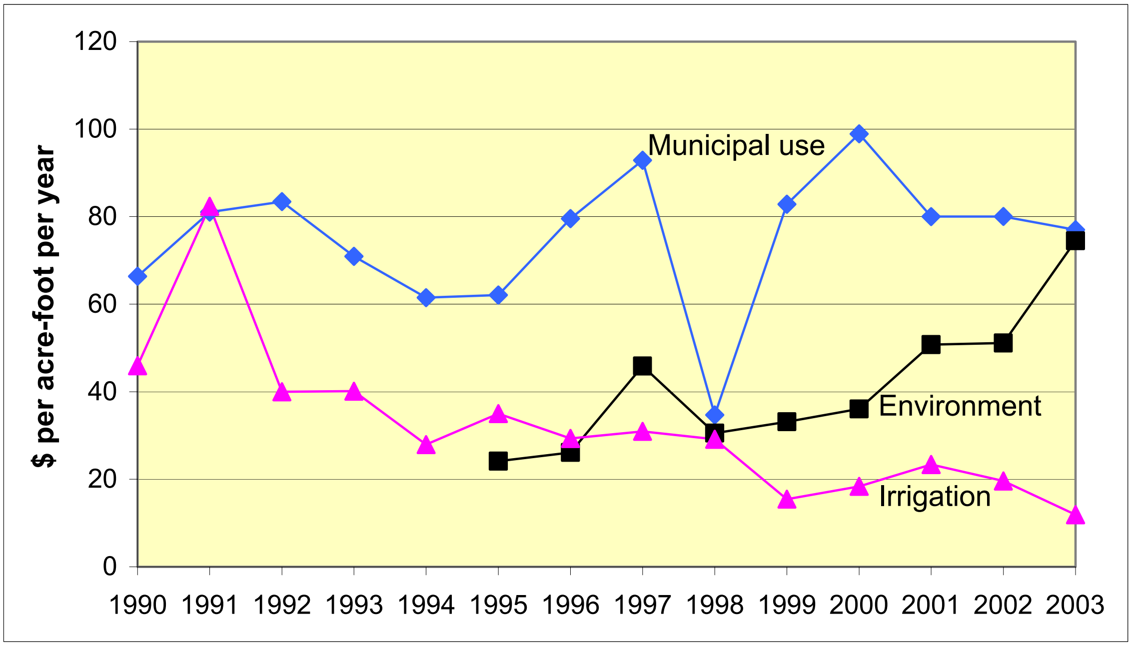


Figure 22. Trends in median price of water leases in selected Western markets (year 2003 dollars)

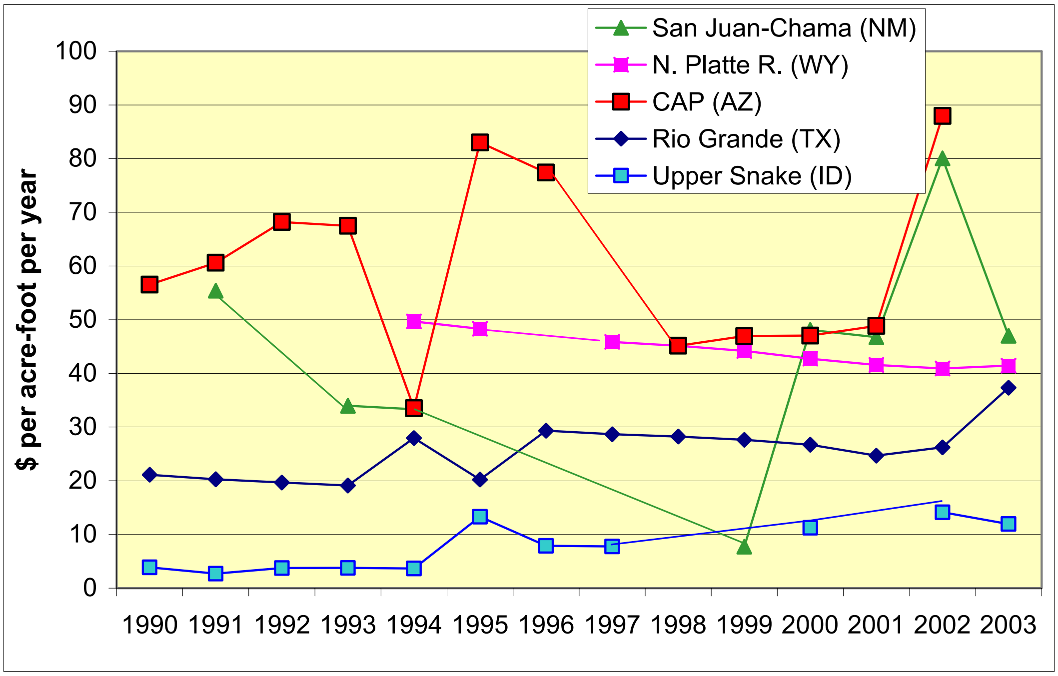


Figure 23. Trends in median price of water rights in selected Colorado markets (year 2003 dollars)

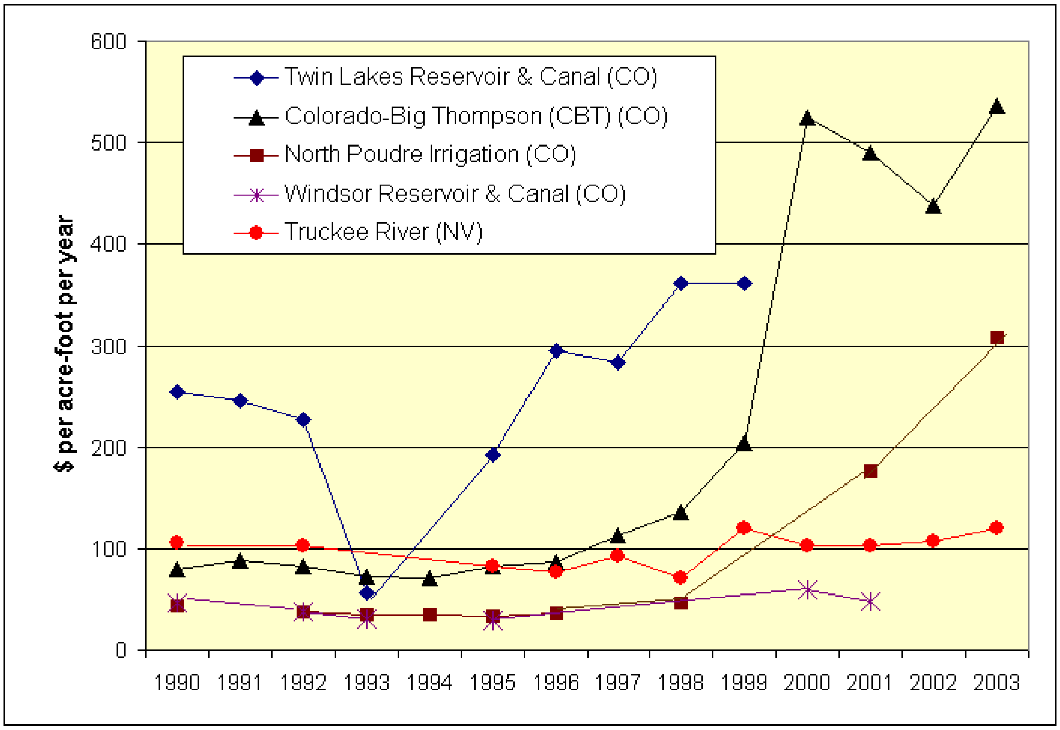


Figure 24. Median price of CBT shares, irrigation and M&I uses

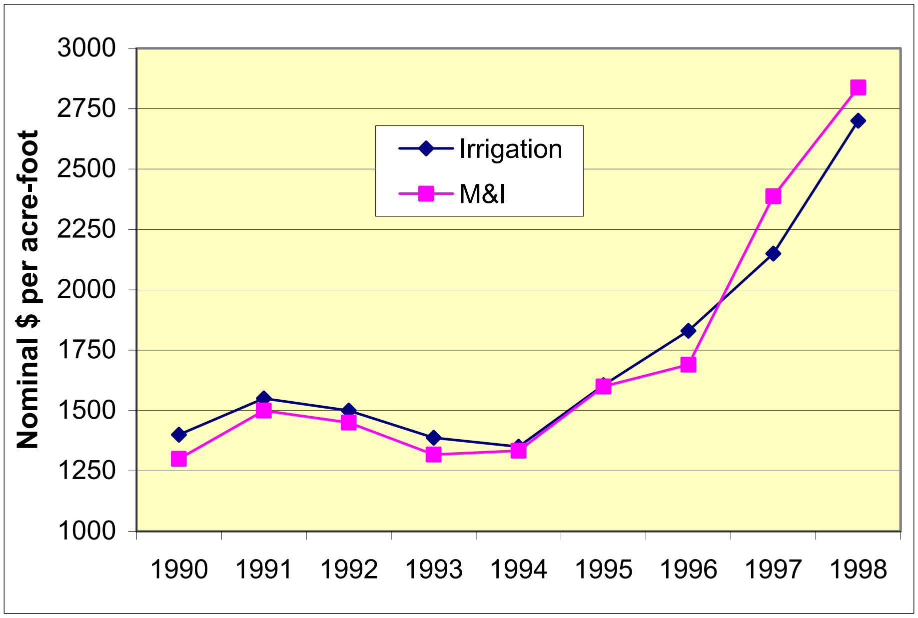


Figure 25. Median price of water (both leases and rights, year 2003 dollars) versus population, by county (not showing one exceptionally high price and one exceptionally high population), 1990 to 2003

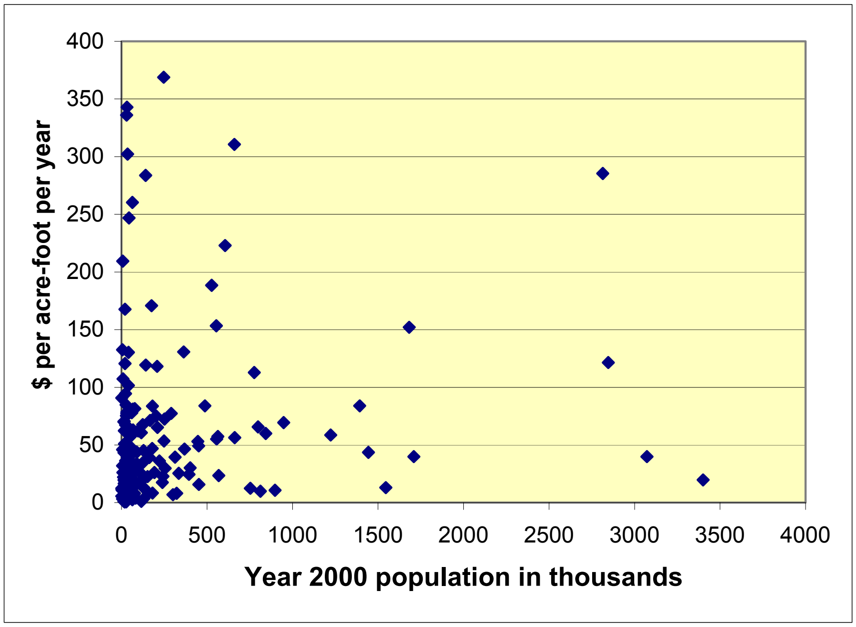


Figure 26. Median price of water (both leases and rights, year 2003 dollars) versus population growth, by county (not showing one exceptionally high price and one exceptionally high population growth rate), 1990 to 2003

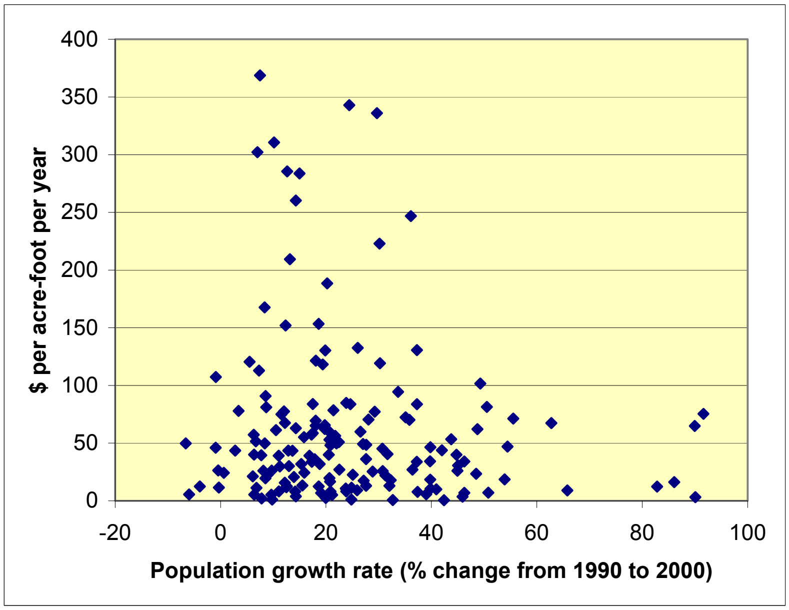


Figure 27. Median price of water (both leases and rights, year 2003 dollars) versus median PDSI, by climatic division, 1990 to 2003

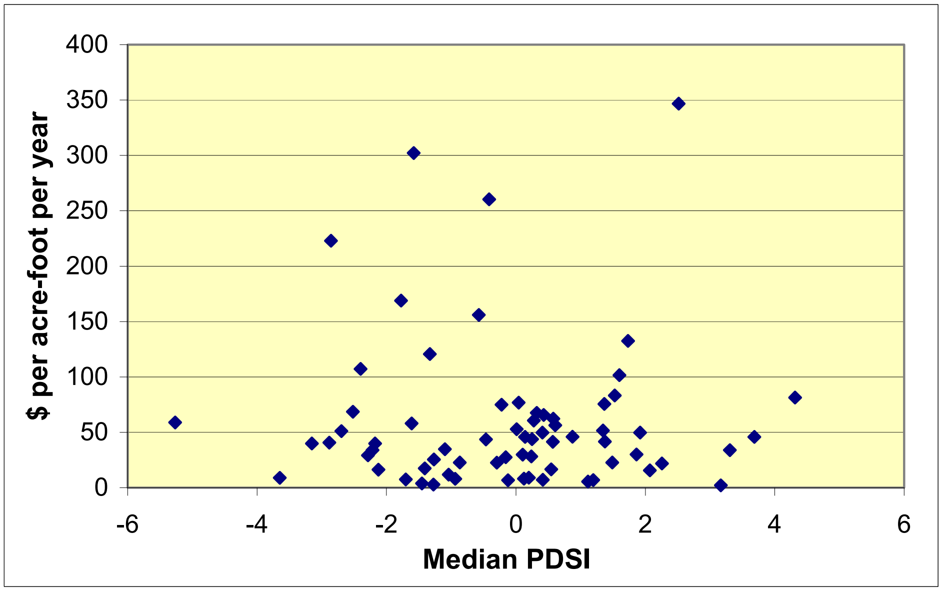


Figure 28. Total volume traded (both leases and rights) versus median PDSI, by climatic division, 1990 to 2003

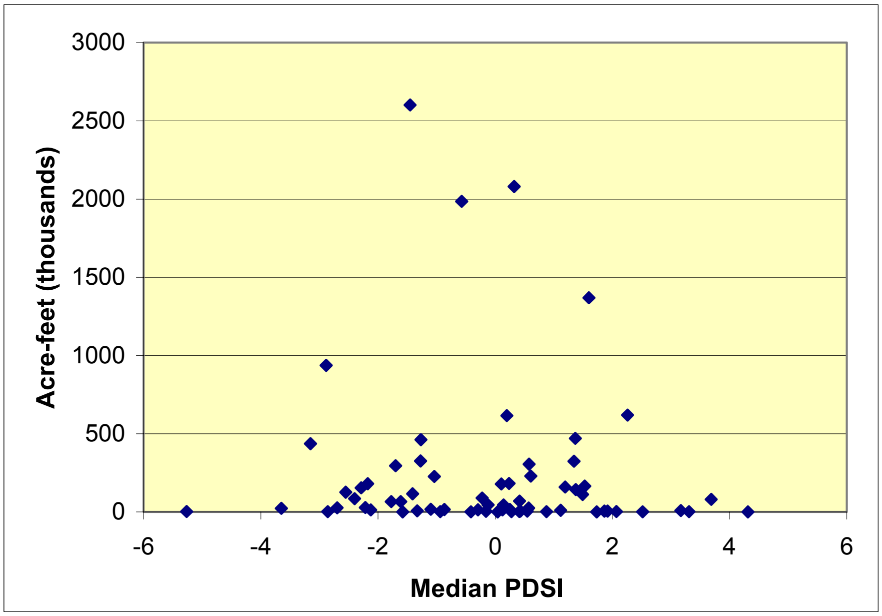


Figure 29. Mean prices of leases and rights by use, 1990 to 2003 (year 2003 dollars)

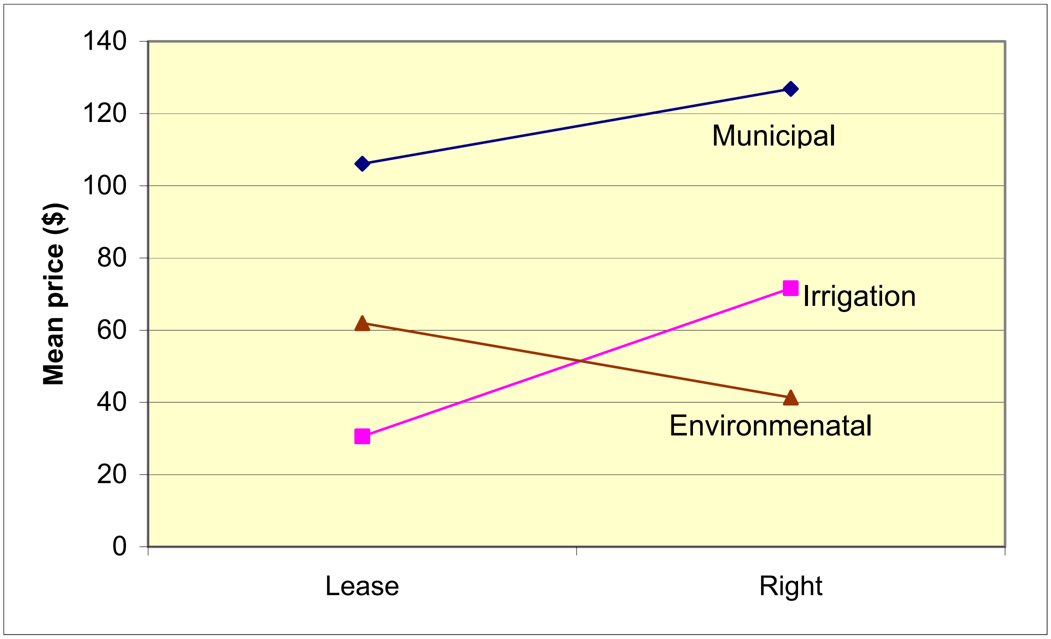


Figure 30. Mean prices of leases and rights by state, 1990 to 2003 (year 2003 dollars)

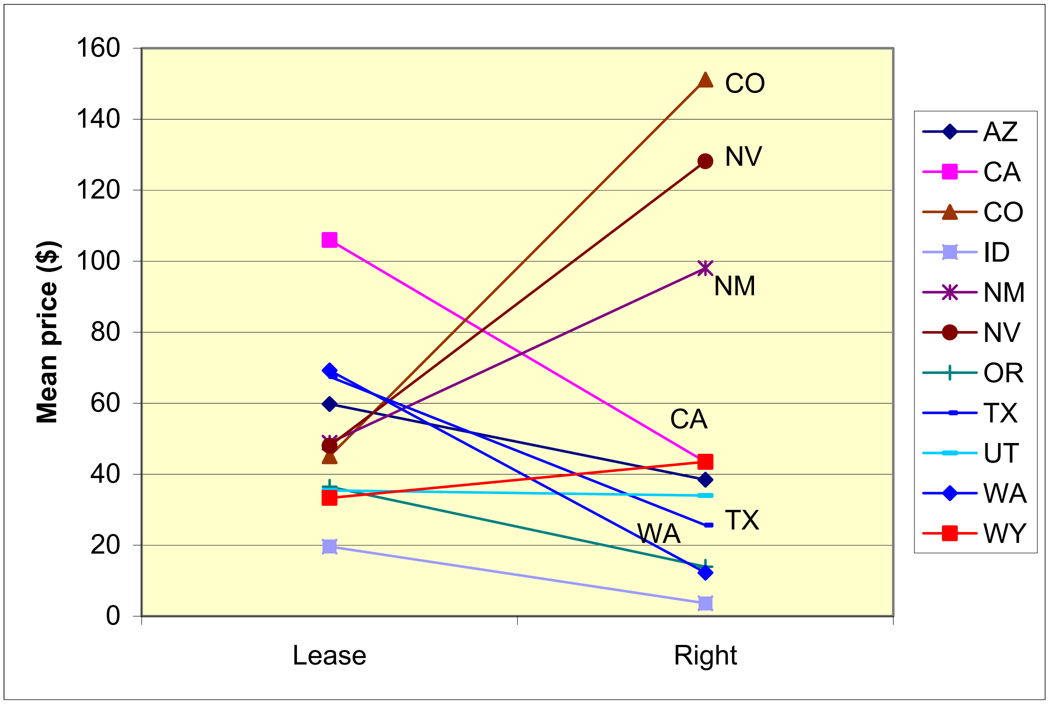


Figure 31. Mean prices of leases and rights by year, 1990 to 2003 (year 2003 dollars)

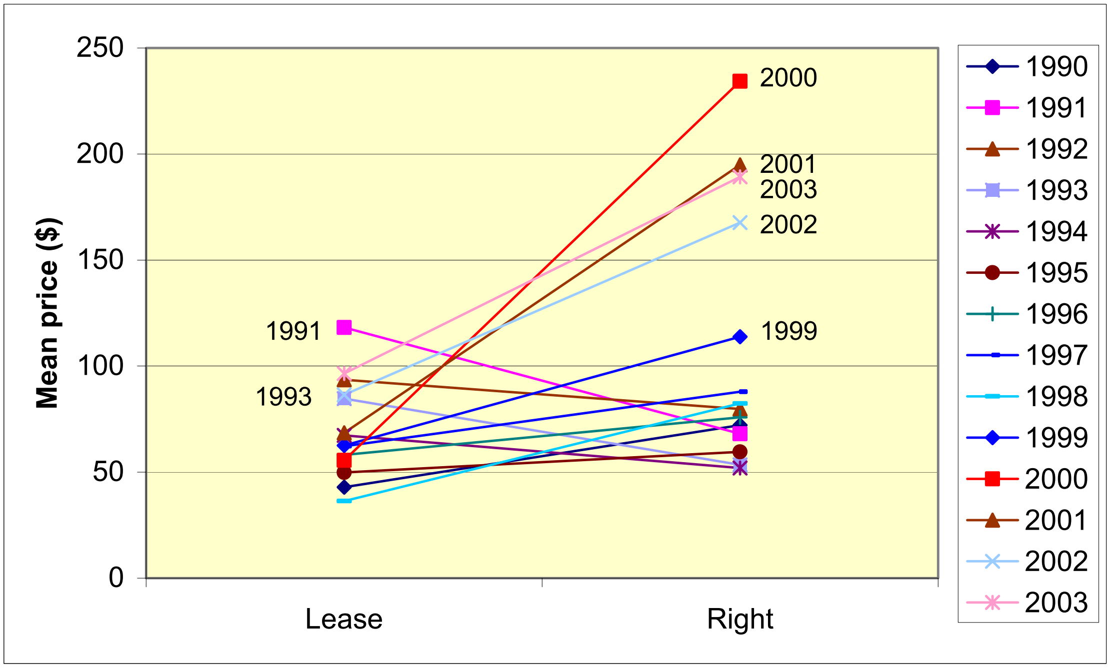
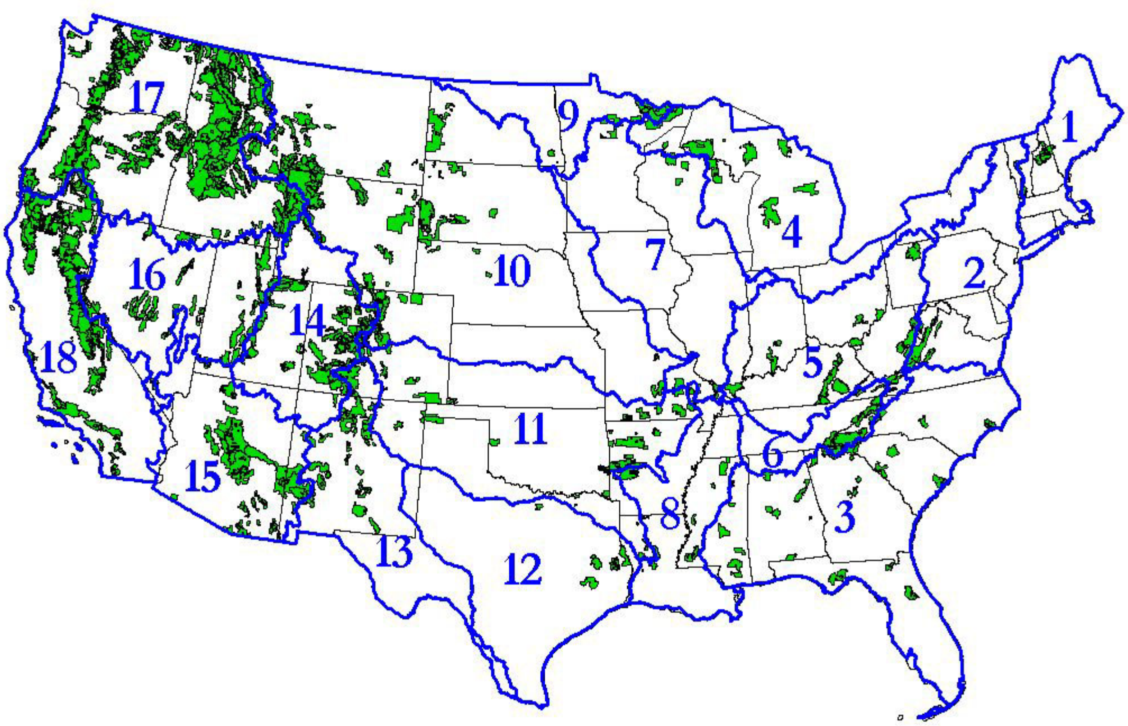


Figure 32. Water resource regions and National Forest System parcels (national forests and grasslands) in the conterminous U.S.



Key

1. New England
2. Mid-Atlantic
3. South-Atlantic-Gulf
4. Great Lakes
5. Ohio
6.Tennessee
7. Upper Mississippi
8. Lower Mississippi
9. Souris-Red-Rainy
10. Missouri
11. Arkansas-White-Red
12.Texas-Gulf
13. Rio Grande
14. Upper Colorado
15. Lower Colorado
16. Great Basin
17. Pacific Northwest
18. California

Appendix A. Water Market Trade Cases for Analysis

Appendix A consists of three tables. The first lists the locations and volume of water traded of all cases considered for analysis. The second lists by county, and the third by climatic division, the number of qualifying cases, median price, and volume of water traded.

Table A.1. Number of cases for each location, as best we could determine the location or project of the water being traded, for 1990-2003.

State	Location (river, ditch, project, or area)	All cases	Qualifying cases	
		Number	Number	Acre-feet
AZ	Bagdad	1	1	1,710
AZ	Boulder Canyon Project	1	1	3,030
AZ	CAP	55	46	7,784,913
AZ	ColoradoR.	8	4	24,162
AZ	Flagstaff	1	0	na
AZ	GilaR.	1	0	na
AZ	Gilbert	3	0	na
AZ	Harquahala Valley	1	1	6,479
AZ	Lake Mead	1	1	7,010
AZ	Little ColoradoR.	1	0	na
AZ	NW of Phoenix	1	1	81
AZ	Phoenix	1	1	150
AZ	Phoenix AMA	12	12	13,809
AZ	Pinal AMA	3	2	1,712
AZ	Pleasant Lake	1	1	60,000
AZ	San PedroR.	2	0	na
AZ	Santa Cruz	1	0	na
AZ	Santa Cruz AMA	1	0	na
AZ	SantaCruzR.	1	0	na
AZ	Scottsdale	2	0	na
AZ	Tempe	1	0	na
AZ	Tucson	9	0	na
AZ	Tucson AMA	15	14	1,700
AZ	VerdeR.	1	1	5,000
CA	AmericanR.	9	9	248,702
CA	Ames Basin	2	1	500
CA	Antelope Valley Basin	3	3	25,843
CA	Bakersfield	1	1	98,005
CA	Bay area	3	3	65,070
CA	Bunker Hill Basin	3	3	60,000
CA	Cachuma Project	1	0	na
CA	Central Basin	20	18	288,183
CA	Clear Creek	1	0	na
CA	ColoradoR.	11	5	413,275

CA	CosumnesR.	1	0	na
CA	CVP	72	49	970,549
CA	Delta-Mendota Canal	12	5	12,281
CA	Downey	1	1	1,219
CA	Drought Water Bank	1	1	20,000
CA	FeatherR.	9	9	282,111
CA	Hemet	2	0	na
CA	Kern County	9	7	519,054
CA	KernR.	6	4	34,000
CA	Klamath Basin	1	1	24,532
CA	Los Angeles	8	3	276,573
CA	Magalia Res.	2	1	60
CA	Main San Gabriel Basin	10	10	148,709
CA	MojaveR. Basin	39	32	161,322
CA	MokelumneR.	1	1	6,000
CA	North of the Delta	1	1	6,442
CA	Oroville	1	1	4,914
CA	Palo Verde Valley	2	1	40,594
CA	Placer County	1	1	10,000
CA	Richvale	1	1	159,023
CA	Riverside	40	0	na
CA	RussianR.	1	1	10,000
CA	Sacramento	1	1	15,000
CA	SacramentoR.	9	7	204,550
CA	San Diego	6	1	20,000
CA	San Luis Res.	3	2	50,000
CA	San Luis Water District	1	1	9,500
CA	SanJoaquinR.	19	18	584,435
CA	San Joaquin Valley	2	2	20,205
CA	Santa Barbara	1	0	na
CA	Santa Clara Valley	4	2	59,500
CA	SGA	1	1	10,000
CA	Shasta Res.	1	0	na
CA	SWP	63	55	2,365,514
CA	Thousand Oaks	1	0	na
CA	Triunfo County	1	0	na
CA	West Basin & Dominguez Water Co.	1	0	na
CA	West Coast Basin	20	17	173,163
CA	Yuba County	1	1	65,000
CA	YubaR.	13	13	640,396
CO	ArkansasR.	18	12	55,980
CO	Arvada	1	1	688
CO	Aurora	2	1	1,000
CO	Base Line Land&Res. Co.	1	1	2,408
CO	Berthoud	1	0	na
CO	Big ThompsonR.	1	1	165

CO	BlueR.	3	3	5,000
CO	Boulder	6	5	327
CO	BoulderCo	23	21	1,852
CO	Burlington-Wellington Ditch Co.	1	1	44
CO	CBT	228	224	38,149
CO	Church Ditch Co.	2	2	3,289
CO	Clear Creek	1	1	450
CO	Climax Mine Direct Flow&Storage Rights	1	0	na
CO	ColoradoR.	1	0	na
CO	Colorado Springs	17	16	189,288
CO	Consolidated Home Supply&Ditch Res. Co.	4	4	238
CO	Denver	4	2	10,045
CO	Denver/Dawson Aq.	1	0	na
CO	EagleR.	1	0	na
CO	ElkR.	1	1	2,000
CO	Farmers' Ditch Co.	2	1	54
CO	Farmers' Highline Canal & Res. Co.	5	5	117
CO	Farmers' Res.&Irr. Co.	5	5	662
CO	FraserR.	3	0	na
CO	Frying PanR.	12	6	23,518
CO	Golden	1	1	7,000
CO	Grand Valley Project	4	1	50,000
CO	Greeley	3	3	345
CO	Greeley Irr. Co.	1	1	42
CO	GunnisonR.	7	6	3,106
CO	Highland Ditch Co.	3	3	12,088
CO	Home Supply&Ditch Co.	4	4	204
CO	Lake Loveland Irr. Co.	4	4	1,346
CO	Larimer & Weld Res. Co.	2	2	92
CO	Left Hand Ditch Co.	3	2	44
CO	Longmont Supply Ditch Co.	1	1	28
CO	Louden Ditch Co.	3	3	108
CO	Loveland	1	0	na
CO	Loveland&Greeley Res. Irr. Co.	9	9	5,076
CO	Mtn.&Plains Irr. Co.	1	0	na
CO	N. Poudre Irr. Co.	25	24	1,652
CO	SE CO	1	0	na
CO	Northglenn	2	2	195
CO	Platte Valley Irr. Ditch	2	2	296
CO	PlatteR.	11	9	7,292
CO	Pleasant Valley&Lake Canal Co.	1	1	17
CO	San Luis Valley	1	0	na
CO	San MiguelR.	1	0	na
CO	Seven Lakes Res. Co.	3	3	1,273
CO	Twin Lakes Res.	15	15	6,962
CO	Union Res. Ditch Co.	2	2	66

CO	Water Supply&Storage Irr. Co.	2	2	265
CO	Westminster	2	0	na
CO	Windsor Res.&Canal Co.	11	11	647
CO	Windy Gap	4	3	9,961
ID	Anderson Ranch Res.	6	4	43,507
ID	Big Wood Canal Co.	1	0	na
ID	BoiseR.	10	6	82,478
ID	Bubb Canal	1	0	na
ID	Eagle Island	2	2	40,457
ID	Glenns Ferry	1	1	300
ID	LemhiR.	2	2	6,830
ID	Little Wood R.	1	0	na
ID	Lucky Peak Res.	7	6	31,464
ID	PayetteR.	1	1	8,177
ID	Plain Aq	1	1	579
ID	Ririe Res.	1	0	na
ID	S. Boise Mutual Irr. Co.	2	1	172
ID	Twin Falls	2	1	276
ID	Twin Falls Canal Co.	10	8	740
ID	UpperSnakeR.	35	31	2,586,953
KS	Big Hill Res.	3	3	5,370
KS	CottonwoodR.	5	5	849
KS	Hays	1	0	na
KS	Hillsdale Res.	2	2	1,363
KS	Kanopolis Lake	1	1	1,228
KS	Little ArkansasR.	1	1	1,028
KS	Wichita	4	4	1,275
MT	BlackfootR.	1	0	na
MT	Canyon Ferry Res.	1	1	1,500
MT	ClearwaterR.	1	0	na
MT	Glacier NP	1	0	na
MT	MadisonR.	1	0	na
MT	TiberR.	1	1	5,390
MT	YellowstoneR.	5	3	8,342
ND	SourisR.	1	0	na
NE	Ogallala Aq	1	0	na
NE	PlatteR.	4	0	na
NE	Rainwater Basin marsh	2	0	na
NM	Alamogordo	1	0	na
NM	Buckhorn	1	1	15
NM	Catron County	1	0	na
NM	CimmaronR.	1	1	70
NM	Clovis	1	0	na
NM	GilaR.	4	4	18
NM	Lea County	1	1	46
NM	Los Lunas	2	0	na

NM	Morphy Lake	1	0	na
NM	Navajo Res.	2	2	16,350
NM	PecosR.	11	11	142,695
NM	RioGrande	25	23	230,203
NM	San Juan-Chama Project	22	15	133,500
NM	Socorro	1	0	na
NM	VermejoR.	1	1	1,700
NV	BruneauR.	1	0	na
NV	CarsonR.	4	4	1,646
NV	ColoradoR.	6	2	1,214,550
NV	Coyote Spring Valley	1	1	7,500
NV	Elko County	1	0	na
NV	Garnet and Hidden Valley	1	0	na
NV	TruckeeR.	76	62	74,912
OK	Frederick	1	0	na
OK	Garber-Wellington Aq	1	1	640
OK	N.CanadianR.	1	1	111
OK	RedR.	1	1	80,000
OK	S.CanadianR.	1	0	na
OR	CrookedR.	1	1	10,000
OR	DeschutesR.	10	7	10,816
OR	Evans Creek	1	1	23
OR	Jackson County	1	0	na
OR	Klamath Basin	6	6	128,809
OR	LostR.	1	1	1,158
OR	NW Oregon	1	0	na
OR	RogueR.	8	5	8,004
OR	SandyR.	1	0	na
OR	SnakeR.	1	0	na
OR	Sucker Creek	2	1	79
OR	UmatillaR.	9	7	41,231
OR	UpperSnakeR.	3	3	25,798
OR	Wickiup Res.	1	1	217
OR	WillametteR.	10	9	33,054
OR	Willow Creek Project	1	1	1,794
TX	BrazosR.	1	0	na
TX	ColoradoR.	4	3	94,484
TX	Edwards Aq	27	25	142,888
TX	El Paso	2	0	na
TX	Fort Stockton	1	0	na
TX	GuadalupeR.	7	7	89,640
TX	Leon Creek	2	2	10,690
TX	Longview	1	0	na
TX	MedinaR.	4	4	39,996
TX	NavasotaR.	1	1	6,945
TX	NavidadR.	8	4	167,031

TX	Ogallala Aq	2	1	40,000
TX	RioGrande	166	157	711,021
TX	San Antonio	2	2	72,500
TX	San MarcosR.	1	1	396
TX	Sweetwater	1	0	na
TX	Verde County	1	0	na
TX	Wharton County	1	0	na
UT	BeaverR.	1	1	15
UT	Cahoon&Maxfield Irr. Co.	1	1	8,539
UT	CUP (Central Utah Project)	1	1	12,000
UT	Davis Weber Canal Co.	3	3	6,051
UT	Lehi	2	0	na
UT	Provo City	1	1	25
UT	ProvoR.	2	2	632
UT	Sand Hollow	1	1	45
UT	Sandy City	2	2	543
UT	St. George	7	6	2,417
UT	Strawberry Res.	1	1	9,038
UT	StrawberryR.	8	8	68,612
UT	UintaR.	1	1	600
UT	Utah Lake	5	5	2,502
UT	VirginR.	5	5	10,439
UT	WeberR.	8	5	928
WA	?	1	0	na
WA	ColumbiaR.	9	6	39,556
WA	DungenessR.	2	1	941
WA	Grand Coulee Res.	1	1	400,000
WA	Granger	1	0	na
WA	GreenR.	1	0	na
WA	MethowR.	1	1	428
WA	NachesR.	1	1	78,000
WA	SultanR.	1	1	2,000
WA	TeanawayR.	8	7	16,939
WA	TouchetR.	1	1	427
WA	Walla WallaR.	2	2	2,165
WA	Warden	1	1	2,388
WA	YakimaR.	5	3	20,640
WY	Canyon Creek	1	0	na
WY	LaramieR.	2	1	10,000
WY	PlatteR.	23	22	28,730
WY	ShoshoneR.	1	0	na
WY	Soda Lakes Preserve	1	0	na
WY	TongueR.	1	0	na
WY	WindR.	13	13	180,481
total		1726	1377	23,731,246

Table A2. Qualifying cases by county

State	County	Number of cases	Median price ($/acre-foot/yr)	Total acre-feet (thousands)
AZ	Coconino	1	61	2
AZ	Gila	3	49	249
AZ	La Paz	2	1	4
AZ	Maricopa	53	41	7520
AZ	Mohave	2	9	22
AZ	Pima	15	60	213
AZ	Pinal	8	47	164
AZ	Yavapai	2	71	7
CA	Alameda	8	44	61
CA	Alpine	1	91	0
CA	Amador	1	39	1
CA	Butte	5	75	185
CA	Colusa	1	13	25
CA	Contra Costa	5	69	34
CA	Fresno	23	66	827
CA	Glenn	5	52	359
CA	Imperial	2	119	170
CA	Kern	31	56	1976
CA	Kings	5	13	50
CA	Los Angeles	64	152	1971
CA	Madera	3	34	19
CA	Marin	1	369	10
CA	Mariposa	2	62	77
CA	Merced	16	65	994
CA	Monterey	1	30	6
CA	Napa	3	68	12
CA	Orange	7	121	46
CA	Placer	2	53	22
CA	Plumas	2	121	20
CA	Riverside	5	13	412
CA	Sacramento	9	59	179
CA	San Benito	1	31	6
CA	San Bernardino	37	40	260
CA	San Diego	3	285	398
CA	San Francisco	4	113	120
CA	San Joaquin	16	57	432
CA	Santa Clara	2	152	55
CA	Santa Cruz	1	30	6
CA	Shasta	2	39	55
CA	Solano	2	24	30
CA	Stanislaus	6	53	237
CA	Sutter	2	27	53
CA	Trinity	1	11	11
CA	Tuolumne	2	12	2
CA	Ventura	1	12	21

CA	Yuba	11	78	736
CO	Adams	20	131	21
CO	Arapahoe	10	84	56
CO	Bent	2	32	16
CO	Boulder	65	77	27
CO	Chaffee	1	70	0
CO	Crowley	17	11	177
CO	Delta	1	1	2
CO	Denver	3	153	8
CO	Douglas	1	171	6
CO	Eagle	6	65	51
CO	Gunnison	5	70	1
CO	Jefferson	13	188	12
CO	Kiowa	1	12	25
CO	Lake	8	247	0
CO	Larimer	84	72	21
CO	Mesa	1	1	60
CO	Montezuma	1	36	0
CO	Morgan	3	85	0
CO	Otero	1	24	1
CO	Prowers	1	19	6
CO	Pueblo	7	284	159
CO	Routt	1	18	2
CO	Summit	10	12	10
CO	Weld	164	84	23
ID	Ada	14	7	531
ID	Adams	1	11	53
ID	Bingham	7	8	563
ID	Boise	1	3	8
ID	Bonneville	14	4	1894
ID	Canyon	1	4	54
ID	Cassia	1	5	7
ID	Elmore	10	8	210
ID	Jerome	1	5	1
ID	Lemhi	3	209	8
ID	Power	1	5	7
ID	Twin Falls	9	2	51
KS	Ellsworth	1	46	1
KS	Johnson	2	49	1
KS	Marion	4	50	1
KS	Miami	1	48	0
KS	Montgomery	3	50	5
KS	Sedgwick	5	16	2
MT	Lewis And Clark	1	34	2
MT	Liberty	1	6	5
MT	Park	3	2	8
NM	Bernalillo	28	55	323
NM	Chaves	2	21	6
NM	Colfax	1	1	2
NM	Eddy	9	57	136

NM	Grant	5	77	0
NM	Lea	1	26	0
NM	Rio Arriba	1	130	0
NM	San Juan	2	44	16
NM	Santa Fe	2	45	3
NM	Socorro	5	51	227
NM	Taos	2	336	0
NM	Valencia	1	34	0
NV	Carson City	4	94	2
NV	Clark	3	102	1369
NV	Washoe	62	107	81
OK	Cleveland	1	118	1
OK	Oklahoma	2	311	90
OR	Clatsop	1	302	0
OR	Deschutes	4	19	21
OR	Jackson	4	8	26
OR	Jefferson	2	6	10
OR	Josephine	3	8	3
OR	Klamath	7	61	130
OR	Lane	1	8	2
OR	Malheur	1	78	46
OR	Polk	9	9	37
OR	Umatilla	7	7	45
OR	Wasco	2	26	0
TX	Bexar	56	84	380
TX	Brazos	1	23	7
TX	Caldwell	1	50	0
TX	Calhoun	1	168	74
TX	Cameron	44	25	142
TX	Comal	2	81	0
TX	El Paso	14	26	148
TX	Guadalupe	5	34	32
TX	Harris	2	20	213
TX	Hays	1	62	5
TX	Hidalgo	14	23	38
TX	Kendall	1	67	2
TX	Lavaca	1	43	43
TX	Lubbock	1	23	40
TX	Nueces	2	39	76
TX	San Patricio	1	63	41
TX	Starr	6	18	3
TX	Travis	1	10	156
TX	Webb	46	26	437
TX	Williamson	1	779	4
TX	Zapata	6	22	2
UT	Beaver	1	133	0
UT	Davis	3	17	6
UT	Duchesne	1	43	1
UT	Salt Lake	9	11	12
UT	Summit	4	75	1

UT	Utah	3	46	3
UT	Wasatch	10	7	90
UT	Washington	12	16	13
WA	Adams	3	17	5
WA	Clallam	1	260	1
WA	Douglas	1	343	400
WA	Franklin	1	41	3
WA	Grant	2	27	3
WA	Kittitas	1	11	5
WA	Klickitat	1	32	33
WA	Okanogan	1	12	0
WA	Snohomish	1	223	2
WA	Walla Walla	3	21	3
WA	Yakima	10	36	123
WY	Fremont	15	40	181
WY	Natrona	1	81	0
WY	Platte	20	26	44
Total		1372		

Table A3. Qualifying cases by climatic division

State	Climatic division	Median PDSI	Number of cases	Median price ($/acre-foot/yr)	Total acre-feet (thousands)
AZ	1	-4.2	2	9	23
AZ	2	-0.3	1	61	2
AZ	3	-0.8	2	30	5
AZ	4	-4.9	2	59	2
AZ	5	-0.4	2	41	25
AZ	6	-0.8	65	44	8079
AZ	7	-2.9	14	58	66
CA	1	-1.4	3	75	89
CA	2	-0.6	56	68	2080
CA	4	-2.4	4	169	66
CA	5	-1.1	123	53	4805
CA	6	-1.9	66	156	1985
CA	7	-3.0	42	41	937
CO	1	1.5	42	22	619
CO	2	-3.5	25	69	126
CO	4	1.6	360	83	165
ID	4	-0.4	7	7	159
ID	5	-1.4	15	8	295
ID	7	-1.8	14	3	326
ID	8	-0.1	2	121	7
ID	10	-1.4	26	4	2602
KS	5	-1.7	1	46	1
KS	6	0.3	7	50	2
KS	8	1.8	5	16	2
KS	9	1.2	3	50	5
MT	3	-0.6	1	6	10
MT	4	2.0	1	34	2
MT	5	-0.4	3	2	8
NM	1	1.3	2	44	16
NM	2	0.9	18	52	323
NM	3	-1.0	2	66	5
NM	4	3.4	1	81	0
NM	5	0.2	21	56	229
NM	7	-0.5	12	42	143
NM	8	-2.0	4	77	0
NV	1	-2.9	66	107	85
NV	4	1.1	3	102	1369
OK	5	1.0	2	347	1
OK	9	4.3	1	46	80
OR	1	-2.7	1	8	2
OR	2	-1.2	9	9	616

OR	3	-1.0	7	8	12
OR	5	-1.3	1	302	0
OR	6	-0.5	7	7	45
OR	7	-1.5	15	30	178
OR	9	-3.2	3	51	26
TX	1	-0.6	1	23	111
TX	2	-2.7	2	12	227
TX	4	1.4	1	23	14
TX	5	-2.0	15	29	154
TX	6	-0.6	29	28	182
TX	7	-0.3	35	76	470
TX	8	0.4	10	62	305
TX	9	-1.8	8	27	4
TX	10	-1.6	106	25	462
UT	1	-1.0	1	133	0
UT	2	-2.6	12	16	13
UT	3	1.5	13	23	15
UT	5	-1.7	8	34	28
UT	6	-0.3	9	7	69
WA	2	0.2	1	260	1
WA	4	-3.0	1	223	2
WA	6	-2.9	7	35	17
WA	7	-2.7	5	40	436
WA	8	-2.5	8	17	116
WA	9	-0.3	3	17	5
WY	8	-0.8	23	46	44
WY	9	-3.4	13	40	180
total			1377		

Appendix B. Total Value of Streamflow from the National Forests

This report has focused on marginal values, which may be useful to land managers making decisions that affect streamflow. Total values for a product such as water, by contrast, do not facilitate land management decision-making. Nevertheless, total values may be of general interest, and thus we address the total value issue here.

Reporting on the total value of resources originating on national forests can leave an incorrect impression, because not all of the value of resources flowing from a national forest (i.e., all the stumpage, all recreation use, all water runoff, all herbage consumed by cattle, all minerals mined, etc.) is attributable to national forest management. The total value of all the resources is to some extent the result of purely natural events. For example, trees grow and water flows without help from land managers. The contribution of national forest management is to enhance or protect these outputs, and to make some of them available for purchase, thereby adding value (e.g., forest management makes timber available for harvest by controlling wildfire and administering sales, and watershed management may protect the quality of water flow). Thus, in reporting on the total value of resource flows from the national forests, the agency is not claiming that all of that value is attributable to the agency's management. Rather, it is asserting that such value originates on the national forests.

In most situations, water, like other commodities, is subject to diminishing marginal utility—initial units of consumption are most precious, and the value of each additional unit is less than the previous one. At some point, additional units become worthless (or, in the case of flooding, they become of negative value). This condition is depicted graphically by a downward sloping demand curve, as in Figure B1. Each point along demand curve (D) in the figure indicates WTP for one more unit of water—the marginal value. Users will consume up to the point where marginal WTP equals marginal cost. If quantity is not limited and cost is zero, consumption occurs at Q_1, and the marginal value is \$0. A zero marginal value, or price, is intuitively sensible once it is realized that users are not willing to pay any more for units they consume than the cost of a perfect substitute. If substitute units are available at zero cost, as can be the case with streamflow in water-rich locations, marginal WTP per unit consumed is \$0.

Although the marginal value can theoretically be \$0, the average value (AV) (and therefore the total value) is probably not. For a linear demand curve, AV is equal to marginal WTP at the midpoint along the demand curve between zero quantity and the current quantity consumed (this quantity is $Q_2 = Q_1/2$ in Figure B1 assuming current consumption at Q_1). The total value (TV) of the water consumed is given by the entire area under the demand curve between zero quantity and the current quantity consumed, which is equal to AV times the quantity consumed (e.g., $TV = Q_1 \bullet AV$ in Figure B1).

Which average value? Because the initial units of water are so valuable in some uses, the total value of the water leaving a national forest, especially a forest contributing a substantial proportion of the water supply, can be quite high. Assuming that estimation of the demand curve is possible, the determination of total value then depends on a methodological decision regarding how the contribution of the national forest to the total water value of a basin is determined. There are two basic options. To see how they differ, consider Figure C2, wherein a total of Q_1 acre-feet are produced and consumed in the basin, and the average value of that water is AV_1 (we are again assuming a linear demand curve). Assume further that the national forest contributes one-third of this flow, an amount equal to $Q_1 – Q_3$. With *option 1* it is assumed that the national forest's portion of the total value of water in the basin is proportional to its contribution to total streamflow. This option allows us to estimate the national forest's portion of the lost value if all streamflow in the basin were somehow suddenly unavailable. In this case, the total value of the water from the national forest would be equal to $AV_1 \bullet (Q_1 – Q_3)$ assuming $Q_2 = Q_1/2$. *Option 2* assumes that the national forest is the marginal contributor of water in the basin. This option allows us to estimate the lost water value in the basin if only the flow from the national forest were somehow suddenly unavailable. In this case, the total value of the water from the national forest would be equal to $AV_2 \bullet (Q_1 – Q_3)$, shown by the shaded area in Figure 2.[64] Because AV_1 can be much greater than AV_2, the option chosen could have a large effect on the estimate of total value of streamflow from the national forest. Because both options relate to purely hypothetical possibilities, there is little basis for choosing between them.

Measurement difficulty. Assuming this methodological issue has been settled, we now must estimate the appropriate average value. Unfortunately, this is a formidable task. The difficulty arises because demand curves and their average values are not observable or easily estimated. Water transactions, like most transactions, occur at or close to the margin, with market prices indicating marginal value. Except for the portion of the demand curve near the current quantity consumed, we have only a vague idea of the slope of the demand curve.[65] Nearly all studies of water value have focused on marginal value or on average values for relatively small portions of the total supply. Thus, any estimate of the average value of water from an entire national forest would be a rough guess. Given this difficulty, we take a simple, conservative approach here, as seen next.

Total Value of Streamflow

The approach taken here for estimating the total value of streamflow originating on national forests relies on multiplying the average annual quantity of water produced on national forests in a WRR by a conservative estimate of the value of that flow. Water supply originating from given land areas in the average year can be approximated with reasonable accuracy as precipitation minus evapotranspiration. Applying this approach with hydrologic and related data, precipitation and evapotranspiration models, and GIS software, Brown et al. (In preparation) estimated the average annual amount of streamflow originating within each WRR and on national forests within each WRR over

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[64] The total value of water from a national forest might be thought of as analogous to total sales of a given product produced by a multi-product firm, but this analogy is not accurate for most national forests. Total sales are computed as quantity times price. For a firm in a purely competitive market, where each firm produces such a small proportion of market supply that marginal value and average value both essentially equal price, such a measure of total sales would (ignoring production costs) equal total value. However, for a firm large enough to produce a substantial portion of market supply (which is analogous to a national forest that provides a substantial portion of a basin's water supply), average value of the firm's production will exceed marginal value and total sales will underestimate total value.

[65] See Diaz and Brown (1997, Chapter 2) for a summary of studies of the elasticity of demand for water at current consumption levels and for conjectures about the shape of demand curves for different water uses.

the period 1953-1994. Comparing these two sets of estimates yields the percentage of water supply originating on national forests, listed in Table B1. These percentages are multiplied by the USGS estimates of water supply originating in the WRRs, listed in Table 21 and reproduced in Table B1, to yield the amount of available water supply originating on national forests.

As a conservative estimate of average value we use marginal value, which can be considered a lower bound on average value. This approach is most reasonable if option 2 for estimating average value (where flow from the national forest is considered marginal to total flow in the watershed—see above) is adopted, for in this case average value is not likely to be a great deal larger than marginal value. This approach is depicted in Figure C3, where supply is constrained at Q_1, marginal value is MV, the national forest contributes Q_1-Q_2 of the water consumed, and the average value of that contribution is AV. Multiplying (Q_1-Q_2 by MV yields a lower bound on having multiplied Q_1-Q_2 by AV.

Adopting option 2 and using the total marginal values from Table 26, reproduced in Table B1, as estimates of the average values by WRR, we obtain a lower bound on total value of the contribution to water supply from national forests by multiplying water supply originating on national forests by the total marginal values. As seen in the table, the total values vary widely across the WRRs, and sum to $7.2 billion per year.

The distance between MV and AV will depend on the slope of the demand curve and on the proportion of total flow contributed by the national forests of the basin—the steeper the slope and the greater the proportion of flow contributed by national forests, the greater is the distance between the two estimates of unit value and thus the more that total value is underestimated by using MV to represent AV. Let us, therefore, consider these two effects. The demand curve will be flatter (i.e., less negative) in basins where a large portion of the water goes to low-valued uses, such as irrigation of low-valued crops (see, for example, the irrigation demand curve in Figure 4). As reported in Table B1, the portion of total water withdrawal used for irrigation is largest in the western WRRs.[66] Finally, as reported in Table B1, the proportion of total flow originating on national forests also tends to be greatest in the western WRRs. Thus, in the western WRRs the underestimation of total value—in using MV for AV—caused by the large contributions of flow from national forests thus tends to be ameliorated by the large proportion of withdrawal going to irrigation.

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[66] In most areas at least 50% of the irrigation water is used on lower-valued crops.

Table B1. Lower bound of total value of runoff from national forests in the 48 states

Water resource region	Mean annual supply (million acre-feet)	Percent from national forests	Marginal value per acre-foot per year	Total value (million dollars per year)	Percent of annual withdrawal used for irrigation*
1. New England	87	4	7	27	4
2. Mid-Atlantic	109	4	9	37	1
3. South-Atlantic-Gulf	238	6	8	114	15
4. Great Lakes	88	9	17	128	1
5. Ohio	157	8	9	110	0
6.Tennessee	49	20	15	151	1
7. Upper Mississippi	87	2	10	18	2
8. Lower Mississippi	85	4	5	19	41
9. Souris-Red-Rainy	9	16	7	9	35
10. Missouri	75	13	42	417	68
11. Arkansas-White-Red	71	9	14	87	58
12.Texas-Gulf	40	3	21	25	31
13. Rio Grande	5	16	46	40	90
14. Upper Colorado	15	30	57	251	95
15. Lower Colorado	3	25	84	73	81
16. Great Basin	9	29	54	143	85
17. Pacific Northwest	326	52	20	3452	80
18. California	93	51	45	2110	80
Total	1545	17		7211	

* Source: Solley et al. (1998)

Figure B1. Consumption with excess supply of a costless commodity

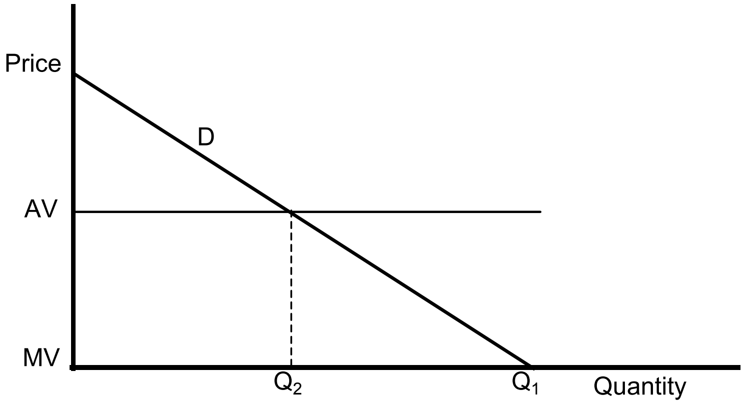

Figure B2. A choice of average values

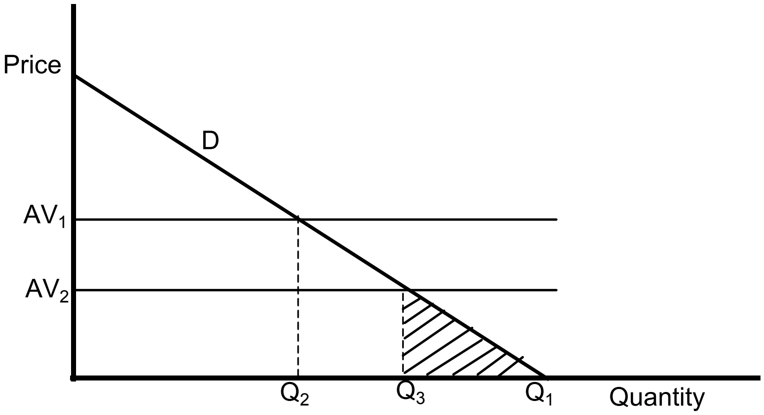

Figure B3. Lower bound on total value