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⑥ THE RAND STUDY OF WATER SUPPLY,\*  
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PREFACE

This paper presents a brief history of the RAND-sponsored study of water supply and a résumé of the design and conclusions of this study. The complete work is presented in the book, Water Supply, Economics, Technology, and Policy, Jack Hirshleifer, James C. DeHaven, and Jerome W. Milliman, University of Chicago Press, Chicago, 1960.

## THE RAND STUDY OF WATER SUPPLY

J. C. DeHaven

One of the earliest RAND-sponsored projects was a short study of water supply with particular emphasis on the technology of sea-water conversion. Some of you may remember the report on this work, entitled A Brief Survey of the Technology and Economics of Water Supply, and our talk to the Board on the subject in 1952. Contrary to quite widely held expectations, this brief study indicated that sea-water conversion was not likely to become a panacea for providing a cheap supply of water, at least in the foreseeable future.

Perhaps the most important conclusion of this brief survey was that the economic understanding of water supply was indeed in a primitive state. Until recent years water has been almost a free good in the humid areas (or a very cheap one in arid regions) and there had been little incentive to develop and apply the economics of its use. With increasing population and enlarging agricultural and industrial demands for water, it is becoming relatively more scarce and costly in respect to other resources. The consequence is that problems of the efficient allocation of present water supplies and the development of new ones are becoming more important in relation to both regional and national welfare and growth.

Those of us who made the original study suggested that if RAND wished to continue research in this field it could make the most significant contribution by supporting work on the economics of water supply rather

than on the technology of some aspect such as sea-water conversion. We suggested, however, that inasmuch as the economics of water was closely tied to the technological aspects of supply and demand and to the legal and other institutional frameworks built up over the years, all of these features of water supply must be a part of any meaningful study of the subject.

With these suggestions in view, several of us were asked to undertake such a study of water as a commodity. With Dr. Jack Hirshleifer, a consultant economist then with the University of Chicago and now at UCLA, later joined by Dr. Jerome W. Milliman, an economist from Indiana University, we started the study in the fall of 1955. Progress was slow, partly because all of us did the work on an intermittent basis and partly because the problems were complex and the data were scarce and hard to collect. Our study was recently completed with the publication of a book by the University of Chicago Press entitled Water Supply, Economics, Technology, and Policy. I would like to try today to summarize some of the findings of this study that we found most interesting and that are perhaps the most controversial.

Our first job was to try to establish just what the water problem or problems actually are. This is no mean task. There is more confused thinking about water supply and use than in any other field of our experience. Some of the confusion is a result of the great natural complexities involved. Water exists partly as a store and partly as a flow; the supply is variable within any one season and over periods of years; there is pervading

competition between uses and among users largely outside of the usual market processes, yet there are many instances of complementarity of use — navigation and waste disposal, for example. Then, too, the technical aspects of the hydrologic cycle are still incompletely understood, yet our water law evolved long before we reached even our present knowledge of where water comes from, where it goes, and how. Lastly, because water supply decisions are largely made in the political arena rather than in the market place, there is a great incentive for special-interest groups to obscure the real issues involved in government-subsidized water projects and to exploit public romanticism for "making the desert bloom even as the rose," thus obtaining support for their own gain. All of this adds to the confusion surrounding an already complex commodity — water.

In attempting to separate the kernels of true problems from the chaff of misconceptions, we divided our analysis into two major stages: (1) an examination of the allocation of our existing water supplies to see whether the use of what we have now meets an acceptable standard of efficiency, and (2) an examination of alternative possible lines for obtaining additional water supplies. For each stage of the analysis we first developed the economic criteria demonstrating the principles upon which the use of existing supplies and the obtaining of future supplies should be based. After developing these criteria, we examined past, current, and proposed practices to see how the more or less theoretical



solutions can best be squared with the hard facts of the real world. In this connection, we undertook two major case studies: (1) the New York City "water crisis," and (2) the proposals for supplying water to Southern California, an arid region.

Perhaps our most surprising finding was that water supplies are often grossly misallocated among users and between uses. This is just another way of saying that there is great waste in the present use of water. Discriminating and subsidized pricing patterns and defective systems of water rights are responsible for this waste, and have led to a typical pattern of overbuilding of water supplies despite the often-heard claims of "shortages." Let me illustrate these points with some practical examples.

In Los Angeles, as in many other cities, large users are charged less than the cost of procuring and delivering to them that increment of water. As a consequence, large water-using industries are not motivated by this low price to install water recirculating devices which could permit a large reduction in the amount of water used per unit of product made. Waste or inefficiency in the use of society's resources result from this discriminatory pricing because more highly valued resources are needed to supply the extra water demanded at the low prices than would be needed to build the water-conserving devices. Industry does not have a fixed "requirement" for water but rather a variable demand which depends importantly on the price of water. Thus, depending on price, steel mills

may demand anywhere from 1400 gallons to 65,000 gallons of water to produce a ton of finished steel; power plants may use between 1.32 gallons and 170 gallons to produce a kilowatt hour of electricity, etc.

New York City presents another example of the effects of an improper pricing policy on encouraging the wasteful use of water. In that city only about 25 per cent of the water used is metered. Those metered are primarily the larger industrial and commercial users. As a consequence, for the users of 75 per cent of the water who pay a flat rate, the cost of using extra units of water is zero so they have no incentive to economize on its use, to fix leaks, or even to turn off faucets. The result is that New York has a large per capita domestic water use and the city has started construction of the costly new Cannonsville Project to further increase their supplies. This Cannonsville Project was started in spite of the fact that other new supplies now on stream will be more than adequate to meet demands for the foreseeable future and in spite of competent studies that showed that just fixing serious leaks in the city mains and extending metering could provide an increment of supply equal to the Cannonsville Project and at a small fraction of its cost.

In arid regions, irrigation agriculture typically pays very low prices for water and uses huge quantities. In California as a whole, 90 per cent of the water is used for irrigation. For example, the Imperial Valley irrigator pays \$2 an acre foot for water while Los Angeles

and other cities in a nearby region are paying \$25 an acre foot, wholesale, to the Metropolitan Water District. Distribution costs to the urban user raise the price to him to about \$80 an acre foot. These cities face very much higher costs for future increments of supply — to \$80 or more per acre foot, wholesale. Inefficiency and waste are strongly indicated when such a wide divergence of prices for the same product exist: a difference much greater than the cost of transfer.

The irrigator will use water until the last unit yields only \$2 in return. The urban user is restrained from using water when the last unit returns \$80 in value. Thus a mutually advantageous exchange of water between the user paying \$2 and the one paying \$80 would result in the production of commodities and services valued more highly by society as a whole: an increase in the efficiency of the use of our resources.

We do not observe this wide divergence in incremental use-values between users and uses in the case of most other commodities. Ordinarily market processes of exchange occur automatically to bring about the economic equilibrium described so that waste is minimized. In the case of water, however, these market processes do not operate, or at best operate very imperfectly. As we shall discuss more fully in a moment, we believe that the persistence of these differences of incremental values in use can be traced to imperfections in water law and its administration, which hinder waste-reducing exchanges of water.

In presenting these advantages of voluntary transfers of water among users and uses, we have been accused of wishing to dry up irrigation agriculture in the West. This is, of course, a completely unwarranted accusation. In the Imperial Valley case mentioned above, irrigators are using their \$2 water to grow large amounts of low-valued crops. Suppose that 25 per cent of their water rights were purchased for transfer to urban use. The irrigators would almost certainly remain in business. They could either reduce the application of water to their initial crops (these crops are often over-irrigated now), shift to crops demanding less moisture, or cut back on their acres irrigated. Alternatively, they could eliminate waste from seepage and evaporation (often reaching 50 per cent of the amount delivered) and thus recoup at least a part of the water lost by sale. In any case, the net return to farming will have been somewhat reduced in exchange for a larger increment of revenue from water sales. The 25 per cent of their water saved for transfer in this manner is a very large amount by urban standards. It is equal to about two-thirds of all of the urban water used in the South Coastal Area of California.

In spite of the potentialities of the type of transfers mentioned above, a costly new import of water from the Feather River in the north is now proposed by the State Department of Water Resources for Southern California. Our studies indicate that at best this import is very premature.

The State calculates a "need" for this new import of water in 1970 by the mechanical process of simply adding up projections of agricultural and urban use. These projections utterly ignore the fact that water demands will be highly responsive to price, so that if the true cost of Feather River water is charged to users, the actual demands will be found to be much less. This procedure repeats the error which led to the premature construction of the Colorado River Aqueduct by the Metropolitan Water District of Southern California.

Our estimates are that prices reflecting the true cost of Feather River Project water would cause a decline in agricultural use of at least 50 per cent, and of urban use 40 per cent as compared with the State's estimates. These reductions would permit the deferment of new construction for at least another decade.

In addition, our study shows that when new supplies may be indicated for Southern California, there are technical possibilities and interregional transfers which promise a lower cost than the proposed Feather River Project — the largest and most costly water project of historical record.

Perhaps the most controversial substantive conclusion of our study, justified by a wide variety of evidence from our separate case studies and from our survey of federal and local experience in water-supply decisions, is that in this country major water investments are typically undertaken prematurely and on an overambitious scale. Consequently, at any given time there exists overinvestment in water supply.

Overinvestment for any particular area is indicated when facilities stand idle or else are put to makeshift uses, either to avoid the appearance of idleness or to minimize the losses due to past mistakes. Or, uneconomic overinvestment may be indicated not by idle facilities but by relatively low return earned on capital invested in water supply. Here the water is actually being put to use, but the price charged is so low that the revenue to the water enterprise is small in relation to cost. There is overinvestment because the same capital investment could have been put to work producing goods and commodities valued more highly on the margin by consumers; consumers' marginal values in use for water are low in comparison with what could have been obtained had the dollars been spent elsewhere. Specifically, our two major area studies both revealed the highly premature nature of the decision to build the Cannonsville Project in the one case and the proposal for construction of the Feather River Project in the other. Or, looking at return to capital, we found that, for the public water-supply systems in general, this is of the order of 2 per cent — an astonishingly low figure.

The reasons for the prevalence of overinvestment in water supply are complex and interrelated, and, to the extent that they are outside the sphere of economic analysis, we can only speculate about them. One possible explanation is that those responsible for the construction of "engineering wonders" become romantic figures, heroes not only to their own age but to later generations — and heroes whether their great

projects were wise or unwise, timely or premature. In contrast, individuals credited only with sound stewardship of the resources of society are scarcely known in their own day and certainly never appear in history books. Political scientists have pointed out the attractiveness to bureaucrats and politicians of the power inherent in being able to influence the award of contracts valued in the millions or hundreds of millions, the enhancement of real estate values on nearby lands, the creation of an enormous variety of business opportunities, etc. Such power cannot but be a temptation to merely human administrators and legislators.

Despite the possible importance of considerations like those adduced above, the emphasis throughout our study has been upon errors of fact or of reasoning which have played a role in bringing about the pattern of over-investment. Perhaps the most important of these might be simple oversight; that, when the total of water use begins to approach system capacity, administrators simply do not think of attempting to make better use of existing supplies as an alternative to initiating new construction. The possibility of adjusting prices does not often occur to those responsible, even though studies have shown that demand is responsive to prices and that the widely divergent price levels and price structures existing in different cities suggest that a schedule presently in effect in a particular city is not necessarily the only one possible or even the best available in the circumstances.

Equally ignored, at times, are possibilities for avoiding or deferring expensive new construction by taking better care of existing supplies or by seeking out possibly unconventional but cheaper sources. Thus, in the New York case, the major construction decision ignored the promise of the extremely large saving that could be made simply by detecting and correcting leaks in the city's own distribution system. And, in the California study, the responsible authorities have shown little interest in such technological possibilities as evaporation control on reservoirs or in economic solutions involving reallocation of water from agricultural uses as urban demand rises.

The third major class of error leading to overinvestment in water supply is the systematic bias toward excessive construction inherent in conventional techniques of project analysis. The most obvious and well-known source of error in these practices consists of the inventing and counting of "secondary" or "intangible" benefits — a topic which we analyzed exhaustively to separate the kernel of validity in these conceptions from the gross errors committed in practice. Rather more interesting to us, because less fully or less successfully analyzed by others, is the history of overoptimism in estimates of project benefits and costs. In part connected with this is the fact that conventional project analyses for government investments discount future benefits and costs at interest rates that reflect the ability to borrow of the agency concerned — and that, consequently, represent little or no allowance for the risk of failure



of the project in question. We have shown that these risks of failure in the most closely comparable private class of investments (privately owned, regulated utilities) require companies to finance new projects at rates that preclude their undertaking investments that promise to yield less than around 10 per cent. Consequently, if our fundamental postulate of neutrality on the margin between publicly and privately owned enterprises is accepted, public agencies also should restrict themselves to investments of comparable apparent yield.

The adoption of such a strict standard would, correctly, indicate as uneconomic the great bulk of the investment programs of the major federal agencies in the field — Bureau of Reclamation, Corps of Engineers, and Department of Agriculture — as well as many of the more grandiose state and local projects. The same conclusion can be arrived at without the use of the high discount rates (10 per cent) which allow for risk; if costs and benefits were correctly rather than optimistically estimated, cost-benefit calculations employing a long-term riskless rate like 4 per cent (5 per cent with property tax adjustment) would also reveal the inefficiency of these programs.

The most sophisticated of the arguments for adoption of inefficient water projects is the claim that the subsidy to water-users involved in construction of an inefficient project is justified because of certain "development" needs of the region in question. (Inefficient projects require subsidy because, by definition, the beneficiaries cannot repay

the cost, and so the taxpayer must.) But such a subsidy will cause the development to occur in a manner ill suited to the natural advantages of the region. In particular, in an arid region where water is costly to provide, a subsidy making water cheap to users will encourage them to be wasteful — to be unconcerned with possible economies in water use. A likely and unfortunate result is the development of water-intensive, low-tax-base industries, irrigation agriculture, for example, for which the area's low water prices but high taxes present the best combination of comparative advantages. The interests of a region will in general be best served by the adoption of efficient projects — whether under government or private auspices, or whether directed to the provision of water supply, power, transport facilities, or consumers' goods and conveniences.

As mentioned briefly, we believe that we have in our study demonstrated that much of the present misuse of water within the sphere governed by the market can be traced to imperfections in water law and its administration. These errors occur because in most jurisdictions water rights are not clearly defined, do not have the necessary legal certainty, and cannot be transferred with ease as are rights to other types of property — land, mineral rights, etc. As a consequence, the market processes that ordinarily direct resources to uses that maximize their productivity — chiefly, voluntary exchange through purchase and sale — are either severely limited or prevented entirely from operating in the case of water. Individuals and local private and public organizations

do not have proper incentives to invest in improving or increasing water-supply resources when their tenure in these resources is uncertain.

Economically desirable transfers of water between lower- and higher-valued uses and among regions, to the mutual advantage of all parties, are discouraged by these imperfections of rights and by the lack of a clear legal basis under which such transfers can be consummated.

The establishment of clear property rights to water does pose difficulties. As mentioned earlier, water is a fleeting resource. It exists partly as a store and partly as a flow. The development of water law occurred when very little was understood about the phases of the hydrologic cycle from which our supplies are obtained. Then, too, water, until fairly recently, has been in a position of surplus supply in relation to demand, so that it has been a free good or at least a very cheap one. Therefore, little consideration had to be given to its efficient allocation or to the laws governing its use and ownership. With increasing demand, however, even the humid regions have begun to recognize the inadequacy of their doctrines of water law. We believe the wrong direction is being taken in modifying present law, as represented by drafts of "model" state water codes and the recent actions of several states in this connection. These actions tend to attenuate the already weak fabric of property rights in water. The tendency is to arrange matters so that allocation of water can take place only through grants or permits to users by central administrative commissions or by cumbersome

court procedures, based on fuzzy criteria of "reasonable" or "beneficial" use. In these circumstances, tenure of water rights becomes uncertain, dependent upon the changing wills of the commissions or courts. This line of legal development, it can be confidently predicted, will lead to serious misallocations of water among competing users; it will, unless revised, seriously weaken or stop altogether the exercise of local and private initiative in the development of water resources.

We believe it to be justifiable, however, for the state to assume ownership of unappropriated water. Rights to this water may then be distributed by auction among the competing claimants against the reservation price representing the value of the state's own public uses. This procedure allows the state, and ultimately the individual citizen-taxpayer of the state, to receive compensation from the fees paid for the rights to use these unappropriated but potentially valuable water resources.

We believe that the law of prior appropriation as developed in some western states has most of the elements required to make the system we suggest work. This type of water law needs to be strengthened primarily in its provisions for the transfer of rights. Under the system we propose the courts would function, as they do for other real property, to adjudicate disputes as to the ownership and extent of the property right and to hear pleas relating to breach of contract in transfers or from parties who consider themselves injured by the actions of the owners of the water rights. The judicial system would be freed of its present inappropriate

administrative-economic function of issuing and revising rights to use water on the basis of criteria like reasonable beneficial use.

In our study, we have stressed the importance of considering a wide range of technical and economic alternatives in planning for increased water supply if maximum efficiency is to be realized. This is not the usual procedure, whether the plans are made at the local, state, or federal level. There is a great tendency to consider dam and aqueduct construction as the only solution for obtaining a net increase in supply. Perhaps this is because civil engineers are usually employed in planning water developments, and aqueduct and dam construction is one of their specialties. Perhaps this narrowness of outlook is a reflection of the "monument syndrome." Commemorative bronze plaques can be prominently displayed on a dam but not on repaired leaks or on an improved schedule of prices.

The relative costs of all the alternatives should be determined, too. In our study we attempted to present the most acceptable ways for determining these costs, both by describing the principles involved and by illustrating their use through specific practical examples. Often these costs are difficult to estimate because of uncertainty in the basic information required as inputs. Even so, the discipline of going through the appropriate cost determinations provides insights not otherwise possible. Although the costs so determined may be but rough first approximations, they can provide a better basis for decision-making than "hunches" or generalized

rules of thumb. The increased use of meters may or may not be economic, increased price may or may not be a better alternative than a new imported supply, etc., depending upon each local situation and time.

Aside from the historical tendency to overemphasize long-distance importation as the source of increased water supply, we believe that among other technical alternatives the possibilities for sea-water conversion are overblown. There should be no objection to a modest research and development program exploring the potentialities of producing fresh water from the sea. However, nothing so far in the laboratory gives any indication of promising a source of supply by conversion for municipal, and certainly not for irrigation, use at costs that approach any but the extreme of many other technical and economic alternatives. Sea-water conversion processes are handicapped by high capital costs or by high power costs, or both.

In contrast, we feel more optimistic about the future costs and returns of some of the possibilities for water-conservation techniques. Monomolecular film control of evaporation is progressing rapidly and will probably be widely used to produce the next increments of supply, especially in the more arid regions. The elimination of non-beneficial vegetation growing in and surrounding reservoirs, along streams, and on watersheds also holds promise for reducing the large water losses attributable to transpiration. Seepage losses from reservoirs and transmission canals appear to be large. At present only expensive lining

techniques are available to reduce these losses. Some research now appears to be directed toward studying inexpensive soil treatments to reduce seepage, especially in reservoirs, and it seems possible that such treatments could be developed. The creation of artificial aquifers in sand dunes for storage purposes, as in the Netherlands, is an especially interesting development in additional entrapment and storage of runoff water for areas near the sea.

The most interesting technological possibility not now being utilized is purposeful reclamation of sewage water. We use the word "purposeful" because reclamation is effectively occurring today in many river supply systems where one city's water intake may be a little below another city's sewage outfall. And, in rural areas, there ordinarily is hydrologic connection between wells and septic tanks. Despite the prevalence of unintended reclamation, and despite the favorable costs of such supplies (a reclamation plant will cost little more than the sewage-treatment plants often required anyway), we are inclined to be conservative here. At least until the mechanism of propagation of virus disease is better understood, we believe it to be a wise precaution to prevent direct human consumption of such supplies unless arrangements can be made to pass the water some distance through the ground before being used. Nevertheless, we feel safe in asserting that sewage reclamation is an important source of supply for the future, as expanding population and industry compete more and more avidly for the limited supply of suitable natural water.

In closing, I feel it important to mention again that in our study we attempted to show by argument and example that the correct application of economic principles will produce the greatest efficiency in water-supply procurement and use in relation to, and in competition with, all the other desires of the community, and as based on the values established by the community. Many of the conclusions we reached are at variance with present practice governing the use of existing water supplies and the development of new supplies. Also, they indicate that certain "reforms" now in process (for example, changes taking place in water law) and supposedly directed to an improvement in the decision-making practice will actually make things worse. In other words, our study indicates that a major change, rather than merely a marginal modification, in the trend of current practice and thought on water-supply problems is in order.