ECONOMICS OF IRRIGATION AND THE INSTITUTIONAL AND PRICING SYSTEMS OF WATER IN ISRAEL

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ABSTRACT


The paper reviews some of the relationships which apparently exist between the progress made in (1) the economics of irrigation, and (2) the institutional framework and system of water pricing. It suggests that under conditions of scarcity of irrigation water and conceptual understanding of the economic relationships involved in irrigation, pressure develops to adapt the institutional and pricing systems to obtain a more rational utilization. Highlights of the development of these two interrelated fields in Israel since 1950 are reviewed and briefly discussed.

INTRODUCTION

In most irrigated areas of the world, the system of allocation of irrigation water to its users has traditionally been dominated by social and institutional factors; Israel has, until recently, been no exception to this rule. However, economic considerations have now started to play an increasing role in water policy making in this country.

The purpose of this paper is to review some of the relationships which apparently exist between the progress made in (1) the economics of irrigation, and (2) the institutional framework and system of water pricing. The essence of their relationships is that under conditions of (a) scarcity of irrigation water as a production factor, (b) conceptual understanding of the economic relationships involved in irrigation, and (c) existence of empirical estimates of the numerous parameters of the value of irrigation water, pressure develops to adapt the institutional and pricing systems to obtain a more rational utilization. The adaptation process must overcome resistance typical of any institutional framework and the pressures of opposing interest groups. The outcome is the result of balancing the various forces pulling in different directions.

In this paper, three stages in the development of the thinking and performance in the field of irrigation economics in Israel are distinguished, and their apparent-
ly existing relationship to the institutional pricing system of water are pointed out. The boundaries between the stages are somewhat arbitrary, and other classifications are possible.

Israel seems to provide a good example for such a review because of its fast rate of development of irrigated land, adaptation and/or development of advanced irrigation methods, and last but not least, the scarcity of irrigation water, which emphasizes the need for an efficient utilization of this resource.

The paper starts with a short review of early economic models of irrigation, assumed to be widely known. Next, recent analyses are reviewed in detail, one dealing with the value of water during peak periods, and the other with that of water quality (chiefly salinity). They are presented in order to illustrate the complexity of the relationships involved. In the second part, the development of the institutional and pricing systems of irrigation water are briefly reviewed. The paper concludes with an evaluation of the interrelationship between the institutional structure and economics of irrigation.

MICROECONOMIC MODELS OF IRRIGATION

History

Stage 1: the fifties. (The period before the establishment of the State of Israel in 1948 is not included; it was basically similar to stage 1.) This stage can be characterized by the domination of irrigation by agronomists and engineers. The major concept employed was one of "irrigation norms" (i.e. given water inputs per land unit of a given crop under given conditions), aimed at achieving "maximal" yields. Agricultural planning was undertaken with budgeting methods, but the impact of economic thinking was limited.

Stage 2: the sixties. During the late fifties and the early sixties, economic concepts and models were introduced in evaluating on-farm irrigation and areawide irrigation projects. The methodology of the analyses described above is assumed to be known and will not be described here. Short reviews of the above studies can be found in Yaron (1967, 1971). A mimeographed, detailed report (Yaron, 1966) can be obtained on request from the author. Subjects covered by agricultural economists at that period included four major topics.

The first were analyses of irrigation experiments and estimation of the response functions of crops to irrigation water. The response functions estimated referred to fixed intraseasonal distribution of water (in accordance with the design of the experiments analyzed) with a general specification of the following form

\[ y = f(X_1, X_2) \]

where \( y \) = crop yield per unit area, \( X_1 \) = depth of soil moistening, and \( X_2 \) = total quantity of water applied. The results were used both in economic analyses of the irrigation of single crops and as a source for the enumeration of a variety of input-output coefficients to be incorporated in detailed farm production analyses.
The second major topic was linear programming normative analyses of irrigation with respect to various farming situations. These incorporated (1) coefficients relating to irrigation intensities (derived from analyses of response functions), (2) varying farm factor proportions (e.g. labor/land area, water/land area, etc.), and (3) typical factor-cost situations and price structures. These analyses provided a better understanding of the economic mechanism of irrigation. They pointed out that seasonal scarcity in water supply is often important as one of the factors seriously limiting agricultural output, and provided estimates of the seasonal marginal value productivity (MVP) of water.

A third topic involved models for interregional competition on water, applying linear and non-linear programming methods. These models provided schemes for interregional and intersectoral allocations of water and estimates of water's MVP by regions and sectors under a variety of scenario situations and assumptions.

Fourth, positive estimates of water's MVP were statistically derived for certain types of farms and regions using the (Cobb–Douglas) production functions approach, the imputed residual value method, and other approaches.

The above-mentioned analyses were performed partly within a research framework and partly as extension work, and were accompanied by educational and extension efforts at various levels. They helped to establish a better understanding of the economic mechanism of irrigation, and the empirical estimates of the MVP of water (and of other production factors) became a factor to be considered by the more advanced farmers, the Ministry of Agriculture, and other agencies involved in water resource management and development. A further discussion of the impact of these concepts on the institutional system will be discussed in the second part of this paper.

Stage 3: The seventies. The third stage in the development of the economics of irrigation is still in progress. It may be characterized as a period of refinement of the techniques of optimization, and refinement in the empirical estimation of the various parameters of the MVP of water. The major subjects seem to be in the fields of (i) estimating "dated" response functions and the optimal timing of irrigation (irrigation scheduling), (ii) irrigation with water of poor quality (saline water), and (iii) economic evaluation of water quality (salinity). In the following a short review of these subjects is given.

"Dated" response functions and optimal timing of irrigation.

Due to the complexity of the relationships involved, it is useful to view irrigation within a system framework in which two subsystems are distinguished. Subsystem I pertains to the relationship between the quantity and timing of irrigation water and the resulting variation of soil moisture over time and depth. Subsystem II contains the relationship between the variation in soil moisture and the crop yield. Using system analysis concepts, a general view of the variables and the relationships involved are schematically presented in Fig.1.
The figure gives the major groups of relevant variables, with arrows indicating the direction of the causal relationships between them.

The presentation in Fig.1 involves a major simplification, namely the omission of the time element. With the exception of the relatively constant soil characteristics, all variables change with time, and the time element is therefore an additional dimension in the complex of input–output relationships in irrigation.

![Diagram](image)

Fig. 1. A general presentation of an input–output system in the irrigation of a single crop.

When the factors under the category of "other management decision variables" are constant, and a relatively constant seasonal cycle of non-rain atmospheric conditions like temperature and solar radiation prevails, the relationship described by Fig.1 can be expressed algebraically as follows: if $Y =$ the economic yield, $SMI =$ an index representing soil moisture over the growing season, $IDV =$ a vector of irrigation decision variables, and $\theta =$ rainfall, we have

\[
Y = f(SMI) \quad (1)
\]

\[
SMI = g(IDV, \theta) \quad (2)
\]

and, substituting (1) into (2)

\[
Y = h(IDV, \theta) \quad (3)
\]

Empirical knowledge of both (1) and (2) may provide a better understanding of the process and a quantitative evaluation of the complex mechanism involved in irrigation and water use by plants. Moreover, the estimates of (1) and (2) may have greater general validity than those of (3) because the response functions as viewed in (1) may be formulated independently of the soil type, and thus may be applicable to a variety of soil conditions.

For the sake of economic analysis and irrigation decisions, the economic output should be expressed as a function of decision variables controlled by
man, as in (3). For analytical purposes it is therefore useful to view the irrigation system of Fig.1 as composed of two subsystems corresponding to functions (1) and (2), with (3) representing the complex of relationships involved.

A necessary condition for the determination of an optimal irrigation policy is information on how soil moisture varies over time and as a function of depth. Various methods are available for evaluating evapotranspiration and fluctuation in soil moisture (e.g. Penman, 1949; Blaney and Criddle, 1950; Thornwaite and Mather, 1955; Shaw, 1964; Jensen, 1967; Jensen and Herman, 1970). The methods differ in sophistication and input requirement. In view of the difficulties often encountered in obtaining the necessary information for more sophisticated models (e.g. solar radiation and wind velocity in Jensen's (1967) approach), a relatively simple model must often be used for prediction purposes.

Such a model has been developed by Yaron et al. (1973) and Shimshi et al. (1975). The model is essentially a system of a daily soil moisture accounting; water infiltration into the soil profile is considered as a simple instantaneous process and evapotranspiration, ET, is expressed by

\[
ET = -\frac{dw}{dt} = a + bw \quad a < 0; \quad b > 0
\]  

where \( w \) is the daily mean soil moisture content of the layer, and \( a, b \) are constants. The function varies with soil layer and growth period. Hence

\[
ET_{ij} = -\frac{dw_{ij}}{dt} = a_{ij} + b_{ij}w_{ij} \quad a_{ij} < 0; \quad b_{ij} > 0
\]

where \( j \) is the growth period index, and \( i \) is the soil layer index. The growth period represents indirectly the atmospheric evaporative conditions. Generally three to five soil layers, each 30 cm in depth, are considered. The parameters \( a_{ij} \) and \( b_{ij} \) are estimated by a computer search technique to achieve a good fit between the computed moisture values and the measured values whenever available. [More details on the approach to the estimation of soil moisture variation can be found in Yaron et al. (1973) and Shimshi et al. (1975).]

The model should be calibrated for different locations and crops. Thus far it has been successfully applied to wheat (Yaron et al., 1973; Shimshi et al., 1975) and sorghum (Bielorai and Yaron, 1978) in the Northern Negev in Israel, and cotton (Yaron and Dinar, 1978) in the south of Israel.

Ideally, the response of a crop to soil moisture should be viewed as a continuous phenomenon with the following general specification

\[
Y = f[w(t,z), a(t), t]
\]

where, \( a(t) \) represents the atmosphere conditions as a function of time, \( t \) is time and \( z \) is depth.

For practical reasons, however, simplifications are to be introduced in (6). These are: (a) time is introduced in discrete terms, such as days, weeks or stages of growth of the crop; (b) depth is referred to in discrete terms, such as soil layers.

Accordingly, (6) is reformulated into (7)

\[
Y = f^* \left[ SM_{ij} ; A_j \right]
\]
where, \( i \) = index of soil layer, \( j \) = index of growth stage, SMI = soil moisture index, \( A \) = index for atmospheric conditions other than rainfall. Note that under conditions of constant atmospheric conditions other than rainfall \((A_j \) constant), (7) converges to (1).

Several approaches have been followed by various workers in the actual specifications of (7) and the choice of the independent variables. The major approaches come to the following:

(a) introducing a relationship between available soil moisture in the root zone and atmospheric evaporative demand (Corsi and Shaw, 1971: Index I);

(b) introducing a relationship between actual and potential evapotranspiration (Corsi and Shaw, 1971: Index III; Flinn and Musgrave, 1967; Jensen, 1967; Minhas et al., 1974).

(c) using soil moisture only (Moore, 1961; Yaron et al., 1973; Yaron and Dinar, 1978).

In several studies (Yaron et al., 1973; Anderson et al., 1977; Bielorai and Yaron, 1978; Yaron and Dinar, 1978) approach (c) was followed with good results; soil moisture was considered as the only independent factor, and atmospheric conditions were assumed to follow a regular pattern over the growing period. In the expression for the soil moisture index during the growing season, the concept of “stress days” or “critical days” was defined as one in which the soil moisture was depleted below a certain critical level, ASM, in the root zone. The number of “critical days” thus defined was used as an explanatory variable in the response functions.

Some of the algebraic formulations of the response function used in the empirical estimation were:

the exponential function

\[
Y = A \prod_{j} b_j^{X_j}
\]  

(8)

with \( Y \) = the crop yield (kg/ha), \( X_j \) = number of critical days in growth period \( j \), \( A \) = the maximal yield, achieved when \( X_j = 0 \) for all \( j \), \( b_j \) = scalar coefficient of reduction of crop yield per critical day \((b_j < 1)\);

the linear function

\[
Y = A - \sum_{j} d_j X_j
\]  

(9)

with, \( Y \), \( X_j \) and \( A \) = as defined above, \( d_j \) = reduction of crop yield (kg/ha) per critical day. The linear function can be easier understood by extension workers and farmers.

Estimates derived by the author and collaborators of the effect of “critical days” during the reproductive stage of growth on the yield of selected crops are shown in Table I. The values should be regarded with some caution as they apply to specific locations, but their order of magnitude is interesting. Even with the low estimate of a 2.5% yield reduction, a delay in irrigation of 1 week will reduce yields by approximately 17%. The reduction in net return
TABLE I

Estimated effect of “critical days” on the yield of selected crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Location</th>
<th>Yield reduction (% of max. yield)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum</td>
<td>Northern Negev, Israel</td>
<td>2.3–3.5</td>
</tr>
<tr>
<td>Corn</td>
<td>Fort Collins, Colo.</td>
<td>2.5</td>
</tr>
<tr>
<td>Cotton</td>
<td>South Israel</td>
<td>7.3–8.6</td>
</tr>
</tbody>
</table>

Source: sorghum: Bielorai and Yaron (1978); corn: Anderson et al. (1977); cotton: Yaron and Dinar (1978).

(or value added) will be significantly higher; indeed, with net return/gross return ratios of 50%, it will be 1/3. Such an order of magnitude should cause concern in areas with seasonal water scarcity. The income lost by a sequence of “critical days” can be linked to the MVP of water during the scarcity season by an analysis which assumes conditions of optimal allocation of water and varies the quantities available to a crop or to a farm to an extent that creates “critical day” conditions. Irrigation scheduling models are available for such analyses using dynamic programming (e.g. Hall and Butcher, 1968) for a single crop or other relatively simple situations, and simulation models for the more realistic cases (e.g. Yaron and Strateener, 1974).

Optimal irrigation with saline water and the value of water quality (salinity)

The interest in irrigation with saline water in Israel is due to: (i) the relative scarcity of high quality water and availability of brackish water; (ii) plans to utilize reclaimed sewage for irrigation, and (iii) plans for desalination of brackish and/or sea water on an experimental or large-scale basis.

A system framework approach was applied for the analysis of the optimal use of saline water in irrigation and the estimation of the value of that water. For a detailed discussion of the processes accompanying irrigation with saline water, the reader is referred to Yaron (1974).

In the analysis of irrigation with saline water, a distinction was made between three ranges of time with corresponding models.

Short-run models referring to relationships, confined within a single irrigation season. The salinity of the soil profile at the beginning of the irrigation season is given. For each initial state they analyze the optimal combination between water quantity and quality without taking into account the effects of salt accumulation over time. To this goal, models which simulate the relationships between irrigation decision variables, including water quality, and variation in soil salinity, were utilized (Bresler, 1967; Bresler and Yaron, 1972). Procedures for the estimation of response functions for crops to soil moisture and salinity were developed (Yaron et al., 1972). An optimal irrigation scheduling model with saline water for a single crop situation was developed,
applying the dynamic programming approach, with two soil state variables: soil salinity and soil moisture (D. Yaron, E. Bresler, H. Bielorai and B. Harpinist, in prep.).

Long-run models taking into account the effects of salt accumulation in the soil profile over time. They are composed of a succession of short-run processes, the initial conditions of which are affected by salt accumulation in previous periods. The irrigation decisions over a single season determine the final conditions for each alternative and the effects thereof for the succeeding seasons. Such a long-run model has been applied (using dynamic programming) to the analysis of citrus irrigation with water of varying salinity (Yaron and Olian, 1973). Simulation was used in another study (Polovin, 1975).

Extended-long-run models taking into account both the salt accumulation in the root zone and in the underground reservoirs.

Under certain conditions (e.g. with a high water table and a quickly deteriorating quality of the ground water) the distinction between the long-run and the extended-long-run model may be small.

The short-run and the long-run models provide guides for the optimal irrigation with water of different degrees of salinity (including leaching and irrigation scheduling) and estimates of the value of water of different quality (salinity).

The results found thus far suggest that there is a large difference between the value of water quality for the irrigation of sensitive crops (e.g. citrus), and non-sensitive ones (e.g. cotton) (see Yaron (1974) for more details). Under conditions where water sources of different quality are available and there is a tendency to grow both salinity-sensitive and non-sensitive crops, the problem of interfarm water allocation becomes increasingly difficult. The same applies to the farms’ demand for water of different quality and the water allocation between farms and between regions.

MODIFICATIONS IN THE INSTITUTIONAL FRAMEWORK AND IN THE PRICING SYSTEM

According to the Israeli Water Law, all water resources in the country belong to the nation and are subject to control by the government. Most of the agricultural land is also nationally owned, and leased to farmers on a long-term basis.

The water supply system of Israel is therefore characterized by a high degree of centralization in operation and management. Approximately 70% of the country’s water supply is operated by the National Water Company, “Mekorot”. Within the framework of the “National Water System”, there are 30 regional projects, most of them connected to the National Water Carrier (the National Water Carrier was completed in 1964/1965), which extends from the Lake of Galilee in the north to the arid Negev area in the south. There are several major pumping stations, aquifers and both natural and artificial surface reservoirs in the system, the Lake of Galilee serving as the major surface reservoir.
Because of the Water Law and the centralistic structure of the water supply system, the water institutions have considerable power to control the use of the resources. The following will review some past and present highlights of the uses of this fact.

History

Stage 1: the fifties. The institutional and pricing systems during the fifties were highly influenced by the following factors.

(1) The pioneering-settlement philosophy dominated the agricultural development of the Jewish settlement before the establishment of the State of Israel in 1948. According to this philosophy any piece of land which could be purchased should be settled, whether the economic conditions were favorable or not.

(2) The egalitarian philosophy which fits very well the ideology of the majority of the farmers-settlers organizations. A "Water Price Equalization Fund" was established with the aim of reducing the differences between water charges in the different parts of the country. The Fund was financed by levies on cheap water and by government subsidies.

(3) Insufficient economic knowledge for proper agricultural planning and evaluation of irrigation projects.

(4) The necessity to provide large-scale employment and to produce food for the new immigrants, most of whom were refugees with very limited means.

During this period, large-scale settlement and irrigation projects were established, and long-run plans for water resource development were outlined. A system of water rights or quotas was established, specifying for each cooperative village both the total yearly supply and the maximal seasonal supply during peak periods. The system of quotas was based on some models for types of farms and their derived need for water, with a limited consideration of the regional differences in the costs of water supply. As mentioned in the previous section and confirmed by the above, the impact of economics on the water system in this decade was insignificant.

Stage 2: the sixties. In this period, the rate of development of agriculture slowed down. Surpluses of agricultural production in certain branches appeared at the end of the fifties and the pressure to expand agriculture food production disappeared. A shift in the composition of the agricultural output was induced, with an emphasis on export products and staple crops. While during the fifties, primarily water resources projects which were easy to construct and inexpensive, were developed, in the sixties more expensive ones were undertaken. So the investment-intensive National Water Carrier was accomplished in the mid-sixties. The optimistic estimates of the water resource potential of the country of the early fifties were revised and became more pessimistic. The scarcity of water on a national level gained recognition.

Against this background the first economic studies of irrigation in Israel
were performed. These studies provided additional and better insights into the problems. For example, a comparison of their newly generated estimates of the marginal value product of water, with the cost of water supplies for new projects indicated that only a few new water projects were justified on economic grounds. At the same time, considerable inefficiencies in the system of the egalitarian quotas were found. Pressure to apply pricing of water to improve efficiency in water allocation between regions and between farms began to develop. It was estimated that by introducing a price incentive for saving, at least 15% of the water used in irrigation could be saved from inefficient uses and transferred to the efficient ones, within the existing framework of the National Water System. However, an extreme shift to a water allocation system based solely on the price mechanism would have too adverse an effect on income distribution. It would drive out of business inefficient farms established only 10--15 years ago by new settlers, many of them immigrants with considerable government aid. Therefore, a mixed quota and pricing system, providing incentives for water saving, and at the same time minimizing the adverse distributional effects was suggested (Yaron, 1966). The essentials of the system were:

(a) the water rights remain valid;
(b) differential prices for water are introduced: (i) a relatively low price (price A) is charged for 85% of the historically approved water quota; (ii) for the remaining 15% of the water quota, a higher price (price B) is charged, set at a level to induce saving, and (iii) for any water use above 100% of the quota, a very high price (price C) is charged to minimize the use of water above the approved quota;
(c) prices A, B and C are determined on a regional basis in accordance with regional differences in water productivity.

By properly setting prices A and B the goal of water saving can be achieved without significantly affecting the farmers’ income. It is possible to introduce variations in the above system, like changing the percentage for which price A is charged or larger differences between prices A and B. Changing the inter-regional price ratios can, of course, affect the interregional water allocation.

The above quota-cum-pricing system, although supported by various officials in water institutions, was not accepted by the government for several years. Only in 1972 was the system adopted, following the recommendations of a government-appointed committee.

Solutions to the problem of water scarcity during peak periods, which became increasingly evident during the sixties, were much easier to achieve. The government has encouraged private commercial contracts between farmers and the National Water Company, in order to expand the peak capacity (pumps, pipes) of the existing water plants and the peak supplies to interested farmers. Because the increased peak supplies did not involve a change in the yearly water quotas, no other institutional restrictions were necessary.

Stage 3: the seventies and the near future. Stage 3 is and will continue to be
influenced by increasing water scarcity and the introduction of water quality as a parameter in water allocation decisions. The only major source of water reserve (excluding desalination, which is too costly for development in the foreseeable future) is reclaimed sewage, now under consideration for development. Current plans show that this source can provide the necessary reserves for maintaining the agricultural water supply on a constant level. As shown in Table II, fresh water would be diverted from agriculture to the municipal and industrial sectors, the diverted amount being replaced by reclaimed sewage. Such plans raise questions about the value of lower quality water, rates of substitution of fresh water by reclaimed sewage, and their relative prices.

Another issue now being discussed concerns some deficiencies in the differential price system established in 1972. The water quota in Moshav cooperative settlements (not in Kibbutz settlements) are allotted to the village as a whole on the basis of the number of farms therein, and the internal distribution is performed by the village itself. Families involved in part-time farming and even those who no longer farm at all, continue to be counted as eligible for water quotas; in fact, their quotas are used by other farms in the village. The village is charged for its water quota as a unit and collects the charges from the families. In villages with many families not fully farming, significant internal reserves of water quotas may develop, and water may be used inefficiently by those families which are involved in farming. As long as the village as a whole does not exceed 85% of its water quota, the village is charged price A. A proposal now under consideration (Water Commissioner's Office, 1976) is that the government buy the unused quotas and grant rebates to the families.

A study dealing with the long-run inventory policy of water on the national level, recently released by Tahal (1976), suggests that a system of constant water quotas over the years, that does not take into account available reserves (stored in the Lake of Galilee and in aquifers), is inefficient. In years with large reserves, there is a loss of water by leakage from the aquifers to the sea.

### Table II

Water consumption in Israel in 1972 and forecast until the end of the century

<table>
<thead>
<tr>
<th>Consumption type</th>
<th>Water consumption (MCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Municipal/industrial sector</td>
<td>370</td>
</tr>
<tr>
<td>(2) Agriculture, fresh water</td>
<td>1170</td>
</tr>
<tr>
<td>(3) Total, fresh water (1 + 2)</td>
<td>1550</td>
</tr>
<tr>
<td>(4) Effluent, agricultural consumption</td>
<td>-</td>
</tr>
<tr>
<td>(5) Total, agricultural consumption</td>
<td>1170</td>
</tr>
<tr>
<td>(2 + 4)</td>
<td></td>
</tr>
<tr>
<td>(6) Total consumption (3 + 4)</td>
<td>1550</td>
</tr>
</tbody>
</table>

It has therefore been proposed to introduce flexible yearly quotas in accordance with inventory management concepts.

It appears that a growing complexity in the allocation and pricing of water in Israel is concomitant with an increasing number of parameters (e.g. time and quality) representing the value of water and enhancing the efficiency of the supply system (e.g. by the introduction of inventory policy concepts). It may become increasingly difficult for a single central authority like the Water Commissioner's Office to administer the system efficiently. Accordingly, suggestions regarding the structure of a decentralized system with a central authority and regional offices have recently been set forth. The regional offices may more properly represent the regional farmers, thus having a relative advantage in dealing with intraregional allocation and pricing, while the interregional problems may most effectively be handled by the central authority.

CONCLUDING REMARKS

In the first section the aim of the review of some of the economic analyses of irrigation which were performed in Israel was to show the many facets and complexity of ascertaining the value of irrigation water. The understanding of the relationships mentioned seems to be a necessary condition for the proper allocation and pricing of irrigation water. Here, the crucial question arises: how far are the reviewed analyses diffused beyond the research sphere? No accurate quantitative answer to this question can be provided, due to lack of information. However, in terms of qualitative evaluation, it seems that the economic concept of shadow prices of water and the estimates of its MVP in different situations have become widely known to and used by farm managers of most of the Kibbutz farms (comprising about one-third of the agricultural settlements of Israel), as well as by most agricultural planners and decision makers. The more refined analyses related to Stage 3 are now in the process of application, development and diffusion. The degree of success of these models in area-wide applications depends on one hand, upon the (existing) need for such models and, on the other, on sufficient initiative in their promotion.

Table III summarizes the development of the economic analyses of irrigation and the institutional and pricing system along a common time scale. It seems that the two parts are interrelated. No general causal relationship is suggested, but an understanding of the economic relationships appears to be a necessary condition for the proper allocation and pricing of water; at the same time, no claim is made that this is sufficient. Additional economic considerations at the sectoral and the national levels and numerous institutional and sociopolitical factors also play an important role in this respect.
### TABLE III

Summary of the development of economics of irrigation and the institutional and pricing systems for water in Israel

<table>
<thead>
<tr>
<th>Period</th>
<th>Economics of irrigation</th>
<th>Institutional and pricing system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Domination by agronomists and engineers</em></td>
<td><em>Domination by egalitarian philosophy</em></td>
</tr>
<tr>
<td></td>
<td><em>Domination by agronomists and engineers</em></td>
<td></td>
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<tr>
<td></td>
<td><em>Early</em> analyses</td>
<td><em>Early</em> analyses</td>
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<tr>
<td></td>
<td>Early response functions</td>
<td>Build-up of the economic case</td>
</tr>
<tr>
<td></td>
<td>Linear programming studies of farms</td>
<td>Build-up of recognition of water scarcity</td>
</tr>
<tr>
<td></td>
<td>Interregional competition analyses</td>
<td>Evidence of inefficiencies in the water rights system</td>
</tr>
<tr>
<td></td>
<td>Positive and normative estimates of MVP of water</td>
<td>Pressures to apply marginal cost pricing</td>
</tr>
<tr>
<td></td>
<td>Interregional competition analyses</td>
<td>Solutions to seasonal scarcity problem</td>
</tr>
<tr>
<td></td>
<td>Recent analyses</td>
<td>Recent developments and possible trends</td>
</tr>
<tr>
<td></td>
<td>System analysis approach</td>
<td>Introduction of a cost pricing scheme</td>
</tr>
<tr>
<td></td>
<td>Dated response functions</td>
<td>Discussions of: (a) pricing for quality</td>
</tr>
<tr>
<td></td>
<td>Optimal irrigation with saline water</td>
<td>(b) inventory oriented water quotas</td>
</tr>
<tr>
<td></td>
<td>and the value of quality</td>
<td>Decomposition of the administrative system</td>
</tr>
</tbody>
</table>

### REFERENCES


