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ASSESSING THE VALUE OF WATER: SOME ALTERNATIVES

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Introduction

The purpose of this paper is to review some of the valuation techniques that have been used to estimate the value of water, to discuss briefly some of the theoretical and empirical strengths and limitations of such efforts, and to present an alternative approach. Section II will provide a discussion of the meaning of value as it is used in water valuation/allocation models. Section III provides a summary of several valuation techniques which have been used in recent attempts to analyze water allocation at the state level and discusses some of their strengths and weaknesses. Section IV describes a proposed approach based on an already existing simulation model for the State of Minnesota. Finally, some advantages of this proposed approach and its relationship to previous approaches are noted in Section V.

The Meaning of Value in Resource Allocation Decisions

When any resource (including water of a given quality at a given location) is so abundant that all users can take as much as they want and still leave some of the resource idle, allocation of the resource is unnecessary. But when all users cannot take as much as they would like without exhausting the available supplies, mechanisms need to be devised to make allocative decisions. While numerous such mechanisms could be developed and utilized (command, lottery, first-come-first-served, etc.), market allocation through the forces of supply and demand is the most often suggested and preferred as the pricing system automatically ensures the transfer of resources from lower to higher valued uses. And thus, under the right conditions, it leads to economic efficiency; that is, leads to an allocation which maximizes the "value" society obtains from the use of the scarce resource [see 1].

However, "the right conditions" often do not exist in the case of water. Noncompetitive conditions, externalities, and a lack of well-defined property rights due to the mobile and public nature of water resources and the uncertainty of their supply make the establishment of market-type institutions difficult and the establishment of "properly-functioning" market-type institutions virtually impossible [18]. Thus, the responsibility of water resource allocation is often shifted from the private to public sector (to the extent that

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institutional arrangements allow this).¹ This allocation may attempt to mirror or replicate competitive market results using estimated "shadow" prices in lieu of "true" prices to guide resource use. Or, since "value" need not be defined as it is implicitly by the market, the decision-maker may choose an allocation based on an alternative measurement of value. In either case, the primary social criteria we will assume the decision-maker uses is that of economic efficiency.

Economic efficiency may be described as a condition wherein all unambiguous possibilities for increasing the "value" obtained from a resource have been exhausted. But what exactly does "value" mean? As noted by Young and Gray [19], value is a relative concept. A prime requisite to defining the value of a resource is then measured as its contribution to this objective function [15]. For example, in the market context the value of a particular unit of some resource is defined as the amount that a perfectly rational user would be willing and able to pay for it, which in turn is derived from the addition the unit makes to the individual user's objective function (usually either a utility or profit function or, more broadly defined, a welfare function). Thus, continuing the market context, economic efficiency is defined by a state wherein no additional exchanges of the resource among individuals can lead to an increase in at least one individual's welfare function without decreasing someone else's.

A different objective function, however, means a different interpretation of value. If one's objective is the maximization of regional income, the value of a resource must be defined by its contribution to this objective. And, in turn, economic efficiency would be attained only when no other allocation of the resource leads to a greater level of regional income. Other possible objectives of the decision-maker, including maximizing regional output, regional employment, or regional growth, could just as easily be discussed by substituting them in for "regional income" above. The point is that there are numerous concepts of value depending on the objective function one chooses. Thus, it should not be surprising that there are numerous valuation methods, each measuring value in its own way. As economists we cannot say which of these objective functions (and so, value interpretations) is the best to consider, but

¹ In the western United States, where water rights are held privately (and protected jealously) under the appropriative doctrine, a transfer of allocation "power" to the public sector would be met with considerable resistance. Some argue that such a transfer isn't desirable anyway. Anderson [2] provides a lucid case for the privatization of water resources. The essence of his argument is that efforts should be made to mitigate some of the market failures associated with current water markets (and then allow market allocation) instead of attempting to develop public allocation schemes. However, even if privatization were to take place, government may still play the role of monitoring the market's allocation decisions against other objective functions in order to analyze the trade-offs that are inevitably taking place.

we may judge the allocation decisions under each in terms of the same criteria, economic efficiency.

In the following section we will summarize some valuation techniques that have been used in water allocation studies at the state or regional level, paying particular note where relevant to the objective function and concept of value being used.

Water Valuation Techniques

A. Observation of Water Market Transactions

Although market transactions involving water are rare (especially in the Midwest and eastern U.S.) and when they do exist they are likely to be imperfect, they can sometimes yield insights into the value of water (value based on the market principle of willingness and ability to pay). When the appropriative doctrine applies (providing the owner with a perpetual right each year to a specified amount of flow), property rights become well-defined enough for reasonable market transactions to occur. Young and Gray [18] cite numerous examples of such transactions for the "irrigation water rental market." Transactions in permanent water rights are rare since many states prohibit the transfer of water rights except when the land to which the right pertains is also transferred [9]. However, Young and Gray [18] note studies which have attempted to infer the value of irrigation water from regression analysis of farmland prices and there have been some recent examples of municipalities buying controlling interest in "ditch companies" in the western U.S. Outside of the agricultural sector, few other examples of free market water transactions exist so that use of this valuation technique is somewhat limited.

B. Estimation of Demand Functions

Related to the last approach are those attempts to estimate the entire demand relationship (i.e., determining a user's response in terms of their water consumption to many different prices) by estimating first the marginal productivity of water (for intermediate users such as the agricultural and industrial sectors) or its marginal utility (for final users such as residential consumers). Numerous experiments have studied the response of different crops to additional acre-feet of irrigation water [13]. Industrial demands for water (in terms of marginal valuation) have not been extensively studied but the work of Calloway, et al. [4] provides an example of water demand for an ammonia plant. Residential water demands have been considered by Howe and Linaweaver [12] and Hanke [7], both indicating a dramatic response to metered versus non-metered use.

Perhaps the greatest obstacles to a generalized use of this approach, as well as the preceding one, on a state-wide basis would be a lack of enough price variation from which to assess user response and an inability to confidently generalize observations which would likely have been based on very location-, time-, and use-specific studies.

C. Cost of Delivery/Intake

We include this approach almost as a footnote to the preceding methods. This valuation technique estimates the value of water to the user by calculating those costs associated with bringing the water on site (including usually, any costs associated with treating it before use). The argument for this approach is simply that the value of water to the user (i.e., the amount the user is willing and able to pay) must exceed these costs or he would not choose to incur them. While this argument is economically sound, the method clearly provides at best only a lower-bound measurement of the value the user obtains from the water itself.

D. Alternative Cost

Much like the cost of delivery approach above, this method also sets a bound, this time an upper-bound on the value of water (again, value based on willingness and ability to pay). In its simplest context, this method attempts to value a resource (such as water) by considering the cost of the next best alternative to achieving a desired end without the marginal unit of the resource. Theoretically, the marginal cost of internal recycling at each quantity of water demanded might represent the ceiling on the price a user would be willing and able to pay for additional new water. The costs of acquiring water from different sources may also play a role. This approach is used most vividly by Young and Gray [18] to determine industrial value of water used primarily as a coolant. The principle problems here are its lack of general applicability outside of industrial uses and a real problem of identifying exactly what is the next best alternative for a given user and assessing its true cost.

E. Residual Imputation

Residual imputation is a method of resource valuation which attempts to allocate the total value of the output of a firm to each of the resources used in its production. If appropriate prices (i.e., prices which reflect their true opportunity costs) can be assigned to all inputs but one, then the remainder of the total value may be "imputed" to the remaining resource [10, 19]. This method, though theoretically simple, relies heavily on the satisfaction of conditions which are likely not to be satisfied in the "real world." For example, production functions satisfying the postulates of Euler's Theorem and competitive conditions are required.

Perhaps even more troublesome is an accounting for managerial and/or entrepreneurial resources — inputs for which no simple, competitive "price" is easily assigned. Clearly, if the value of these resources (or any other resource) is not correctly assigned (or even worse, omitted altogether), the remaining value imputed to the water resource would also be in error. This problem becomes even more significant in light of the small percentage of the total value of the output for which the water resource would be expected to account. Even small miscalculations of the value of the total output accounted for by the rest of the inputs (the larger percent) could conceivably leave no value to be assigned to the water resource, or at the other extreme, could magnify its value far beyond its true contribution.

Several state water valuation studies have utilized this approach which once again utilizes the market-based concept of value. Griffin [6], for example, analyzes industrial and agricultural uses of water in southwestern North Dakota with variations of this technique. Young and Gray [19] defend the approach as being more consistent with the principles of welfare economics than are other approaches (in particular, the value-added approach to follow). The principle empirical problem with the method from the perspective of state-wide water allocation would be the data requirements necessary to adequately specify production technologies, costs, and returns to risk-bearing for all water users. Further, the method is largely only applicable to the agricultural and industrial sectors where "outputs" are well-defined.

F. Input-Output: Value Added

Input-output analysis allows one to estimate the change in regional output and value added from a given change in final demand for the goods and services produced in a region. While some sectors produce mainly for final demand, other sectors provide goods for local consumption and inputs to other sectors in the region. The strength of an input-output model is, of course, its explicit recognition of these interindustry linkages. This is important in regional water allocation schemes since it takes into account that each sector's continued output is not only dependent upon the availability of water to it but also at least partially dependent upon water availability to the other sectors of the economy from which it must purchase its inputs.

It is with this approach that we first see a concept of value different, but no less correct, from that used in the previous five approaches. The value added imputation of water value in its simplest form, which considers only direct effects (ignoring indirect or induced effects), can be expressed as:

$$P(j) = V(j)/W(j) = GRI(j)/W(j)$$

where $P(j)$ is the "value" of water per unit to sector j ; $V(j)$ is the total value added by sector j (the total expenditure by sector j on primary resources minus any imports purchased by sector j); $W(j)$ is the total physical quantity of water consumed by sector j ; and $GRI(j)$ is the gross regional income generated in sector j (equal to $V(j)$ given the accounting relationships required by the Leontief input-output system). As with the market-based allocation, the assumed goal here is to transfer water to those sectors where it is most highly "valued." The objective function here, however, is not welfare but instead the gross regional income. Given this objective, water should properly be valued according to its contribution to increasing GRI or its equivalent, $V (= \sum V(j))$. Thus, under this approach, any additional water would best be transferred to the sectors with the largest $P(j)$'s or conversely, in the event of a shortage, water should be restricted first to those sectors with the lowest $P(j)$'s.

This approach too is not without its problems; however, they do not include as Young and Gray [19] maintain, an incorrect value base. As just noted, the objective function is different than that implicit under market allocation, but whether or not it is better or worse is a value judgment about which economists can say little. One principle problem is the asymmetric behavior of the

approach. While reducing the water allocated to a given sector would likely lead to an impact on GRI as suggested by the model, increasing the amount of water to a sector could easily have no impact at all if other resources required to increase output are constrained or if final demand levels are not sufficient to warrant additional production.² These are largely problems caused by the static nature of the input-output model and its necessary reliance on fixed-proportion production relationships subject to constant returns-to-scale.

As noted by Young and Gray [19], $P(j)$ must by definition be including (especially when considering additional water supplies) the contribution of inputs other than water which must also be increasing if output is to increase. However, if the additional water is required before these additional inputs will be employed, it is appropriate to assign all the value of increasing gross regional income to the water resource. Young and Gray maintain this ignores the opportunity costs of the other resources or incorrectly assumes them to be zero. The opportunity costs of these resources here is their contribution to increasing gross regional income in other uses. However, since they won't (can't) be used in the region without additional water, their "regional" opportunity cost is zero as far as their contribution to GRI is concerned.

This method of dealing with water valuation/allocation has become widely utilized at the state-level, including the work of Bradley and Gander [3] for Utah, Lofting and McGauhey [14] for California, d'Arge [5] for New Mexico, Moncur [16] for Hawaii, Henry and Bowen [11] for South Carolina, and Harris and Rea [8] for Nevada. Its principal strength beyond considering interindustry relationships is its simplicity once one has a reasonably well-developed input-output table for a given region. This coupled with water use data by industry may be used to easily generate the $P(j)$'s.

G. Linear Programming

A final valuation technique we will note utilizes the approach above in combination with linear programming. The work of Henry and Bowen [11] is an example. The marginal value of allocating water to alternative sectors is estimated by comparing the optimal output levels of each of the sectors of the input-output model under different levels of water availability. Value here is defined as water's contribution to maximizing gross regional output and so may be assessed by varying water availability and solving for the shadow price of water. One advantage of this method over the previous is its ability to also consider possible constraints imposed by other primary resources (labor, for example, was explicitly constrained in the Henry and Bowen study). Thus, increases in water availability do not necessarily lead to changes in gross regional output (an increase in value) if the availability of other resources is sufficiently constrained.

² In the case of water restriction, it is also difficult for the model to account for possible input substitutions or additional efficiencies in water use which would reduce the impact on output.

A Simulation Approach to Water Valuation/Allocation

Many previous water research efforts have called for a systems approach to valuing water resources³. However, to our knowledge no one has attempted such an approach in their own analysis. Probably the closest to such analysis is to be found in the South Carolina study [11] where alternative water supply possibilities were hypothesized and resulting changes in the value of water among 64 interrelated industries were estimated.

Our current effort builds on a combination of many earlier efforts, including some of the techniques of water valuation discussed earlier in this paper and other works related to the development of a large-scale simulation model capable of dealing with the changing parameters of a functioning economic system.

More specifically, we propose to apply an up-dated version of a simulation system developed by Doug Olson and others [17] to the State of Minnesota and to five planning regions within the state. To this system we will add a water module for use in evaluating economic impacts of water allocation under varying assumptions concerning the objective function of the state or the regional economies. The simulation system itself is called IPASS for "Interactive Policy Analysis Simulation System."

IPASS is an input-output based model containing eight interactive modules: investment, final demand, production, regional output, population, labor force, employment, and primary input. The production module is the Leontief inverse matrix used to measure direct and indirect effects from economic activity levels. These levels of activity are derived from the investment and final demand modules. The key feature of IPASS, unlike most other analyses that utilize input-output tables, is that IPASS does not assume investment and other components of final demand to be exogenous. These components of final demand are tracked on a yearly basis through the system's modules, and the output implications from changes in these final demands are calculated through the production module. The output projections then form the basis for population, labor force, employment, and other primary input demand.

More specifically the system works as follows (see [17] for details):

(1) The amount of investment required to replace worn out capital or to increase output is calculated in the investment module. The capacity increasing investment is that required to service the output of the economy calculated from the previous year's economic activity. The required investment is checked against available funds from depreciation allowances and from accumulated business income. If the funds for investment are not available, the module calculates the investment that is possible, and the difference between

³ Young and Gray [18], pg. 96, note "Computer simulation models which can begin to incorporate the stochastic flows, the interdependencies among uses and the spatial, temporal and quality factors are likely to be of greater use in making public management decisions."

required investment and actual investment becomes a constraint to increasing output for the region in question. Thus, capital represents the first constraint against production within the IPASS system.

(2) The Final Demand module calculates regional final demands in the form of capital formation, consumption, inventory changes, state, local and federal expenditures, and exports for the region where:

A. Capital formation is the local production and sale of capital goods in order to service new investment. The estimates for the proportion of total investment that is made up by local industries comes out of an investment matrix for the region. The difference is made up by imported capital goods.

B. Consumption is a function of total population, income, and income elasticities of demand. Population estimates come out of the population module. Income comes out of the primary input module.

C. Inventory changes are related to levels of inventory accumulation (rates) as a function of lagged output estimates.

D. State, Federal, and Local Government Expenditures are presently calculated as a function of population. However, efforts are under way to develop a more sophisticated government module with more realistic assumptions.

E. Exports are calculated as a function of the projected performance of the national economy and the market share of national activity made up by regional production for export purposes. The regional market shares are adjusted by changes in regional to national activity represented by a parameter termed "the rate of change in regional market share."

The estimated levels for each of these components of final demand are inserted into the system for some base year. Estimated rates of change or changes coming out of the other modules then drive the system in what is known as a baseline (all other things being equal) run. The user can access the system through an interactive program which allows one to change some parameters in the system. This ability to change parameters creates a "what happens if" range of possibilities with the modified runs being compared to the baseline for impact analysis.

(3) The production module takes the final demand estimates from the previous module and calculates the regional output that is consistent with those estimated levels of final demand. If the investment or employment constraints hold, the production module will calculate both potential output and actual output. The difference represents the effect of the investment or employment constraint. Since the production module has as its major component the Leontief inverse of an input-output system, the output estimates are some multiple of final demand levels, i.e., the direct and indirect output implications from given levels of final demand. With the exception of the implications from an investment or employment constraint and from the dynamic nature of final demand within the IPASS system, the production module works pretty much like any other input-output system in calculating direct and indirect output levels that are consistent with levels of final demand.

(4) The employment, labor force, population and primary input modules then calculate the implications for these components of a regional economy from the calculated levels of output out of the production module. Parameters dealing with worker productivity, labor demand based on occupational matrices, birth, death, and migration rates (the latter based on changes in unemployment related to the demand for and the supply of labor), and value added to output coefficients are used to calculate output-consistent levels of economic and demographic activity for the region. As mentioned before, estimated levels of income and employment are fed back into the system's final demand, the former as a component of consumption and the latter as a potential constraint to production.

It is to this system that we propose to add the water module to operate as follows:

(1) Total Water Supply is calculated as the total water available in a given region minus the water that is "held back" or not available for production. The total water available and the amount of water held back are parameters of the system; i.e., the user may vary them as supply (rainfall) conditions, ecological needs, or recreational and navigational demands warrant. Estimates of total water availability will be supplied by the U.S. Geological Survey, the University of Minnesota Water Resources Research Center, and the Minnesota Department of Natural Resources.

(2) Total Water Demand is based on water-to-output ratios generated for each of the seventy-five industrial sectors handled by the IPASS system. These ratios serve as parameters in the system so that the user can modify them to reflect known or expected changes (such as increased efficiencies in water use or changes in technology related to water use). The water-to-output ratios will also be modified for the various agricultural sectors on the basis of drought probabilities calculated on a yearly basis. Yearly drought projections are a modifiable parameter with initial values provided by the University of Minnesota Water Resources Research Center's calculations of annual drought indexes. Thus, total water demand is represented by a matrix of direct and indirect water requirements to satisfy regional final demands.

(3) Water availability is next compared to water demands. If there is enough water available to satisfy the demands, actual output will equal potential output and the IPASS system will project economic activity on that basis. If water availability is less than water demand, water becomes a constraint to production and actual output will fall below potential output. It should be noted that the original IPASS model used investment as a constraint to output. Employment is the second constraint. The new model containing the water module will have water be the first constraint followed by investment and employment.

(4) If water does represent a constraint, a separate component will be activated by the system. This component essentially decides how much of each sector's water demand is to be met. This decision could be based on any of the methods discussed earlier or even by a "seat-of-the-pants" judgment by the user. However the water is allocated, the rest of IPASS will then continue and will calculate the resulting levels of employment, population, value added,

etc. In other words, the user will be able to view the simulated effect of any allocation decision which may then be compared to the baseline run.

Under such an approach, the value of water may be expressed as its contribution to the minimizing of a given impact. For example, suppose value added (or GRI) is determined over a course of several years in a baseline run without a binding water constraint. Next suppose water is made an effective constraint at some time during this period, forcing an allocation decision. If the decision-maker's objective is to minimize the impact of the water shortage on value-added, then an allocation decision based on value-added is suggested. The value of water would thus be the difference in value-added between the baseline run and the constrained run with the allocation decision which best minimizes the impact.

Advantages

There are several advantages to such an approach to water value estimation. The most obvious relates to the advantages of any simulation system. The simulation user has available to him or her a number of options for parameter modification. Observations of the sensitivity of the system to such parameter adjustments provide a great deal of information concerning the implications from a "scenario" arrangement provided by the system's user.

It should be pointed out again that there are several value bases for allocating water. One such basis is economic welfare that is associated with the workings of a competitive market. Other bases are generally politically determined, such as the objective functions related to regional output, income, growth, employment, or similar such variables. An attempt will be made to make the model flexible enough to allow the user at least a limited range of options as to what the allocation basis might be. Under such circumstances, the water allocation scenario developed by the user will result in allocations based on that user's perception of the community's objective function. Thus, the implications of the objective function chosen, as well as the implications of the other system parameters and equations, can be analyzed by the user.

The water availability function containing a parameter dealing with water held out of production allows further flexibility. This parameter will be such that the user can modify it to reflect various scenario possibilities. Water can be withheld from production for the purpose of preserving the environment, for the purpose of making water available to future generations, for the purpose of exporting that water to other states and regions, and for the purpose of maintaining navigatable waters, etc. Scenarios can be developed for these or for many other possibilities, and the implications of such scenarios for water values and allocations can be analyzed.

Such flexibilities will be especially useful for a state such as Minnesota where large water reserves are available over most of the state. The system's user will have the capability of placing water constraints where none exist at the present time for the purpose of analyzing the importance of water to industrial development during future water-short periods. Implications from a water export policy or from any of the other possibilities mentioned above can

be analyzed and discussed.

A model such as the one being described here is consistent with all of the approaches discussed earlier in this paper in that the allocation scheme to be used could theoretically be based on any of them. What is gained here, however, over the alternative techniques is a greater flexibility in choosing the objective of water allocation and a dynamic picture of the implications of allocative decisions where other constraints on the system (i.e., labor, capital, and final demands) are fully considered.

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