Economics and Ground-Water Development[a]

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Abstract

The economics of ground-water resource development and use are discussed. After a consideration of the welfare criteria, problems of defining and managing property rights are presented. The interrelated nature of ground-water use and external effects resulting from uncoordinated individual action lead to inefficiencies in ground-water development and use unless appropriate institutional arrangements have been made.

This paper reviews some of the economic problems associated with ground-water resources. The author's experience with ground water has been in the context of arid conditions, where irrigation is the most extensive ground-water use. However, this presentation is not concerned specifically with the problems of the different uses but is intended to paint a broad picture of ground water as an economic resource. The principle difference between the economic problem of ground-water development in the humid Eastern United States as compared to the arid West would be one of a difference in relative scarcity and a difference in the kinds of predominant uses, not a basic difference in the physical and economic aspects of problems. The legal-institutional setting for ground-water development and use is different for these two regions. However, the continued development of ground water for municipal and industrial use in the East may lead to a need for legal and institutional arrangements similar to those which have been developed in the West. The evolution of ground-water institutions has progressed in parts of the West because of a need imposed by water scarcity.

Public interest objectives for any natural resource concern the development and use of available supplies in such a manner as to make the greatest contribution to national welfare. Welfare as an operational concept in traditional economics has been measured primarily in monetary terms of income, where consideration is also given to the effects of incremental policy changes upon the distribution of income. The approach to general resource problems has been to arrive at economic principles derived from an analysis which postulates goals of income maximization for society and which presupposes rational utility and profit maximizing behavior for resource owners, business managers and consumers of resource output. The general economic principles derived from this analysis, termed welfare theory in the literature, are then applied to specific resource problems in a given institutional setting. Or more usefully, the conclusions from an abstract welfare analysis of specific resource problems is carried through to recommendations for various institutional arrangements, which appear capable of facilitating achievement of the postulated resource development and use objectives. Ground water as an economic resource fits into this general framework of economic analysis. The approach in this paper will be to review the welfare criteria of resource development and use, to point out some of the institutional aspects of the problem and to briefly review a few specific problems.

Welfare Criteria

The traditional domain and datum of economics, as a social science, has been the social process whereby scarce resources of land, labor and capital are converted into goods and services which satisfy wants. Thus, to consider ground water as an economic resource implies that it is scarce in relation to the demands for its use and that its use serves in some way to satisfy human wants. In western democracies the economic process has been left largely in the hands of private enterprise, with public regulation limited and designed to aid the market institutions. In this context, the consumer is enthroned as king of the economic process and consumer satisfaction as the ultimate goal of economic activity, which is tantamount to maximization of national income. Thus, maximization of consumer satisfaction, as expressed in the market place, becomes the criteria for judging the performance of economic institutions. Maximizing consumer satisfaction presupposes a given distribution of income and consequently of purchasing power. Allegedly, a desirable income distribution cannot be specified on purely economic grounds, so this is taken as given in welfare analysis (see Pigou, 1938 and Little, 1950).

If we pose the question of how well is a natural resource being used to satisfy consumers wants, then we open up two related but distinct economic aspects, viz., development and allocation between uses. Development involves the decision to allocate labor and capital to making the resource in its natural occurrence available as a productive input. Allocation between uses involves the decision of what output is the most desirable to be derived from the input of the resources.

Specification of decision criteria for public agencies involved in water resource development has been treated quite extensively in recent literature (see Krutilla and Eckstein, 1958 and Eckstein, 1958). The rationale of the benefit-cost criteria, of this literature,

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for public water resource development is applicable to the quasi-public investment in pump facilities by municipalities or investment in recharge facilities by various kinds of ground-water districts. The essential aspects of investment criteria are a comparison of present and discounted future costs with discounted future income flows, where for public agencies or from a public interest point of view, benefits include utility or income which may or may not accrue to the developer or developing agency. Costs, on the other hand, are measured in terms of opportunity costs rather than monetary costs. In this criteria, if future income or benefits from the investment discounted with the appropriate rate are greater than present and future discounted costs, then a commitment of capital to the investment is justified from a welfare point of view since future consumer satisfaction will be greater with than without it.

Private investment criteria for profit maximization would be of the same form as benefit-cost criteria but considerations of benefits and costs would be different. Supposedly, the pacing of new development of ground water would be taken care of by the market where profits are the primary goal of the individual and would be most importantly determined by scarcity of water and the availability and cost of capital. Whether this is true or not becomes part of the economic problem. Questions to be answered regarding this problem would be: is capital readily available to potential developers, are legal rules of ownership conducive to sound investment decisions, are all parties affected involved in the decision process so that all benefits and costs are counted, and so forth?

It can be shown that a resource is optimally allocated between different uses in terms of the greatest contribution to consumer satisfaction if the conditions hold that the incremental addition to income from the last input unit of the resource is equal in all uses. This has been termed an efficient use, since at this point the average income per unit of resource use is the largest. The analogy to engineering efficiency should be obvious. The measure of economic efficiency is a ratio of valued output to input rather than a ratio in physical terms as in an engineering efficiency measure. It can also be shown that a market system where entrepreneurs are guided by the profit motive, will under certain conditions, achieve an efficient use of a resource.

Designating X as the quantity of a limited resource and Y_1, Y_2 ... Y_n as valued output from the uses of X, then the allocation of X to produce the highest valued output will be when

$$\frac{\Delta Y_1}{\Delta X} = \frac{\Delta Y_2}{\Delta X} \cdots \frac{\Delta Y_n}{\Delta X}$$

where the Δ refers to the last increment of input or value of output. The practical implication of this abstract rule is straightforward. If X is marketable, then profit maximization by resource users will tend to bid the resource to its highest valued use such that the above equality holds. For example, if $\frac{\Delta Y_1}{\Delta X}$ is larger than $\frac{\Delta Y_2}{\Delta X}$ then the producer of Y_1 can bid X away from producing Y_2 because it is profitable to do so. Since the consumer is setting the value on the different outputs because of their want-satisfying ability, it seems reasonable to look upon this allocation rule as desirable or optimal from a public interest viewpoint. Further, it would seem reasonable to use this model in judging the performance of existing practices for different resource uses and for delineating problem areas.

This conception is probably also the common sense view held by most practitioners in the field; i.e., the common sense notion of economizing in the use of scarce goods or resources is identical to the above presentation. It is a formal development of common sense notions and its application to resource problems should not violate anyone's sense of propriety.

Natural resource use and development is especially subject to deviations from the free market model. Private interest decisions regarding development and use have external effects or repercussions upon other parties. In the above example, the private decisions regarding the use of X which are in the interest of the several parties involved in the direct transaction, e.g., the buyers and sellers in the resource market, will also be in the public interest if no third parties are affected by the action resulting from the decision. If third parties are affected, i.e., there are external effects, then obviously some extra-private negotiation is needed to represent the third parties in the transaction so that compensation is made and welfare gains are balanced against losses.

The conditions for economically efficient development and use of resources where external effects occur are the crux of one conceptual approach to water resource problems.

Institutional Arrangements

Important legal considerations for an economic use of resources regard defining and instituting rules for property right management. In general, water resources in their natural occurrence are interrelated in supply and uses, so that defining a right to use which is protected as other property rights are and, also, marketable is difficult (see Hartman and Seastone, 1963).

Ciriacy-Wantrup has specified some general economic criteria for defining property rights to water (1956). His criteria are flexibility and certainty of tenure. Appropriate investment planning decisions require certainty of tenure to the right to use some specified flow of water. In other words municipalities, industrial entrepreneurs, irrigators etc. will not commit capital to develop a water source unless their rights to this source are assured for an indefinite planning period. On the other hand, as population

growth and economic development progress demands for water resources change, so that transfers from one use to another are desirable from the viewpoint of economic efficiency. These two requirements for property rights in water are not necessarily incompatible but present complexities in devising legal and organizational institutions permissive of letting economic forces operate in development and allocation decisions.

The unique nature of ground-water supplies which give rise to a need for unique institutions to facilitate an efficient use is that no specified quantity of ground water can be claimed as individual property. The "common property" nature of ground water does not become crucial until development has reached a stage where there are more demands than supply can maintain; then questions of defining rights to use and protection of those rights in terms of regulation are necessary. The individual pursuit of self-interest to capture the services of a "common property" resource does not lead to the furtherance of the public interest. The "invisible hand" of Adam Smith fails in this situation and achievement of public interest objectives requires either collective action from the users or administrative control by an outside agency.

For discussion purposes, two levels of institutional arrangements pertaining to water resource development and use may be distinguished. One level pertains to the state system of water law and accompanying legal procedure for giving substance to the law (Hartman and Seastone, 1963). The second relates to various public and quasi-public organizations which exist or have existed at various times, which have been used to develop, allocate and deliver specified quantities of water to specific users. Federal, state and local resource agencies, public districts and water users' associations are examples of this type of organization. One could think of these institutions as consisting of externally applied laws or as internally organized interests, or a combination of both.

Ground-water law with procedures for acquiring and transferring rights to use provide the framework for defining a property right. Certainty of tenure and flexibility criteria, which have been discussed above and which follow from the more general efficiency conditions, would specify that this right be defined in such a way that it was protected from infringement by other users and marketable, in the sense that the right could be sold to someone else. How would a ground-water right be specified to satisfy these criteria? Analogous to western appropriation doctrine for surface water rights, the right could be defined in terms of quantity, time, place and type of use. That is, so many acre-feet or cubic feet per second per year, pumped during specified months, for municipal, industrial or irrigation use at a specified place. Protection of this right would involve regulating development of the ground-water source such that later users did not deplete earlier rights. Continuing the appropriation doctrine analogy, rights could be qualified according to a priority scheme based on dates of establishment of the right. Questions regarding the level of the water table to be maintained to protect earlier rights would have to be answered, also. In order to satisfy the flexibility criteria, transfers of ownership would need to be allowed and also, changes in use. These would have to be supervised such that other rights were not damaged by the transfer.

As has been pointed out elsewhere with regard to property rights to surface water, specification of rights and supervision of ownership transfers require hydrologic data (Hartman and Seastone, 1963). Data requirements for rational decision making by entrepreneurs using ground-water sources is an argument for involving state government agencies who are staffed by personnel with experience in ground-water hydrology to handle establishment of rights and ownership transfer procedures.

Western states have followed a variety of legal doctrines regarding ground-water use, these being riparian, appropriation, California's correlative rights doctrine and combinations of these doctrines. These states also have varied in administration of the law in some cases leaving this to the courts, and in other cases to state government agencies. California has a modified court reference procedure which uses both the court and a state government agency (Snyder, 1957). Colorado has essentially no ground-water law except that the courts in specific cases have tended to follow the appropriation doctrine. New Mexico and California are probably the leading states in the West in developing new approaches to ground-water management. California has developed the correlative rights doctrine, the court reference procedure and public district organization; and New Mexico, through the leadership of the State Engineer's office, has developed effective procedures for controlling pumping and pump development in critical water short areas.

John Dewey, in a much quoted essay, delineated some essential differences between private and public acts (1946). His discussion was a justification for the state but it is pertinent for considering resource use activities with external economic consequences. Dewey pointed out that if we observe the actions of individuals performed for specific causes it will be noted that their actions have effects upon individuals other than the persons immediately involved. From this, he stated, one can discern two basic types of consequences of human activities: those who are directly affected and those indirectly affected. Indirect effects are the basis for a first distinction between the public and the private, for in any attempt to regulate the indirect effects of private action the shadow of the state begins to appear. A public may be defined by all those individuals who are affected by the indirect consequences of transactions to such an extent that it is deemed necessary to have those consequences systematically cared for (Dewey, 1946). The existence of this situation for ground-water use is immediately obvious. User A's actions impinge upon

and have consequences affecting the action of users B, C, etc., and their actions have more indirect consequences upon the economic community with which they trade and do business. Regulation in the public interest requires some form of political organization or some legal system to ensure control. As Dahl and Lindbloom have pointed out, society has many values or goals which determine forms of social organization, the basic fundamental of a democratic society being the retention by the individual of ultimate control on the body politic (1953). And to paraphrase Dewey (1946) there is no formal organization which can be said to be perfect, no two societies are alike and the best for one may not meet the needs of another. One can safely conclude that rules of social organization are not one of the eternal verities of the social sciences. The proliferation of different legal and administrative systems, of public districts and of private organizations in water are a convincing argument on this score. The process is one of trial and error to meet changing conditions and the contribution of the social scientists is to clearly conceptualize the problem and analyze the kinds of social-economic forces involved, so the policy maker and the individual can select more rationally the course of action which best serves public and private ends.

State administrative agencies and courts can establish and/or enforce rules to regulate ground water but it appears to have been the experience in critical water short areas in the West that some form of public district serves an irreplaceable function (Smith, 1956). As Smith and Bittinger have pointed out with regard to carrying out management functions, particularly artificial recharge, "individual motivation and ability generally are not capable of initiating such programs although benefits would accrue back to the individual. Thus, the requirement is for group action" (Smith and Bittinger, 1964). Following Dewey's definition, the public would include all those individuals affected by ground-water use decisions and their formation for action would involve aspects of a government, i.e., officers, internal rules of operation, etc.

Some of the advantages of group action, in the form of public district formation, are readily apparent. Some of the disadvantages, such as loss of some individual autonomy are not so apparent or easily measured. Regulation of rate of use from an aquifer can be accomplished, by taxing or district policing, to extend the life of a ground-water stock or to regulate drawdown in a flow-type aquifer. Also, as in the case of California, public district organizations are used for management of recharge facilities and importation of surface supplies for recharge.

The public district is a public corporation which receives its powers from state enabling acts (Smith and Bittinger, 1964). Public district enabling acts have provisions, setting forth the procedures for district establishment, implementation of a governing board, taxation of members, making of contracts, etc. Enabling acts can be drawn up by state legislatures to meet special needs and provide flexible organizational rules (Smith and Bittinger, 1964). And as has been pointed out, this type of organization serves to organize both development and allocation decisions; it internalizes many of the externalities resulting from individual's decisions. It affords a framework for internal political decisions within the water using community and serves as a bargaining entity in the larger community of a state or region. The laws regulating the form the organization takes and the operating rules adopted by the organization at the time of its inception are deciding factors in determining how well subsequent performance will achieve welfare goals (Hartman and Seastone, 1963).

Specific Management Problems

The physical occurrence of ground water may be classified into renewable and non-renewable resource categories. That is, for ground-water sources where recharge is relatively slight compared to the quantity of stored water, the supply is, for all practical purposes, a stock resource and development is essentially a mining operation. Where recharge is great relative to the aquifer capacity the ground water is essentially a flow and development planning problem involving use of the aquifer as a storage reservoir. Both of these types of situations have been subject to some study for hydrologic and economic management purposes. The economics of development planning for mining a stock ground-water source are based on considerations of rates of use (development) which give the greatest discounted future net income flow (Davis, 1960). A too rapid rate of use will deplete the stock before capital assets associated with use have been amortized. Secondary or service type economic activities related to primary water-using production need to be considered, also, from the public point of view. Ghost towns resulting from the depletion of a stock resource, e.g., coal mining, are graphic examples of what happens to a community dependent upon a depleted stock resource.

In situations where ground water is a flow resource the rate of use (development) can be regulated so that aquifer storage is adequate to maintain the uses (Bittinger, 1964). If annual recharge is fairly constant then stable ground-water levels can be achieved at some level of use. However, if annual recharge is quite variable the water table will also vary and rate of use can be regulated to permit build up of storage in some years and depletion in other years. The aquifers of the alluvial river valleys in the West are hydraulically connected to streams so that management of both surface and ground-water supplies is necessary and additional complexities are involved in defining property rights and devising management systems (Bittinger, 1964).

Overdevelopment of an aquifer receiving recharge would result in periodic shortages which one would suppose would have a cost and create undesirable

planning uncertainties for established users. Legal recourse under the appropriation doctrine in this type of situation would probably come from earlier appropriators who would seek court action to enjoin junior rights to cease pumping. In New Mexico the State Engineer has authority to declare a basin closed to further development when he has determined that present uses are equal to the average annual recharge. California, under the correlative rights doctrine, has in some cases carried out studies to estimate annual recharge and where overdevelopment exists have proportioned this amount, i.e., average annual recharge, to all pumpers on the basis of amounts pumped in past years. That is, all pumpers existing at the time of adjudication share in a non-depleting use of the aquifer on the basis of past records of rates of pumping. In other cases, ground-water districts have been formed and surface water supplies have been imported to artifically recharge the aquifer.

It might be noted that overdraft of an aquifer can result in serious physical damage which destroys the resource. Los Angeles County in California is an example where overdraft has resulted in salt water intrusion and consequent deterioration of the aquifer. In this case the rate of use is not reversible. Reduction in rates of pumping would stop additional damage but would not restore this source of water to its original capacity. As conservation economists have pointed out, physical criteria of management set limits within which economic criteria become the major consideration (Ciriacy-Wantrup, 1952). Within the critical limits of physical criteria for resource maintenance the institutional arrangements for management should be such that economic forces determine rates and kinds of uses.

Another aspect of ground-water management is maintenance of ground-water levels to reduce pumping costs (Renshaw, 1963). As the water table falls, pumping costs increase so that water left in the aquifer has value to the extent it reduces these costs. Using the concepts of the ground-water engineer, and designating specific yield as S, then one acre foot of stored water for each acre of aquifer reduces pumping lift by 1/S feet and annual savings from leaving an acre foot in the aquifer is C/S times average annual pumping per acre overlying the aquifer, where C = the variable cost per acre foot pumped. For example, if C = $.05, S = 0.2 and average pumping for each acre overlying the aquifer is 2 acre feet, then the cost saving is 2(.05/0.2) = $.50 and this amount may be interpreted as the annual value of water left in storage. At the margin, the value of water in use must be greater than the value of water in storage for continued pumping to be economically feasible. The individual user left to his own ends will not make an optimal decision on this score, since the additional costs of lowered water levels resulting from his pumping are mostly external to his interests.

The formation of a district representing all the users' interests would internalize this effect, i.e., the combined management outlook would encompass any lowering of water levels as an additive cost to all the individuals. One approach to imposing the aggregate effect cost on the individual would be to levy a tax on individuals of the amount of the value of water in storage, e.g., $.50 per acre foot from the above example. A public district with taxing privileges could levy such a tax merely to achieve overall management objectives. Conceivably the individuals would be just as well off after the tax because of reduction in cost, i.e., the tax would be offset by a reduction in cost if the tax had the desired effect of inducing an efficient pumping decision. In this example, pumping of one acre foot lowers the water table by 5 feet over the area of one acre and if it costs $.05 per acre foot of lift then the savings would be $.25 per acre foot pumped. An average of two acre feet pumped per year gives the result of $.50 as the value of water in storage. However, for the individual user his own pumping may not lower the water table appreciably under his own well as water flows in from the surrounding aquifer; thus the individual would tend to ignore this aggregate effect.

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