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WATER LAW, WATER TRANSFERS, AND ECONOMIC EFFICIENCY: THE COLORADO RIVER*

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ALLOCATIVE inefficiency in water use arising from restrictions on the transfer of water rights is not a new theme. However, the doctrine of prior appropriation, by which users acquiring water rights earlier in time have seniority in periods of "low" river flow, generates additional inefficiencies as a consequence of unequal sharing of risk among appropriators.[1] Inefficiencies can also arise from suboptimal storage policies.[2] Finally, most uses of water generally result in return flows to the rivercourse, which, in the face of inadequately defined entitlements to water, generate externalities that can present substantial obstructions to the transfer of water rights, hence fostering further inefficiencies.

While the analysis of the present paper is intended to be general, we have set it in the backdrop of the Colorado River so as to fix the concepts and problems more concretely. As the Colorado River is the single most important source of water supply in the arid West, it seems an appropriate context in which to perform the analysis.

In the tradition of Posner[3] and others we consider economic efficiency the major determinant in the development of legal doctrines, so that generally, at least in a naive sense, we cannot discriminate between economic and legal efficiency. However, in those instances where there is a distinction—emanating from the failure of statutes to adapt to changing economic climates—administrative efficiency and distributional considerations may suggest a second best answer to the problem of economic efficiency.

We first present a brief description of the Colorado River and the historical events that have led to its present state of development. We then present

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[1] This result is developed in detail in Section II-A *infra*.

[2] See H. Stuart Burness & James P. Quirk, Water Rights and Optimal Reservoir Management (December, 1977) (Calif. Inst. Tech., Soc. Sci. Working Paper No. 165).

[3] Richard A. Posner, Economic Analysis of Law (2nd ed. 1977).

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a descriptive model of a river economy based on the doctrine of prior appropriation water rights and find that unequal sharing of risks generates inefficiencies in the absence of transferable water rights. In examining the obstacles to water-rights transfer, we find that the current doctrine is inadequate to resolve the attendant problems; in particular, under current water law, externalities in the form of return flows cannot be internalized. A characterization of optimal river development suggests possible modifications of the appropriative doctrine.

I. The Colorado River: Background

Since the closing of Hoover Dam in 1936, the Colorado River with its elaborate system of diversion and storage works has become perhaps the most controlled and closely monitored watercourse in the entire world. Of the 13.5 million acre feet (MAF) average yearly runoff, scarcely a bucketful more than the 1.5 MAF required by treaty is delivered to Mexico. Everything else is either consumed for agricultural, domestic, municipal, and industrial purposes or stored for possible future uses.

The importance of the Colorado derives not from its size but from the fact that it is essentially the only source of surface water in this arid region.[4] Consequently, the history of the river is marked by repeated and continual controversy, resulting in a plethora of institutions that account for the current patterns of water rights, water use, and water storage. What is surprising is that, for the most part, allocation of the river among interested parties has been accomplished primarily through compact and legislation rather than litigation.

The cornerstone of the Colorado River's institutional structure is the Colorado River Compact of 1922. In principle the compact divided the waters of the Colorado between the Upper and Lower Basin states.[5] The desire to consummate such a division was mutual. The Reclamation Act of 1902 had encouraged the development of the Lower Basin with its richer soil and longer growing season. The Upper Basin was concerned that acquisition of water rights in the Lower Basin might preclude later Upper Basin development.

[4] The Colorado River Basin comprises some 242,000 square miles of drainage area, and the Colorado River's average historical runoff at Lee Ferry of 13.5 MAF is small compared to other river basins. For example, the Columbia River's drainage area is considerably smaller while its runoff exceeds that of the Colorado by an order of magnitude. At the other extreme, the Delaware River has a runoff that approximates that of the Colorado River while its drainage area is only a tenth of the Colorado River Basin. The geographical location of the Colorado River Basin is shown in Figure I.

[5] Colorado, Wyoming, Utah, and New Mexico comprise the Upper Basin while California, Arizona, and Nevada comprise the Lower Basin.

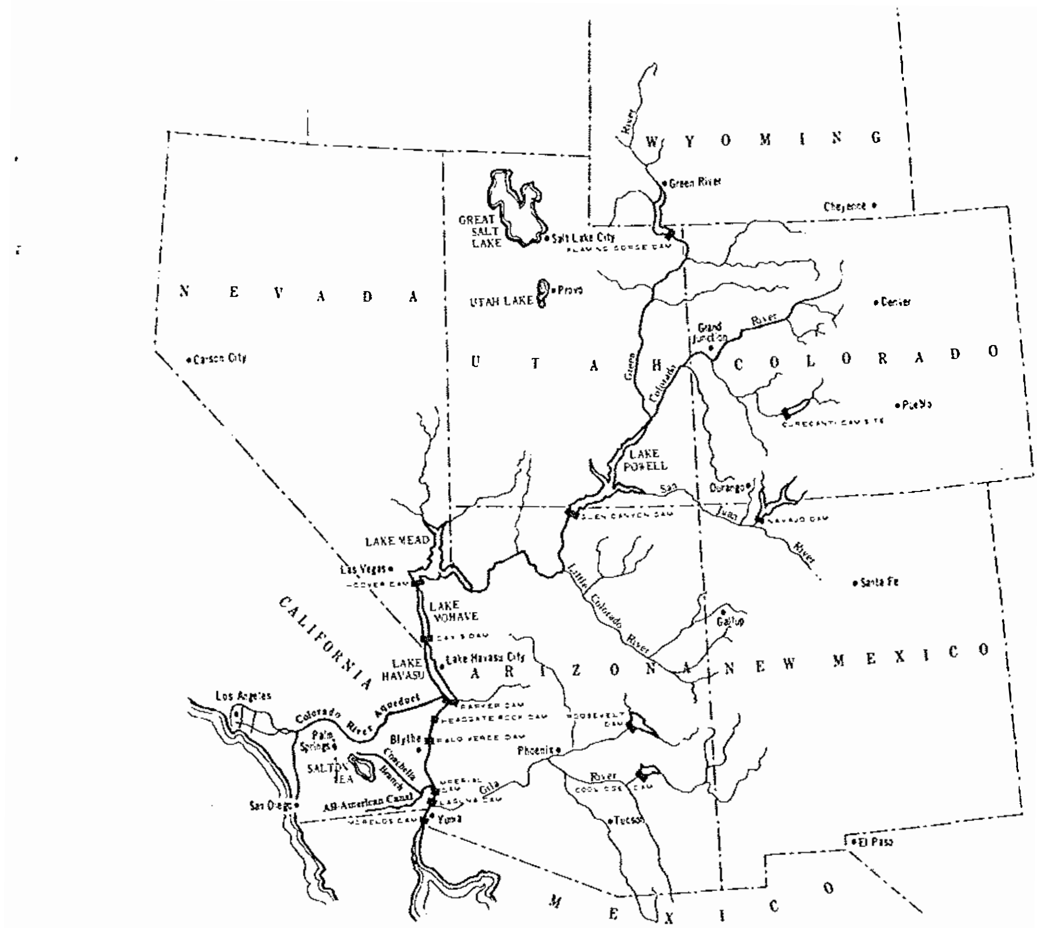

FIGURE I
THE COLORADO RIVER BASIN
Source: Annual Report, 1975, Colorado River Board of California

However, the Lower Basin was not without problems of its own. The diversion works for the Imperial Valley irrigation area in Southern California required the delivery of water through Mexico via the Alamo Canal. The problems associated with dual sovereignty were compounded by a ruinous flood in 1904-1905, and pressures for an all-American canal and a Lower Basin storage facility to regulate river flow grew steadily.

Due to the enormous costs and the legal aspects of controlling an interstate stream, the participation of the federal government was required. As the construction of such a project would worsen the Upper Basin's position vis-à-vis the Lower Basin, it was clear that a guarantee for Upper Basin rights would be required as a part of any agreement to control the river. This guarantee appeared in the terms of the compact.[6]

The dominant provision of the compact was the Upper Basin's requirement to deliver 75 MAF of water at Lee Ferry, Arizona (the dividing point between the Upper and Lower Basins) during every ten-year period. At the time the compact was struck, best estimates placed the average annual runoff of the Colorado at 15 to 16 MAF per year. Given an average flow of 15 MAF per year, the Upper Basin's obligation to deliver 7.5 MAF each year on the average effectively meant that the Upper Basin shouldered the brunt of the stream-variability burden.[7] More importantly, recent studies by the Lake Powell Research Group indicate that earlier estimates of river flows were biased upwards and that actual long-run average flows are roughly 13.5 MAF per year. Thus after deliveries to the Lower Basin (7.5 MAF) adjusted upward to reflect the Upper Basin's share (.75 MAF) of the 1.5 MAF required by treaty for delivery to Mexico, only 5.25 MAF per year is available, on average, for consumption in the Upper Basin; and even this must be reduced (to 4.75 MAF) to account for evaporation losses in Upper Basin reservoirs.

In contrast with this, consider the situation in the Lower Basin where gross deliveries of 8.25 MAF are received. Inflows between Lee Ferry and Lake Mead average .8 MAF per year, just offsetting evaporation losses in Lake Mead. Subtracting the Mexican requirement of 1.5 MAF per year, approximately 6.75 MAF of water is available for Lower Basin consumption in a given year. While the Upper Basin is about 1 MAF from complete appropriation, almost all Lower Basin water is used. Current uses of the Lower Basin's allocation are: Arizona, 1.2 MAF; California, 5.0 MAF (al-

[6] The compact was the outcome of the first of a series of controversies concerning the Colorado River. Other controversies concerned the division of waters among the Upper Basin states (the Boulder Canyon Project Act of 1928, which transformed the compact into law had already allocated water among the Lower Basin states—4.4 MAF to California, 2.8 MAF to Arizona, and .3 MAF to Nevada), the extent of the United States's obligation to deliver water to Mexico, and a continuing feud between Arizona and California arising from Arizona's fear of losing its undeveloped water allocations to California. The latter feud ended with the U.S. Supreme Court decision in Arizona v. California 373 U.S. 546 (1963), which, among other things, ultimately led to the commencement of the construction on the Central Arizona Project, a highline canal to deliver 1.3 MAF of water annually to the Phoenix-Tucson area at a cost of $1.4 billion. For a thorough analysis of the events leading up to the legislation and litigation arising from these controversies see Charles J. Meyers, The Colorado River, 19 Stanford L. Rev. 1 (1966); and Charles J. Meyers & Richard L. Noble, The Colorado River: The Treaty with Mexico, 19 Stanford L. Rev. 367 (1967). For an historical narrative of the compact see Norris Hundley, Water and the West (1975).

[7] While the compact actually requires 75 MAF to be delivered every ten years, the Bureau of Reclamation's release policy makes it appear that the Upper Basin would have little latitude in passing variability on to the Lower Basin.

though California's consumption had been as high as 5.4 MAF in previous years); Nevada, .1 MAF. Allocations for the three states are: Arizona, 2.8 MAF; California, 4.4 MAF; Nevada, 0.3 MAF. However, after the Central Arizona Project comes on line in 1985, none of these states will receive their full allotment. After prorationing for Mexican deliveries, available water will be: Arizona, 2.5 MAF; California, 4.0 MAF; Nevada, 0.29 MAF, assuming no drawdown on reservoir levels. This will be felt most severely in California which must experience 1 MAF loss in reduced consumption of Colorado River water yearly.[8]

II. Economic Aspects of Colorado River Use

In the previous section we outlined aggregate allocational problems pertinent to the Colorado River. Other problems arise from the doctrine of appropriative water rights, past and present storage policies—and the Bureau of Reclamation's implicit policy of determining limitations on appropriations and its corresponding release policies—and inadequate definition of rights to return flows. The technical aspects of appropriative water rights and questions related to storage are analyzed elsewhere.[9] In the following sections we attempt to identify the inefficiencies fostered by the appropriative doctrine.

A. *The Pure Doctrine of Prior Appropriation*

In the humid eastern United States the doctrine of riparian water rights descended from the English common law. Riparian water rights are based on the right of a landowner whose property is bordered by water to use that water on his land. The right is usufructuary so that, strictly speaking, the owner may not diminish the supply of water. However, the doctrine is interpreted so that riparians may make withdrawals that are "reasonable" in relation to the needs of downstream riparians.

The dominant use of water in the United States is consumptive private use primarily in irrigation, industry, and municipal water supplies. Use in the arid Colorado River Basin is dominated by irrigated agriculture. Because irrigation diverts large quantities of water with low return flows, significant quantities of water are not returned to the river. Thus, in spite of "reasonable use" modifications, the riparian doctrine is inadequate in the case of rivers used for irrigation. Consequently, a western American innovation emerged in the form of the doctrine of appropriative water rights. Under this

[8] Claims on the river will be even greater when the questions of Indian and federal reserved rights are addressed. The figures stated in the text are a matter of dispute among the Lower Basin states.

[9] See, respectively, H. Stuart Burness & James P. Quirk, Appropriative Water Rights and the Efficient Allocation of Resources, 69 Am. Econ. Rev. 25 (1979); and *id.* Water Rights and Optimal Reservoir Management, *supra* note 2.

doctrine, rights are obtained by physically diverting water and putting it to beneficial consumptive use. Under the appropriative doctrine, priorities are determined by the chronological pattern in which uses are developed: "first in time means first in right." However, in times of extreme drought, priorities are generally established in the order: (1) municipal and domestic; (2) irrigation; (3) commercial and industrial. In this event compensation may be required for senior appropriators whose rights are temporarily usurped.

Adopting beneficial consumptive use as the standard for obtaining the water property right was necessary in order to encourage investment in facilities for diverting water, on the one hand, and to limit appropriation and thus discourage undue speculation in unappropriated waters, on the other.[10] However, following Dales[11] we observe that the property right is not an absolute right to the associated property but rather a right to use the property in a prescribed fashion. Under the appropriative doctrine the tenet of beneficial consumptive use in essence allows the use or diversion of a quantity of water for a specified purpose as prescribed by contract, but ignores the question of ownership of return flows. We examine the nature of return-flow externalities in more detail later. In the remainder of this section we analyze the efficiency properties of the appropriative doctrine for a simplified paradigm in which there are no return flows.

With zero-return flows, the pattern of priorities established by the chronological sequence of an appropriator's diversions might seem to guarantee the tenure certainty of senior rights owners.[12] Unfortunately in practice this is not always easy to assure. Due to spatial dispersion of appropriators, informational inadequacies, and random elements, it is often difficult to determine whether a diminished downstream flow to appropriators is the result of the stochastic nature of river flows or of the actions of upstream appropriators. Moreover, this tenet of the appropriative doctrine, while assuring an aspect of legal efficiency, is bought at the cost of economic inefficiency, for each subsequent appropriator faces a distribution over river flows which is less desirable than that faced by his immediate predecessor. The probability of the first appropriator's delivery exceeding a certain benchmark quantity is always greater than the probability of the second appropriator's delivery exceeding that benchmark quantity; this relationship holds for any given benchmark quantity and for any senior-junior comparison.

[10] C. J. Meyers & Richard A. Posner, Market Transfers of Water Rights: Toward an Improved Market in Water Resources (National Water Commission, Legal Study No. 4, NWC-L-71-009, July 1971), indicate that the limitation to beneficial consumptive use does not necessarily eliminate speculation or always preclude uneconomic uses. They suggest as an alternative that rights to unappropriated waters be auctioned off.

[11] J. H. Dales, Land, Water and Ownership, 1 Can. J. Econ. 791 (1968).

[12] Tenure certainty is the protection of a rights owner against the loss of right through the legal action of others.

To see this, number appropriators in order of their seniority in claims to water, with the most senior appropriator being number 1, the next most senior number 2, and so forth. Let a_i denote the amount of water rights of appropriator i and let $A_{i-1} = \sum_{j=1}^{i-1} a_j$ denote the total of water rights senior to appropriator i. Let $f(x)$ denote the probability density function (*pdf*) over streamflows x, and let $g_i(x_i)$ denote the *pdf* over streamflows facing appropriator i. Then we have $g_i(0) = F(A_{i-1})$, with $g_i(z) = f(A_{i-1} + z)$ for any $z \geqslant 0$.

In particular, the probability that appropriator i will receive b units of water or more is given by

$$1 - G_i(b) \equiv \int_b^{\infty} g_i(z)dz = 1 - F(A_{i-1} + b).$$

Since $A_{i-1} < A_{j-1}$ for $i < j$, it follows that $1 - F(A_{i-1} + b) \geqq 1 - F(A_{j-1} + b)$ for any $i < j$, with strict inequality for $F(A_{i-1} + b) > 0$, $F(A_{j-1} + b) < 1$. That is, senior appropriators face more desirable probability distributions over streamflows than do junior appropriators. This is illustrated in Figure II.

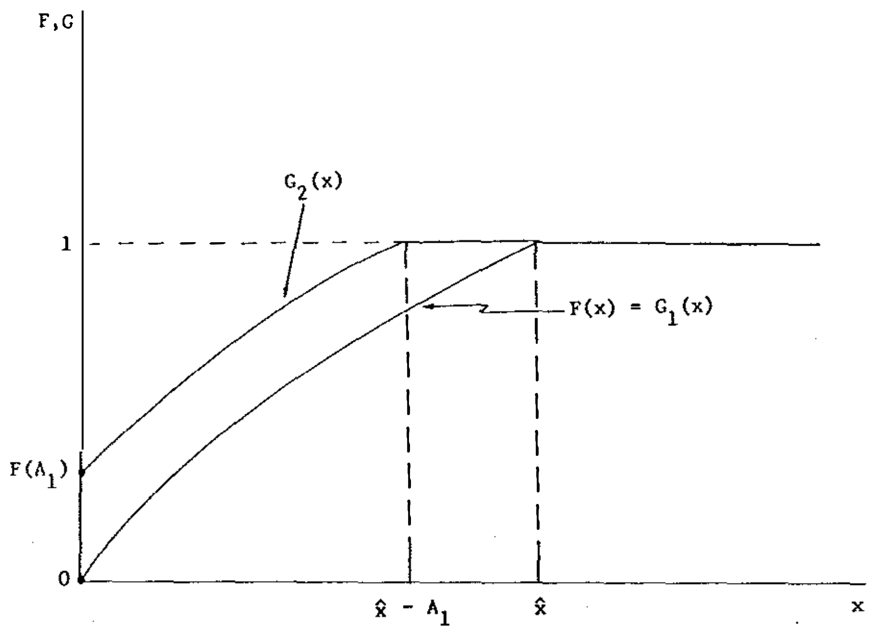

FIGURE II
PROBABILITY DISTRIBUTIONS OVER RIVER FLOWS FACED BY THE FIRST APPROPRIATOR ($G_1(X)$) AND THE SECOND APPROPRIATOR ($G_2(X)$)
($\hat{x}$ Is the Maximum Flow of the River)

Because of the natural applicability to the Colorado River system of downstream water use, we conduct our analysis of the appropriative doctrine in the context of a paradigm of downstream water use. When available, appropriators receive their allocation and consume it in its entirety; there are zero return flows. In addition, surplus water bypasses appropriators; there are no flood damages. We also knowingly omit scenic, recreational, and public good properties as well as hydroelectric possibilities.[13] In a sense such a model, given its limitations, is quite appropriate for the Colorado River Basin. Consider especially the Lower Basin, where of the 6.75 MAF available for use, approximately 5.5 MAF is used in agriculture. The presence of diversion facilities along the river renders the possibilities of flood damage minimal. In the quest for simplicity we posit the existence of firms producing identical products, with the same production function. This assumption can be relaxed with no qualitative change in results but at the cost of much more cumbersome arguments.

The profits for a representative firm consist of revenues minus costs. Revenues (R) depend on deliveries of water (d) while costs (C) depend on diversion capacity (a) installed. Thus $C(a)$ is the annualized construction and maintenance costs of a diversion facility of size a. We assume that costs are, within a range, independent of deliveries so that facilities deteriorate with age and not with use. As no firm constructs capacity in excess of its right to receive water and the limitation of beneficial consumptive use precludes the user from having rights in excess of his ability to divert water, we can identify a as the firm's water right.[14] As a first approximation, we suppose that the revenue function is nondecreasing with nonincreasing marginal returns to diversion. As the firm's diversions cannot exceed its diversion capacity, the assumption of no flood damages implies that water in excess of a merely bypasses the diverter, giving the revenue function the appearance in Figure III.

Without loss of generality, we assume there are no delivery costs; capacity costs are shown in Figure IV.[15] The latter are assumed to be increasing with nondecreasing marginal costs as well.[16]

[13] These are not negligible. Hoover Dam produces in excess of 3,000 MW. However, the situation is perhaps self-correcting. One-half of this power goes to Southern California Edison, of which two-thirds is needed to pump water up over the Palo Verde mountain range so it can begin its descent into the metropolitan Southern California area. However, as the Metropolitan Water District has lowest priority among the California water users, in the event of a water shortage they would be the first to lose service and hence power needs would be lessened. In this case the reduction of a generating head in Lake Mead would be only of secondary importance.

[14] When return flows are nonzero, we will no longer be unambiguously able to equate diversion capacity with water rights.

[15] In fact, the Bureau of Reclamation charges Lower Basin users 25 cents to 50 cents per acre foot of water to cover operating costs of its reservoirs.

[16] Note that once diversion capacity is installed, the related costs are sunk.

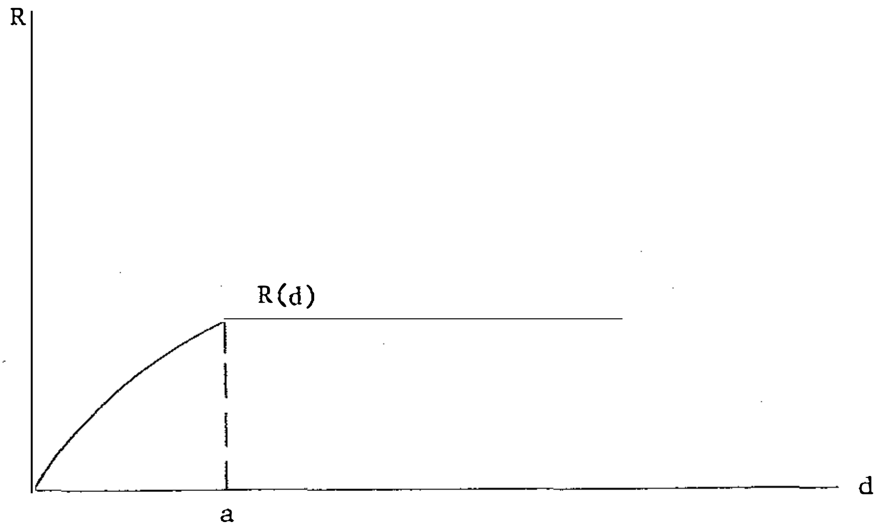

FIGURE III
THE APPROPRIATOR'S REVENUE FUNCTION

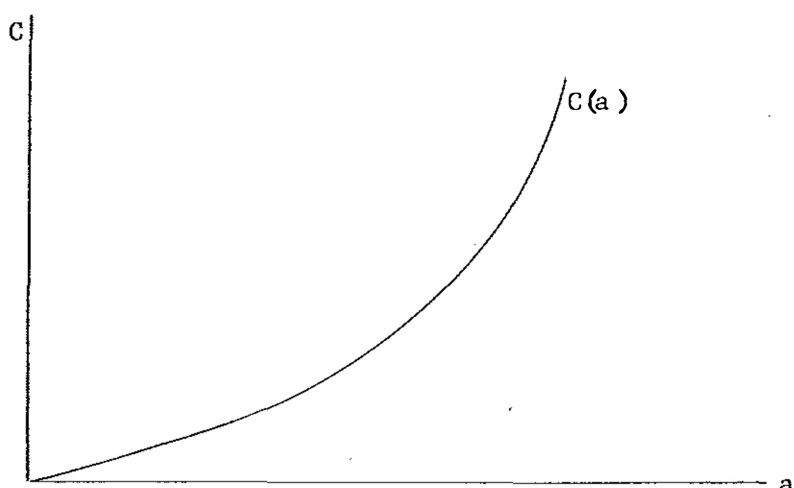

FIGURE IV
ANNUALIZED CAPACITY COSTS

As shown above, senior appropriators face preferred distributions over streamflows. Hence senior appropriators tend to build larger diversion capacities vis-à-vis junior appropriators. To see this we employ an argument analogous to the river-flow argument above. Given the assumption of identical firms, the probability that revenues for the first firm exceed a certain benchmark level is at least as great as the probability that revenues for the second firm exceed that benchmark level, and so on. This implies that at any level of capacity expected revenues for the first firm exceed those for the second. Since expected profits equal expected revenues minus (deterministic) capacity construction costs, the expected profit-maximizing diversion capacity must satisfy marginal expected revenue equal to marginal cost. For any level of capacity, we have marginal expected revenue for the first appropriator exceeding that of the second. With diminishing marginal revenue and each firm facing identical cost functions, at a maximum of expected profits the first firm builds diversion capacity which exceeds that of the second firm.[17] (See Figure V.)

Given that senior appropriators build larger diversion facilities and obtain rights to larger quantities of water than do junior appropriators, we can now identify the economic inefficiencies due to the appropriate doctrine. To do this we construct an alternative to the appropriative doctrine.

Our alternative is similar to the doctrine of correlative water rights in ground water law. The correlative doctrine emerged as a consequence of the

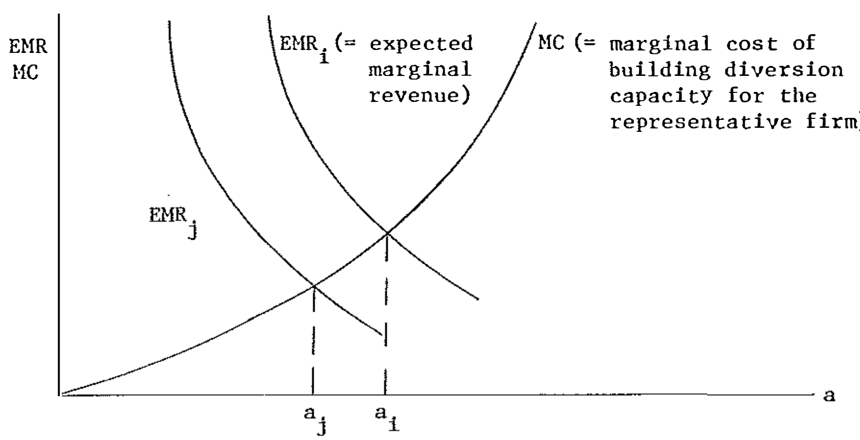

FIGURE V
SENIOR APPROPRIATORS APPROPRIATE MORE WATER
($a_i > a_j$ for $i < j$; i Is the Senior Appropriator and j Is the Junior Appropriator)

[17] For a more detailed statement of this argument, see Burness & Quirk, *supra* note 9.

common property characteristics of percolating ground water with the landowner's rights in the common pool limited to the proportion of his overlying land to all land overlying the pool. In our paradigm all firms are identical, so we propose as an alternative a doctrine of equal sharing; thus all streamflows are divided equally among appropriators. We show that for any streamflow equal sharing leads to greater aggregate profits than does the appropriative doctrine.

When water is reallocated, diversion capacity must be reallocated; but we can ignore this fact since all capacity costs are sunk. Thus we need consider only revenues. We consider the case of two appropriators.[18] Under decreasing marginal productivity in water use we observe that, at capacity, marginal revenue of the first appropriator is less than that of the second appropriator for any level of deliveries to the second appropriator. Since under the appropriative doctrine the second appropriator receives no water until the first appropriator is diverting at maximum capacity, the productivity of the last unit of water received by the second appropriator is always greater than that of the last unit of water received by the first appropriator, for any level of river flows. Consequently, aggregate productivity and hence revenue can be increased by reallocating water from the first appropriator to the second. In fact aggregate productivity (revenues) is maximized when the marginal productivity of the first appropriator equals that of the second appropriator for all levels of river flows. But this means that aggregate diversion capacity and river flows are divided equally between them. Since aggregate revenues (profits) are maximized in all possible states of nature under equal sharing, it follows that the appropriative system is inefficient.[19] A graphical exposition appears in Figure VI.

An application of the Coase theorem[20] provides a straightforward mechanism to effect an equal-sharing allocation. With the establishment of competitive markets in which water rights can be freely bought and sold, the inefficiencies identified above can be eliminated. While all water economists espouse freely transferable water rights, it is for a somewhat more basic reason that do we. Usually when the transfer of water rights is advocated, it

[18] The argument immediately generalizes to an arbitrary finite number of appropriators.

[19] This result holds, *ceteris paribus*, regardless of whether or not diversion capacity is reallocated among appropriators. If diversion capacity is not reallocated, then aggregrate profits are maximized by equating, if possible, the marginal revenue product of water between the two users; otherwise, one can completely satisfy the needs of the junior appropriator and deliver all remaining water to the senior appropriator. If diversion capacity can be reallocated, intuition suggests that diversion capacity and water delivered be divided equally among all appropriators. In Burness & Quirk, *supra* note 9, we show that such an allocation is Pareto optimal, given increasing marginal costs of constructing diversion capacity, with appropriate extensions to the case where a range of decreasing marginal costs are allowed.

[20] R. H. Coase, The Problem of Social Cost, 3 J. Law & Econ. 1 (1960).

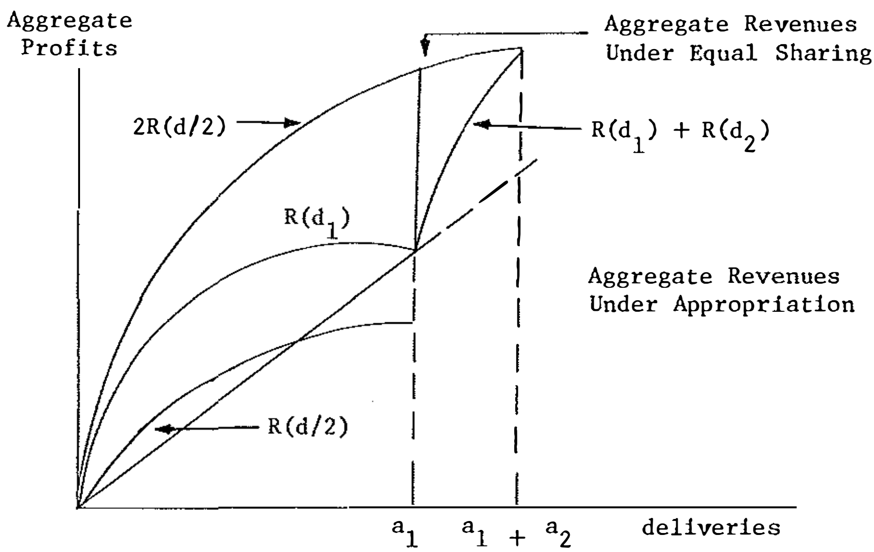

FIGURE VI
REVENUES UNDER APPROPRIATION AND EQUAL SHARING

is in order that, among different alternative uses, water will be assigned to its most productive use.[21] We have observed that even among identical users inefficiencies remain under the appropriative doctrine when the transfer of water rights is prohibited. These inefficiencies stem from the unequal sharing of risk along the river and the resultant priority-related allocations and actual deliveries of water.[22]

However the transfer of water rights is not without problems. Because of imperfect substitutability among priority levels of water availability, monopoly problems may exist. Presumably this could be eliminated through an appropriate system of bribes.

At a competitive equilibrium with N identical firms and with freely transferable water rights, each appropriator purchases $1/N$th of every other appropriator's water right and diversion capacity: the doctrine of equal sharing is effected. As all diversion works are perfect substitutes for each other, the price per unit of capacity is the same for all firms. The price per unit of firm i's water right, including the associated diversion capacity cost, is equal to the marginal expected profitability of water use by the ith firm at the equilibrium allocation. As senior appropriators originally possessed a more attrac-

[21] See, for example, J. W. Milliman, Water Law and Private Decision Making: A Critique, 2 J. Law & Econ. 41 (1959).

[22] Even in our scenario, which abstracts from risk aversion, this is true, as by the profit function profits are nonlinear in water deliveries.

tive right, the per unit price of their rights exceeds that of junior appropriators. However, at the equilibrium prices purchasers are indifferent among suppliers at the margin; equilibrium prices are risk adjusted.

B. *The Problem of Return Flows*

Ultimately, the cause of inefficiency in the appropriative doctrine is the restrictions on the transfer of water rights. Limitations on the transferability of water rights exist in the form of federal, interstate, interregional, and intrastate restrictions. Federal controls stem primarily from concerns over the repayment of construction and operation and maintenance costs of storage and diversion facilities. Interregional restrictions in the case of the Colorado River exist in the 1948 compact (Upper Basin) and the 1963 Supreme Court decision, *Arizona v. California* (Lower Basin). Intrastate restrictions stem from the historical notion that water rights should be tied to the land and, to some extent, the purpose to which the original right was assigned.

Under the appropriative doctrine, one way in which water transfers can be prevented is the following. If the proposed transfer of an existing water right would impair the right of a third party, then the transfer is not allowed. If challenged, the seller bears the burden of proving nonimpairment, generally a quite costly process. While the appropriative doctrine seems clear on the matter of rights of senior vis-à-vis junior appropriators, in fact the doctrine does not adequately delineate rights to return flows.

In the bulk of the literature on the appropriative doctrine, wherever the tenet of "beneficial consumptive use" is discussed, the focus is on "beneficial." Although there is doubt whether the limitation to "beneficial" use is meaningful, there is more doubt whether it is appropriate.[23]

In conjunction with the issue of return flows, focus falls more naturally on the "consumptive" aspect of water use.[24] Most uses of water require the diversion or application of more water than is actually consumed: return flows may be as low as 5 to 10 per cent for evaporative cooling, range from 30 to 60 per cent in agricultural use, or be as high as 80 to 90 per cent for domestic and municipal use. The return flows thus generated are externalities which upstream appropriators create and downstream users capture.

[23] F. C. Struckmeyer & J. E. Butler, Water: A Review of Rights in Arizona, Arizona Weekly Gazette, 1960, recount the case of a California farmer who, during the off-season, used his irrigation water to flood gophers from their holes. The courts subsequently enjoined this use.

[24] Both the Upper and Lower Basin employ accounting methods for water use based on the notion of beneficial consumptive use, or at least a close proxy. The Lower Basin uses "diversions less return flows" as the accounting method; the Upper Basin uses "net depletions." The former is exactly "beneficial consumptive use," the latter is diversions less return flow *plus* any water that the user could salvage, say by employing more efficient methods (as opposed to types) of use, such as lining of diversion canals, and so on. While these practices account for water consumed, they do not assign rights to return flows.

As current water law does not adequately specify rights to return flows, we investigate the economic aspects of return flows and suggest modifications to the existing doctrine.

We follow the notation introduced in the previous section and let β be the fraction of water diverted by the typical firm that is actually consumed.[25] Thus $1 - \beta$ is the fraction of return flows. Given this, two possible configurations of river use are considered. In one the river develops from its mouth upstream, in the other from its source downstream. In either case successive appropriators face a less "desirable" river than before, so that, by the analysis of the previous section, junior appropriators build smaller diversion capacities. We assert that the development from a source downstream leads to higher profits. When developing from the mouth upstream, the largest appropriator is farthest downstream and no one is there to capture his (large) return flow. Alternatively we can ask whether a new appropriator would prefer to locate upstream or downstream relative to an existing appropriator, *ceteris paribus*. We answer the question in the context of a deterministic river flow although the argument generalizes, with some additional complexity, for stochastic river flows.

Suppose the river flow is 1000-acre feet per year with certainty and an existing appropriator has a delivery contract for that entire amount. Clearly our new appropriator prefers to locate downstream as in that case he can divert the existing appropriator's return flow; upstream he can divert nothing. Thus, optimally, the river develops from the source downstream.[26] In this way downstream junior appropriators can capture the return flows generated by their upstream seniors. Moreover, the argument shows that this manner of river development is incentive-compatible on an individual decision-making basis as well.

Although there are no market-related forces that guarantee the delivery of return flows to downstream users, it appears that the limitation of beneficial consumptive use would suffice to ensure the production of return-flow externalities. In fact it does, and the limitation of beneficial consumptive use has the potential to disrupt economic efficiency only when the transfer of rights is considered and, in particular, only when the right is transferred outside the hydrologic system within which the right is defined.

[25] The value of β, to an extent, dictates the most suitable rights doctrine. For example, if $\beta = 1$ there are no return flows, indicating the suitability of the appropriative doctrine. On the other hand, when $\beta = 0$ there are 100% return flows, or, alternatively, no actual consumption of diverted water occurs. In this case the riparian doctrine seems natural.

[26] The generally observed pattern of development from the mouth upstream, as in the case of the Colorado River, occurs then in spite of the nature of water rights rather than because of them. Generally this is attributed to climatic factors, longer growing seasons, more productive soil, and so forth. It also might be noted that among the furthest downstream divertors is the Imperial Valley, where there is no return flow; instead the runoff drains into the Salton Sea.

C. *Solutions to the Problem of Return Flows*

We now separate the problems inherent in the appropriative doctrine from the problems of return flows. We assume that among a fixed number of appropriators (N) with fixed aggregate diversion capacity (A_N), individual diversion capacities and the schedule of deliveries to individual divertors are determined so as to produce a maximum of aggregate profits along the river.

Somewhat surprisingly, at least at first blush, are the observations that when aggregate profits are maximized upstream firms (1) build larger diversion facilities (acquire a right to divert a larger quantity of water) and (2) have the delivery of water biased in their favor. At second glance these results are fairly intuitive: the superiority of upstream appropriators in producing externalities suggests that such a scheme is in fact Pareto optimal. One-acre foot of water delivered to the first appropriator generates externalities (return flows) of

$$(1 - \beta) + (1 - \beta)^2 + \ldots + (1 - \beta)^{N-1}$$

acre feet assuming that all downstream appropriators divert the maximum amount possible. In general an acre foot of water delivered to the ith appropriator generates return flows (including those by downstream users) in the amount

$$(1 - \beta) + (1 - \beta)^2 + \ldots + (1 - \beta)^{N-i}$$

acre feet. Thus for any given amount of water available (less than that which satisfies all appropriators) the first appropriator receives a larger proportion than the second, the second a larger proportion than the third, and so on, with the Nth appropriator receiving the smallest proportion. This is depicted in Figure VII for the case of three appropriators, with $\hat{x}$ the maximum flow of the river. It is well for us to emphasize at this juncture that this result holds for diversions from water available and not simply diversions from river flows; that is, $d_i(x)$ is diversions by firm i from river flows plus diversions from return flows. For any streamflow x, we have $\beta d_1(x) + \beta d_2(x) + d_3(x) = x$, while the fact that the river is completely appropriated implies that $\beta A_2 + a_3 = \hat{x}$. ($a_i = d_i(\hat{x})$ for $i = 1, 2, 3$).[27]

We now consider a hypothetical river whose (deterministic) flow is $\hat{x}$. If diversion capacity is costless to construct, the optimal allocation of water requires that $\hat{x}$ be assigned to the first firm, $(1 - \beta)\hat{x}$ to the second, and so on,

[27] Recall that $A_N = \sum_{i=1}^{N} a_i$, where a_i is the diversion capacity of firm i, and the quantity $\beta A_2 + a_3$ is the level of river flows at which all users will be satisfied; βA_2 is the amount consumed by the first two firms, while a_3, in a sense, is the amount consumed by the last appropriator since no one captures his return flow.

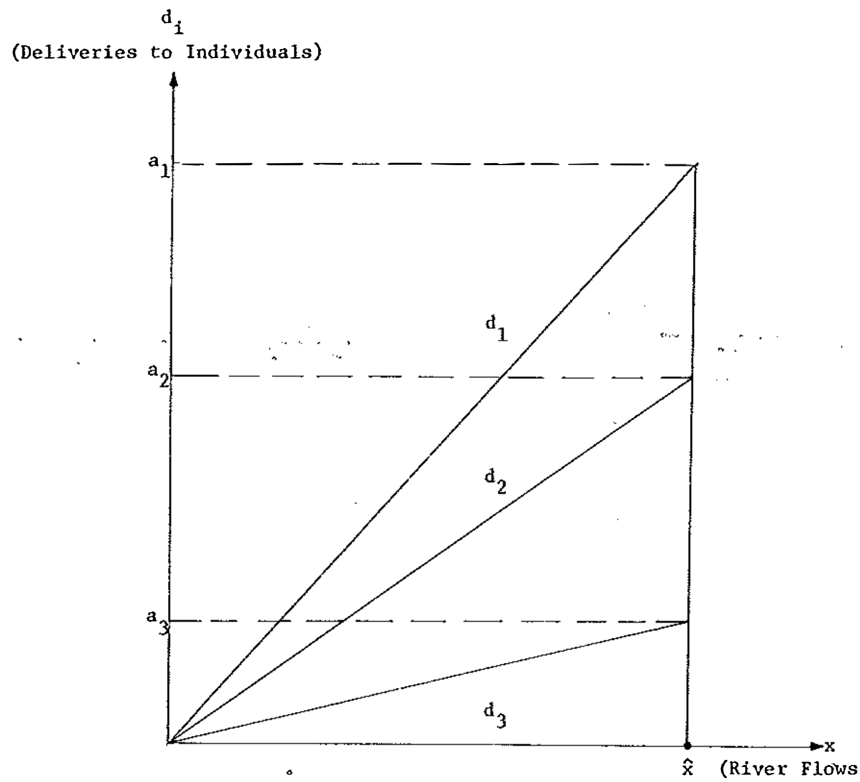

FIGURE VII
OPTIMAL INDIVIDUAL ALLOCATIONS AS A FUNCTION OF RIVER FLOWS: STOCHASTIC (VARIABLE) RIVER FLOWS
($N = 3$)

with each subsequent firm receiving only the return flow of his upstream neighbor; thus $a_1 = \hat{x}$, $a_2 = (1 - \beta)\hat{x}$, $a_3 = (1 - \beta)^2\hat{x}$, . . . , $a_N = (1 - \beta)^{N-1}\hat{x}$, where a_i is the diversion capacity of firm i. We assume that return flows are produced costlessly, so that given the pattern of river allocation, external benefits are equal to the total profits of firms 2 through N. We write the profit function of the first firm as $R(a_1) = R(\hat{x})$, that of the second firm as $R(a_2) = R((1 - \beta)\hat{x})$, and so on. The marginal revenue function of each firm is then $MR(d_i)$, $i = 1, \ldots, n$, as shown in Figure VIII. In particular note that the marginal revenue function for the representative firm is the change in that firm's revenue induced by a change in its water allocation.

Contrast this with the change in benefits resulting from, say, the importation of a marginal unit of water by the ith firm. In this case additional benefits of $MR(a_i)$ accrue to the ith firm, as well as additional benefits of (1 –

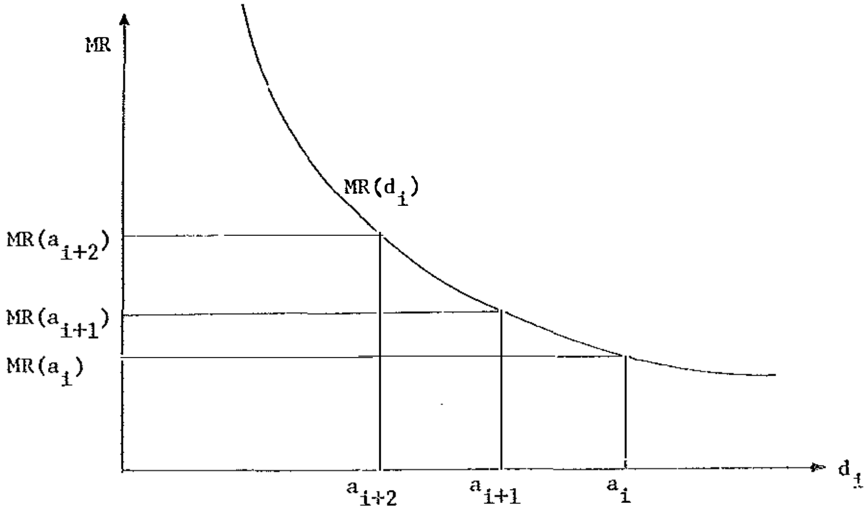

FIGURE VIII
THE MARGINAL REVENUE SCHEDULE

$\beta)MR(a_{i+1}) \equiv (1 - \beta)MR((1 - \beta)a_i)$ to the i + 1st firm, $(1 - \beta)^2MR(a_{i+2}) \equiv (1 - \beta)^2MR((1 - \beta)^2a_i)$ to the i + 2nd firm, and so on. That is, the ith firm's decision to import an acre foot of water generates a benefit to itself and benefits also all downstream firms through increased return flows. The potential for market failure is clear: unless the ith firm's decision to import reflects the downstream benefits it confers by doing so, too little water will be imported. Table 1 lists the additional benefits received and generated by each representative firm through importation of a marginal unit of water by that firm. Multiplication of each entry by minus one reflects the effect of diminished return flow due to water exports. In reading the table, the entry in, say, the fourth column and second row is the marginal benefit to the fourth firm resulting from the second firm's importation of a marginal unit of water. Summing across each row yields the aggregate additional benefits generated through the importation of a marginal unit of water by that firm. Summing down a given column yields the aggregate additional benefits accruing to that respective firm if it and all firms senior to it import a marginal unit of water.

In this manner Table 1 provides the answer to the problem of internalizing the externalities of return flows from importing or exporting water. In the fashion of Coase we find that the solution is symmetric; for example, the entry in column four and row two can be viewed either as the amount that firm four should pay to receive the externality or the amount that firm two

TABLE 1
MARGINAL BENEFITS RECEIVED AND GENERATED
($\alpha = 1 - \beta$)

FIRMS	Firm 1	Firm 2	Firm 3	Firm 4	. . .	Firm N	Total Generated
F.1	$MR(a_1)$	$\alpha MR(a_2)$	$\alpha^2 MR(a_3)$	$\alpha^3 MR(a_4)$	. . .	$\alpha^{N-1} MR(a_N)$	$\sum_{i=1}^{N} \alpha^{i-1} MR(a_i)$
F.2	0	$MR(a_2)$	$\alpha MR(a_3)$	$\alpha MR(a_4)$	. . .	$\alpha^{N-2} MR(a_N)$	$\sum_{i=1}^{N-1} \alpha^{i-1} MR(a_{i+1})$
F.3	0	0	$MR(a_3)$	$\alpha^1 MR(a_4)$	. . .	$\alpha^{N-3} MR(a_N)$	$\sum_{i=1}^{N-2} \alpha^{i-1} MR(a_{i+2})$
⋮	⋮	⋮	⋮	$MR(a_4)$	. . .	⋮	⋮
F.N-1	⋮	⋮	⋮	⋮	. . .	$\alpha MR(a_N)$	$\sum_{i=1}^{2} \alpha^{i-1} MR(a_{i+N-2})$
F.N	0	0	0	0	. . .	$MR(a_N)$	$MR(a_N)$
Total Received	$MR(a_1)$	$MR(a_2)(1 + \alpha)$	$MR(a_3) \sum_{i=0}^{2} \alpha_i$	$MR(a_4) \sum_{i=0}^{3} \alpha_i$	. . .	$MR(a_N) \sum_{i=0}^{N-1} \alpha_i$	$\sum_{k=0}^{N-1} \sum_{i=1}^{k-1} \alpha^k MR(a_i)$

should be fined if he fails to supply it (to firm four).[28] As is usual one cannot say, in the absence of transaction costs, which party should bear the burden or how it should be shared.

D. *Water Rights and Water Transfers*

We consider a river in which there are N users, as in the previous section, where all uses are consumptive and all uses provide return flows. We limit the analysis to the case where all existing and potential firms face the same technology.

There are two fundamental problems which need to be sorted out. One concerns the pattern of entitlements along the river; the other is water transfers. Entitlements delimit the pattern of river ownership and thus, within limits, the distribution of income along the river. Consider Figure IX. The

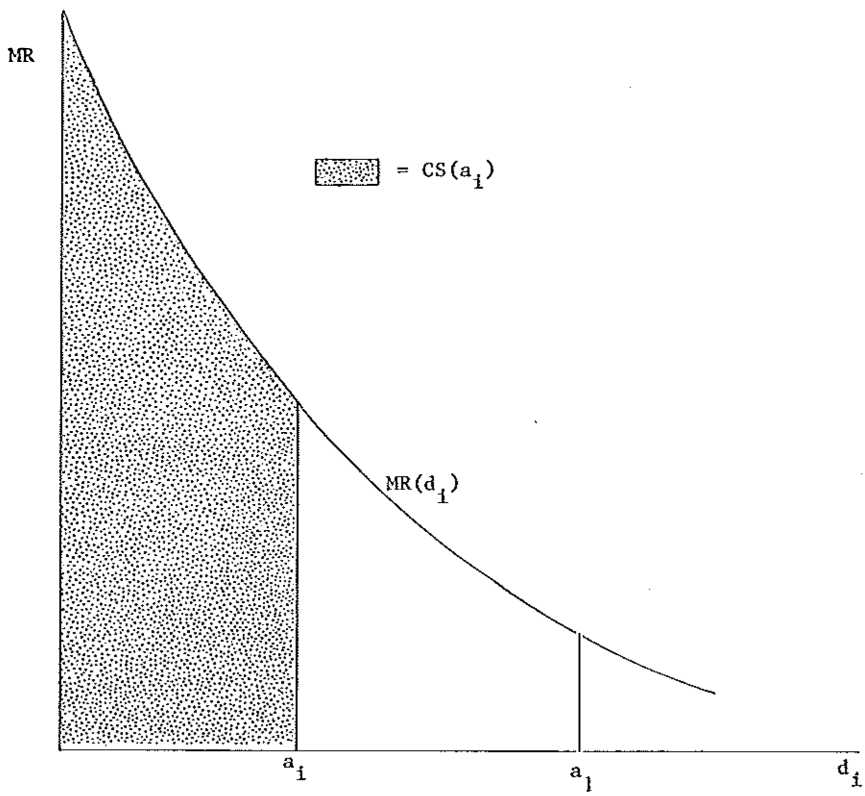

FIGURE IX
CONSUMER SURPLUS (CS(A_i)) OF THE iTH FIRM UNDER THE ORIGINAL RIVER ALLOCATION

[28] That is, it is the charge arising, say, if firm two changed its diversion point, return-flow point, time of diversion, and so on, such that only firm four were deprived of the return flow.

shaded area represents the gains from the ith firm's use of water. However, if all of the entitlements are in one firm, all these gains will be captured by that one firm. A number of different patterns of entitlements might be observed: all entitlements in one firm, equal sharing of entitlements by all firms, and so forth. Since the original entitlement of water rights defines the limit on the export of water from the river, no firm may export more than its entitlement. Thus one restriction is obvious: the sum of all entitlements must not exceed the flow of the river.

Given numerous possible patterns of entitlements, we conduct our analysis in the context of one that we feel is in a sense natural. We assume that each firm's entitlement is equal to its beneficial consumptive use. As we now recognize the existence of return flows, by beneficial consumptive use we mean the water actually consumed by the firm; that is, beneficial consumptive use equals diversions minus return flows. Barring excessive transaction costs one might expect to arrive at this allocation regardless of the initial holding of water rights through the operation of a market in entitlements. To illustrate, suppose one firm begins with rights to the entire flow. The firm uses β per cent of the river as an input in production and has a return flow of $(1 - \beta)\hat{x}$. Auctioning off this flow in a market with many potential water users, the firm should be able to sell the right to this water for an amount equal to the sum of all the profits that will be earned by all downstream users, assuming that the water is used in the most efficient (highest-profit) way. The firm acquiring the right to the return flow of the first firm, $(1 - \beta)\hat{x}$, uses β per cent of it and generates a return flow of $(1 - \beta)^2\hat{x}$ which in turn is auctioned off at a price equal to the sum of all profits that could be earned from the efficient downstream use of this quantity of water (including return flows). Under this regime, we end with a situation in which each firm on the river owns rights only to its own beneficial consumptive use.

Alternatively, the state could auction off rights to beneficial consumptive use at various locations along the river and presumably would find the pattern of rights by location identical to that achieved hy the operation of a market in entitlements, where rights are assigned on the basis of diversions rather than on consumptive use.

So long as there are zero transaction costs and no restrictions on the buying and selling of rights, any initial pattern of entitlements is consistent with a pattern of water use that satisfies economic efficiency. All of the externalities associated with return flows are completely internalized.

The same is true with respect to the importing or exporting of water. Given that under any initial assignment of rights we end up with a pattern of rights by location consisting of beneficial consumptive use at each location, exporting creates no problems. Each firm has the right to export its consumptive use so that no interference with return flows occurs and there are no problems of externalities present. Importing, on the other hand, does involve externalities. However, so long as there are zero transaction costs, these externalities are also internalized. A firm importing water will negotiate with the next firm downstream and sell its return flows at a price equal to the sum of all profits that are generated by the efficient use of the water by downstream users, and the same kind of bargain will be made at each succeeding downstream location. Admittedly, we are talking about idealized solutions to bilateral monopoly problems. To attain such solutions generally requires the capability on the part of each water user to export his return flows as an alternative to releasing them. If this capability is present then the entire amount of increases in downstream profits can be extracted from each succeeding user. Moreover, if the pattern of water use through the economy is to be efficient, firms must be able to extract the entire amount of downstream profits generated by return flows.

Problems arise when transaction costs are nonzero. Specifically suppose that firms do not have the capability of exporting return flows, so that an amount of water equal to diversions less consumptive use automatically returns to the river. This destroys the bargaining position of upstream firms in negotiations with downstream users. Moreover, in complex situations where return flows of one firm are mixed with mainstream flows to downstream users, it becomes difficult to enforce water rights when the rights are assigned on the basis of diversions rather than on consumptive use. The consequence is that firms tend to use water inefficiently (using flow through irrigation rather than sprinklers, using unlined diversion canals, and so forth), and import less than optimal amounts of water.

In principle a centralized authority could correct for the noninternalized externalities by an appropriate system of taxes or subsidies. Looking simply at the problem of imports, the central authority could pay a subsidy to firms importing water, the subsidy being equal to the sum of profits from downstream users of the return flows. With a correctly chosen subsidy, an optimal amount of imports is assured. Funds to pay the subsidy would be generated from lump-sum taxes, say on the downstream firms. The distributional impact of this is consistent with a situation in which upstream firms have rights to any earnings of downstream firms due to return flows. Alternatively, firms could be taxed for *not* importing water. In this scenario, it is as though downstream firms have the right to receive the optimal amount of water from upstream firms. Upstream firms can supply the needed water by reducing their own use or by importing water. The tax per acre foot of water should be equal to the sum of increased downstream profits due to return flows assuming efficient use of the water.[29]

[29] While this solution may seem somewhat strange, observe that it is analogous to bribing a polluter to cease polluting in the case where the externality is a diseconomy.

In a more realistic world a legal system that limited rights to imported water to beneficial consumptive use and threatened upstream firms with fines for failure to import socially desirable water would prove unsatisfactory for a number of reasons. First, it might provide an incentive for the blackmail of upstream firms by downstream firms.[30] Second, it might prove conducive to excessively consumptive ("wasteful") uses by upstream firms so as to minimize their possible downstream liability and maximize the magnitude of their transferable right. One might expect the transaction costs to be excessive as a result of choosing the stick over the carrot for persuasion. Also we would question the distributional implications of requiring an uncompensated subsidization of downstream firms in the form of free water imports. This may cause additional problems if upstream firms go bankrupt and exit the industry as a result of the subsidization process.

The above arguments suggest the inappropriateness of this latter method of internalizing externalities from return flows. Consequently it appears preferable that the importing firm be assigned water rights to the entire quantity imported and allow or require downstream firms to bribe the importer (purchase rights to his return flows) as an inducement to import the socially optimal amount of water.[31] However, some attention must be given to the real-world implementation of this scheme.

Our proposal is two-fold. We suggest that rights be limited to beneficial consumptive use with entitled firms selling the rights to water which they do not consume to firms which have no rights. This would minimize transaction costs, primarily by rendering exports of water nonproblematic, as no firm would have the ability to alter the pattern of return flows.[32] Second, whenever water is imported, the importing firm retains title to the quantity imported with title to return flows relinquished upon purchase by downstream users. Due to the difficulty in identifying return flows and their users when a substantial length of stream bed is involved, there may be free riders; but if the importer's return flow is not purchased, he retains the right to transfer (export) it at a later date.

Perhaps one of the most pervasive problems is the historical lack of precision in defining original entitlements. As a consequence it is possible to observe a sum of entitlements that exceeds river flow, leading to problems of rights conflict rather than external economies or diseconomies. In such an event one would expect bitter controversies.

[30] See E. J. Mishan, The Choice of L Law or $\bar{L}$ Law, in E. J. Mishan, Cost-Benefit Analysis (1975).

[31] Observe that our solution is to an extent dependent on the original entitlement of water rights. One could easily adapt our analysis to handle other entitlements.

[32] In principle, transfers of water within a hydrologic system are not problematic. However, in fact, most rivers consist of many sources and a single mouth: several separable hydrologic subsystems. Consequently not intrariver-basin but intersubsystem transfers can be problematic.

Our observations are the outcome of a simplified examination of transaction costs under a very restrictive axiom set. We cannot be sure that our conclusions hold "without loss of generality" when complications are introduced: positive costs of building diversion capacity, positive costs of delivering return flows, variable and uncertain streamflows, informational uncertainties, misrepresentation, salinity buildup, and so on. In addition, we have for the most part ignored equity questions, which may prove dominant in the final analysis. Thus we do not claim to have presented a definitive answer, but rather a convenient point of departure for future research.

III. SUMMARY

Under the priority hierarchy of the appropriative doctrine of water rights with "first in time, first in right," restrictions on the transfer of water rights lead to inefficient use of water due to an unequal sharing of risk among otherwise identical firms. The introduction of competitive markets in water rights eliminates these inefficiencies. However, obstructions to transfer of water rights exist in the form of federal, interstate, and intrastate restrictions. In addition return-flow externalities constitute a natural economic obstruction to efficient transfer of water rights. For a simple example we have determined how these externalities might be internalized and, in the spirit of Coase, outlined potential solutions in terms of systems of water rights. In essence our results say: (1) regardless of entitlements, if transaction costs are zero, return-flow externalities will be internalized; (2) for any given pattern of entitlements, return-flow externalities may be internalized by either bribes or charges, subject to the usual caveats.

In the context of the Colorado River Basin, we would assert that often what appears to be a shortage of water is actually the manifestation of restrictions on water rights transfer. For example, the Colorado River Aqueduct, which delivers water to the Metropolitan Water District in Southern California, is operating at capacity. When the Central Arizona Project comes on line in 1985, assuming prorationing of Mexican water requirements, California deliveries can decrease from 5 MAF to as little as 4 MAF per year. As the Metropolitan Water District holds the lowest California priority, its allotment would be the first to be curtailed, and such curtailment would leave excess capacity in the aqueduct. Thus the means for delivering water would exist if the water could be obtained. A potential supply source exists among the water users in the Imperial and Coachella irrigation districts, by far the largest water users in Southern California. However, existing California statutes preclude the transfer of water outside irrigation districts; one would hope enabling legislation to be quickly forthcoming at that time.

Generalizing we observe that 85 per cent of all Colorado River water is used in irrigated agriculture. A 10 per cent decrease in agricultural usage allows close to a 60 per cent increase in water availability for other purposes. Moreover, a 10 per cent decrease in agricultural usage would not be difficult to attain with lining of irrigation ditches, alternative irrigation technologies, changes in crop patterns, and elimination of low-profitability crops. The incentive to do so would be provided by proceeds from the sale of water rights.