9

ECONOMIC MODELS

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9-1 INTRODUCTION: CONTEMPORARY ISSUES IN THE SOCIAL VALUATION OF WATER RESOURCES

Any taxonomy of subject matter is bound to be somewhat arbitrary and difficult to observe when one attempts to summarize the accomplishments in a scientific field. It is difficult to know just where hydrology, ecology, and water quality end and where economic modeling begins. Emphasis has been placed on issues relating to the evaluation or ranking (i.e., the objective function) of alternative water developments and on recent types of modeling which extend the set of variables assumed to be under the policy maker's control, rather than on programming techniques or solution algorithms.

The modeling of physical and social systems can be descriptive or normative in nature; i.e., one can attempt to describe how a given system works without attempting to interject change or control into the system, or one can select some subset of variables capable of policy control and attempt to find ways of "improving" the system performance. The distinction is only a matter of degree and depends upon the model builder's perception of the set of variables capable of being directly controlled. Examples of models and planning procedures spanning this range would be: (1) an input-output model or econometric (multiequation) model which purports to show how a regional or national economy operates (e.g., Klein and Goldberger[1]); (2) the frequently encountered planning approach in which descriptive trends or possibly behavioral relationships are used to calculate water "requirements," and plans are drawn to meet these requirements at minimum cost; (3) the projection by trend relationships of population, incomes, and food demands by region, but calculating the demand for water as a function of water price and permitting the optimization of location of agriculture production among regions; and (4) inclusion in the plan of incentive programs capable of affecting population trends and optimizing with respect to population distribution, as well as the variables mentioned in the previous examples.

Economic modeling is intended to relate decisions on the use of scarce water resources to necessarily related uses of other scarce resources (investment and operating inputs in public and private sectors) and to provide criteria for ranking different water development and management policies. Despite recent skepticism (Silk et al.[2]), economic modeling is distinguished from operations research or management science by its concern with quantifiable impacts of policy on human welfare, very broadly interpreted. Naturally, it becomes necessary to model the physical system by which natural hydrologic resources influence those dimensions of human welfare measured by income, its distribution among subsets of the population, the generation of employment, and physical environmental conditions. This linkage is provided by the conceptual production function

$$\mathbf{Y} = \phi\,(\mathbf{W},\mathbf{X},\mathbf{Z}) \cdots \tag{9-1}$$

where $\mathbf{Y}$ is a vector of outputs, $\mathbf{W}$ a vector of hydrologic inputs, $\mathbf{X}$ a vector of scarce resource inputs directly related to the transformation of $\mathbf{W}$, and $\mathbf{Z}$ a vector of other scarce inputs related to the production of $\mathbf{Y}$. Depending upon the problem, ϕ may vary from a single algebraic function to a complex computer simulation of a river system. It is here that the engineer, hydrologist, sanitary engineer, and agricultural scientist provide the technological inputs.

The outputs $\mathbf{Y}$ and the inputs $\mathbf{W}$, $\mathbf{X}$, and $\mathbf{Z}$ must then be valued, perhaps in terms of several incomensurable dimensions $\mathbf{V}_i\,(\mathbf{W},\ldots,\mathbf{Z})$, $i = 1,\ldots,k$. The valuation model itself can vary from a set of market prices to a general equilibrium model in which prices, money incomes, and the benefits and costs of public goods are determined simultaneously with $\mathbf{Y}$.

Before surveying our current capabilities in the modeling of production functions and calculating meaningful values for system inputs and outputs, it seems appropriate to briefly review some of the basic contemporary issues involved in measuring values and in aggregating values over the individuals affected by water-resource systems. The issues to be included are (1) the appropriateness of market prices as value measures; (2) problems of meaningfully aggregating values over different persons or classes of persons; (3) attempts to extend marketlike valuation processes to publicly provided goods and public goods;* and (4) the desirability of or need for multiobjective planning in which dimensions other than national economic efficiency are estimated and made part of the project-ranking process.

9-1.1 The Appropriateness of Market Prices as Value Measures

The question of the appropriateness of market price as a measure of value has (at least) two aspects: (1) does there exist a rationale for prices as formulated by market processes that will make them generally acceptable to society or to society's chosen decision makers; and (2) will market prices change as a result of the existence of the project or policy being evaluated?

Rationale for market prices The rationale for market prices is found in economic theory, which has demonstrated that a competitive economic system tends toward an equilibrium that has many desirable characteristics: (1) that goods are produced in proportions corresponding to consumer demands; (2) that goods will be produced from a mix of inputs which minimizes the costs of production; (3) that outputs will be distributed among firms so as to minimize costs; (4) that consumable goods will be distributed among consumers in such a way that, given incomes, consumer satisfactions will be maximized; (5) that the supply of human effort will be extended just to the point where the utility from additional income offsets the disutility of additional labor; (6) that the wages for human effort will just equal the market value of the marginal product of that labor; and (7) that saving out of income is extended just to the point where the greater future product made possible by investment is offset in present value by the natural preference for present over future consumption.

All these results are shown to occur in a competitive market setting in which buyers and sellers respond to prices. The resultant equilibrium prices have the following properties:

> *Consumer goods*: The price for each good equals the marginal valuation of that good for *every* consumer of the good and simultaneously equals the *incremental* cost of producing that good for every producer of it.
>
> *Human effort*: For each class of skills, the wage will just equal the market value of incremental product produced, wherever that effort is applied, and will simultaneously reflect the disutility of that effort (i.e., the incremental valuation of leisure) to every worker.
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> *Capital goods*: For each type of good, the market value will just equal the present value of the anticipated excess of revenues over operating costs, measured at the margin of investment.

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* Any commodity or service may be publicly provided if its production is controlled by the public sector. The term *public good* has a definite technical meaning in economics. It refers to a service the benefits (or disbenefits) of which are spread in fixed proportion among the affected population. It is also true of a public good that it is not practicable to exclude nonpaying persons from its use, and that the cost of extending its use to another person is so low that a zero price is called for.

Prices having such properties would seem to be excellent measures of value for purposes of evaluating different projects or policies. Two major difficulties stand in the way of our asserting that real-world market prices have these properties: (1) real-world economic systems, even when operating under fairly competitive conditions, frequently do not generate a socially acceptable distribution of income among persons; and (2) real-world economic systems often do not exhibit the competitiveness assumed in the derivation of the above results. Each of these points will be briefly discussed.

Income distribution Competitive market prices are formulated on the basis of producers' costs and buyers' willingness to pay, given the incomes of the buyers. If these incomes are socially sanctioned as providing adequate living levels, then the individual's willingness to pay for various commodities (expressed as demand functions of negative slope) becomes simply an expression of his own freely chosen priorities in a milieu of adequate if not abundant resources. On the other hand, if the distribution of income is not socially sanctioned as adequate but persists because of lack of knowledge of how to correct it or because of the ability of power groups to prevent corrective measures, then market prices cannot be taken as an acceptable measure of value for the evaluation of projects or policies affecting economically disadvantaged segments of the population.

As simple examples, we would be willing to accept as a measure of value the explicit or inferred willingness to pay for outdoor recreation of a middle-income worker who arrives at the reservoir with outboard-motorboat in tow, but we would not attempt to calculate the willingness to pay of ghetto dwellers for water recreation in evaluating a proposal to build a neighborhood swimming pool or to put spray nozzles on the fire hydrants. We would accept the middle-income worker's willingness to pay for beefsteak as a value measure, but not the Appalachian poors' willingness to pay for milk.

A curious perversion of this reasoning is found in the "water is different" syndrome often cited by water planners. Reasoning that the pricing of water at appropriate levels will deny the poor, or that water is "essential for life," such planners fail to acknowledge that price structures can be built which place a low price on the quantities necessary for health, and that the expanding demands for water are from the nonpoor to whom water for gardening, car washing, and water-driven household gadgets is just another commodity along with beef, bread, and beer.

Deviations from competitiveness The economist includes under "competitiveness" the tendency of the economic systems toward full employment of its human and capital resources. Presumably if prices are flexible, the price of an underemployed resource, whether it be construction workers or capacity on an assembly line, will fall until it becomes profitable for someone to buy and use the resources. Unfortunately, many factors—from minimum wage laws and union rules to faulty monetary policy and the dynamics of innovation and obso-

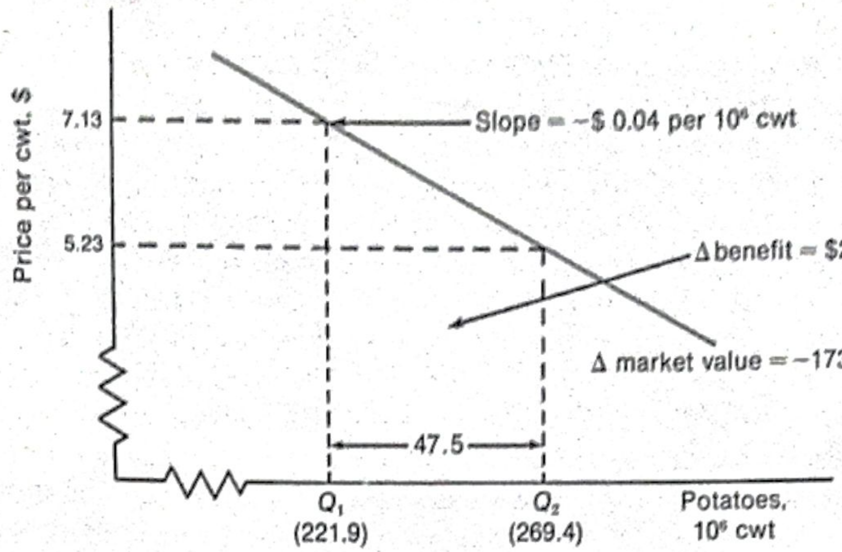

FIGURE 9-1
Impact of increased potato production on economic benefits and producer income, 1964–65.

lescence—can prevent approximate full employment from occurring. This happens, of course, without the prices of the underemployed resources falling to zero. Under such circumstances, market prices (of productive inputs) fail as acceptable measures of value. The measure of value of an input which is appropriate in project or policy evaluation is the "opportunity cost" of that input, meaning the value of benefits being foregone elsewhere by virtue of this use of the input. If the input would otherwise be unemployed, its opportunity cost is zero and is not reflected by its nominal market price. Here, adjustments in market prices must be made for socially correct benefit-cost assessments to be carried out.

It is appropriate in this connection to call attention to the work of Haveman, Krutilla, and Steinberg,[3] who developed a model capable of estimating by region the total impact of the construction of a project on the employment of manufacturing capacity by industry and of labor by skill category. There are other ways in which deviations from competitive conditions can lead to the inappropriateness of market prices as value measures (particularly the existence of monopoly power among the few dominant producers in a market), but none as important as the income distribution and unemployment issues dealt with above.

Changes in prices resulting from project The second issue relating to the appropriateness of market prices as value measures is that the presence of the project or execution of the policy being evaluated may so affect input and product markets that prices will be substantially changed. Figure 9-1 illustrates an important case where this occurred.* During 1964–65, U.S. production of

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* The data on the potato market are taken from Howe and Easter.[4]

Irish potatoes increased from 221.9 to 269.4 million hundredweight. The farm price of potatoes fell from $7.13 to $5.23 per hundredweight.

The increase in output was largely attributable to the increase in irrigated potato acreage. The question is, if one were attempting to calculate the gross benefits of the irrigation from market data, how should one go about it? It is clear that the total on-farm value of potatoes *fell* by $173 million, since the lower price was applicable not only to the increment of production but to the total crop. Is this loss of $173 million to be taken as the benefit of the increment? From the overall farm point of view, one might argue yes, since farmers as a group lost income equal to that amount plus the production costs of the increment. From the point of view of the farmers on the newly irrigated lands, it was clear that a profit was to be made even at the new lower price since they did not absorb the decrease in value of existing levels of production. From the national viewpoint, it was quite clear that the increase in output had a high value calculated in terms of the willingness of customers to pay for the increment. This willingness to pay is calculated as the *area under the potato demand function* between the quantities Q_1 and Q_2, as illustrated in Fig. 9-1. This area was approximately $294 million annually, quite a difference from the observed market value change.

Such a result is not unusual in the markets for agricultural commodities, for it is a consequence of what the economist calls the "inelastic demand" for farm products, meaning that the percentage fall in price is greater than the percentage increase in output. Two points should be garnered from the example, however: (1) where projects are large relative to existing regional or national markets (whichever is relevant, depending upon the relative size of transport to production costs), it will be necessary to use the *demand function*(*s*) for the *project's output*(*s*) to arrive at a correct valuation of the output; and (2) the demand function also permits us to learn more about the *distribution* of project benefits between producers and buyers. In the potato case, the buyers benefitted not only by the excess of their willingness to pay over the market price of the increment of output (approximately $45 million), but they experienced a reduced cost of about $422 million on the volume of potatoes formerly being bought. These facts could be learned only from a knowledge of the demand function. The importance of the *distribution* of benefits will be discussed at greater length later.

The estimation of demand functions is carried out somewhat differently for the group of commodities directly serving consumer needs (foods at the retail level, autos, consumer durables, household water) than for the group constituting intermediate inputs into production processes. The distinction is particularly relevant to the demand for water in the agricultural sector. For consumer goods and many producer inputs, we have data on prices, quantities sold, and other relevant variables sufficient to permit estimation of the demand function. For irrigation water, markets generally do not exist; prices are usually nominal and highly subsidized and are unrelated to either costs or willingness to pay. Transfers among uses are infrequent and sluggish. Thus, often we simply do not have the data needed to estimate the demand functions for irrigation water. It is then necessary to estimate farmers' willingness to pay for water by modeling their production operations and, assuming that the farmer consciously or unconsciously is attempting to maximize profits, deducing how his applications of water would vary as the price of water is varied. This is most frequently done through linear programming models in which the activities represent different crops and methods of cropping (including different amounts of water). The same results can be deduced by placing a water constraint on production, plotting the relationship between the *shadow price* of water and the quantity available. Examples of excellent studies following this approach to the estimation of irrigation water demand are Moore and Hedges,[5] Young and Bredehoeft,[6] Cummings,[7,8] Stults,[9] and Gisser.[10] The resultant demand functions are either for an individual farm or farms of different types (Moore and Hedges[5]), for a farming area (Young and Bredehoeft[6] and Cummings[8]), or for an entire region (Cummings,[7] Stults,[9] and Gisser[10]). In Sec. 9-2 we shall discuss three models which make possible the derivation of irrigation water demand functions by region for the entire nation (United States and Mexico).

Other methods are possible for estimating irrigation water demand functions. Hartman and Anderson[11] estimated the value of irrigation water from farm sales data. Anderson[12] has estimated irrigation water values from data on seasonal water rental markets in northeastern Colorado. Gardner and Fullerton[13] have estimated irrigation water values from time-series data on water rental values before and after consolidation of two Utah irrigation districts.

The value of water may have to be inferred from the value of output less operating costs made possible by the availability of different quantities of water. For large projects, this requires the demand functions for project outputs as in the potato case above. A detailed study of demand functions for farm commodities at the farm and retail levels was carried out by Brandow.[14]

Relevant to our present interests in water are the residential water demand studies of Howe and Linaweaver,[15] Hanke,[16] and Grima,[17] which estimate demand functions from cross-sectional and time-series data, respectively, and which clearly illustrate the responsiveness of residential demands (particularly outdoor demands) to changes in price. A general discussion of water demand functions in municipal, industrial, agricultural, recreational, and other in-stream uses can be found in the volume by Sewell, Bower, et al.[18]

9-1.2 Logical Problems in Aggregating Values Over Persons: The Income Distribution Issue

From a scientific viewpoint, it is interesting to see how far one can proceed in setting up a system of valuation without interjecting value judgments. For example, in adding up the national income from personal and corporate income data, are we interjecting a value judgment in simply adding X's income to that of Y and Z, i.e., in giving equal weight to each?

Early economists took a pragmatic approach to this issue, assuming either that a dollar was a dollar, regardless of recipient, or that it was obvious that a dollar meant less to a millionaire than to a pauper. Later economists, desiring to be more "scientific," attempted to confine their judgments regarding projects or policy changes to those which were "Pareto optimal," i.e., to those changes which left all persons at least as well off as they were before and improved the lot of some. This interest in Pareto optimal changes was reinforced by the theoretical demonstration (once again) that competitive economic systems tend toward an equilibrium which is Pareto optimal, i.e., an equilibrium in the distribution of output and provision of labor such that any change would be disadvantageous to someone.

Now it is quite clear that all projects, whether in the public or private sectors, affect some people positively and others negatively. If project beneficiaries always paid the full project costs in proportion to benefits received, this might not be so; but there are always some negative externalities, and especially in the public sector, it is highly likely that beneficiaries and cost bearers will be different groups. Thus, the concept of the Pareto optimality of a project or policy change is too weak to be useful as a standard for passing judgment on 99.9 percent of real-world changes. It is simply true that some people bear more benefits than costs from a project, while others bear more costs than benefits. Should this *distribution* of benefits and costs affect the way we add them up? For example, should we give certain premiums to benefits and costs borne by some subsets of society (maybe the poor) and discount benefits and costs borne by others (maybe the rich)?

It was long argued that the distribution could be *ignored*. The main argument was that society had various mechanisms such as progressive taxes and welfare programs for the express purpose of keeping the income distribution socially acceptable. If income distribution could be guaranteed acceptable, then welfare could be pursued by choosing projects or policy changes having the highest net benefits regardless of the parties to whom they accrued.

Another argument was that the distributional aspects of a project could not be judged in isolation from all public sector projects. If one project favored the rich over the poor, some other project had the reverse effect. The distributional effects on all public projects and policies would "even out" and not result in unacceptable distributions of income. Maximum net economic benefits (national economic efficiency) could again be pursued without concern about distribution.

Unfortunately, things have not worked out that way in most countries. Income distributions have not taken acceptable forms under the molding pressures of progressive taxes and welfare programs. The distributional effects of major government programs have not "evened out" but continue to benefit particular groups and exacerbate the spread of income between rich and poor (for the United States, see especially Bonnen,[19,20] Hansen and Weisbrod,[21] and Schultze et al.[22,23]).

Two things are clear today: (1) if public-policy makers are not informed about the income distribution implications of the programs they are asked to pass upon, there is no hope that the distributional impacts of all the government programs will "even out" or that specific redistributional programs such as the progressive income tax and special welfare programs will be scaled adequately to offset the effects of specific functional projects (highways, waterways, farm support programs, oil import quotas, etc.); (2) societies today are very much concerned with equity and the income distribution issue. In the United States, the resurgence of interest in the income distribution issue is seen in the prominence given to the issue in "Principles and Standards for Planning Water and Related Land Resources," promulgated by the Federal Water Resources Council (Federal Register, September 10, 1973) as prospective regulations governing all federal agencies involved in water development. Thus, partly as a result of public pressure, partly as a result of economists' urging, the explicit analysis of *who* gets the benefits and *who* bears the costs has become an important part of the assessment process. Even though we do not have explicit weights to attach to the benefits and costs of particular groups within society, we are now obligated to point out who gets what.

9-1.3 Extension of Marketlike Valuation Processes to Public Goods and Publicly Provided Goods

Public goods and publicly provided goods have been previously defined. Markets generally do not exist for these goods and services, so prices are not available and the usual kinds of data are not available for estimating demand functions. As examples, first consider air-quality improvement as a public good. The proportions in which it is enjoyed by the public are not entirely under their control. It would not be administratively feasible to exclude those who are not willing to pay for the improvement as a public good. The proportions in which it is enjoyed by the public are not entirely under their control. It would not be administratively feasible to exclude those who are not willing to pay for the improvement. Thus, there will be no market price for the improvement. Does this mean that we cannot place a value on alternative levels of air pollution clean-up? Clearly not. In this case, as with flood control, we can attempt to analyze the differential damages occasioned by different pollution levels and thus compute the value of achieving different degrees of improvement. Naturally, there may be difficulties in imputing dollar values to esthetic aspects of the clean-up. But this is nothing new. Incomes and relative values have been changing and we are just newly aware of the importance of the "quality of life."

As with air quality, we will find no demand function for water-quality clean-up, but we can deduce the relevant values from the differential damages to all classes of water users of different water-quality levels. This is not to say that such an assessment will be easy; in fact, it has been tried very few times (e.g., see Davidson, Adams, and Seneca,[24] Frankel,[25] Stevens,[26] U.S. Federal Water Pollution Control Administration,[27] Kneese[28]).

The most extensive work in extending marketlike valuation processes to publicly provided goods is in the field of water-based recreation. Now quite well known, the initial methodology was developed by Clawson[29] on the basis of earlier work by Hotelling and has been substantially refined and extended by Knetsch,[30] Kalter,[31] Todros and Kalter,[32] and Cicchetti, Smith, et al.[33] An excellent summary of these techniques and of environmental assessment techniques is provided by Coomber and Biswas.[34] Perhaps the most illuminating example of the application of these techniques for estimating the demand function for water-based recreation is found in the work of Grubb and Goodwin as it was used in reservoir site evaluation in the preliminary Texas Water Plan.[35] The reasons for having to simulate the values of recreation on public water bodies are that:

1 Admission fees are frequently not charged and are often nominal when they exist. Thus, there is no market test of willingness to pay.
2 The value of recreation needs to be known for planning purposes before the project exists so that the planner has no opportunity to observe how people respond to prices, if charged, or even to survey them to ask questions.

We thus need methods which are capable of estimating willingness to pay and which are transferable among project types so they can be used in planning. The basic idea of Clawson and Knetsch is to assume that people who live X miles from a reservoir recreation site and who face certain time and travel costs in getting to the site would utilize the site just as frequently as comparable groups of people $(X - h)$ miles from the site when faced with an admission fee to the site equal to the additional time and travel costs associated with the distance h. From this assumption and observations regarding the frequency of use of different groups, one can deduce a demand function for the site.* Insofar as new sites are located in areas similar to those from which the estimating data were taken, these estimated demand functions can be used to estimate both (1) *rates of use* of prospective sites, and (2) the *value* of a new site as expressed by user's estimated willingness to pay.

The Texas Water Development Board has used this technique to evaluate the recreational values of reservoir sites which were being considered for inclusion in the Texas Water Plan. To illustrate, their analysis started with the following participation rate function:

$$\log_e Z = -8.60 + 0.57 \log_e X_1 - 1.19 \log_e X_2 + 0.75 \log_e X_3 - 0.33 \log_e X_4 + 0.21 \log_e X_5 \cdots \qquad (9\text{-}2)$$

where $Z \equiv$ (approximately) the number of visitor-days per year from a particular county to a particular reservoir
$X_1 \equiv$ population of the county of origin

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*In the procedure, allowances are made for differences in income of the groups of users and for differences in alternative recreational opportunities.

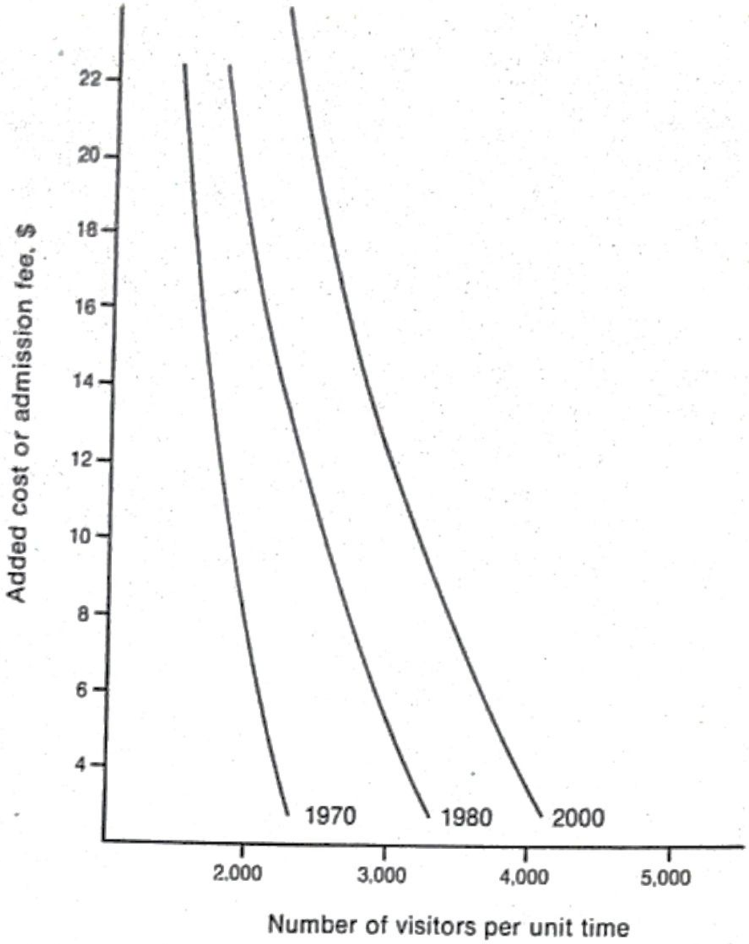

FIGURE 9-2
Shifting recreation-demand curves.

$X_2 \equiv$ the round trip cost from the county of origin
$X_3 \equiv$ per capita income in the county of origin
$X_4 \equiv$ a "gravity" variable to reflect the offsetting attractions of other lakes available
$X_5 \equiv$ size of the surface area of the conservation pool of the lake

The above function was statistically fitted from actual observations on the uses of Texas lakes. This participation function is then used to estimate the demand function for new sites by inserting values of the variables for the counties surrounding the new site and a sequence of additions to the travel cost variable representing a sequence of increasing admission charges. Adding the participation rates over all counties for each hypothetical admission rate ($0, 1, . . .) will yield points on the demand function, which is illustrated in Fig. 9-2. The approximate area under the curve up to the rate of visitation consistent with the intended admission charge is the measure of recreation benefits yielded annually by the lake.

This is clearly a complicated procedure, but similar procedures are in wide use today to estimate and forecast participation rates and values of various types of outdoor recreation: salmon and steelhead fishing; various types of outdoor recreation in New York State; and big game hunting.

9-1.4 The Need for Multiobjective Planning

The preceding discussion dealt almost exclusively with economic net benefits as seen from a national viewpoint and the distribution of those benefits among various subsets of society. It is clear that society also seeks other goals through water-resource development, or at least has fairly clear ideas about constraints it wants to impose on projects. These other goals or constraints include environmental and social impacts, such as the saving of life, causing people to migrate, the preservation of historical sites, and so on, factors which probably never can be quantified in monetary terms. Similar situations arise in the evaluation of projects which yield short-term economic benefits but result in long-run, difficult-to-quantify costs, such as the strip mining of coal. It can be argued that one (but not the only) cause of the distortions often found in benefit estimates in traditional benefit-cost analyses has been the fact that the accepted methodology had no place for these other dimensions of project impacts. While it seems likely that national economic efficiency will continue to receive primary weight in public water-project design and evaluation (see Howe[36]) these other factors must be brought into the process.

When we are asked to include objectives or impacts which cannot be reduced to monetary measures, there appear to be three major ways to approach the problems of project design and ranking:

1 The maximization of national economic net benefits, subject to constraints on the other objectives
2 The use of a system of explicit weights to make the several objectives commensurable
3 The generation of several alternative designs for each project, each emphasizing a different objective, permitting the legislature or decision-making body to choose according to their interpretation of society's needs

These approaches will be discussed briefly.

Maximizing economic efficiency subject to constraints First, let us discuss the problem of project design. If all project outputs were quantifiable in comparable value terms, the project capacity to produce each output (for multiple-purpose projects) could be expanded until incremental benefits equaled incremental costs, a point beyond which further expansion would not be warranted. Since the values of certain project outputs (or impacts) are not quantifiable on commensurable bases, we must determine whether there are any minimally acceptable levels of those outputs required either by law or by other expressions of public taste. These values then would constitute *constraints* on our designing subject to which we proceed to design the project yielding the greatest net economic efficiency benefits.

Consider a hypothetical example where the development of a power site is being considered. The power could be used by a city or power grid considerably removed from the dam site and reservoir, but it has been determined that any recreational and flood-control benefits would accrue to the residents of the immediate area of the site. To provide compensation to persons whose lives will be disrupted by the construction and existence of the project, the legislature or other relevant political decision-making body has determined that *X* dollars of recreational and flood-control benefits (or perhaps an amount equal to *Y* percent of power benefits) should accrue to such parties. Furthermore, the same decision-making body might specify that, for esthetic reasons, the maximum allowable drawdown should be *Z* feet and that all timber and trash should be removed from the reservoir site to a contour *K* feet below mean pool level. These then would constitute quantitative constraints under which the project designer would be obligated to work. He would then presumably proceed to locate the dam, determine its height, the size of the spillways, the length of the penstocks, etc., so as to maximize economic benefits as seen from the appropriate accounting stance.

This procedure through which an informed and representative decision-making body constrains project design so as to reflect broader social objectives is highly desirable, but in fact it is not often followed. It is much more common for the project designer to impose such constraints and to submit them to the decision-making body for approval. It is important for the decision makers to have an opportunity to review the design and some alternatives before the design becomes fixed.

The decision-making body has now tried to act wisely in setting or approving constraints on some of the noneconomic efficiency impacts of the project but, at best, their information on the trade-offs that are possible among those impacts and between the economic and noneconomic impacts will be extremely limited when they first consider the project. An extremely important part of the design procedure is to perform sensitivity analyses with respect to the constraint parameters X, Y, Z, and K; i.e., estimates should be made of how much the quantifiable economic benefits could be increased if each constraint were relaxed (one at a time) by some amount representing a reasonable change in the design constraints. Following this, perhaps other sensitivity analyses could show the trade-offs among the various constraint parameters holding the quantifiable net economic benefits constant.

Sensitivity analyses of this type are certainly not easy, but they generate valuable information regarding the reasonableness of the initial values of the constraints. Such an investigation might show that the initial constraint on income distribution or drawdown so increased the cost of the project that net economic benefits were reduced to an unacceptable level. The constraint might then be reconsidered.

Historically, a major difficulty has been that government institutions and the public have not had the capability to use and comprehend the types of information generated by sensitivity analyses. Water project designers may have to work hard not only to elicit public or legislative feelings on the noneconomic efficiency objectives associated with a project, but also to interpret to the public possible trade-offs and results of sensitivity analyses. Such efforts during the initial design phases may well prevent a public rejection of the project during later stages of project planning.

An example of a policy model that seeks to maximize net national economic benefits subject to constraints on the incomes accruing to particular social groups will be exhibited in Sec. 9-2 (Duloy and Norton[37]).

Weighting the several objectives Let us suppose that two noncommensurable but quantifiable objectives are relevant to the design and evaluation of projects. The first might be net national economic benefits and the second an index of environmental impact; or, the second might be the net benefits accruing to a group, say, peasant farmers, of particular interest to society. Let us denote the positive (beneficial) changes in the attainment of each objective $B_1(X_1, X_2, \ldots, X_n)$ and $B_2(X_1, \ldots, X_n)$ and the costs in terms of each objective $C_1(X_1, \ldots, X_n)$ and $C_2(X_1, \ldots, X_n)$, where $X_1, \ldots, X_n$ are dimensions of the design of the project. Since the net benefits $(B_1 - C_1)$ and $(B_2 - C_2)$ are noncommensurable, there really is no way of comparing alternative designs $(X_1, \ldots, X_n)$ and $(X_1, \ldots, X_n)$ unless $(B_1 - C_1) > (\hat{B}_1 - \hat{C}_1)$ and $(B_2 - C_2) > (\hat{B}_2 - \hat{C}_2)$. However, if the "legislature" handed us two weights w_1 and w_2, representing the relative social importance of the two objectives, the overall social value of a particular design for project j would be

$$\begin{aligned} V_j(X_1, \ldots, X_n) = w_1[B_1(X_1, \ldots, X_n) - C_1(X_1, \ldots, X_n)] \\ + w_2[B_2(X_1, \ldots, X_n) - C_2(X_1, \ldots, X_n)] \cdots \qquad (9\text{-}3) \end{aligned}$$

Then we could select $(X_1^*, \ldots, X_n^*)$ so as to maximize V_j and could compare the resultant V_j^* with the optimized values of other projects, V_k^*, etc.

Some have argued that legislatures can formulate and express such weights or that the weights can be discerned from the history of past choices made among projects (see Maass[38] and Major[39]). The latter possibility seems unlikely to yield any sensible results since, in the past, legislatures have never been provided information on the noneconomic efficiency impacts of the projects they have been asked to consider. It seems unlikely that legislators would be able to specify particular weights in the abstract, removed from consideration of particular projects. It is possible, however, for them to choose among alternative projects if they are informed about the effects of the projects on the relevant objectives. From these informed but still intuitive choices, the planner can begin to discern what the decision makers' weights are.

The alternative designs approach The third major approach represents a pragmatic compromise with the operational difficulties of the preceding methods: if there are three or four well-defined objectives to be served by public programs generally and by water-resource development in particular, then three or four project designs each "favoring" a particular objective will be created and presented to the decision makers for their selection on the best design. Naturally, this approach is closely linked to the preceding one, for through a sequence of choices, the technician may be able to discern the weights being used by the decision makers.

The U.S. Water Resources Council[40] has proposed a multiobjective planning scheme which would encompass the following objectives:

1 National economic development (national economic efficiency)
2 Enhancement of the quality of the environment
3 Enhancement of regional development through (*a*) increases in regional income; (*b*) employment increases; (*c*) changes in distribution of population; (*d*) improvement in the regional economic, educational, cultural, and recreational bases; and (*e*) improvement in physical environment

The planning process, then, is to involve the design and evaluation of alternatives, at least one of which favors each of the above broadly specified objectives. The components of the plan which correspond to each objective are to be defined so that "meaningful alternative levels of achievement" can be identified and are capable of execution. These different levels of possible achievement for each objective then serve to denumerate the number of alternative plans that might be considered.

Under this scheme, one alternative is always the maximum economic efficiency plan, which provides a kind of benchmark from which the economic efficiency costs of designing for other objectives can be assessed.

One of the earliest attempts to utilize this approach was that of the U.S. Interagency Susquehanna River Basin Study (see Werner[41]). That group developed essentially four alternative development plans for the basin: (1) a least-cost conventional plan to meet the "study developed needs" of the basin which had evolved from stated objectives of the states involved, including conditions considered necessary for local political acceptability; (2) a variant which maximized economic efficiency; (3) a variant emphasizing benefits to the region; and (4) an "environmental control" variant which emphasized preservation and recreation. It was intended that the plan finally selected would be formulated from different features of the various single-objective plans.

This brief discussion of multiobjective planning closes consideration of conceptual issues which are basic to any economic modeling of hydrologic-social system interactions. We now turn to a selected review of recent economic modeling achievements in the water-resources area which have significantly extended either the geographical extent of the systems being analyzed or the set of variables assumed to be under the policy maker's control.

9-2 ILLUSTRATIONS OF RECENT ECONOMIC-HYDROLOGIC MODELING ADVANCES

The following classes of modeling achievements have been dictated primarily by this writer's acquaintance with the published and unpublished work of the past 5 years or so, not by his conviction that this taxonomy is exhaustive, nonoverlapping, or in any other sense optimal. The seven classes of work represent important model types and/or problem areas in which important advances have been made.

The categories to be illustrated are as follows:

1 "Projection" models
2 Models of agricultural development, location, and water use
3 Detailed water development—investment programming for multiregional areas
4 Regional water-quality management models
5 Ground-water management models
6 Salinity management in irrigation

9-2.1 Projection Models

These are models in which the major economic features, such as income, population, industrial output, agriculture and mineral industry outputs, etc., are simply projected into the future without any feedback or constraints from the water sector. The usual intent is to project a consistent set of economic variables at values which are considered "likely" to occur; to relate to these economic variables likely levels of water "demands" and water-borne waste loads; and then to consider alternative programs of *water supply* which will satisfy these demands at an acceptable level of reliability and at minimum cost. This was the intent of the early river basin plans in the United States, as represented by the Ohio River Basin Study (Arthur D. Little, Inc.[42]).

While the shortcomings of projection models of this sort for water planning are obvious (particularly the omission of very relevant alternatives such as locational change for industry and agriculture), they usually mark an advance over earlier projection studies by providing consistent, integrated economic projections which take into account the interdependence of one economic activity on another. To indicate the nature of advances in this field, we describe three recent models.

The first model is that of Davis,[43] "Multiregional Input-Output Techniques and Western Water Resources Development," which is also reported by Lofting and Davis.[44] In this model, the input-output (I-0) approach is applied to an eight-region area consisting of Washington, New Mexico, Utah, California, Oregon, Arizona, Colorado, and the combined states of Nevada, Idaho, Montana, and Wyoming. The usual input-output relationships among economic sectors are written in matrix notation as

$$\mathbf{X} - AX = \mathbf{F}, \ldots \tag{9-4}$$

and are "solved" as

$$\mathbf{X} = (I - A)^{-1}\mathbf{F}, \ldots \tag{9-5}$$

where **X** represents the vector of industry outputs, *A* the matrix of technical coefficients, and **F** the vector of final demands (net outputs to be produced by the system). The model is usually applied to a national economy, but may (at some risk) be applied to state or other regions.

Davis expanded the format to include eight regions. Equation (9-4) is expanded to

$$\begin{vmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_8 \end{vmatrix} - \begin{vmatrix} A_1 & A_{12} & \cdots A_{18} \\ A_{21} & A_2 & \cdots A_{28} \\ \cdots & \cdots & \cdots \\ A_{81} & & \cdots A_{88} \end{vmatrix} \cdot \begin{vmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_8 \end{vmatrix} = \begin{vmatrix} \mathbf{F}_1 \\ \mathbf{F}_2 \\ \vdots \\ \mathbf{F}_8 \end{vmatrix}, \ldots \tag{9-6}$$

where the m industry classifications have been standardized, the subscripts refer to regions, and the A_{ij} elements represent trade flow among the industries of the various regions. This expanded model can be solved as before.

The usefulness of such a model is found in the capability of tracing indirect as well as direct water demands. If we let the I-O inverse of Eq. (9-6) be designated $(I - A)^{-1}$ and let W be a diagonal matrix containing the consumptive water use coefficients of each industry in each region (gallons per $\$10^6$ of output), a direct and indirect water use matrix is generated:

$$(\overline{I - A})^{-1}\, W = [w_{ij}], \ldots \tag{9-7}$$

where w_{ij} gives the direct and indirect water use in industry i per $\$10^6$ of *net* output (deliveries to final demand) of industry j (identified also by region). We then let

$$W_j \equiv \sum_i w_{ij}, \ldots \tag{9-8}$$

giving the total consumptive water use, direct and indirect, per $\$10^6$ of *net* output of industry j. Thus, it is possible to see how, through trade flows, the expansion of net outputs in one region results in expanded water demands in other regions.

Lofting and Davis used the model to compute the "embodied" water content of trade flows among the regions, calculating the water required in each region to permit the expansion of net exports from a particular region. Such "water trade balances" are of interest in evaluating the water problems of, say, the arid Southwest vis-à-vis the humid Northwest.

Forecasting of water uses can be accomplished through this model by projecting the final demands in each region as a function of time, $F_i(t)$, $i = 1, \ldots, 8$. Naturally, the coefficients of the model will tend to change with time as embodied technology, water prices, and water-quality standards change. Prediction of such change must be outside the model.

Another recent modeling effort of this type is represented by the North Atlantic Regional Water Resources Study, undertaken as one of 20 framework planning studies covering the United States. This study (Schwarz[45]) aimed at the formulation of alternative supply development plans consistent with the projected levels of demand for a diverse area of some 160,000 square miles, approximately 1,000 × 200 miles. The planning effort and related modeling were characterized by a conscientious attempt to implement a multiple-objective approach by designing alternative supply systems most consistent with the national efficiency, environmental, and regional development objectives.

The NAR Study embodied projection methods to the extent that regional product, per capita incomes, population, the distribution of economic activity, technology, and water-use coefficients (or regression functions) were extrapolated on a consistent basis through a regional I-O model. The supply was then "optimized" for meeting the extrapolated demands at various future times through a linear programming model of feasible water supply activities for the 50 subbasins of the region. Efficiency costs in annual terms were minimized, costs being based on standardized cost curves for various types of supply development in each subbasin. Objectives other than national economic efficiency were handled through manipulations of the objective function parameters and the constraints of the problem.

A third major projection-type study is the recent work of Wollman and Bonem[46] in which regional water supply and demand conditions for the 22 water supply regions of the United States were projected for the years 1980, 2000, and 2020. That modeling effort projects the basic economic and demographic variables and the related withdrawal and consumptive uses. Total demand for *instream* uses, however, is explicitly made a function of the desired level of *water quality* as measured by dissolved oxygen. For a given level of DO, alternative combinations of waste treatment and water storage for the maintenance of dilution flows were costed out, yielding for each basin at each year three alternatives: a maximum storage (minimum treatment) program, a minimum storage (maximum treatment) program, and a minimum cost program. The feedback from water supply to the economic model was limited to constraints on the size of the irrigated agriculture sector.

The Wollman-Bonem study marks a major advance over earlier nationwide survey type studies. First, storage-cost data and storage-yield relationships are based on detailed regional data. Second, the study permits the explicit costing out of alternative water-quality standards and levels of supply reliability. Third, it develops and costs three alternative programs of water development for each region and thereby generates an awareness of one range of alternatives open to the region.

9-2.2 Models of Agricultural Development, Location, and Water Use

In most of the semiarid parts of the earth, agriculture is by far the largest consumptive user of water. In the southwestern United States, approximately 90 percent of total consumption takes place in agriculture. Clearly, an understanding of the economic implications of changing water-use patterns in agriculture is vital to the national management of water. Curiosities like using water on forage crops whose income-generating value is $15 per acre-foot of water consumed while importing into the same area water costing $150 per acre-foot must be either explained or exposed through appropriate economic analyses.

There are particularly great difficulties involved in analyzing the economics of agricultural water use, because local and regional production areas are interconnected by national markets. An expansion of Idaho potato farming depresses prices nationally and forces Maine farmers out of production. The expansion of irrigated cotton in the West forces growers in the Mississippi Delta out of business—even under the protection of price support programs. Thus, it is usually not adequate to study only one area or one project, but frequently one must look at the whole set of market related areas simultaneously.

Many policies that are not labeled "water policy" have profound effects on the patterns of agricultural water use and, by implication, on the availability of water for other purposes. Price supports and acreage allotments make it profitable to produce surplus cotton under irrigation in water-short areas. Quota protection against foreign competition makes it profitable to irrigate sugar beets and high mountain pasture. Even transportation policy affects the location of agricultural production.

The differing soil, climate, and rainfall endowments of various producing regions, as well as such constraints as the size of land holdings, must be reflected in economic modeling of agricultural water use. The consideration of all the above desiderata makes large size and complexity necessary characteristics of agricultural economic modeling. Two illustrations of major advances along these lines will now be given.

Heady et al. For at least 15 years, Heady and his coworkers at the Center for Agricultural and Rural Development at Iowa State University have been modeling production and marketing activities of United States agriculture. There has been a continuing, cumulative effort toward more detailed and more geographically inclusive modeling. Heady and others have recently completed a large-scale study for the U.S. National Water Commission based on a very large interregional programming model which allows for substitutions among water, land (location), and capital in determining the optimum configuration of United States agriculture for the year 2000 under different assumptions.

The Heady model, at its present state of development, might also be called a "projection" model, for it is based on extrapolations of income, population and export demands, and alternative assumptions about farm technology, water prices, and government intervention in the commodity markets. The objective function represents minimization of labor, capital, water transfer, and commodity transportation costs:

$$TC = \sum_{i=1}^{223} \sum_{j=1}^{25} c_{ij} \times_{ij} + \sum_{m=1}^{51} (p_m^B W_m^B + \sum_{m=1}^{51} p_{m'm}^T W_{m'm}^T)$$

$$+ \sum_{k=1}^{27} \sum_{k'=1}^{27} \sum_{q=1}^{8} z_{qk'k} T_{qk'k} \cdots \qquad (9\text{-}9)$$

where c_{ij} is labor and capital cost for output j in area i, p_m^B is the cost of water per acre-foot, $p^{T}_{m'm}$ is the water transfer cost per acre-foot, and $Z_{qk'k}$ is the commodity transport cost per ton.

The model is completely linear and is characterized by 5,426 activities, 3,220 rows (1,650 are limits on the activities), 223 producing areas, 51 water supply regions, and 27 consuming regions centered on major metropolitan areas. Local water supplies are represented in the model by net surface runoff, and water transfers are permitted between adjacent producing areas. The constraints imposed on the model relate to the following: cropland, irrigated cropland, wild hayland, (dry, irrigated), pasture, total land, agronomic restraints, population, particular crop acreages, bounds on land retirement, water, farm incomes within particular regions, livestock outputs, nutritional constraints, and imports. The relevance to national policy making of the alternatives generated by a large-scale model for this type is obvious (see Table 9-1). To quote from Heady:[47]

> As study results indicate, an increase of the water price to $30.00 per acre-foot as a minimum for the seventeen Western States would allow the release of an additional 36.2 million acre-feet per year from agriculture compared with Model A.... Clearly then, if value of water in non-farm uses specifies it, water can be released from agriculture to uses in other sectors and locations. This transfer of water from agriculture to other uses would not put pressure on the nation's food supplies or export possibilities. Neither would it have other than minimal effects on the cost of food to the nation's consumers. (Heady, pp. v–3, 1971)

and

> Assuming a population of 300 million and no government program restraints, instituting a water pricing system and increasing the price from $15.00 to $22.50 per acre foot of irrigation water would reduce total irrigated land (and hence water use) in the 17 Western States by 5.5 million acres. Concurrently, 3.1 million additional acres of annual crops (including corn and sorghum silages) would be grown on non-irrigated land. Also, 3.5 million additional acres of all hays and pasture would be grown on non-irrigated land. Increasing the water price further, from $22.50 to $30.00, would reduce total irrigated acreage by an additional 4.8 million acres and increase all crops grown on non-irrigated land by 3.7 million acres. In comparisons between the lowest price, $15.00 and the highest price, $30.00, for water, annual crops (including corn and sorghum silages) grown on irrigated land would decline by 72.4 percent. Hence, the pricing of water not only would alter its allocation among agricultural, municipal and industrial uses but also would bring about reallocations within agriculture. Water could still be used for irrigation but its concentration would be on high value crops. Much less would be employed for lower-return uses such as pasture and hay production. For example, of the total water consumed by all crops with a water price of $15.00 about 70 percent is consumed by hays and pasture. With a water price of $30.00, hays and pasture consume about 50 percent of the total. As identified by this study, water supplies not only are large enough to allow ready attainment of projected food demand at reasonable real costs but also allow some diversion of water to municipal and industrial uses at the scattered scarcity locations for year 2000. Pricing and compensation means prevail whereby these reallocations can be attained with gains to some population and locational groups without sacrifice to others. (Heady, pp. v–14, 15, 1971)

Table 9-1 ILLUSTRATIVE ALTERNATIVES GENERATED BY THE HEADY AGRICULTURAL MODEL (YEAR 2000)

Alternative sets of assumptions	A	A-1	A-2	A-3	B	C	D
U.S. population (10^6)	300	300	300	300	280	280	325
Farm policy	Market	Market	Market	Market	Market	Land retirement	Market
Water price ($/acre-ft)	Present	15	22	30	Present	Present	Present
Export level (year)	67–69	67–69	67–69	67–69	67–69	67–69	Double
Farm technology	Trend	Trend	Trend	Trend	Trend	Trend	Advanced
Model results:							
Dryland acreage (10^6)	1,227	1,232	1,238	1,242	1,192	1,197	1,238
Irrigated acreage (10^6)	27.2	22.6	17.2	12.4	26.0	29.2	28.6
Unused acreage (10^6)	27.6	26.1	23.9	23.4	63.9	55.8	15.8
Water withdrawal (10^6 acre-ft)	156	139	120	105	147	155	163
Consumptive use (10^6 acre-ft)	97	86	72	61	92	97	101
Water "surplus"	142	154	167	178	147	143	139

SOURCE: Tables 5-6, 5-7, and 5-8 in U.S. National Water Commission, "Water Policies for the Future; Final Report to the President and to the Congress of the United States," U.S. Government Printing Office, Washington, D.C., June 1973.

The model has some definite shortcomings, of which the Heady group is quite aware. The principal shortcoming is the absence of demand functions for the commodities in the model. Using projected "requirements" as a substitute for demand functions means that we do not have any measure of benefits from different production levels and that it is not possible to investigate the implications for market prices and national benefits of letting production diverge from the pattern of requirements.

A second drawback is the linear presentation of water transfer activities. Naturally, there would be no difficulty in incorporating transfer costs between regions if incremental transfer costs rose with the quality transported. In reality, however, with incremental transfer costs falling (vast economies of scale), there is no way of properly incorporating transfer costs short of turning to integer programming trickery. One can say of the model in general that land and water development costs are not adequately treated.

Finally, the model takes no account of water quality or instream uses. Thus, the constrains on water supply are almost certainly overly liberal, and the regional quantities labeled "surplus" are biased upward.

Duloy and Norton: a programming model of Mexican agriculture For a number of years, Alan Manne and others, under the sponsorship of the Basic Research Center of the World Bank, have been working on the problems of integrated, multilevel national planning. They chose, as a problem area, to construct a dynamic, multisector model for the Mexican economy. The model includes placing a great deal of emphasis on the labor market, differentiating among skills, permitting migration of labor from one region to another, and containing activities for the upgrading of labor. Other components of the model include a current-account interindustry matrix, a labor-skill matrix, *and* capital coefficients linking investment demands to capacity expansion. The model allows for decreasing marginal revenues in international trade, piecewise linear schedules for the supply of foreign capital, and foreign demand for manufactured exports. The model is to be used to investigate many issues, among them alternative paths of dependence on foreign capital, near-future versus far-future increases in the consumption-investment composition of national product, and rates of labor absorption in various sectors, the latter reflecting the increasingly intense interest in employment creation per se (see Manne[48]).

The largest single component of this modeling effort is CHAC, a programming model of the agricultural sector of Mexico, developed by Duloy and Norton.[37]* Perhaps the single most outstanding feature of this model (in contrast to the Heady model, for example) is the detailed treatment given the demand for agricultural products. Not only are the national demand functions

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* The authors note that this model is now operating in the Ministry of the Presidency in Mexico and will continue to undergo added development there.

for 33 short-cycle crops included, but import and export activities are included for 21 of the crops. Prices for those commodities not entering foreign trade are determined completely within the model, but traded commodity prices are bounded above and below by the FOB and CIF prices. The model is thus a market-clearing, general-equilibrium type with respect to commodity production.

For the 33 short-cycle crops of the model, 20 geographically differentiated sets of production conditions are represented to distinguish among different natural endowments of land and climate, and different production techniques ranging from completely nonmechanical to completely mechanized are represented. Thus, a total of 2,345 production activities are present in the model, subject to approximately 1,500 constraints.

The model is static but is solved for different points in time. Since investment activities are included, it is possible to evaluate various investment alternatives. Risk relating to different types of crops is reflected by the inclusion of the cost of crop insurance as a production cost.

The demand site of the model is emphasized here. The explicit incorporation of demand functions instead of fixed product prices (or instead of using projected fixed "requirements") certainly provides a more realistic description of aggregate market conditions and avoids the usual tendency of linear programming models to generate solutions with extreme degrees of specialization. In contrast to the Heady model, this approach permits:

1 Solutions which correspond to market equilibria and which can reflect the impacts of taxes, subsidies, changes in tariffs, etc.

2 (Implicitly) a greater flexibility in substitution among inputs since relative product prices are permitted to influence the proportions in which final goods are produced

3 An explicit analysis of the *distribution* of benefits between producers and consumers

Duloy and Norton[49] are able to characterize within the *linear* programming framework both competitive and noncompetitive market equilibria. While agricultural markets are typically competitive, the incomes accruing to agricultural producers under large changes in output respond like the gross revenues which would be experienced by a monopolistic producer. The devices they have developed for CHAC permit a very detailed and sophisticated treatment of demand and mark a very significant advance in the modeling of large economic systems.

9-2.3 Other Modeling Advances

In the interests of brevity, we shall mention several other areas in which significant advances warrant attention. Brevity of treatment does not necessarily indicate a lesser importance than the models discussed at length in the two sections above.

Detailed investment programming for multiregional areas The preceding models either did (Heady) or could (Duloy and Norton) incorporate linear water production and transfer activities. These activities generally give a broad (average) characterization of the investment opportunities open to the regions but do not represent specific projects, although a schedule of potential projects would certainly be the basis of the parameter values of the development activity. It would be desirable in many cases to have a detailed characterization of the specific investments that might be made.

Bargur[50] has developed a dynamic multisector linear programming input-output model which is capable of characterizing in detail the sectoral, spatial, and temporal aspects of investment undertakings. The model thus is capable of producing consistent, integrated forecasts of water demands, interregional transfer requirements, commodity production patterns, and something approximating an optimal investment program for water projects.

R. G. Cummings of the University of Rhode Island has programmed large interbasin transfers of water along the northwestern coast of Mexico and alternatives to those transfers. The major components modeled by Cummings are

1 An existing major coastal ground-water irrigation area from which water is being rapidly mined and which is being rapidly degraded by salt-water intrusion

2 Very inefficient application of surface water above the coastal irrigation area

3 Potential irrigation of large areas along several other rivers, the waters of which are still largely unused

The modeling of the exhaustion of the aquifer has been reported by Cummings.[7,8] The major points which have been treated innovatively by Cummings include:

1 Modeling of the aquifer with salt intrusion in such a way as to derive the optimum rates and loci of pumping as opposed to the current, grossly uneconomic rate of mining*

2 Modeling of specific, large-scale interbasin transfers among a south-to-north sequence of river basins, with many possible combinations

3 Examination of the income distribution implications of various water development patterns, especially as between small farmers and areas committed to large-scale commercial farming

These modeling efforts have greatly increased the flexibility and realism with which we can model the economic aspects of water investment projects, but they (and the earlier agricultural models) still suffer from the inability to handle realistically sized problems in the face of economies of scale, a nasty

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* The reader may recognize this as the classical "common property resource problem," wherein no one party will economize on withdrawals for fear that the water saved will be exploited by others.

feature which nearly always crops up in the form of average costs which decrease with project size. While one can approximate and iterate in various ad hoc ways, no satisfactory way of dealing with large numbers of convex unit cost function is yet available.

Regional water-quality management Mention of this topic is intended to remind the reader of the need to consider a broad range of alternative policies and technologies in attempting to arrive at an optimum program of control. The importance of this in cost terms was clearly pointed out by Davis[51] and has been formalized in an optimizing format by Graves, Hatfield, and Whinston[52] and many others. The modeling by Graves et al. allows for source treatment, regional collective treatment, and bypass piping.

Most water-quality work to date has dealt with "end-of-pipe" treatment in various forms (including in-river reaeration, etc.). This overlooks the most important mechanism for reducing pollution for many industries: changing the basic production technology being used. Such results could be induced through the use of effluent charges or taxes which would cause polluters to seek the least costly way of abating pollution. Current highly inefficient policies subsidize "end-of-pipe" treatment, thus turning polluters toward high-cost solutions.

Ground-water management A great deal of attention has been paid in the past few years to the inclusion of ground water in water planning. Theoretical treatment of optimum ground-water management has been most extensively developed by Burt.[53] Many other authors deserve mention in this field. However, recent work by Bredehoeft and Young[6,54] has shown the importance for conjunctive management purposes of an accurate and detailed modeling of the aquifer system. The earlier theoretical work generally used the simple bucket model of the aquifer. The first study by Bredehoeft and Young indicated the importance of the location of pumping from an aquifer to the economic value of the aquifer. The second study emphasizes with great clarity the need to manage surface and ground waters as a unit if the maximum value and equity among users are to be achieved. This is clearly an area where additional hydrologic-economic-agronomic collaboration is needed.

Salinity management One common water problem around the world is the presence and increase of salinity in water sources. This appears to be the single most important problem of the Colorado River Basin in the United States, and it has been the cause of lost agricultural production on a vast scale around the world. Much technical work is involved with ways of reducing salt loadings of rivers or of diluting it when present. An obvious partial solution for many areas (e.g., the upper Colorado Basin) would be to reduce or eliminate irrigated farming where the return flows carry heavy loads of nutrients and natural salts. For political reasons, this problem usually is ignored.

Economists, in collaboration with hydrologists and agricultural scientists, have been working on the problems of measuring damage from salinity in terms of lost productivity and of designing optimum water application rules under different degrees of salinity in the irrigation water. EPA[55] developed approximate procedures for assessing salinity damages to agriculture. More recently, Yaron and his colleagues at the Hebrew University, Jerusalem, have completed detailed studies of the impacts of the timing, quantity, and quality of irrigation water on major crops. The intent is to optimize timing, leaching operations, and quantities and to take maximum advantage of the availability of water of different qualities at different costs (see Yaron et al.[56]). This work merits replication and extension to other soil types, water regimes, and crops.

9-3 NEEDED FURTHER DEVELOPMENTS

In conclusion, it seems desirable to list without much elaboration areas that appear to warrant substantial additional research:

1 Ex post analyses of projects and planning procedures. We still fail to make evaluations of how projects have actually turned out, how they have affected society, and how the forecasts used in their design and justification have fared. Recent work by Haveman[57] and the U.S. Army Corps of Engineers[58] is illustrative of the kinds of analyses needed.

2 Further analyses of the longer term effects of water pricing and less direct forms of cost sharing on patterns of water use. While a number of studies have been done, further work, especially on commercial and industrial uses, needs to be done. The study of indirect cost sharing (such as stages sharing project costs but not charging direct project beneficiaries) on the demand for projects would be important and timely.

3 Study of the importance of water quantity and quality (both intake and outfall) to the location decisions of industry. The importance of the topic is emphasized by the current uncertainty about the ultimate locational impacts of water-quality standards.

Finally, we badly need to develop new strategies for the use and refinement of models once they are created. Too often our modeling gathers dust on a shelf, and all value is lost because the creators fail to get support for keeping the model alive or because they fail to prepare it for passing on to others. Large-scale models, like large-scale projects, need post audits of effectiveness and proper preventive maintenance.

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