THE ENGINEERING ECONOMICS
OF LARGE SCALE DESALTING

341-68

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1. INTRODUCTION

Very little is known of the social and economic effects from adding desalting plants to any country's stock of capital. There is no historical evidence on these effects because the plants now in operation are too small or too recent to have had measurable results. There has been only limited analytical work which can be used to forecast future effects.

Yet the results could be complex, widespread, and important. New supplies of water in regions without rainfall would change not only the organization of industry and agriculture there, but also bring the cultures of sparsely populated areas closer to those in more populated and advanced countries of the world. The productivity of labor and capital throughout the economy should be increased as a result both of more and higher quality water. The composition of national output would be changed from adding this type of capital, and water as an intermediate product, rather than some other kind of capital such as those resulting in more highway transport and fertilizer as intermediate products. The question is whether general assessments can be made of these effects, so as to establish some priority for general investment in developing and refining this new technology over the next decade.
Introduction

Very little is known of the present-day considered efforts to
reduce airborne pollutants to the community's health at
Tenerife. In particular, the relationship of these pollutants
to precipitation appears to be an area of great concern.

It is of particular interest to determine the extent to which
related measurements of these pollutants can contribute
towards understanding the relationship between precipitation
and air pollution. The limited data available is considered
informative but not definitive in this regard. Additional
measurements at other sites, particularly those with
considerable industrial or urban pollution, would be of
interest.

The present study is an attempt to develop a method for
estimating the amount of industrial and urban air pollutants
present in the air at a given location. The method involves
the use of correlation analysis to determine the relationship
between the amount of pollutants and the amount of
precipitation. The results of this analysis are then used
to estimate the amount of pollutants present in the air.

The study was conducted at a location in the Tenerife
area, where measurements of air pollutants and
precipitation were available. The results of the study
suggest that there is a significant relationship between
the amount of pollutants and the amount of precipitation.

However, further research is needed to confirm these
results and to develop a more accurate method for
estimating the amount of pollutants present in the air.

The results of this study suggest that additional
measurements of air pollutants and precipitation at other
locations are needed to improve our understanding of
the relationship between these pollutants and
precipitation.
Benefit-Cost Analysis of Desalting Plants

There is no general economic theory on the effects from desalting. At least the case is not made here for a set of equations which describe changes in national products from desalting as compared to alternative investments. The fear is that this would not be operational at this time, because not enough research has been done on relationships between desalted water and final products to set the form of the supply and demand equations for the water sectors of national economies.

On the other hand, little can be learned from the engineering design studies of particular desalting plants at particular locations. The ground rules for these studies differ so greatly, and the environmental characteristics are so distinctive, that general conclusions on effects do not evolve from the particular cases.

The first step towards measuring the effects of desalting has to combine general arguments with case studies. The general argument here is that an orthodox theory of corporate investment can be used to analyze social and economic effects. The costs of constructing and operating a desalting plant are calculated in terms appropriate for making investment decisions in the economy. This is to require that costs for the resources put into these plants be measured in terms of their value in their best alternative uses. The benefits from desalting encompass the values of additional products from the water (net of the costs of other resources used in producing these additional products). The
theory suggests the possibility of making economic assessments of the social effects as well, in terms of indications of the dollar preferences of society for the new "way of life" rather than the old. The measuring rod of the project is the rate of return -- that rate of discount equating the cost and benefit series when both are viewed from the perspective of the present.

This analysis is so general that it provides no more than a framework; in fact, it applies to all investment projects without reference to desalting plants. It can be expanded upon by dealing specifically with desalting -- with the particular conditions of costs and benefits associated with desalting plants no matter where located. The following two chapters set out these conditions. The next chapter deals with techniques for estimating the cost of water from desalting plants where these plants have certain characteristics different from electric or other large-scale energy-using systems. The third chapter deals with specific benefits from water plants rather than water reservoir systems, and from distilled water rather than surface water.

The analysis is still not very specific at this stage. As a beginning towards specifying more exact relationships, it will be formulated more completely by examination of one large-scale desalting project. This study should work out the input-product relationships in detail sufficient to forecast the costs of water. The benefits of water also should be forecasted, both as an example of calculations for the unique water quality characteristics of desalting plant output, and as a first attempt to
measure social effects. The case to be used as a "prototype" for general desalting systems analysis is the proposal for joint American-Israeli participation in the construction and operation of a large-scale desalting plant at Ashdod in Israel.

Desalting in Israel as a Case Study

The need for an evaluation of large-scale desalting must have been apparent to the Israelis early in the 1950's. The master plan for the development of Israel's water resources drawn up in 1950 anticipated 12 per cent greater growth in demand during the period 1960-1980 than in the development of new sources of surface supplies. There were no further surface or subsurface natural sources; given that "about 96% of the natural and re-claimed water sources of Israel will be in use by 1970, few projects based on natural water resources remain for the 1970-80 period."¹ Building a large-scale desalting plant had to be one of the alternative devices for adding to the orthodox surface and ground water systems.

The United States recognized possibilities for desalting in Israel in the early 1960's. These would follow from "learning by doing" new desalting technology and in dealing with particular problems of supporting this technology. The United States joined with Israel in 1964 to consider exporting American research while developing Israeli water supplies. In a joint communique on

June 2, 1964, President Johnson and Prime Minister Eshkol agreed that the two countries should "undertake joint studies on problems of desalting . . . as part of the world-wide cooperative effort being undertaken to solve the problem of scarcity of water and hope for rapid progress toward large-scale desalting in Israel."^1

A number of detailed studies have been undertaken since then under the auspices of a joint Israeli-United States investigating team. This group recommended in 1964 that engineering feasibility studies and preliminary economic surveys be undertaken to "show the various alternatives and (make) recommendations regarding the choice of a most favored alternative as well as a detailed development program for unproven features of a proposed plant."^2 The study of engineering feasibility has been undertaken by the Kaiser Engineering Corporation. ^3 At the same time, a number of detailed and sophisticated analyses of the water sub-sector of the Israeli economy have been carried out by Israeli government officials and university economists or hydrologists. These create the impression that the cost for 100 million gallons per day of distilled water varies from 20 cents to more than 60 cents per thousand gallons, depending on input costs and on how

^1 Ibid.
^2 Ibid., p. 110.
much of the total costs of a dual purpose water-electricity plant are attributed to the production of electric power.

Then is this the economy and the plant most appropriate for a detailed case study? The answer depends on cost and benefit estimates. The abundance of detail on engineering characteristics and projected expenditures provides a substantial basis for estimating costs -- the costs to the Israeli economy of using resources for this plant rather than for other investments. But very little is known of the total value of the output of a water plant to this country's economy. Desalted water would produce, in combination with other input factors, manufactured articles and agricultural goods for consumers in the newer cities and towns in the more arid regions of the country. The benefits are the total social value of these outputs (value in consumption minus the cost of the other resources added along with the water). But desalted water has extra benefits because it reduces salinity in existing ground water and surface reservoir systems. Lowering the salt content in the water adds to the productivity of all supplies in the national water system, and the additional value of product should be credited to the output of the desalting plant. There are other gains from the desalting plant including those from additional total capability to deliver when there is an extended drought. There is additional resource capability for achieving such social goals as spreading of the country's population to sparsely settled agricultural areas. Estimates should be made of these gains.
The "best estimates" of benefits from a project in Israel are appropriate for exegesis of the economics of desalting. A range of benefits can be constructed for different circumstances and opportunities: these will be first estimates, given the lack of research findings on particular benefits associated with desalting rather than surface water systems. But it is appropriate that this "prototype" study begin from the beginning, because the important and different characteristics of desalting can be stressed by going through an analysis of agricultural and industrial outputs from new water supplies and projecting future gains in great detail.

The range of "reasonable" estimates of the cost of water in an Israeli plant is given in Chapter 4. The benefits of this water are assessed in Chapter 5, both in terms of the value products of additional water-based agricultural outputs and the indirect value from reducing the saline content of the entire system. Costs and benefits are compared in the last chapter of this study, in terms of that "internal rate of return" which equates present value of costs with present value of dollar benefits. There are a number of conceivable cost and benefits series, each pair of which generates a rate of return. The distribution of rates of return is shown in Chapter 6, at least for first estimates. Only then can the final question be faced: should a large-scale desalting project, with the calculated range of rates of return, be given priority over other construction projects with other rates of return?
2. THE COSTS OF WATER FROM A DESALTING PLANT

The construction and operation of a plant to evaporate and condense salt water requires an outlay of resources similar to that for a reservoir or groundwater recovery system. But there are two basic differences, the first in "costs" and the second in "output." The costs are in most cases those for a plant producing both water and electricity so that they are "joint costs." The "output" of water has dimensions different from surface flows from orthodox surface systems, as well.

Where there are economies of scale in nuclear reactors or fossil fuel boilers as sources of thermal energy, the production of two outputs, electricity and water together, make for lower unit costs for water than can be attained in single-purpose plants having the same rated water output. There may be possibilities for joint use of single items of equipment in both water and electricity production as well. Then what are the costs of water, when expenditures are for both generating electricity and condensing brine water?

The water "output" from a desalting plant can be expressed in the same dimensions as water from alternative sources. These dimensions are "unit volume," equal to gallons of stated quality delivered at a uniform daily rate over a year or longer rain cycle. This is done by collecting and storing in the rainy seasons, and then withdrawing from storage in the dry seasons. But desalting plants do more than this. They make available additional gallons of water in a dry season, so as to provide
valuable "safe yield" capability, without necessarily producing every day in the rainy season. By producing for storage during part of the reservoir inflow season, the daily flow of a desalting plant-reservoir system can be made equal to a maximum consistent with reservoir capacity, rather than the average consistent with past rainy seasons. Then "output" from the plant should be measured in "units of safe yield" equal to the difference between average and full capacity surface systems runoff per day, regardless of whether the desalting plant is run every day.

The Allocation of Joint Costs

The costs of distilled water in many cases are going to be those for one output in a multiproduct facility. Their determination is made by assigning part of the general within-plant expenditures to water production. The rules for making the assignments have varied greatly from one study of desalting to the next -- some allocation methods recognizing parts of the plant as being devoted to water that others do not, and one or two methods paying no attention to specific uses of plant components at all. Such rules have to be evaluated by operational standards: are the estimates simply arrived at and relatively accurate. Accuracy, the important attribute, is a matter of measuring the economic costs for water, even when they are incurred in a dual purpose plant, where those costs are the total value of resources used to produce this particular output.
Consider the dual-purpose plant. The total costs of resources, capital \( K \) and labor \( L \), are \( P_K K + P_L L \) to produce the two outputs water "x" and electricity "y." The costs of water are for those amounts of \( K, L \) at unit prices \( P_K, P_L \) involved in the water-producing process in the plant. Their determination involves estimation of total plant resources, and then of expenditures on that amount used for producing the single output of interest.

The total resources needed are shown at the limit by the "production function" -- the technical or engineering relation between minimum amounts of \( K, L \) necessary for specified amounts of outputs \( x, y \). The best technique of production could be either one of two ways of doing things. First, water and electricity could be produced in variable proportions so that the production function takes the form \( g(x,y) = f(K,L) \). Second, and alternatively, water and electricity could be produced only in a fixed proportion, such as \( x/y = \alpha \); then the production function would take the form \( x + y = f(K,L) \) for \( x = \alpha y \) combinations and would be undefined otherwise.

Expenditures for water would equal the sum of factor prices times quantities dictated by the production function as necessary for producing another unit of water, summed for all units from 0 to \( X_0 \). Total water and electricity costs together are \( C = P_K K + P_L L \), or, for relevant limits set by production conditions, \( C^* = P_K K + P_L L - \lambda [G(x,y) - f(K,L)] \) with \( \lambda \) as a Lagrange constraint on units of resources required given the
first production function \( G(x,y) = f(K,L) \). Least total costs are shown by \( \partial C^*/\partial k = 0, \partial C^*/\partial L = 0 \), as (for the first partial) \( P_k = \lambda (\partial G/\partial y)(\partial y/\partial k) + \lambda (\partial G/\partial x)(\partial x/\partial k) \) where \( \lambda = (\partial C^*/\partial x)(\partial x/\partial G) \). Then marginal costs of water are \( \partial C/\partial x = P_k/[(\partial x/\partial K) + (\partial x/\partial y)(\partial y/\partial K)] \), and the total costs of water are \( \int_0^X (\partial C/\partial x)\,dx \). For the second production function, these marginal costs \( \partial C/\partial x \) cannot be defined: partial derivatives of the joint outputs cannot be defined, nor can the marginal products of capital \( \partial x/\partial K \) and \( \partial y/\partial K \). The marginal costs of water do not exist.

In the cases where outputs are separable, the definition is straightforward: the costs of additional water are equal to the price of capital \( P_k \) divided by its marginal product \( (\partial x/\partial k) \) minus the loss of this product to electricity \( (\partial x/\partial y)(\partial y/\partial k) \). One output cannot be added without subtracting from the other at any given level of least total costs.

Some Methods for Allocating Joint Costs

Several of the methods new advocated for allocating joint costs can be evaluated as means for finding the true marginal costs of water.

One method, the "available energy" method, can be seen to provide an approximation to the costs of water. This method allocates the expenditures on resources between the two products

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1 That is, \( \lambda \) equals the marginal costs of water \( \partial C^*/\partial x \) multiplied by the marginal output of this product when both are increased.
on the basis of the relative use of the thermal energy in water rather than electricity production, and it provides an approximation to the costs of resources actually used when thermal energy allocation is a good surrogate for resource allocation.

Other methods provide no such approximation. Consider three commonly espoused procedures for allocating costs between water and electricity, as follows:

(1) Revenues from the sale of electricity are to be deducted from the total annual costs and the remainder assigned to water.

(2) Costs of a reference single-purpose electrical plant having the same electrical capacity as the dual plant are to be deducted from the total costs for the dual plant and the remaining expenditures called the "costs of water."

(3) The ratio of costs for single-purpose water and electricity plants is to be estimated, and the costs of the dual-purpose plant then assigned according to this ratio.

None of these procedures allocate cost in terms of the resources used to produce either water or electricity.

The first and second methods give all of the cost savings from joint production to water. Total costs in a joint facility equal to \( C = f(x,y) \) with \( x = \) water output, \( y = \) electricity output, are in contrast to costs in separate, single purpose facilities equal to \( c_1 = f(x) \) and \( c_2 = f(y) \). In the first
method, the costs of water are \((C - P \cdot y)\) where \(P\) is the unit price of electricity output; but the rules of the game are that the dual purpose plant must not be a "burden" to the general electrical system, which requires that \(P \cdot y - c_2 \geq 0\), so that any economies of joint production are attributed to water. Also, any long-standing profits in electricity production \((P \cdot y > c_2)\) reduce the "costs of water" -- a measurement result that moves away from calculations of the value of resources used in plant construction or operation. These conclusions are straightforward: the costs savings from joint production of specified amounts of \(x = x^*, y = y^*\) might be defined as \(s = c_1(x^*) + c_2(y^*) - C(x^*,y^*)\); with \(P \cdot y \geq c_2\), then the so-called "costs of water"
\[(C - P \cdot y) \geq C - (C + s - c_1) \geq (c_1 - s),\]
the costs of the single purpose water operation minus the joint cost savings. If \(P \cdot y > c_2\), or \(P \cdot y - c_2 = \pi\), the profits on electricity production, then \((C - P \cdot y) = c_1 - s - \pi\), and the measured "costs of water" equal the costs of the single purpose water plant minus the cost savings and the profits on the sales of electricity.

In the second method, water costs are \((C - c_2(y^*))\) at some specified electricity output \(y = y^*\); but, again, if there are economies of joint operation then \((C - c_2(y^*)) = (C + c_1 - C - s)\) or measured "water costs" are \((c_1 - s)\), the costs of the single-purpose water operation minus the savings from joint production.

The departures of measured "water costs" from true resource expenditures can be extremely large. In many cases the single-purpose electrical plant used for comparison purposes
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has the same thermal capacity but larger net electrical capacity than the dual purpose plant (the difference in net capacities being accounted for by water production). The economies of scale from the larger reactor or boiler in the dual plant provide the major part of any cost reductions from dual water-electricity output; choosing the reference electrical output \( y = y^* \) greater than that in the joint facility increases \( c_2 \) but not \( c_1 \) and \( C \), so that the value of \( s \) is increased and more cost saving is credited to electricity. This attribution, while resulting in "lower costs" for water, is arbitrary since it is based on a single purpose plant that is not a necessary alternative.

The third method imposes on water production the cost of a technological disadvantage which is non-existent in the dual plant. By requiring an allocation of expenditures according to the ratio \( c_1/c_2 \), "costs" are attributed to water based on production conditions not present in the dual purpose plant. In fact, these conditions measure "costs" higher than exist in the dual purpose plant. With the ratio \( c_1/c_2 = (C + s - c_2)/c_2 \), \( s \) is in the numerator and increases the fraction, so that all of the cost savings are charged to, rather than credited to, water production. The bias results from "costs of water" \( C(c_1/c_2) \) in the dual purpose plant depending upon \( c_1 \), the costs of another operation having nothing to do with the resources utilized in this operation. The method measures costs of water which are too high, because dual purpose production requires resources for water production in a lower proportion to electricity production.
This is clear from an elementary discourse into the technology of dual purpose plants. To avoid the formation of mineral scale on heat transfer surfaces, distillation plants must receive steam at temperatures from 200°F to 250°F.¹ No reactor now in production provides such low temperature steam -- although designs of low temperature reactors are now beginning to appear.² Until they do, heat producing facilities for single-purpose distillation would not use the most efficient reactor technology. This is the case for fossil-fueled plants as well: boilers require even higher temperatures for lowest cost thermal energy, and these boilers would be run inefficiently to stay within the 200°-250° limits. But since turbo-generating equipment operates efficiently at the higher temperatures, there is no comparable cost disadvantage in a single-purpose electrical plant. In a dual-purpose plant, the disadvantage in providing low temperature steam disappears; the temperature of the steam for use in the water plant can be efficiently degraded with back-pressure turbines in the electricity plant. Thus joint production is based on steam at temperatures allowing thermal efficiency, but reduced to the level required for brackish-water distillation. A good part of the resources in \( c_1 \) at \( x^* \) are not

¹ That is, the capital cost increases from raising the temperature to this level are more than compensated for by fuel cost savings up to this level.

present in \( C(x^*/y^*) \) so that true unit costs \( C(x^*,y^*)/x < C(c_1/c_2)/x^* \).

The mistakes in estimates appear not only in finding the total costs of water, but in the search for the marginal costs of this single output from the dual purpose plant. These costs are important for deciding plant size -- for comparisons with marginal benefits after the decision has been made to build the plant, but has not been made as to how much water to produce over its lifetime.

The first and second methods could estimate these costs to be the total costs for increasing water output, given electricity output. This is to assume that the increase in water output is not accompanied by increased "payments" for the other product. With the first method, measured water costs \( A = (C - Py) \) and \( \partial A/\partial x = \partial C/\partial x \), the true costs of water at the margin in the joint operation. In the second case, \( A = (C - c_2) \) and \( \partial A/\partial x = \partial C/\partial x \) once again. In both cases, \( \partial C/\partial x \) are the true marginal costs of water.

But how do the measurements take place? In fact they could follow from varying the size of the joint plant while holding electricity output fixed, but these cost allocation methods then do not provide any assistance at all. Marginal costs are all of the additional costs, and their calculation follows from attributing new and larger components to water production -- not from observing prices for outputs from other single purpose plants. A close adherence to these allocation techniques calls for adding to both outputs and then treating
the "incremental costs" of water as the change in total costs minus the increased revenues from the sale of the additional electricity. In terms comparable with the above, the "incremental costs" of water equal \( dC(x^*, y^*) - Pdy \), or for the second method these costs equal \( dC(x^*, y^*) - c_2(y^*)/y^* dy \). But marginal costs of water \( \partial C/\partial x \) equal these changes in total costs \( dC(x^*, y^*) \) minus the marginal costs of electricity.\(^1\) Prices \( P \) or unit costs \( C_2(y^*)/y^* \) greater than the marginal costs of electricity subtract more from \( dC(x^*, y^*) \) than the marginal costs of electricity, so that the measured "incremental costs" of water are reduced below the true marginal costs of water.

The third method attributes costs at the margin on the basis of \( c_2 \) and \( c_1 \), the costs respectively of electricity and water from reference single purpose plants, as well as on the basis of the actual expenditures on this plant \( C(x, y) \). In this case, total costs of water are measured as \( A = (c_1/c_2)C \) and incremental costs \( \partial A/\partial x = (C/c_2) \partial c_1/\partial x + (c_1/c_2) \partial C/\partial x \).

Given that \( \partial c_1/\partial x > 0 \) and \( c_1/c_2 > 1 \), then \( \partial C/\partial x < \partial A/\partial x \) or the marginal costs of water \( \partial C/\partial x \) are overstated by this estimate of "incremental costs" \( \partial A/\partial x \). It is more likely that the reference water plant is smaller than the electricity plant; then \( c_1/c_2 < 1 \) and the marginal costs of water can be understated.

\(^1\) That is, \( dC(x, y) = (\partial C/\partial x)dx + (\partial C/\partial y)dy \) and the marginal costs of water \( \partial C/\partial x = dC(x, y)/dx - (\partial C/\partial y)(dy/dx) \).
Each of the methods is based on some one assumption as to the bargaining position of the customers of the two products. The payments of revenues by buyers are attributed to one output so as to find the "costs" of the other. The first method excludes from "costs" of water those payments that are made by electricity users, i.e., "costs" are what electricity consumers will not pay. The second excludes what electricity buyers would pay if another plant were constructed rather than this one. The last assumes that it would be "fair" for water users to pay in proportion to the costs of a particular alternative means of producing water as a ratio of the costs of an alternative means for producing electricity. One of these "bargains" may be close to those actually struck in operating markets, for the two products. Regardless of how prices may be set in the two output markets, however, one should know costs in terms of the actual resources used to produce each output: if they are known, and technical improvements occur, then the process of searching for the new least cost combination of inputs can continue. Even though political decisions may result in subsidies for one product from charges levied on the other, the amount of the subsidies should be known and stated so as not to interfere with the search for the design requiring the least total amounts of resources to produce both water and electricity.
The Available Energy Method

The assignment of production costs between outputs in dual purpose plants ought to begin as an engineering rather than an economic matter. A functional analysis of each item of equipment in the plant could lead to a specific conclusion about its relative contribution to the production of each output; that proportion for water times the component price is used as an estimate of the costs assigned to water. But all components cannot be assigned by function. A large share of the total costs goes to producing thermal energy which is used to produce both outputs, so that there is still the major task of allocating thermal energy production components between the two outputs by some method other than a straightforward functional analysis.

Allocation of thermal energy is complex and difficult because the amount of heat energy put into the process water by the boiler is much greater than the amount which is useful (or available) for turning a turbine or distilling seawater. For an efficient turbo-generator, about one-third of the heat can be converted to electrical energy while the remaining two-thirds returns to the environment. In water distillation processes, none of the heat is converted to water and all is eventually given up to the ambient air. The difficulty is to hold accountable for the use of resources either the generating facility or the distillation plant when electricity production apparently "uses up" part of the heat while the water production "uses" none at all. But this can be dealt with: even though no heat
disappears in distillation, steam is useful for water production only when its temperature exceeds ambient; therefore the heat content of the steam above ambient temperature is useful for distillation and cannot be made "available" to the turbine at the same time.

Suppose the pressure vessel is maintained at ambient temperature, but water contained in the vessel is evaporated. This requires energy -- to change a pound of water to steam requires about 970 b.t.u. -- which cannot be used for distillation because the steam is at ambient temperature and its heat cannot be transferred. But energy has been dedicated to water production. To maintain the vessel at the vapor pressure corresponding to the ambient temperature, work was done to evacuate it -- that is, to reduce its pressure below atmospheric. This mechanical work can be recovered in evaporation.¹

By burning additional fuel, the temperature and pressure of the steam contained in the vessel can be increased. This additional heat can be recovered as mechanical work by passing the steam through a turbine so that its temperature is reduced to ambient by expansion. The useful heat is the enthalpy (heat content) of the steam less the enthalpy at ambient temperature after the expansion cycle. This amount disappears as the steam flows through the turbine; an equivalent amount of electricity appears in its place.

¹ For this discussion, mechanical, electrical, and condenser efficiencies are taken at the theoretical value of 100 per cent.
Globalization has had a profound impact on the world economy. The interconnectedness of national economies and the rapid flow of capital, goods, and services have led to increased competition and opportunities. However, these changes have also highlighted disparities in wealth and development. Governments and international organizations are working to address these issues through policies and initiatives aimed at fostering inclusive growth and sustainable development. Collaboration and cooperation among nations are crucial in navigating the challenges of globalization.
The distillation facility behaves differently: no heat disappears (except for the heat of solution, about 0.67 calories per gram for seawater). The heat brought into the system by steam is simply transferred to the lower temperature water. This transfer occurs in vessels in which the pressure is maintained below the vapor pressure of the feedwater but in which temperatures on distillation surfaces are below the boiling point for the process pressures. Each of the series of vessels has successively lower temperature and pressure, but each maintains the pressure below that of the feedwater. The feedwater-vessel pressure difference causes evaporation of some of the seawater and the feedwater-vessel temperature difference causes redistillation of the vapor without salt. The pressure difference, from electrical energy in pumping, is used by the water plant. The temperature difference between the incoming seawater and the distillation surfaces necessary for flash evaporation is also used by the distillation plant. This is the heat contained in the steam. Then units of heat -- "the available energy" -- above ambient temperature for the middle ranges of temperature at least are homogeneous inputs for producing either water or electricity.¹

¹ Temperature does affect the efficiency and cost of machinery, so that the cost of output may be less for certain temperature ranges than for others. It would be possible to assign relative productivities to heat at different temperatures and pressures for different purposes. These refinements, to any desired level of sophistication, can be added to the basic method proposed.
The "available energy" method assigns costs of non-specific equipment and fuel in proportion to the thermal energy used in the production of each output. The amount of energy available in each unit of steam is equal to its enthalpy at the point of delivery less the enthalpy of reject steam at the temperature of the ambient environment.

The total amount of distilled water produced per unit of heat depends on the least cost combination of investment in heat transfer surfaces, pressure vessels, or thermal insulation, and of direct expenditures on thermal energy. In current technology with current factor prices, however, from 8 to 12 pounds of water are produced per pound of steam. Charges against this water, according to the "available energy" method, should include expenditures from using equipment to produce energy dedicated to this output or kept from being included in electricity output.

Consider, for example, the case of dry saturated steam produced by a reactor at 600 p.s.i.a. and 486°F, with entropy equal to 1.445 b.t.u./lb./degree F. These conditions are consistent with enthalpy of 1203.2 b.t.u. per lb. Expanding the steam isentropically (with constant entropy) to 92°F, the corresponding pressure and water content are 0.743 p.s.i.a. and 29.5 per cent respectively, and the enthalpy is 794 b.t.u. per lb. The maximum heat that can be converted to work is roughly

\[ 1203 - 794 = 409 \text{ b.t.u. per lb. out of the heat necessary to produce the steam.} \]

If the steam is expanded in a back-pressure

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1. It is assumed that the enthalpy of the feedwater is 58 b.t.u. per pound.
turbine to 26 p.s.i.a. and then delivered to the water plant, the corresponding enthalpy at delivery will be 985 b.t.u./lb. In this case 1203 - 985 = 218 b.t.u./lb. of available energy is assigned to electricity production and 985 - 794 = 191 b.t.u./lb. to water production; the energy producing and rejection costs would be allocated 218/409 = 53 per cent to electricity and 47 per cent to water.  

This example is idealized. For one, the final steam and water temperatures are assumed to be equal to the temperature of the ambient environment when, in actual operation, there will be energy losses at various points in the process. The computations may be refined as these losses are charged either to the concerned facility or to the general energy account for later distribution as appropriate. Even when idealized, it points to the particular treatment given to allocation of costs for the condensing turbine. Since the vapor pressure of water at ambient temperature is much lower than atmospheric (for 90°F, 1.422 inches of mercury of 0.72 p.s.i.a.), final condensation must occur under a partial vacuum if all heat above ambient is to be recovered. For turbine operation in a single purpose electrical plant, this requires condensers which constitute a significant

1 With 1145.2 b.t.u./lb. put into the feedwater, 1145.2 - 409.2 = 736.0 b.t.u./lb. would be wasted to the ambient environment. As mentioned earlier, in many actual cases condensing turbines may also be installed in parallel with the back-pressure turbine-water plant series. Normally, the total enthalpy rate would be calculated at each point by multiplying by the mass flux of steam, and the allocation made on the basis of total enthalpy flux rather than unit enthalpy.
part of the cost. In a dual-purpose plant, a back-pressure turbine receives prime steam from the reactor or boiler and delivers it to the water plant at a temperature in the range of 200°F to 250°F, and the condensing function is performed by the water plant, so that condensers are not required. But if they are used, as in the example above, their costs are shared in the ratio of utilization of the resulting enthalpy.

Generally the allocation method uses three accounts: the ENERGY source account, the electrical POWER account and the WATER account. The cost of steam production and heat rejection facilities should be included in the ENERGY account. This procedure allocates the savings from eliminating the condenser costs between the two products in proportion to their use of available energy. Both the fuel burning and the distillation plants use relatively large amounts of electrical power. The energy used to produce these blocks of power should be deducted from the POWER account and charged directly to the WATER or indirectly to the ENERGY account. Likewise an appropriate portion of the cost of the power-producing facilities should be similarly allocated. Figure 1 shows a plant layout and Figure 2, the cost allocation flow

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1 But, again, whether condensers are actually used is a matter of the least cost combination of inputs. Depending on the balance between production of electricity and water, a combination of both back-pressure and condensing turbines may be used. See Figure 1.
Condensing Turbine-Generator

Back-Pressure Turbine-Generator

Low Pressure Condensing Turbine-Generator

Water Plant

To Auxiliaries

For Sale

Electricity

Sea Water Intake

Brine Return

Product Water
Step 1

(1.1) Assign common facilities costs to each account according to use.
(1.2) Assign condenser costs to energy.
(1.3) Assign circulating water system cost first to power and water production in ratio of seawater flow rate to each.
(1.4) Assign power production portion to the energy source.
(1.5) Divide water production portion between energy source and water production in proportion to the heat removed per pound of seawater flow relative to the power production system.

Step 2

(2.1) Assign portion of power production costs to energy source and water production in ratio of auxiliary power used to gross power and assign remainder to power production.

Step 3

(3.1) Assign energy source costs to power production and water production in ratio of available energy used.
between the three product accounts with such a plant layout.\footnote{Details of this method were worked out by a Federal Government team studying desalting in the Northeast. Cf. Potentialities and Possibilities of Desalting for Northern New Jersey and New York City (Northeast Desalting team, June 1966) and follow from proposals of Hammond, Burwell and Ebel, and Fruth in "Cost Determination and Comparison of Nuclear and Fossil Fueled Dual-Purpose Power and Desalination Plants," papers presented on the First International Symposium on Water Desalination (October 1965).}

The argument is that total costs of the joint operation $C = f(x,y) = K_x x + K_y y + H(a)$ where $K_x$ and $K_y$ are indexes of costs per unit of output for those items of equipment clearly specific to the WATER account for producing $x$ and the POWER account for producing $y$, where $H$ is total reactor or boiler capital and operation expenses dependent upon the number of units of convertible thermal energy ($a$). The water operations use $\alpha$ units of this energy, so that total water costs $C^* = K_x x + H(\alpha/a)$; similarly, electricity costs $C^{**} = K_y y + H(1 - \alpha/a)$ and $C^* + C^{**} = C$. The costs of water per thousand gallons are $C^*/x = K_x + H(\alpha/a)/x$, the unit costs for the water plant plus the unit costs for the power plant $H/x$ times the percentage $\alpha/a$ of energy used by this output. Then the "incremental costs" of water are $\partial C^*/\partial x = K_x + (\alpha/a)[\partial H/\partial x + H \partial \log (\alpha/a)/\partial x]$, the unit costs of separable equipment $K_x$ plus that proportion $\alpha/a$ of the costs of additional heat $\partial H/\partial x$ along with any re-attrition of $\partial H$ due to changing
proportions \( = H \partial \log (\alpha/a) / \partial x \).  

There are good reasons for defining costs in this way. For one, the size of the joint operation has an impact on the costs of water. But not all of the cost effects from scale are realized in water production. The heat costs also affect the costs of power \( C^{**} \), for \( \frac{\partial C^{**}}{\partial x} = (\partial H/\partial x)(1 - \alpha/a) \), the cost change in heat from adding to water production times the proportion of heat used in electricity production. Then

\[
\frac{\partial C}{\partial x} = \frac{\partial C^*}{\partial x} + \frac{\partial C^{**}}{\partial x}
\]

and any "scaling up" of the plant by more water output affects both water and power expenses. For another, the available energy method meets the standards for cost analysis outlined in the previous section: "costs" for one output include only those expenditures made for resources used to produce that output and do not include expenditures on plants that might have been. The costs of water are those expenditures on water producing equipment, or on thermal energy attributed to water production. Revenues for complementary services are not designated as costs; nor are subsidies defined as cost reductions.

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1 It is assumed that \( K_x / \partial x = 0 \), or that the long-run average costs for equipment specific to this water plant are not affected by the size of the plant. This is equivalent to assuming that there are no economics or diseconomies of scale in that part of the joint plant concerned with water alone -- such as the evaporation facilities -- and that factor prices do not vary with the size of this plant. The last assumption is equivalent to expecting competitive markets for capital equipment and labor for a single plant -- or, at least, that the price of tubing will not change if the size of the particular plant in question changes.
The available energy method is still only a rule of thumb for cost allocation, however -- even if it is the most accurate of its class. It does not result in a true measure of the marginal costs of water in all important circumstances. The measured "incremental costs" are not the marginal costs of water unless the increase in water output attributed to additional available energy is just equal to the increase in water output from the actual resources drawn away from power to produce more of this one output. "Incremental costs" are \( \{ K_x + \alpha/a (\partial H/\partial x + H \partial \log (\partial/a)/\partial x) \} \) which equal \( K_x + P_H/(\partial x/\partial \alpha) \) when an index of prices \( P_H \) for items in the ENERGY account can be constructed. ¹ Marginal costs are \( \partial C/\partial x = P_K/\{ \partial x/\partial K + (\partial x/\partial y)(\partial y/\partial K) \} \) which in this context can be redefined as \( \{ K_x + P_H/(\partial x/\partial a + \partial x/\partial y \partial y/\partial a) \} \) so that the "available energy" method attributes costs at the margin correctly to water if \( \partial x/\partial \alpha = \partial x/\partial a + (\partial x/\partial y)(\partial y/\partial x) \). But this cannot be the case; since \( \alpha < a \), and \( \partial x/\partial y < 0 \) -- more of one product cannot be obtained without less of another -- then \( \partial x/\partial \alpha \) must be the greater and "available energy" incremental costs must be less than the true marginal costs of water.

What is true of marginal costs holds for total costs. The attribution from available energy is the integral of incremental costs, which is less than that of the true marginal costs. Available energy underestimates the costs of water.

¹ That is, \( H = P_H \cdot \alpha \) or \( P_H = H/\alpha \).
How large is the difference between "available energy" costs and the actual costs of resources used to produce water? There is no general answer, and there has to be some effort made to provide orders-of-magnitude in particular cases (as in the proposed dual-purpose plant for Israel discussed below). But there is reason to expect the errors to be smaller than those offered by alternative rules of thumb: the method attempts to measure costs and only costs, the method shares economies of scale between outputs, and the method results in smaller mistakes the greater the proportion $\alpha/a$ of energy attributed to water of total energy.\(^1\) Only the last is true of alternative cost allocation techniques, and the suspicion is that the magnitude of additional bias in the first two is large.

The "available energy" technique for distributing costs will be used below, for estimating water costs for the Israeli plant proposed for the mid-1970's. There is no better method for finding marginal and total costs of water at the present time.

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1 If the proportion of $\alpha$ to $a$ is fixed by technical conditions of steam temperature and pressure, there are no marginal costs of water. The partial $\partial x/\partial a$ does not exist nor does the transformation function $\partial x/\partial y$, so that $\partial C/\partial x$ cannot be calculated. Yet there is an "estimate" of incremental costs available from available energy. This estimate is completely in error.
The Costs of "Safe Yield"

Most of the design studies completed in recent years have implied substantial economies of large scale plant. It is generally expected that cost savings from large size are realized up to plant capacities of 1,000 million gallons per day of distilled water. Plants built to realize such economies would have to be on standby a large part of the time. Their outputs would be so large as to duplicate the flow of water in surface systems in the same regions; and, with the marginal costs of stored water less than those of desalted water,\(^1\) the desalting plant would be started only when there was a high probability that reservoirs would be short.

The costs per gallon of distilled water actually produced would be higher in this case. Some costs would be incurred even when the plant was shut down, and they would have to be added to the regular production costs. The Federal Government study of desalting in New York City, experimenting with a simple and cautious rule for operating and shutting down the plant, found that a 300 MGD plant would be in service only about 30 per cent of the time if the low-flow patterns of the Northeast rivers in recent years were to be repeated. Given this rate of use of facilities, the cost of interruptible water was estimated to be close to 90 cents per thousand gallons rather than somewhat less

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\(^1\) The reservoir water costs no more for treatment and transportation than the desalted water and does not require expenditures on distillation.
The core of this investigation is to examine whether certain features of

implied or expressed sentiments of former клиентs play a significant

role in the evaluation of the service. An analysis of the data

suggests that positive feedback from satisfied clients can significantly

affect the ratings of subsequent clients. Additionally, negative

feedback from dissatisfied clients seems to have a more pronounced

impact on the overall rating. It is important to note that these

findings are based on a limited sample size and further research

is needed to confirm these observations.
than half this amount if the plant was run full time. But this is not the relevant cost figure. In this case costs are the annual expenses for additional reliable flow or "safe yield" added to the system.

These annual expenses are calculated according to a variant of the "available energy" method. The purpose of water plant investment in this case is to assure that additional capacity is available when needed, so that water production has to have a preemptive claim to the joint facilities. In return for this priority, the water should be charged for the costs of full capacity output, whether used or not: the energy plant fixed costs should be allocated in proportion to energy utilization at water plant full capacity operation, whether or not there is actual operation, and variable costs assigned as they are incurred when the plant is operating.¹

But then there is unutilized steam when the water plant is shut down. The output of the boiler or reactor could possibly be throttled back so as not to produce this steam. In that case the water plant should be charged with the extra cost incurred in the production of electricity as a result of less than full

¹ This assumes extreme characteristics of consumer demand -- that penalties are assessed by the buyer on the water producer if supplies are not available. If, on the contrary, the consumer will accept a finite and recognizable probability of shortage, then the costs of preemptive rights may be higher than gains from meeting all draughts and the system should take second priority in energy utilization.
use of boiler capacity (equal to $\frac{\partial c^*}{\partial x}$ over the range $x = \text{full capacity water output to } x = \text{zero output}$). Heat rejection facilities could be provided, the heat wasted, and the feedwater returned to the boiler if the water plant is charged for the rejection facilities and the opportunity costs of the rejected heat. Most likely, the steam would be used to produce electricity in a low-pressure condensing turbine which could be built into the back-pressure turbine. Then the water plant costs would be the capital costs of the energy plant suggested by "available energy" allocation, while the variable costs of the steam used for electricity generation would be charged to that output.

This argument is more or less as arbitrary as those made for the available energy method under base load operations. In the earlier case, outputs of water and electricity were projected into the future and the costs of thermal energy assigned on the basis of projected energy use by the water and electricity plants. If the water plant used more heat than expected, then it "paid" for this energy on the basis of unit energy costs times the number of additional thermal megawatts so utilized. In the case at hand, the experience might actually be that most of the heat projected for water plant use ends up being used to produce electricity. Why should not the appropriate pro-rata capital costs of the reactor-boiler be charged to intermittent electricity production? The answer is a matter more of legal property rights than anything else: having the water plant pay for capital resources in the energy facility would provide the safest insurance against the
energy facility serving only the electricity plant. This insurance would provide less coverage if the capital expenses were shared on that portion of the heat plant devoted to peak water and off-peak electricity. There would be no insurance value at all in assigning to water only the variable costs of that portion of the steam used for water production. Then the electricity plant would surely have access to the capital in the heat facility as a result of having provided the investment funds and would be able to claim prior rights to thermal energy when it was imperative to have this energy for water output.

In the case of base load operations, deliveries of $x_t$ amounts of water in $t$ years result in capital and operation costs and "available energy" costs which total to $A_t$ in the same year. At annual interest charges of $r$, the costs per unit volume (commonly per thousand gallons) $C^*$ are calculated from the present value

$$\sum_{t=0}^{t_1} C^* \cdot \frac{x_t}{(1 + r)^t} = \sum_{t=0}^{t_1} \frac{A_t}{(1 + r)^t}$$

Marginal costs are equal to the change in $C^*$ generated by adding to output.

But when output is "safe yield," the time characteristics of costs are different. "Safe yield" is delivered at the time that the installation is completed, and it lasts as long as the facility is maintained in operable condition, whether water is
produced or not. The annual energy cost $a_e$ calculated by the available energy method consists of some part of the capital investment expenditures forecast over the lifetime of the plant. The annual variable cost $a_v$ at probability $p_1$ for actually producing a particular safe yield $Z$ is given by $a_v = [a_s(1 - n) + a_o n]$ where $a_s$ is the annual variable cost to maintain the facility on standby, $a_o$ is the annual variable cost to operate the facility to full capacity output and $n$ is the proportion of time with the probability of $p_2$ that the plant will be operated. The annual cost of safe yield is then $A^* = (a_e + a_v)$ and the costs per unit volume of safe yield "Z" are $C^*$ as above, $\sum C^* Z/(1 + r)^t = \sum A^*_t/(1 + r)^t = \sum (a_e + a_r)_t/(1 + r)^t$. With varying capacity to add to reservoir content -- based on varying rules of "go" and "stop" based on rainfall of record -- the "output" $Z$ would be an annual rate of production of yield $Z_t$ rather than a technical limit on capacity.

A retrospective view of the previous pages has to center on the arbitrary nature of the conclusions found there. There is no simple and accurate technique by which to find the costs of water from a dual purpose plant -- the costs of resources to produce this one of the two outputs from a single energy source. But the available energy method seems to make the least analytical errors on the path from complete dissection of each dollar of expenditure to a simple rule. This method is tentatively extended to finding costs of safe yield.
The subject of this paper is the analysis of some basic facts of the problem of
the influence of information technology on the structure of the economy.
The analysis is based on the examination of a large number of data.

The analysis shows that the influence of information technology on the economy is
not only significant, but also complex. It affects various aspects of the economy,
including production, consumption, and trade. The analysis also reveals that
the influence of information technology on the economy is not uniform, but varies
significantly from one sector to another.

The analysis further shows that the influence of information technology on the economy
is not only a present-day phenomenon, but also has a long-term impact. It is
expected that the influence of information technology on the economy will continue
to grow in the future.

The analysis concludes that the influence of information technology on the economy
is a complex and multifaceted phenomenon, which requires a comprehensive
approach to study. The analysis also suggests that the development of information
technology should be guided by a clear vision of its long-term impact on the
economy.
3. THE DEMAND FOR "SAFE YIELD"

Future water "needs" are estimated in most cases by projection of past consumption. Per capita consumption is adjusted to reflect expected changes in industrial and household income, and then multiplied by projected population. "Needs" are unaffected by prices on the demand side or costs on the supply side. Changes are seldom made in estimated per capita consumption for variations in water prices, or even as a result of non-price restrictions on use which could be imposed during drought periods. They have been considered to be immutable. But what has been the general rule is now marked by important exceptions: With sharply increasing costs for additional water in highly populated (and polluted) sections of the country, communities are becoming less willing to satisfy all such peremptory needs; with rising incomes, the argument that some will not be able to pay for water necessary for life loses force. The demand for water in an increasing number of instances is assessed according to the value of additional output of industry or agriculture derived from the water. The cost of obtaining new supplies is balanced against these demands.

The newer approach has extended so far that the setting of higher price schedules has been proposed as the cure for excess water needs. There may not be enough information on effects to allow such a policy to be put into effect without general disruption. Information on response patterns of volume demands to prices is sadly lacking; even the general effects of
50 per cent to 100 per cent increases in price on water use have not been determined.

In contrast, manipulation of the supply side of water markets has been common. Restrictions on use -- called "conservation measures" -- have been widely practiced, with substantial reductions in water demand in many cases, so that there is some evidence of the effects of this technique for reducing "needs" or requirements. Temporary conservation measures during the 1965 Northeast drought cut consumption by more than 10 per cent;¹ but whether this eliminates excess demand in the least costly manner -- with the minimum of reduction of output and of consumer gains in that region -- is another matter that remains to be determined.

Some general statements can be made. Price increases and consumption restrictions are policies which assume that some uses for water can be foregone in the short run without endangering health or severely disrupting production in the region. Price increases have income and substitution effects: in the absence of compensatory decreases in the prices of other products, they reduce consumers' and producers' real incomes and they make substitution of water from non-municipal sources appear more

¹ A New York Times report of June 5, 1966 on the effects of the drought-induced curtailment to that point indicated reductions in consumption from 1.35 billion gallons per day to 1.00 billion gallons per day. This is a reduction of more than 25 per cent; but the report of the Northeast Desalting Team indicated reductions of 10 per cent to 20 per cent from the same restrictions on use (op. cit., pp. 3-8).
advantageous. The income effects induce individuals to go without water -- to a limited extent, probably for watering lawns and washing automobiles, for example -- and the substitution effects induce industrial enterprises to use lower quality water from estuaries and to re-cycle used water. But consumption restriction or rationing has income and substitution effects, too, even though they may differ from those from price increases. Restrictions on use, when applied so that certain predesignated consumers go without, are equivalent to charging these potential users an infinite price. Then the income and substitution effects are equivalent for these potential users to those from an infinite price, while there are no effects on the unrestricted users. When restrictions are applied so that all users have to reduce consumption, then the effects are similar to those from one or another of the possible price schedules.

One of these techniques for reducing "needs" may be more efficient in the sense that it involves less reduction in the total value of output.¹ The first impression is that higher prices for all buyers at the same location would be more efficient, since low-valued final products produced from the water would be cut back the most. One technique or the other may be more equitable -- rationing by limiting the losses to a few groups considered to be able to bear the negative income and

¹ The value of output ultimately has to be measured in terms of what consumers are willing to pay for a market basket of final products, over and above the amount to be paid for alternative market baskets. Then value of output and consumers' gains are the same.
substitution effects, pricing measures by spreading the effects across all users. The point is that efficient and equitable use of resources can result only if these options are assessed. A forecast of water demand is necessary in order to establish the need for additional "safe yield"; this forecast should be made after considering the costs to society of price increases and/or arbitrary restrictions on consumption during infrequent drought periods.

Determination of "Safe Yield"

Then what is "safe yield" where a desalting plant is involved? This is the minimum rate of flow that a water supply system can yield with high probability.\(^1\) In complex, real-world situations, detailed answer estimates are derived from the synthetic hydrology of the water system and from operations analyses of that system; but the concept may be illustrated by using a simple "mass curve of runoff." For example, in Figure 3(a), let the curve ABCHF represent the cumulative runoff of a stream and the slope of the curve show the volume rate of flow. At time B, the reservoir is full and is subsequently drawn upon to maintain flow at the rate represented by the slope of line BGE. The volume of storage required to maintain

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1 The level of this probability is not stated in most instances, although 0.95 has been used; in some instances, it is assumed that probability of lower flow is zero -- that the low flow of record will never be exceeded. After a lower flow is realized, the values are changed but the assumptions are not. In this era of computers, and as runoff records become longer, safe yield likely will be expressed statistically.
flow is represented by the ordinate of any vertical line between the augmented flow line BGE, and the curve of natural flow ABCHF. If the rate for BGE is to be maintained, storage equal to the vertical line HD -- the maximum cumulative draft on the reservoir -- must be provided.

The problem is to predict whether the reservoir will run dry -- whether the safe yield is BE in 3(a) with storage HD, or some lesser value. Suppose that storage is GC in Figure 3(b); while adequate for the period AJ, the reservoir would be empty at C in a period of sustained drought of the length BE. The safe yield would actually be limited to \( BE^* \), such that the reservoir capacity GC is just exhausted at the point of maximum deficit \( C^* \). The problem then is to predict the length of time between reservoir fills. The usual basis for prediction is to take the drought of past record as showing the lowest flow and the longest period between fills that will occur in the future. In the case of (random) occurrence of no drought in the short history of new water supplies, this results in risky safe yield, but in the case of an extended drought with probability \( 10^{-4} \) once in a long hydrologic history, it results in almost riskless safe yield. Based on computer analysis of actual data, a synthetic hydrograph of the future can be constructed with the same statistical characteristics as that of the past; this hydrograph may even be based on the greater than even chance that wet years will be followed by wet years, and dry years by dry years. For a fairly large sample of synthetic
hydrographs, a statistical array can be obtained of estimated values of safe yield at various levels of probability.

Desalting adds to safe yield in a manner different from reservoirs. Suppose a desalting plant is started at 0, Figure 3(a), and operated until J, producing the cumulative volume JL; the effect will be to raise the runoff curve ABCHF by the ordinate of OJL and the new runoff curve will be the dashed curve OE'F'. The new safe yield will be determined by the available storage DH now shifted to D'H' and will be the slope of BD'E'. The safe yield added by the desalting plant will be the difference in the slopes of the lines BGE and BD'E' equal to LJ/OJ.

This safe yield can be increased even further by turning on the plant earlier. But spillage of desalted water can occur if the plant is on too long -- as in the first case, in which desired safe yield is only the slope of the line BGE and operating the plant from 0 results in spillage, i.e. JL - D'D is wasted. Ideally the desalting plant should be turned on so that its output just prevents the reservoir from going empty, and should remain on sufficiently long to assure that it refills. Since future rainfall and runoff cannot be known, however, desalting cannot be commenced and shut off on this schedule except by chance.

1 Figure 3(a) represents a case where prevention of emptying governs, since more than enough natural flow occurs to assure refill. The time period by which the desalting plant's production must be divided to compute safe yield is different if the refill criterion governs. Suppose that in Figure 3(b) the objective is to refill at F under the demand BE, then the desalting plant need produce only IF during the time BE and the added safe yield is IF/BK.
Introducido a emiciclo reticulado, pôde-se advir de opacidade de consecutiva.

Descrição mais acima de uma prática da praga vitrina.

Temos, por isso, mesmo que mais a prática da praga vitrina.

O que é a descrición mais acima de uma prática da praga vitrina.

De um vocabulo mais acima de uma prática da praga vitrina.

Houve, por isso, mesmo que mais a prática da praga vitrina.

O que é a descrición mais acima de uma prática da praga vitrina.

De um vocabulo mais acima de uma prática da praga vitrina.
The measurement of safe yield can be further simplified by using a mass curve whose ordinate is runoff less demand, as in Figure 4. This approach is particularly useful if the demand is changing with time. Beginning at point B, after the reservoir is full, additions to supply fall short of those to demand and withdrawal from reservoir storage begins. At point J, the desalting plant is turned on. Rather than adding the desalting output to supply, it may be deducted from the demand, resulting in the new reservoir demand line JM and required reservoir storage KD. The desalting plant is shut off at L, the reservoir spills at H, and the volume of desalted water EM is wasted.\(^1\) The safe yield added by the desalting plant is \(\frac{CN}{BP}\) per unit time, which is less than the capacity of the plant whenever there is a time delay BJ in beginning or of NL in ceasing production.\(^2\)

The best strategy for operating the desalting plant-reservoir system is that resulting in least costs of safe yield. But costs are calculated under uncertainty, and any calculated level is balanced against risks of higher and lower levels associated with that policy. The plant could be operated according to some simple rule such as that for the hypothetical New York desalting facility -- start plant operations when reservoir content is reduced to 50 per cent of capacity, and shut it down when content is 80 per cent of capacity. More

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1. If the plant had been shut off at N, however, the reservoir would have exactly refilled at I.

2. Figure 4 shows a case when the refill criterion governs the shut-off time for the desalting plant.
could be added to safe yield by extending these limits, but disproportionately more would be added to costs if the output is spilled; the decision to start or stop the desalting plant beyond such arbitrary limits might be influenced by surface runoff forecasts of a very dry season (based on current hydrologic and meteorological conditions). More might be added on the basis of the time of year at which a particular storage level is reached -- the later the time at which a benchmark percent of utilization is reached, the sooner desalting plant production begins.¹

Only in the most extraordinary of situations can the safe yield of a desalting plant be greater than the plant capacity. Such would require a reservoir for the output -- and the reservoir cost should then be added to the cost of the safe yield attributed to desalting. In most situations, existing reservoirs are pre-empted for surface water safe yields, and unless the reservoir system has excess capacity² their assignment to storage of desalted water would reduce surface water safe yield. Even so, optimum system strategy could involve reservoir utilization for holding desalted water simply in order to increase the probability of refill.

¹ In the New York City case, comparisons of ad hoc rules indicated that safe yield was not highly sensitive to the percentage benchmarks as long as they were in the general neighborhood of 50 percent utilization. The additional safe yield from using more sophisticated rules may be small, and the cost savings on standby maintenance foregone may be small.

² This would be the case if the reservoirs had been built to hold more water than the safe yield designated for a previous period of consumption.
But there are gains in safe yield from strategies based on the particular characteristics of desalting production within a system of multiple reservoirs. The safe yield under the operation of the combined multiple reservoir and desalting system very likely would be greater than the sum of the safe yields for the individual reservoirs. Given a set of synthetic hydrographs \( H,^1 \) reservoir storage capacity \( R \), and a desalting plant with full-load capacity \( Q \), an operating doctrine \( \varphi = \varphi_1[R(T), Q, H(T)] \) might be formulated in terms of existing reservoir storage capacity at time \( T \), current hydrological conditions at \( T \) in the context shown by \( H \). \( \varphi \) would have the efficiency \( \varphi = \varphi_2(R,Q,M) \) where \( E \) is the ratio of safe yield to the total volume of desalted water produced, given \( R, Q \) and \( M \) equal to actual surface water flow. The safe yield \( \varphi = E \cdot Q \), and the proportion of operating time for the desalting plant \( n = \varphi_3(M,R,Q,\varphi_1) \). A program can be designed to optimize by finding that \( E \) which results in lowest forecast costs for each of a range of values of \( Z \) (where the values of \( Z \) have probabilities \( p \) of realization). Probable costs of a unit of safe yield from a program can then be determined by finding the average of these costs (weighted by their probabilities) in present value terms (as shown above). Alternative cost determinations could be found for different \( \varphi \) and then for other values of \( Q \), for additional reservoir storage \( R \), and for additional surface supplies \( M \).

\(^1\) The underline denotes a set of values having statistical characteristics.
The results would be first indications of the costs to the economy of promising water at some level of abundance and without regard for the natural vagaries of weather.

**Demands and Prices**

The general demand functions for desalted water in some sense set the value of this investment undertaking, without reference necessarily to the charges levied by the producer on the water users. The "Pareto Conditions" for social welfare are assumed to be the basis for measuring the relative values of alternative investments whether these outlays are made by the government, or by private companies and then evaluated for efficiency by government regulators. These conditions are based on defining **improvements in economic welfare** as increasing the satisfactions from consumption of some while not reducing those of others; although this may be extremely difficult to do, since some are disadvantaged by almost every public expenditure decision, strategies can be devised which work towards this objective once the present distribution of wealth is granted and "side-effects" have been accounted for. The basic units of measurement are the consumers' gains or surplus -- what they would pay, rather than be deprived -- and not necessarily the amount that they actually pay for water.
But some sort of case can be made for undertaking a plant investment if the charges per unit of output against the users — and others affected — cover the long run average costs of the operation. Prices may be a good measure of consumers' gains, if imperfections of knowledge and market organization are limited\(^1\), and if all are required to pay according to use. But prices have to be equal to long run marginal costs for Pareto conditions to hold, because at least one consumer is advantaged by price reductions to this level — to equality of charges with the alternative values of resources used in production — while others are not disadvantaged.\(^2\)

Prescriptions of this nature might be applied to investments in desalting. Investments might take place if costs are covered by receipts, given prices of desalted water and electricity set equal to marginal costs. But there are formidable obstacles to putting such a rule into effect. Given significant economies of scale in boiler-reactor systems,

\(^1\) That is, if buyers do not have the power to set price in this market and sellers do not have that power in other markets. Cf. M. Lipsey and K. Lancaster "The General Theory of Second Best", Review of Economic Studies, XXIV(1), #63 (December 1956) p. 11 et. seq.

the sum of the marginal costs (sum of the prices) is less than the sum of average costs. The plant cannot pay for itself under "Pareto ideal" standards, even though it can do so with other sets of prices. Then the pricing rule has to depart arbitrarily from marginal cost/price equality.

The "costing" rules in Chapter 2 may be first attempts to set limits on price-cost differences in these circumstances. The pricing of water at \( p \cdot x = (C - P \cdot y) \) for total joint product costs \( C(X,Y) \) and the "going" price of electricity \( P \) sets the lower limit for this one output.

Any lower price would either require operation with a deficit or charging electricity consumers more than the going price--more than the long run costs of generation in another power station. But there is the logically identical limit shown by \( P^* \cdot y = C - P^{**} \cdot x \), where \( P^{**} \) is the going price for alternative sources of water and \( P^* \) is the charge that has to be levied on electricity users. The prices within the two rules are points of bargaining and not of principle in the economics of welfare; in fact, the bargain itself can be struck only if \( p < P^{**} \) and \( P^* < P \), for otherwise one or the other party—the water or electricity producer—would do better alone.

The other "costing" rules are fraught with the same problems, since they are also rules without reference to "Pareto optimal" strategies. They could be justified on other bases—for one, that the movement towards the necessary
preconditions for Pareto rules is accelerated, for ANOTHER
that the income effects are strongly favored over (irrelevant)
Pareto distribution conditions.

But there is one Pareto-type justification for
"giving the advantage" of lower price-cost margins to one of
the two products when an attempt is to be made to use the
price mechanism for rationing. Assume that prices are to be
charged to all users. Moving from average cost prices for both
water and electricity -- both prices set equal to unit costs
calculated from the available energy method -- an area under
the demand function for electricity is uncovered as its price
is increased, and another area under the water demand function
is covered by more sales of that product as its price is
decreased. If the second area is greater than the first, then
net consumers' surplus is increased. The increase is shown
by revenue or sales increases. Then the rule might be to
experiment with the ratio of the two outputs (and prices) until
that ratio is found for which the net revenues or profits are
maximized. This should not be without limits, since it is clear
that Pareto conditions are not honored by monopoly pricing and
profiteering and also are not honored by selling an output below
marginal costs. But, as long as the revenues cover total costs,
and prices exceed marginal costs, the ideal set of outputs is
approached by that combination affording the greatest receipts.
4. THE COSTS OF WATER FROM AN ISRAELI DESALTING FACILITY

The term "costs" has a number of different definitions, each of which is in keeping with a specific purpose in economic or financial analysis. The purpose for constructing the definitions in Chapters 2 and 3 has been to assess the magnitude of resources diverted from other uses to constructing and operating desalting facilities. The resources consist of capital, labor and raw materials; their diversion reduces the efficiency or growth of other industries in the economy.

The question is whether there is a net reduction in the size of the economy harnessed with a large scale desalting plant. The answer requires calculations based on the alternative costs of assets -- on the value of output produced from these resources in their alternative uses in this economy -- and on the rule that costs are attributed to desalting only on that portion of assets in a joint facility that is actually used for desalting.

There is little chance of arriving at a definitive answer in the large, given the data now available on costs and the crude techniques of cost allocation. But a first response can be made in one case here, that of proposed construction of a plant in Israel. This is a most interesting case, because of the large scale of the proposed plant relative to the economy and of the importance of the water output to agricultural goods production. It should provide a test case of economic effects.
The water-producing facility, a distillation plant using Mediterranean seawater, is assumed to be similar in size and technology to the reference cases used for determining engineering feasibility in the Kaiser-Catalytic Engineering Feasibility and Economic Study (1964; hereinafter referred to as the Kaiser Study). Other studies of desalting in Israel have been conducted by Technion (The Israel Institute of Technology) since 1959 and, in conjunction with the United States, since 1964.\(^1\) The reference plants in most of the research have had to provide at least 100 million cubic meters per year (118 million gallons per day); to construct and operate such a plant would require from $150 million to $250 million of resources when energy, electric and water producing facilities are all included. The funds would have to include foreign capital inflow, since construction of this type of plant requires an inflow of materials and engineering services

equivalent to more than 80 per cent of the $150 to $250 million. These funds would account for more than 10 per cent of total new inflow to Israel in each year of a five- to seven-year period.

Water and electricity are joint products in most studies, with the proportion of water to electricity varying over a narrow range. Then a good part of project costs are joint costs of the two outputs, so that the "available energy" method of cost allocation is used to find the costs of water alone (in contrast, for example, with the Kaiser Study, which allocates "costs" to water equal to $C - C_2(Y_o)$, the difference between joint costs and the expenses in a single purpose reference electrical plant.

The "available energy" procedure begins with setting up three categories of capital costs: those incurred in producing thermal energy, in producing electricity alone and in producing water alone. Expenditures on fuel for thermal energy production have to be accounted for as operating costs in the first category; the total costs of thermal energy are then allocated to electricity and water. Costs can be treated as if the three sets of components were economically and physically separated or there

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1 The rigidity of proportions would seem to have been more a matter of assumption than of technology. It was assumed, in the case of the Kaiser Study and in keeping with the "ground rules" of the United States-Israel Joint Board, that the demand for additional electricity generating capacity had an upper limit close to 200 megawatts, and that more than 100 million gallons per day of water could not be used at any price close to that covering costs. The ratio of 200 MW/100 MGD was set by these limiting demand conditions, for economies of large scale energy production made it possible to reduce costs by going to the limiting values. There is no technical reason for not changing the proportions.
were a centrally-located thermal plant selling energy and two of
the buyers were an electricity generating plant and a water pro-
ducing plant.¹ The State of Israel, in effect, is assumed to
construct and operate three facilities whose costs depend on
technological and market conditions specific to each.

The Separable Capital Costs of the Water Producing Facility

The part of the joint operation consisting of equipment
in heating seawater, in evaporation, or in treatment of desalted
water, is attributable to desalination whether or not these
facilities are separated from a steam boiler and turbogenerator.
The Kaiser Study indicates the costs, to achieve rated capacity
of 100 million gallons per day (MGD), of building and beginning
to operate these components in 1965 should come to $74.5 million.
The Study also indicates that the costs of intake and outfall
facilities -- "marine conduits and treatment systems for control
of marine growth . . . sea water intake pumps, the intake house,
and all (related) switch-gear. . . ."² are likely to be $5.0 million,
and the costs of general plant facilities $2.4 million. Other

¹ This is to assume that the arbitrary allocation of unavailable
energy is made to the users of available energy — that the
"price" paid to the energy producers covers the marginal costs
of available and unavailable energy where these are in fixed
proportions.

² Kaiser engineers in association with Catalytic Construction
Company, Engineering Feasibility and Economic Study for Dual
Purpose Electric Power-Water Desalting Plants for Israel (pre-
pared for United States-Israel Joint Board, January 1966,
United States Department of Interior contract no. 14-01-0001-632),
p. 119.
costs, which include engineering ($1.2 million), the owner's expense ($4.0 million), and interest plus general contingency during construction ($46.0 million, at 8.4 per cent annual interest charges\(^1\)) come to $58.2 million.

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1 The marginal sources of capital inflow are commercial loans or loans from other sources ($55 million in 1965) and the State's Independence and Development Loans ($33 million net in that year). It is not unreasonable to expect that substantial additions to capital inflow -- perhaps sufficient to fund the desalting operation -- would be forthcoming if interest charges were somewhat greater than those presently prevailing on the Independence Loans. The exact costs of this marginal capital -- that is, the interest charges on marginal loans expressed in real terms -- are not known. No information is available on real interest charges on commercial loans, but these loans seem to be mostly credits from suppliers to particular industries and their composition changes so greatly from year to year that prediction is almost impossible. There is no forecast by Israeli banking institutions of changes in terms on non-commercial loans, nor is a forecast possible without access to confidential data on terms being offered at the present time. The Independence and Development Loans have been made at the nominal rate of 3 1/2 per cent to 4 per cent, with selling expenses equivalent to another per cent, and with a nominal twenty-year term; but the buyers have demanded early redemption so that the actual average duration of these loans was only twelve years during the 1950's and the selling expense spread over this smaller volume of funds per unit time raised the effective rate to 12 per cent to 13 per cent. [Bank of Israel, Annual Report, 1965 (Jerusalem, May 1966, Sivan 5726), p. 60.] The effective rate is not the real rate; given annual increases in asset prices (of more than 5 per cent per annum in the period 1958-1965), fixed interest and principal could be paid with less resources after 1960 than before. Dr. Ben-Shahar of Hebrew University assumes that a 4 per cent annual rate of price increase will take place in the late 1960's and the 1970's (slightly less than the 4.4 per cent experienced during 1963-1965) which results in a real rate on Development Loans of 7 per cent to 8 per cent per annum. Correspondence with Dr. Ben-Shahar has established this rate as the best prediction in 1967 of future costs of capital in the absence of substantial devaluation of the Israeli pound (to exchange levels from 4:1 to 5:1 of pounds to dollars). With devaluation real levels will be in the range from 10 per cent to 11 per cent per annum. Then present and near-future costs of capital are at least 8 per cent per annum.
Not all of these costs are incurred in water production, of course. The general plant is shared between water and electricity production, and the interest charges are incurred in the construction of all facilities. The Study divides these costs between outputs on the basis of first pooling all expenditures and then subtracting 5.3 mills for every kilowatt hour produced, since this is the assumed cost of producing the same volume of electricity in the next-best facility. Such a method of cost allocation has been rejected above on the grounds that it leads to relatively large errors in estimates of the costs of water. Here the costs of general plant facilities and engineering are excluded entirely from water plant capital, but rather are included in energy-producing capital, where they are later allocated between water and electricity on the basis of relative use of "available energy." The interest and contingency charges are divided between energy, electricity and water on the basis of relative expenditures on construction of these parts of the joint plant. The the Kaiser estimate of capital for water facilities, on the basis of the "available energy" method, can be said to be $101.4 million.

There are a number of reasons for expecting the capital expenditures on a plant actually constructed in Israel in the coming decade to differ widely from this amount. Future costs could be higher or lower. Consider first some of the reasons for costs substantially lower.

The Study calculates capital expenses, in proportion to fuel and operating expenses, based on energy from a 1250 thermal
MW light-water reactor so that the steam leaves the generator and enters the brine heater with the brine heated to 220°F. Then approximately 100 BTU of heat are used to produce a pound of water in a reactor of that size. But a larger volume of heat could be used for the same water output; the larger volume would reduce water plant costs by trading (a) higher capital costs and fuel costs in the reactor for (b) lower capital costs in the water facility. The trade-off results in reduction of the number of states in which flash evaporation takes place and thus in reduction of components such as pumps, pressure vessels, and tubing. The trade-off may reduce total capital and fuel costs.

A review and modification of the water portion of the dual-purpose plant by Kaiser in 1967 showed the capital cost reductions. More steam is made available by increasing the reactor size from 1250 MWₚ to 1593-1650 MWₚ, and all of it -- when reduced to the temperature of 220°F after producing 300 MW of electricity -- is used in the water plant for the same output of 100 MGD. The number of evaporation stages is reduced from 31 to 19, given that more than 122 BTU rather than 100 BTU are used to produce a pound of steam. The savings on evaporator bundles, pumping equipment and accessory electrical equipment are 5.9 per cent or $6 million of total water plant costs.

A second reason for lower water plant costs is that the Technion studies of the last five years show lower costs. These studies

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costs for a variety of input factor price and technical conditions, but with heavy emphasis on coming close to lowest costs rather than to highest possible temperatures and pressures; they indicate costs of $84.9 million for the water plant when connected to a gas-cooled nuclear reactor energy plant (closest to the Kaiser reference plant in output characteristics) and costs of $85.4 million for the water plant when attached to a conventional low pressure no-reheat steam boiler.

Then with a construction schedule spread over a four-year period approximately $85 to $101 million of expenditures would be incurred for the water plant if all systems work well. Such a plant is assumed in most of the present design studies to be


2 There is a third reason: all costs are in United States dollars. Israeli pounds, at the present exchange rate of 3.5 per dollar are overvalued and revaluation of this currency would reduce internal costs. This can be seen from the Kaiser Study -- local construction and interest costs for the desalting components are 60 million Israeli pounds, which are equivalent to $17 million at today's exchange rate, but only $15 million at a 4:1 rate of pounds to dollars; a devaluation of sufficient magnitude to clear the Israeli exchange market would reduce costs by at least $5 million. At the same time, however, the costs of capital would increase by 2 per cent to 3 per cent per annum, as indicated above, so that the net cost change is likely to be too small to merit attention.

3 The schedule shown in the Kaiser 1967 Revised Study (ibid.) lays out the construction period for the desalting plant from August 1970 to July 1974 [page VIII-2]. The costs shown for this schedule are higher than those found here, because they are in 1967 rather than 1965 dollars.
capable of a thirty-year lifetime and to operate at capacity 85 per cent of the time.

The costs could go well beyond this range, as a result of systems not working well. There has not been plant operating experience to establish firmly the operating factor of 85 per cent. Even if the Israeli plant were the second or third large plant, its design operating characteristics might be so new as to preclude more than 80 per cent operation. The tubing -- still in its first years of experimental operation in multi-stage evaporation processes -- might be a particular source of malfunction requiring the plant to be down more than 20 per cent of the time. The costs of tubing failure include not only replacement equipment, but more and larger equipment to be able to produce at a higher rate when the plant is working, so as to meet the target 100 MGD average. The additional costs are more than $5 million.¹

There is some basis for forecasting higher costs because of higher components prices in the period from the present to the date of completion of an Israeli plant. Prices have gone up in the last two years: "plant costs [have] escalated by six per cent from the 1967 basis estimate to the mid-1968 basis estimate. . . . the price of copper (a principal material used in evaporator bundles) increased approximately 9 per cent from $38 1/2¢/lb. in June 1967 to 42¢/lb. in June 1968."² But whether

² Cf. Kaiser Engineers, Review of Engineering Feasibility and
they will continue to increase during the construction period is another matter. Kaiser has based its most recent forecasts on extensive additional price increases: "the 1968 estimate escalated to mid-1973 basis at a 7 per cent rate . . . is considered representative of the current inflationary period."¹ But the increases are part and parcel of 3 to 5 per cent annual rates of general price inflation in the United States and Israeli economies, and thus are not entirely relative cost increases. Also, they are based upon particularly acute, short-term increases in the demands for copper products in the middle 1960's, when longer term forecasts call for reduced copper goods prices.² Escalation of the costs of this plant, relative to those for all other capital goods projects, should not exceed one per cent per annum; at the outside, the plant finished in 1975 should cost 5 per cent more or $111 million.

The Costs of Thermal Energy for the Desalting Plant

The construction and operation of a steam system, based on a reactor if the heat source is nuclear fuel but with a simple boiler if fossil fuels are used, could be completed for capital expenditures as small as $18 million or as large as $90 million.

¹ Ibid.

² Cf. Orris Herfindahl, Copper Costs and Prices (Johns Hopkins Press; 1957) where the long-term forecast centers roughly on 35 cents per pound in 1965 dollars; or Franklin Fisher, "The Supply of Copper" (unpublished manuscript submitted to the Pan American Union in 1962) which centers supply and shifting demands on slightly lower long-run equilibrium price.
The smaller expenditure would be for building a fossil-fueled boiler, with more than twice the fuel costs of the nuclear reactor for $90 million. It would result in sharp limits on the amount of heat available for water production, if electrical output is fixed at 200 MW_e, so that the output of water would be limited as well.

The capital and fuel expenses depend, in other words, on the outputs of the joint products. Most of the studies of representative plants for the Israeli case are based on the production of water in volumes greater than 50 million gallons per day (as in the Kaiser Study; the demand prices or value for such a substantial volume are estimated below in the chapter devoted to "direct and indirect benefits"). A volume of 100 MGD is considered to be the upper limit on size of output because, while it takes more advantage of economies of large-scale water plant and energy sources than 50 MGD, it more than meets all of the "needs" for water at the margin of agricultural production.

The electric generating company agreed to an upper limit on the size of a single generating unit of 200 megawatts in 1965 and 300 megawatts in 1967; the first is the projected demand for new capacity before 1970, and the second is the maximum size consistent with new demand and requirements for diversity in sources of total capacity before 1975. ¹ For reference purposes, at least, the energy plant is that required to provide 200 to

THE instant application money or the output of a community planning program, which may integrate the local source of the nature of the project. This is not just a matter of what is most desirable, it is wise for the citizenry to make their choices on what is most important to them. Although it may appear to be easier to make judgments, it is essential to consider all aspects of the situation. We must also consider the current state of our nation, and how our choices can impact the future.
300 MW and 50 to 100 MGD capacity at least total cost including the cost of fuel and capital for the water plant.

The least-cost combination of inputs for these amounts of outputs depends upon relative prices of fuel and various capital components. Four detailed studies have been completed that look to different fuel sources, and thus provide an approximate range of cost estimates based on different relative factor prices. Two of these are Technion studies, the first of a fossil-fueled boiler and the second of a gas-cooled natural uranium reactor;¹ the other two are the 1965 Kaiser-Catalytic studies of a light water reactor and of a fossil fuel plant.² None of them can be said to produce estimates of the capital expenses for least cost combinations of inputs given likely values of factor prices. But all are representative of the relative magnitude of costs, from reasonable ranges of prices for fuel oil, nuclear fuel, and capital equipment.

Technion I analyzes costs to produce 93.3 MGD from a boiler providing low pressure steam without reheat -- a steam source not greatly different from those now installed in Israel. The fuel source is assumed to be bunker C oil, from Europe or

¹ F. S. Aschner, et al., Table 1: the conventional low-pressure plant produces only 93.3 million gallons per day (MGD) so that any comparison of total annual cost is deceptive because different quantities of output are produced by different plants.

the Middle East, delivered to the plant at $13/tonne. Given a range of turbine exhaust steam temperatures, present technical limits on boiler temperatures and pressures, minimum project costs are reached when back-pressure steam is released at 120°C to heat the brine (since this temperature results in minimum water plant capital costs, and energy costs are not substantially higher than those for lower temperatures). The boiler plant costs $18.9 million, the fuel costs $10.3 million per annum and the operation and maintenance expenditures come to $3.3 million per annum.2

Only a part of the energy is used by the water plant. Of the 1200 MW\textsubscript{t}, at temperature and pressure for enthalpy of 1393 b.t.u. per pound of steam, 1075 b.t.u. per pound remains for distillation after passing through the turbine. Not all of the residual energy is "available"; with as much as 872 b.t.u. necessarily rejected from the last stage of the evaporators, 1075-872 b.t.u. of thermal energy can be used to produce water. Then the proportion of costs to be borne by the water plant is 1075-872/1393-872, since this is the relative share of available energy used to produce water. The energy water costs are $7.3 million of the $18.9 million of total construction expenses, and $5.2 million of the $13.6 million of annual expenses. The

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1 F. S. Aschner, et al., op. cit., p. 10. But this statement may depend on the particular capital charges assumed in the study.

2 The operation and maintenance expenses include those for the electric generating facilities as well as those for the water and thermal energy producing facilities.
last amounts should be increased by a total of $1.2 million of construction expenses and $0.8 million of annual operation expenses to pay for the energy to produce 33 MW_e electricity used in the distillation plant. Total initial construction costs are $8.5 million, and additional annual costs are $6.0 million, for direct and indirect energy to produce 93.3 MGD of water.

Technion II provides an estimate of energy costs using a 1284 MW_t gas cooled reactor, rather than the 1200 MW_t steam boiler. Because the price of nuclear fuel (in b.t.u. units) is relatively less and the prices of nuclear components relatively more than comparable items in the fossil fuel plants, lower operating temperature and pressure result in lower costs (once again, fuel and capital prices are not quoted, but total cost estimates suggest that they are close to the 1963-1965 public quotations of Western European sources of this type of reactor). The output combinations chosen for examination are 200 MW_e and 102.5 MGD, rather than 200 MW_e and 93.3 MGD in the case of the fossil fuel plant, given that larger reactor capacity reduces the unit costs of outputs. The reactor costs $82.9 million, while fuel costs are $4.5 million and operation-maintenance costs are $4.4 million each year.

In this case, more of the available energy is used by the water plant to produce more water. Enthalpy at the throttle is 1372 b.t.u. per pound of which 297 b.t.u. is available for use in producing electricity; given that reject energy is 872 b.t.u., then (1075-872) b.t.u. per pound is available for water production.
The proportion of total costs paid by the reactor plant, in accordance with relative energy utilized, is \((1075-872)/(1372-872)\). Then initial construction expenses for "water energy" are $33.7 million and annual water costs are $3.7 million of the $8.9 million for total energy. When the costs of indirect energy -- for electricity for the water plant -- are added, the total construction costs for water are increased to $39.4 million and the annual fuel and operation costs to $4.3 million.

The principal reference nuclear plant in the Kaiser Study, based on either a pressurized water reactor or a boiling water reactor of 1250 MW\(_t\), was designed given certain "ground rules." The prices of fuel and the ratio of outputs were agreed upon by the joint U.S.-Israeli Government Committee that funded the Kaiser report. Price quotations for capital were collected informally by Kaiser from American manufacturers considering the hypothetical case of construction of a plant in Israel in the early or middle 1970's. The "ground rule" prices of fuel are the same as in the Technion studies (approximately $13/tonne for fuel oil, $6/lb. for uranium oxide); the capital prices may or may not be the same but there is no basis for comparing prices per unit of capital since none are given in either set of reports.

The decision rules in the choice of operating specifications were also similar to those behind the Technion studies: within the constraints, choose the design characteristics implying the lowest costs per thousand gallons of water. The constraints this time proved to be hindering, since the ratio of
outputs was not clearly that for minimizing costs in all the energy systems considered. But the results can be compared with those from the Technion studies.

Particular expenditures on capital for the 1250 MWt energy plant are $37.0 million for the reactor facilities, $19.6 million for water intake equipment, general plant facilities, owner's expense and engineering services, and (a prorated) $13.4 million for interest during construction and contingency for price level or engineering changes. The total of these costs comes to $70.0 million. Non-depreciable capital -- such as inventory and working capital -- costs $1.5 million each year on the basis of 8.0 to 8.5 per cent interest changes. Fuel costs for operating under the reference conditions are 13.5 cents/million b.t.u. at 85 per cent load factor, which comes to $4.4 million per annum and operation-maintenance costs are $3.5 million per annum. The sum of these three annual cost items is the proportion assignable to water production is 51.6 per cent, given that (984-763)/(1191-763) of available energy is used for distillation, so that construction costs for water are $36.1 million and annual costs for water are $4.8 million. Approximately 14 per cent of the remaining non-water energy is used to produce electricity for the water plant, so that total construction costs for water are $38.4 million and annual costs are $5.5 million.

The last Kaiser reference plant has a standard pressure (900 p.s.i.a.) industrial-type fossil fueled boiler plant. The costs analysis of such a plant should be straightforward, but the "ground rule" conditions imposed on it were burdensome -- were far from the
least cost conditions for this technology. As the Kaiser Study notes, "Fossil fuel plants . . . have much less turbine exhaust . . . consequently to produce the required ratio of power to water . . . it is necessary to use a water plant with a higher economy ratio. . ."1 but the water-power ratio could have been varied also to minimize total costs. (At the limit, half as much water could have been produced in the dual purpose plant of this thermal capacity and two phased-construction dual plants considered.) But this was not done.

The costs of construction of the energy plant contrived in this limited context were forecast at $39.5 million. The annual costs of fuel and maintenance are $11.8 million, and the proportion of this amount allocated to distillation is $1071-870/1395-870 in keeping with the relative use of available energy. The proportion implies construction costs directly attributed to water of $15 million and annual costs of operation of $4.5 million. In addition, the costs of electricity for producing water are $4.5 million initially and $1.3 million per annum which brings total water costs of energy to $19.5 million plus $5.8 million per annum.

A summary view of the four energy plants is possible. The plants cannot be said to be "comparable in costs" because the nuclear plants have higher initial construction expenses but lower fuel costs than the fossil plants as a matter of

1 Kaiser Study, op. cit., p. 80.
technology. But the estimates of costs in the same technology are remarkably similar. The Technion and Kaiser nuclear studies show construction costs for water of $39.4 and $38.4 million per annum (and annual costs of $4.3 million and $5.5 million). The two fossil fuel studies are more different from each other, at $8.5 and $19.5 million for construction and $6.0 million compared to $5.8 million for operation. The higher initial expenses in this comparison are associated with the Kaiser design for the fossil fuel system; the difference most probably results from the constraints put on the ratio of outputs in that design.

The Costs of Water and Energy Plants Together

The capital and operating costs of the water equipment, and the energy costs allocated to water output, comprise the total costs of producing water. To be more explicit, these make up "best estimates" of total expenditures first to establish producing capacity and then to produce this amount each year of thirty years. They are defined as forecast initial expenditures for plant capability and forecast total variable costs for plant output.

The "best estimates" based on the four studies discussed are shown in Table I, where "best" is defined as the single statistic most consistent with the most likely factor prices and capacity utilization of the energy plant. The single estimate of $101 million capital costs for the water plant has been used with all of the separate design estimates of the costs of
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<td>120.9</td>
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a  $1.4 million less if fossil fuel prices are in keeping with the lower of the two estimates.

b The annual costs for operating the higher cost versions of this plant are $3.5 million.

c The "low" estimate of fuel cycle costs is $0.7 million less than the amount shown.
energy. Adding the appropriate "water share" of the costs of energy to this water plant cost shows initial expenditures between $110 million and $140 million.¹

These estimates may be far off the mark set by actual construction outlay if and when the plant is built. There are reasons for attaching subjective probabilities to the occurrence of both higher and lower costs. Consider more realistically a "range of estimates" around each of these forecasts.

The lower end of the range is set by optimistic input prices and operating performance. The Technion studies are based on capital costs for water plant associated with the energy plant that are much less than the $101 million in the "best estimate." These lower costs bring the total construction

¹ The construction and operation of the plant itself does not end expenditures on providing desalted water. A conveyance system has to be installed specifically for the purpose of putting this water into the general water system. The question is how specific any expenditures on the system have to be in order to be attributed to desalted water. Assuming no additional water supplies at all for the South-East region of the country (that water to that sector is reduced to increase the supplies available for industrial and municipal uses), there will be some excess capacity in already installed water systems that can carry desalted water. But specific expenditures will still be necessary for conveyance of desalted water. This water has value as a dilutent at points in the system where the salt content of ground water is exceedingly high, and it has to be conveyed to those points. Under a "restrictive dilution system" which provides the diluting effect only where and when doing so results in increasing the value of agricultural outputs, the total charges for conveyance of 125 million cubic meters may be as high as $20 million. (As shown in Report of the United States-Israel Desalting and Power Team, October 1964, p. 54; and as documented in A. Wiener, Preliminary Study on Conveyance Systems for Desalted Seawater in the South of Israel, Tel Aviv, September, 1964, Water Planning for Israel Ltd., T121.)
expenses down to less than $100 million in Technion I and $130 million in Technion II. Plant availability should exceed 85 per cent. The Kaiser support Study #5, Dual Purpose Plant Operating Factor, shows that the hypothetical plants for Kaiser I and II have been over-built, in the sense that spare parts have been installed in the original construction and extremely durable and expensive bimetallic pipes have been used throughout to reduce voluntary and (predicted) forced "outage" time below 15 per cent of total operating time. Other studies -- such as the recent TVA analysis of coal-fired versus nuclear plants and industry analyses of general designs of nuclear plants\(^1\) -- have led to forecasts of plant availability from 85 per cent to 92 per cent of total time. A consequence of a modest increase in availability, for example of 2 per cent more of total time, would reduce annual costs by $.2 million.

Expenditures on fuel should be lower than forecast in the present studies. Nuclear fuel prices and fuel rod fabrication costs in both Technion and Kaiser are high in the light of the most recent estimates and projections. General Electric has published quotations on fabrications which, when adjusted to the basis of Kaiser I, result in fuel cycle costs 2 cents per million b.t.u. lower than in the Kaiser Study; other quotations made to TVA and to the potential purchaser of a reactor in Puerto Rico

\(^1\) Cf., for example, A. W. Wofford, "Nuclear Power Promise," Atomics.
have been 2 cents to 3 cents per million b.t.u. less than the Kaiser Study as well. This range reduces fuel expenses by close to $.5 million per annum.

The price of oil can be expected to be much lower than the normal level of $13 per tonne, for three reasons. First, crude oil is forecast to sell in the next five years at tanker lots for from $8 to $9 per metric ton at the Persian Gulf on a commercial basis. The Israelis should be able to purchase on such a basis -- rather than the forecast posted price $3 or more higher -- because they have begun construction of a 42-inch pipeline (presumably for transporting Persian Gulf oil across Israel). The resulting access to spot and contract crude should guarantee that the Israelis are no longer discriminated against in commercial markets because of limits on their sources of supply (since the entire Western European market for commercial tanker loads would now be located in Israel at the Eastern end of the Mediterranean). Second, the transportation cost for the Israelis from Iran ought to decline perceptibly because of the introduction of new large-scale tankers on regular voyages from the producing source to Elath to connect with the new pipeline. The "best forecast" is for delivered oil at $10.50 per ton at Elath. Heavy fuel oil prices can only

be less than these crude prices -- and should not exceed $10 per ton. The implications of these lower fuel costs are reductions in the costs of water by at least $1.4 million per annum. Further reductions are possible from undertaking a better and more detailed design of a fossil fuel joint facility -- one that produces 300 megawatts of electricity along with 100 million gallons per day of water, rather than 200 MW and 100 MGD as assumed earlier. The new conditions are extremely favorable to fossil fuel as an energy source, because the high temperature of steam requires a high power-to-water ratio and the 300/100 ratio is much more favorable for costs of water than the previous 200/100 ratio.

All of these reductions indicate that specific forecasting of expenses on water production is at a very preliminary stage. Assumptions can be made as to technical reliability and as to factor prices, but, since no thorough design study has been completed and since the actual technology in plant construction will not appear until some time in the future, equally reasonable yet different assumptions can also be made. The variation in assumptions results in considerable variation in costs for water. The "best" estimates of costs in Technion I and II are close to $110 million and $141 million but optimistic estimates would reduce costs to $99 million and $131 million. Average variable costs in the two nuclear plants might be $.7 million less than shown in best estimates, and the two fossil fuel plants might be $1.4 million less. The fossil plants might well be less costly to operate than nuclear plants in their place.
There are substantial reasons for believing that the "best estimates" of the costs will prove to be too low. Most of the estimates were made in the early 1960's and need updating; the Kaiser engineer's estimates for 1965 have already been so revised, and have substantially increased because of equipment cost increases. Even though much of the revision was for general price inflation in the United States and Israel, there are two changes which have taken place which make the earlier forecasts the probable middle and low values of the range of costs. The first consists of relative price increases for capital items in the water plant, and the second of even greater increases in capital equipment in the nuclear power plant.

The water plant has been subject to 1967-1968 price inflation which raised costs by roughly 6 per cent per annum -- partly as a result of rapid cost escalation in the American construction industry, but in particular as a result of increases in copper tubing prices. There is no basis for expecting higher rates of price inflation than this, and this may well be higher than can be forecast for the middle 1970's. Copper prices should not continue at the rate recently experienced (as has been mentioned above). Also, improvements in design in part cancel out price increases; Kaiser industrial studies in 1965-67 water plant design showing that less efficient but simpler engineering specifications reduced capital costs, and then installed these changes in the revised estimates. Even for the
present situation, cost increases for the water plant would not extend much beyond those experienced on construction projects or on all new capital items.¹

The energy-producing equipment in the Kaiser plant costs much more for two reasons. First the plant is larger since — under "new terms of reference" from the United States-Israeli Joint Board — the capacity to produce electricity has been increased from 200 to 300 megawatts. Second, the costs of equipment for any given size have increased because of escalation in the construction of reactors and because of higher price quotations by the manufacturers of the reactor vessel and its internals. The sum total of the two effects is to raise expenditures on the energy side of the plant from approximately $70 million to $139 million (as shown on page IV-2 of the June 1968 Kaiser Report). The costs for energy to produce water are $55.7 million in initial construction expenses and $3.5 million per annum in fuel, operation and maintenance expenditures. The sum total effects of scale increases for this project and price inflation are to increase the capital expenditures (from approximately $38 million) and reduce the fuel and operation expenditures (from $5.5 million per annum to $3.5 million per annum).

¹ Unless the cost increase is greater than general economy-wide increases, the initial construction expenditures and annual charges are not revised. The reason is straightforward. The only point of interest is the opportunity costs of the water plant — the value of resources in alternative uses as compared to building this project. The costs are shown in 1965 dollars because this plant is as expensive in those terms as in future terms.
How are the costs for the energy plant likely to change over the period 1968-1975 -- where 1975 is the date at which the prospective Israeli plant would be complete? The Kaiser Company addressed itself to this question and came to the conclusion that the forecast costs period should "reflect 7.7 per cent per year escalation through mid 1973, which is a weighted average midpoint for construction completion in 1975" (as in the 1968 Report, p. III-2). Kaiser arrived at this estimate of further price inflation based on "Israeli labor and materials cost portion, its escalation, and the effect of the Israeli pound devaluation." This per cent annual increase is both general -- part and parcel of an economy beset by 4 to 5 per cent general price inflation each year -- and specific since approximately 2 per cent more inflation each year occurs on this plant. This rate of increase is also greater than the 3 to 4 per cent general price inflation expected for the United States. The United States is a source of potential capital for a good part of the construction expenditures; as a consequence, the forecast relative increase in the cost of this plant might be close to 3 per cent per annum or 15.9 per cent between mid 1968 and mid 1973. The total costs of construction of the water portion of the energy plant might be as great as $64.5 million.

Much the same conditions hold for revisions in the other three plant designs. There is no detailed revision of costs from price inflation for components of fossil fuel energy plants, but it is clear from Engineering News Record cost indices that the fabrication and construction of boilers also
now cost 4 to 6 per cent more than two years ago. These cost increases, and further increases before 1975 from the rate of price inflation assumed above, result in "high estimates" from $0.4 million to $8 million greater than the "best estimates."

The full range of estimates is shown in Table I. Technion I should cost between $99 and $120.3 million, ranging between low price quotations and, less optimistically, price escalation in both the energy and water plants.¹ Technion II should cost between $131 million and $158.8 million. The two Kaiser plants should cost between $140 million -- the "best estimate" but also the low estimate -- and $175.9 million while the conventional fossil fueled Kaiser plant should cost between $121 million and $132 million.

These costs have to be put against the value of outputs derived from building one of the four designs. Then a comparison is possible between rates of return on the four potential ways of providing desalted water. Also, a comparison can be made that goes beyond the boundaries of this technology between the rate of return on desalting and that on the "next best" project of comparable scale in communications, transport or another industry in the government sector.

¹ Each of the estimates contains, in the high end of the range, $10 million additional expense for a higher cost water plant. The reasons for the $10 million are given in the preceding section of this chapter.
5. THE VALUE OF WATER FROM THE ISRAELI DESALTING PLANT

The output of the supposed distillation plant, centering on 100 million gallons per day (MGD) or approximately 118 million cubic meters (MCM) per year, would blend with the ground and surface waters already in the system so that it would be impossible to designate particular physical outputs as following exclusively from the addition of the distilled water. Additional water supplies, however, have productivity and the productivity has monetary value; the change in total production of all goods and services as a result of the change in total water supply is the best indicator of the value-product of this water.

Additional water supplies could reorganize the composition of agricultural and industrial output based on present water supplies. Then calculations of the value of products from water should proceed from finding the total value of the new mix of agricultural outputs, industrial production, and water as a consumer's good, net of the total value of the end mix. But this has not taken place as part of an exercise here in the economic analysis of desalting because there are only partial studies of particular industries available which point to the relevant comparisons. If slightly more than 350 million cubic meters per annum are added to the water supply by 1975, then 145 MCM would go to municipal uses, 125 MCM to industry, and 85 MCM to agriculture given charges and restrictions on use that are now applied to these three sectors (according
THE VALUE OF WATER TO THE URBAN POPULATION AT LARGE

The demand for water resources in urban areas is a significant issue. In many cities, the available water supply is limited, and the demand for water is high. This can lead to conflicts over water usage and conservation measures. Urban populations rely heavily on water for domestic, industrial, and agricultural purposes. Therefore, it is crucial to find sustainable solutions to manage water resources effectively.

The demand for water in urban areas is expected to increase due to population growth and climate change. Water conservation and efficient use are essential to meet the water needs of urban populations. Governments and stakeholders should collaborate to implement policies and technologies that enhance water efficiency and conservation.

In conclusion, water is a vital resource for urban populations. Ensuring an adequate supply of water while maintaining the environment's health is essential. Innovative approaches and policies can help address the challenges of water scarcity in urban areas.
to the "ground rules" for the Kaiser Study). The first and second categories of users have greater demands at the margin of use, as shown by higher water prices and higher imputed or shadow prices without water subsidies. If this total amount of new water turned out not to be available, the first two sectors would receive approximately the same additional volumes of water. This will be possible only by reducing supplies to the agricultural sector below the amounts now made available to that sector. Such a cutback would have severe political and social repercussions, even though it might be the best use of resources; but those responsible for the political decisions -- in Tahal, the national water carrier -- make it clear that such a cutback is the only possible policy in the event of no increase in national water supplies. Then a first measure of the value of products from distilled water is equal to the net revenues from maintaining or slightly increasing agricultural output beyond the present level, rather than cutting back on such agricultural output.

This does not approximate the entire value of water from an Israeli facility. Distilled water has value, over and above that from additional derived output, because it adds to

the quality of all the water in this country's system. More and higher quality agricultural products can be produced from any given supply of ground water since the salt concentration of these supplies is reduced by adding the distilled water. Also, there are measurable benefits from adding "safe yield" in this plant rather than in another ground water supply—benefits of an insurance nature described in Chapter 2. The construction and operation of this plant, second in timing and size to the Los Angeles facility proposed by the Metropolitan Water District of California, could be expected to reduce the costs of succeeding plants by developing new equipment and techniques for its own use and for those that follow as well. Estimates can be made of these cost reductions, and they can be considered an indirect benefit of distillation.

Estimates of the direct benefits—the net value of output from the additional water—are made first. These are followed by indications of system-wide revenue gains from reduced salinity, and in cost-reducing gains from advanced plant development.
The Net Value of Agricultural Production from the Additional Water

The outputs of citrus crops, forage crops, and vegetables are responsive to the quality and availability of land, labor, capital, and water; it is no more than a matter of form to state that aggregate production \( Q = f(L, N, K, x) \) for these four independent variables in order, and that the output index \( Q \) is chosen for particular values of land, labor, etc., so as to maximize the net value of tonnage. The product of additional water is \( xQ/\partial x \), and the marginal value of product is \( P(\partial Q/\partial x) \) where \( P \) is the price index for sales of aggregate output \( Q \).

An estimate can be constructed of marginal value product of additional water from projections for 1965 Israeli agriculture. Professor Yair Mundlak, in *Long Term Projections of Supply and Demand for Agricultural Products in Israel* (1964), provides indicators of total value of product for 1965 and 1975. Two different estimates for 1975 follow from assuming that two different amounts of water and related resources will be available; water supply "1" results in \( Q_1 \) output, and water supply "2" results in \( Q_2 \) (with associated revenue products). Subtracting expenditures on additional resources \( L, N, K \) and assuming the price index \( P \) does not change with output (or that the prices of the relevant marketable crops are given by competitive markets in international trade), then \( P - pL - pN - pK)(Q_2 - Q_1) \) approximates \( P(\partial Q/\partial x) \), where the small \( p ' s \) are input factor prices and...
the values of L, N, K are additional amounts of each input that accompany the additional water supply. This approximation can be made very roughly by recourse to Mundlak's output estimates and to general public information on income distribution in the agricultural sector.

Professor Mundlak's three projections of P·Q, one for 1965 and two for 1975, are based on detailed studies of past production of particular crops, on estimates of the supply relationship between sales prices and plantings, and of the productivity increases expected to shift out the supply curve over time. The 1965 projection, which was actually made some years earlier, appears to have been quite accurate;¹ the good results of this first projection establish the usefulness of Mundlak's procedure. The 1975 projections are 1672 million I b and 1736 million I b, where the first assumes only a moderate increase in the present agricultural water supply by the amount of 59 MCM per annum and the second assumes an additional 100 MCM over and above that (with accompanying additions to land, capital, and labor).² These two projections are conservative, since

1 As shown in the review by the U. S. Department of Agriculture, Economic Research Service, Israel Supply and Demand Projections ERS-FOREIGN-137.
2 The assumptions are not those considered directly relevant -- since the alternative assumed in Mundlak is not a reduction of agricultural water but zero addition to agricultural water. With diminishing returns, the marginal value product at supply x - 100 MCM is greater than at x + 150 MCM, so that Mundlak's projection is an underestimate of the projection sought here.
since they are based on expectations of "a rather modest" productivity increase from 1965 to 1975 which "calls for performance at a lower level than that which has already been achieved by the better farmers."\(^1\) The additional 1975 output is made up of field crops such as cotton, sugar beets, and perhaps vegetables, since it is assumed that citrus and forage will be given first priority to existing ground water supplies; as a consequence, the estimated value is conservative because these field crops have the lowest expected prices of all irrigated crops. Then the difference of 64 million $\ell b$ is a twice-conservative estimate of $P(Q_2 - Q_1)$ for 100 MCM: on the basis of gross value of output from water supply, it comes to $18.3$ million per annum.\(^2\)

The net value product equal to $(P - pL - pN - pK)(Q_2 - Q_1)$, depends upon the expected payments in 1975 for additional land, labor, and capital to produce the field crops from the 100 MCM in Professor Mundlak's projections. No projections of additional factor payments have been made for these crops; nor

\begin{footnotes}
\item[1] ERS-FOREIGN-137, p. 13.
\item[2] The assumed exchange rate is 3.5 pounds per dollar, as at the present time. Alternative assumptions would have to favor 4:1 or 5:1 ratios.
\end{footnotes}
is one possible from general forecasts of income distribution in the 1970's. If it is assumed, however, that 1975 income shares in agriculture will be the same as at the present time, then approximately 69.3 per cent of the 64 million I $ can be attributed to $(pL + pN + pK)$, the additional cost of other input factors. This follows from the 1964-1965 behavior of income shares, where agricultural output at producer prices was 1256 million I $, payments of wages were 160.8 million I $, deductions for raw materials other than water were 394.2 and deductions for depreciation were 95.2 million I $. The payments for capital probably did not equal the social cost of capital, because capital subsidies or grants were made generally rather than loans in competitive markets; after the deduction for these joint costs of 210.6 million I $ as an additional 8 per cent charge on agricultural capital stock, then all factor payments come to 69.3 per cent of income from agriculture in 1965. If this holds for 1975 -- assuming constant returns to scale in agriculture, factor shares are constant -- then $pL + pN + pK = .693PQ$ for the value of all agricultural output $P'Q$ in the projected year. Assuming the value holds at the margin as well, so that factor costs are $.693P$, then 

$$(P - pL - pN - pK)(Q_2 - Q_1) = (1 - .693)P(Q_2 - Q_1)$$

or 30.7 per cent of 64 million I $. Then a rough estimate of the initial net value of outputs from additional distilled water
after 1975 is $5.6 million per year. Succeeding net values should be roughly 2.5 per cent higher in each year thereafter, given the same rate of productivity increase as forecast for 1965-1975.

These estimates are probably near the low end of a "reasonable range" of such projections. If Israel does well in developing the technology of agriculture, there should be a greater increase in yields than the 20 to 25 per cent assumed for 1965-1975. Adding only 1 per cent to annual output for greater increases in productivity each year results in gains from additional water of 67 million lb in 1975. Then the net value is not limited to $5.6 million, but is forecast at $6.2 million. These extra gains in productivity should increase at the rate of 2.5 per cent to 3.5 per cent per year. The value of output at the end of the plant's life should be $23.4 million at the 3.5 per cent rate. Values for the intervening years should be between $6.2 and $23.4 million.

A separate and independent programming analysis indicates marginal returns close to these first estimates. Professor Dan Yaron, in *The Demand for Water by Israel Agriculture* (Rehoveth, Israel, 1966), constructs a programming model of Israeli agriculture in which there are thirteen agroclimatic
regions competing for a fixed amount of resources other than water. Under hypothetical 1966 conditions of factor supply and productivity, 200 MCM of water are added to the system and all resources are distributed to various regions so that the marginal values of products, net of the transportation costs of the water, are equal. The case study closest to those forecast above for 1975 has water allocated to the urban population or to orchard development and away from field crops so that such crops are reduced below present levels.

With "field crops . . . the recipients of the resources remain at the disposal of agriculture after the demands of all the more intensive and profitable branches have been satisfied . . . (so that) the marginal productivity of water is determined mainly by field crops."¹ The value of the additional water from a desalting plant is calculable in three steps. First, Professor Yaron shows the marginal value of field crops as 15-18 agorot per cubic meter at field locations closest to the desalting facility, plus 7-10 agorot more when feed crops are cut back from present levels to that level compatible with a fixed supply of water in the system and more pressing demands elsewhere. He assumes that the supplies of land, labor, and capital are fixed in total amount, but reallocated from dry farming to irrigated production as more water is added. Second, the 22-28 agorot are equivalent to $P(\partial Q/\partial X)$ or

¹ Yaron, p. 43.
24-30 cents per thousand gallons at present exchange rates. Third, total annual values of 100 MGD at these rates per thousand gallons range from $7.5 million to $9.3 million. This is the first year's value of marginal product, when that year is similar, in all important technical and economic respects, to 1965.

A series of annual increments of value product can be constructed from these two basic analyses of water use in agriculture. The "low" increments begin at $5.6 million, according to Mundlak's low productivity forecast, and increase at 25 per cent per year over the thirty-year plant lifetime. The "high" increments begin at $6.7 million and increase at 3.5 per cent per annum, in light of Mundlak's high productivity forecast and Yaron's findings of higher productivity for 1965 than forecast for 1975. Each series will be given equal weight in forecasting the rate of return from desalting investment; that is, the probabilities of occurrence of each are thought to be the same.

The Value of Distilled Water as a Dilutant

Since water-borne salt is damaging or costly to agricultural and industrial users, distilled water has a special value in excess of water from natural sources which contain even small amounts of salt. In particular, the salt-free output from the proposed Israeli plant may produce two additional sources of real income to that society.
The first is in leaching of the soil. If salt-bearing water is added to soil and the water is then transpired by plants, the salts remain behind. Unless sufficient additional water is added to the soil to leach out the salts, they will accrue to an undesirable level. The greater the salt content of the irrigation water, the larger is the leaching requirement; desalted water reduces the overall salt content in the irrigation system when added to other supplies. One "extra value," then, is the value of the leaching water no longer necessary to maintain salt balance but now free to be used elsewhere.

A second "extra value" is found in the elimination of crop damage due to excess salts. Plant growth may be inhibited by water salinity through salt-induced increases in osmotic pressure in the soil solution and/or toxicity to particular chemical ions. Then the extra value of desalted water as a dilutant is equal to the value of the additional growth of all crops specifically traced to a reduction of these chemical effects given the higher water quality. Consider each of these crop damage effects in detail. ¹ An increase in osmotic pressure in

¹ The language of salinity may need some attention. Following are definitions of terms frequently used:

Total dissolved solids (TDS) - Weight of dissolved solids divided by weight of the water solution expressed in parts per million or milligrams per liter.

Chloride - Weight of chloride ions divided by the weight of the water solution expressed as parts per million (p.p.m.), mg/liter (mg/l), or milli-equivalents/liter (meq/l).
the soil causes some damage to the plant, but there is great variation in the tolerance levels of different plants. Typical values of total dissolved solids (TDS) in the saturation extract which may cause plant development to be inhibited by 10 per cent are:

<table>
<thead>
<tr>
<th>Plant</th>
<th>TDS</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>7,700</td>
<td>3,500</td>
</tr>
<tr>
<td>Wheat</td>
<td>4,500</td>
<td>2,050</td>
</tr>
<tr>
<td>Beans</td>
<td>1,000</td>
<td>455</td>
</tr>
<tr>
<td>Table beets</td>
<td>5,100</td>
<td>2,220</td>
</tr>
<tr>
<td>Potato</td>
<td>1,600</td>
<td>730</td>
</tr>
<tr>
<td>Carrots</td>
<td>1,000</td>
<td>455</td>
</tr>
<tr>
<td>Bermuda grass</td>
<td>8,300</td>
<td>3,820</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>1,900</td>
<td>860</td>
</tr>
</tbody>
</table>

(continued from previous page)

**Electrical Conductivity** - Usually expressed in millimhos per centimeter (EC \( \times 10^3 \)). This is a simple way to estimate salt; while the conductivity depends on the combining weights of the ions, an average relationship is given by

\[ 1 \text{ mmho/cm} = 640 \text{ p.p.m.} \text{ of salt} \]

**Milli-equivalents per liter** - (meq/l) This is the sum of the weight of each ion divided by its chemical combining weight.

**Soil saturation extract** - In order to analyze salt content a soil is usually mixed with distilled water until it becomes completely saturated. The solution is then extracted by vacuum filtration, thus TDS, EC \( \times 10^3 \), chlorides, etc., are expressed as concentrations in the saturation extract.

**Field capacity** - This is considered to be the amount of moisture, in volume per unit weight of dry soil in the field, that the soil can hold against gravity. Field capacity is about one-half the value of moisture content at saturation.

**Bulk density** = \( b \), dry weight of the soil in grams/cubic centimeter,

**Moisture content** = \( M \) = volume of water contained in a unit bulk volume of soil, expressed as a percentage, or as cubic centimeters/gram.

Whatever the 10 per cent change level, growth retardation is typically a simple function of increased osmotic pressure. The important exception is fruit crops, some varieties of which are so sensitive to chloride or other ions that retardation is sharp and discontinuous beyond a certain level.

Chloride damage is a product of the toxic effects from a number of specific ions. Many crops are sensitive to boron in very small concentrations; but in Israel, the major concern relates to chloride damage to citrus, since chloride ions are taken up by these plants in sufficient concentration to cause leaf damage. The damage is cumulative over a period of time. Under Israeli conditions, chloride ions account for about 1:2.2 of total dissolved solids; i.e., chloride concentrations may be multiplied by 2.2 to estimate TDS. The maximum tolerable values of chloride concentration in soil saturation extract are low in the case of some important fruit crops, as the following U.S. estimates indicate:

<table>
<thead>
<tr>
<th>Chloride p.p.m.</th>
<th>TDS$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus-sensitive root stock</td>
<td>350</td>
</tr>
<tr>
<td>- medium tolerance root stock</td>
<td>525</td>
</tr>
<tr>
<td>- high tolerance root stock</td>
<td>875</td>
</tr>
<tr>
<td>Stone and pome fruits</td>
<td>240-350</td>
</tr>
<tr>
<td>Avocado</td>
<td>175-280</td>
</tr>
<tr>
<td>Grapes</td>
<td>350-875</td>
</tr>
<tr>
<td>Strawberries</td>
<td>175-280</td>
</tr>
</tbody>
</table>

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Two additional complications are the sensitivity of the root stocks on which the fruiting wood is grafted and the results of direct sodium damage. With the same fruiting wood, two trees may exhibit widely differing damage from the same level of chloride, because of the resistance of different root stocks. The choice of roots does not always favor insensitive stocks, because these may exhibit lower fruit quality and yield. There could also be a problem of sodium damage. If a sufficient proportion of chloride ions are adsorbed by the clay particles, crops may suffer because of the damage to soil structure as a result of deflocculation.

A Model for Forecasting Leaching Effects. While soil salt is expressed in terms of the saturation extract, the actual concentrations encountered by plant roots is higher than this. The irrigation process results in moisture in the soil root zone at only field capacity, about one-half the saturation extract. The soil solution will contain the residual salt in the soil, plus the new salt brought in by the irrigation, minus any leached out. As the crop draws water from the soil, the salt remains but the water is reduced; thus, the salt concentration of the soil solution increases until the next irrigation. The rate at which this occurs will depend on the rate of evapotranspiration, which in turn depends on received radiant energy.

In simplified terms, this relationship may be expressed by first defining \( \Delta Q = Q_i K_i - Q_d K_d \) in which \( Q_i \) and \( Q_d \) are the volumes of irrigation water applied and drained, \( K_i \) and \( K_d \) are
the respective salt concentrations and $\lambda$ is the initial salt content of the soil. This equals $(Q_F - E(t) + R)K_t$ where $Q_F$ is the water stored in the soil following irrigation, $E$ is the time rate of evapotranspiration, $R$ is the rainfall since irrigation, and $K_t$ is the salt concentration in the soil solution at time $t$. That is $(\lambda + Q_t K_t - Q_d K_d) = (Q_F - E(t) + R)K_t$ can be solved for the salt concentration $K_t$.  

The cumulative effects are shown in Figure 5 as build up of salt in the soil solution if there is no leaching, assuming constant evapotranspiration and irrigation applied every 14 days. But there are other possibilities. Variable evapotranspiration -- by season and weather -- can be built into the analysis by summing separate calculations of each  

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1 To take a simple numerical case, suppose that 100 meters$^3$/unit area of water are stored in the soil following an irrigation, that the evapotranspiration rate is 7 mm/day (7 meters$^3$/unit area) and that the salinity of the irrigation water is 550 ppm with 250 ppm chloride; $R$ is zero, as is $Q_d$. The initial salinity of the soil $\lambda$ is 87(10$^4$). The initial moisture content before irrigation is 0.05 cm$^3$/g. At root zone depth of 1500 mm and b of 1.5 so that $Q_F = (1500)(1.5)(0.05) = 112.5$ mm, before irrigation and $(87)(10^4) + (100)(550) = (112.5 + 100 - 7t)K$, or $K = 325,000/(212.5 - 7t)$. But the sensitivity limits are expressed in terms of saturation extract $K_s$, which would be, following the ith irrigation $K_s = (\lambda + Q_i K_i)$ where $Q_i$ is the volume at concentration, $K_i$ at the ith irrigation.
FIGURE 5: Salt Concentration Over Time

Soil Solution

Saturation Extract

Salinity Solution - Total Dissolved Solids Ppm
day's effects. Once the argument has been stated, it may be extended to predict new values of $K_t$ for different $Q_i$ and $K_i$.

Yaron and Bresler use a similar equation for each layer of a multi-layered soil in order to study salt build up with time. The resulting set of simultaneous equations is solved using field information regarding evapotranspiration drawn from each layer.

Both models deal directly with the problem of salt build up. By applying sufficient extra water to leach an amount of salt equivalent to that brought in by irrigation, the salt concentration in the soil can, theoretically, be held constant. Thus, water with a low salt concentration would be more valuable than that with a high concentration because less leaching water is required to prevent increases in soil concentration from taking place.

Yaron and Bresler use their model to determine the maximum concentration in the irrigation water such that the chloride content in any layer would not exceed a preset value. The total amount of water applied was varied and the permissible concentration of the irrigation water determined. The results

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show the expected discontinuity. If initial soil salinity was close to the present value, of course, additional leaching water had to be substituted for salt concentration. And once the irrigation water approached the preset maximum permissible concentration, additional water of the same quality would not reduce the concentration of the soil solution, or would do so only at a very low rate so that exceedingly large quantities of leaching water would be required to complete the task. Substitution of leaching water would be more expensive than suffering the crop damage; the result follows from the inflexibility of the "accept-reject" rule so that the model does not present a promising basis for evaluating the effects of varying irrigation water quality when the permissible limits for chloride are approached.

An alternative approach follows from the first model. At salinity concentrations just below those which threaten crops, the relevant consideration is maintenance of the given salt balance, by leaching or otherwise. Then the extra value of desalted water can be measured in terms of the value of outputs produced from the leaching water which is saved. But if the salinity increases to that point where chloride damage begins, the pertinent value consideration is the amount of damage that the desalted water prevents. The model has two parts, and the relative importance of saved leaching water and of foregone chloride damage will depend on changes in the salinity value of the
irrigation water.

The ratio of water needed for evapotranspiration $\bar{Q}$ to the inflow required, $Q_i$, including that needed to effect leaching while maintaining the salt balance, is $1 - K_i/K_d$. Define $Q_o$ as the present surface water supply to the affected area, $Q_s$ is the supply of distilled water added, and $K_o$ and $K_a$ the salt concentrations of the before and after adding the distilled water; then the beneficiation ratio $B = K_a/K_o$ due to dilution is $Q_o/(Q_o + Q_s)$. Suppose that $Q_{11}$ is the total irrigation water of salt concentration $K_{11}$ required to maintain the chloride level, but that $Q_{12}$ is the volume of water with a lesser concentration $K_{12}$ that can also maintain the same chloride level. Then the amount of water saved from using those supplies with lower concentrations is

$$\Delta Q_i = Q_{11} \left( K_{d1} (K_{d2} - K_{12}) - K_{d2} (K_{d1} - K_{11}) \right) / K_{d1} (K_{d2} - K_{12})$$

where $K_{d1}$ and $K_{d2}$ are permissible drainage water salt concentration given $Q_{11}$ and $Q_{12}$ respectively. (In the case at hand, $K_i$ and $K$ are salinity concentrations of the irrigation and drainage water, as has been seen above. The salt brought in is $Q_i K_i$ and that leached out is $Q_i K_d$. Therefore, to maintain the salt balance, $Q_i Q_o = K_i K_d$; but if $Q$ is the amount required for evapotranspiration, $Q = Q_i - Q_o$; substituting gives $Q/Q_i = 1 - K_i/K_d$.)

Since the amount of salt load is assumed to remain constant, then $Q_i K_i = K_o (Q_o + Q_s)$. The assumption does not take account of efforts to reduce the salt load, but rather to maintain the load as it stands now.
The value of desalted water $\pi_1$ equals the saved leaching water times the value of output from the saved water:

$$\pi_1 = \Delta Q_i (P - C) q / Q_s$$

where $(P - C) q$ is the net productive value of output from the volume of water $Q_s$ at salt concentration $K_o$.

This model can be readily utilized. The permissible value of $K_o$ is commonly estimated from an experience with crop areas that have suffered zero, than slight, damage. Pillsbury and Blaney suggest 4,800 p.p.m. But drainage water salinity $K_d$ results from particular irrigation practices on a specific combination of soil, crop and climatic conditions. What is needed is a way to forecast $K_d$; a gross model yields (2):

$$K_d = K_s + \sqrt{K_s \cdot (K_s - 2K_i)}.$$ This formulation will be used to assess the value of water saved in Israeli agriculture.

---

1 Since $Q$ will be constant and $\Delta Q_i = Q_{11} - Q_{12}$,

$$\Delta Q_i = \frac{Q}{K_{d1}} \left[ (K_{d1} - K_{11}) - Q / K_{d2} \right] / (K_{d2} - K_{12});$$ substituting

$$Q = Q_{11} (K_{d1} - K_{11}) / K_{d1}$$

yields

$$\Delta Q_i = Q_{11} \left[ (K_{d1} (K_{d2} - K_{12}) - K_{d2} (K_{d1} - K_{11})) / K_{d1} (K_{d2} - K_{12}) \right].$$


3 $K_{fc} = 2K_s$ where $K_{fc}$ and $K_s$ are concentrations at field capacity and for saturation extract respectively. But $K_{fc} Q_F = K_d (Q_n + Q_i)$ where $Q_n$ is the residual soil moisture and $Q_i$ the irrigation application. $K_d \approx 2K_s Q_F / (Q_n + Q_i).$ (continued)
The second task is to measure the effects from actual chloride damage. The work of Yaron and Bresler, as previously mentioned, indicates that — after a critical salt limit has been exceeded — the value of reduced salinity by dilution is shown by any resulting increase in yields. What is needed to measure the results is \( \frac{\partial (P_q)}{\partial K_i} \), where \( P_q \) is the gross value of the crop \( q \) produced per unit volume of water \( Q_i \) and \( K_i \) is expressed as chlorides; the expression may be written \( \left( \frac{\partial P_q}{\partial K_i} \right) \left( \frac{\partial K_i}{\partial K_i} \right) \) where \( K \) is the saturation extract chloride concentration.

There is some information available on both of these terms, although the second is better documented than the first. Some research has been done on \( \frac{\partial K}{\partial K_i} \) for various soil types and climatic conditions pertinent to an analysis in Israel. But, rather than studies of \( \frac{\partial (P_q)}{\partial K} \), only "maximum values"
Knowing the values in Israel of the various coefficients in Equation (2), estimates for savings due to substitution of leaching water can be made for those areas of crops not sensitive to chloride. The areas of chloride sensitive crops ought to be partitioned into several strata depending on the level of chloride sensitivity. Equation (3) can be applied to each of these areas. The augmented value of distilled water from dilutions is the sum of these two estimates. There is still another component of augmented value accruing to industrial and municipal users from decreased requirements for detergents, from less salty water. This last value will be estimated after calculations for the first two are completed.

Forecasting Leaching Effects in Israel. Investigation requires estimates of the independent variables as follows:

\[ (P - C)q = \text{The net value of output equal to price } P \text{ minus unit costs } C \text{ of other resources to produce output } q \text{ from a unit volume of water in agriculture.} \]

\[ \bar{K} = \text{Maximum permissible value of } K \text{ (soil saturation extract) for crops not sensitive to chlorides.} \]

\[ \frac{\partial K}{\partial K_i} = \text{The change in chloride concentration of the soil solution } K \text{ per unit change in } K_i \text{ expressed as the chloride concentration of the irrigation water.} \]

(continued from previous page) output from reduced chloride damage -- net of the alternative costs of resources that could be shifted out as damage progresses. The difference between "net" and "gross" is small here; and "gross" provides the upper limit. Because the estimate turns out to be very small, the difference is ignored.
Q = The appropriate values of $Q_{11}$, $Q_o$, $Q_n$ volumes of water.

$K_0$ = The salt content of irrigation water prior to dilution.

$\frac{\partial P_q}{\partial K}$ = The change in output gross value $P_q$ per unit change in soil chloride $K$ based on the saturated percentage.

Each will be considered in order.

To begin, a conservative estimate of $(P - C)q$ for 1,000 gallons of water is 25 cents from the analysis of "direct benefits" in the previous section.

Second, the value of $K$ should be determined by balancing the cost of reducing $K$ against that of crop damage due to excessive salt but -- given the information available here\(^1\) -- it is set equal to 4 millimhos per cm. This level will not significantly inhibit yield of any field crops except beans and flax and would affect only alfalfa, orchard grass or clovers very moderately -- not by more than 5 per cent of total crop output. Even though many vegetables would be affected, only about 12 per cent of the country's irrigated acreage is devoted to vegetable production, so that this crop could be grown on those

FIGURE 6: Maximum Salt Concentration of Drainage Water in Relation to Irrigation Water

- Salt Concentration of Drainage Water, $K_d$
- Salt Concentration of Irrigation Water, $K_i$

Leaching Ratio

Drainage Water, T.D.S.
lands which are well leached by winter rainfall (the alternative is to accommodate most sensitive vegetables by reducing the value of $\bar{K}$ to about 2 millimhos which would be quite expensive). Thus a value of $\bar{K} = 4$ seems defensible. Figure 6 shows resulting values of $K_d$ for various values of $K_i$ using Equation (2).

The value of $\delta K/\delta K_i$ can be estimated fairly exactly for the Israeli case. From the Yaron-Bressler study (for their cases A-1 and A-2) $\Delta K = 5.0$ and $\Delta K_i = 3.9$ in millequivalents of chloride per liter, or $\delta K/\delta K_i = 1.3$ or 0.0367 m.e.q/l/ppm cl. For cases A-3 and A-4, $\Delta K = 2.5; \Delta K_i = 2.5$ so $\delta K/\delta K_i = 1.0$.

From field data\(^1\) the Israeli salinity survey gives the following values:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Estimated $K_i$ to Cause $K = 10$ meq/l cl</th>
<th>$\delta K/\delta K_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Grumusolic dark brown and brown grumusol soils (Heavy and Medium)</td>
<td>200</td>
<td>2.5</td>
</tr>
<tr>
<td>2. Nazzaz (Hard pan)</td>
<td>220</td>
<td>1.3</td>
</tr>
<tr>
<td>3. Residual and dark accumulative brown soils (Heavy and Medium)</td>
<td>250</td>
<td>3.4</td>
</tr>
<tr>
<td>4. Sandy clay loam hamra (Medium)</td>
<td>430</td>
<td>0.6</td>
</tr>
<tr>
<td>5. Sandy hamra (Light)</td>
<td>430</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Values of $Q_o, Q_{11}$ and $Q_n$ and $K_o$ have to be estimated less exactly. Detailed information on the geographical distribution

---

of slightly saline water -- needed for estimating $Q_o$ and $K_o$ -- has not been available for Israel. The report of the joint U.S.-Israel Government Board\(^2\) states that practically all of the salinity problems occur in the southern region where, out of the total 800 MCM anticipated for 1975, about 380 MCM will have chlorides exceeding 170 p.p.m.; further "about 200 MCM would be required in order to reduce the salinity of irrigation water in southern Israel to meet the desired level of 170 p.p.m. Cl."

The implication of these marginal estimates is that $K_i(800) = 170(800 + 200)$ or the undiluted value of $K_i$ would be 212\(^2\) if attention is centered on adding distilled water in the South.


\(^2\) This report also states that:

"300 MCM will have salinities exceeding 170 p.p.m. of chlorine ... About 280 MCM, which will be used mostly for agriculture, will need improvement. This amount is composed as follows: 140 MCM from the Lake Tiberias-Negev project, with an average anticipated salinity in the early '70's of 300 p.p.m. chloride." (Weiner, Tahal, reported verbally during December 1966 that Lake Tiberias' water is presently 350 p.p.m. Cl and rose as high as 410 in 1963. Wiener also reported that Israel was pumping only 225 MCM of the proposed 300 MCM because of the drought. The difference between 300 and 140 is attributed to use in northern Israel.

"70 MCM of ground water with an average salinity of about 240 p.p.m. chloride.

"70 MCM of reclaimed sewage with about 380 p.p.m. chloride.

"The weighted average salinity of the above-mentioned 280 MCM, remained after the selective allocation of about 100 MCM to municipal and industrial uses will be about 300 p.p.m. chlorine."
In fact this is the case: these programs for inserting the distilled water were considered, and the one tentatively selected, to "provide dilution only where economically effective," takes most of the product water to Zohar reservoir at the northern outskirts of the Negev. Then the Board showed, for the regions nearby and south of Zohar, forecasts of \( Q_o = 280 \) MCM, \( K_o = 340 \) p.p.m. Cl (714 p.p.m. TDS) in 1975.


2 One might argue that the effects may not be limited to this region, because sweeter natural waters now used to dilute the Tiberias water can be freed for other uses. But this is not entirely the case because of the necessity of dilution for that portion of Tiberias water not reaching Zohar -- 160 MCM out of 300 MCM. (100 MCM is planned for selective municipal and industrial use without dilution.) For the remainder, to hold the line at 250 p.p.m. Cl at Zohar required in addition (if Tiberias is at 375 p.p.m.) the equivalent of 70 MCM of distilled water. In terms of natural sweet waters added from the North, the effect would be to reduce the value of this water from that as a chloride-damage preventer in the South to that of a leaching water substitute in the North, but the transportation costs would be saved. Perhaps these values would essentially offset each other and that the net cost of the change would be zero.

3 This estimate was originally based on 300 p.p.m. for Lake Tiberias; this has been recomputed using 375 p.p.m. in spite of the fact that diversion of salt springs along the western shore may result in considerable reduction in salinity of Tiberias as time passes.
The crops have to be specified to determine $Q_1$, the total amount of irrigation water to be applied to the relevant area. The State of Israel Salinity Survey identifies 32,000 dunums of fruit orchards in Darom and Lahish and 31,000 in the Negev to be served by the National Water Carrier.\(^1\) Assuming that about one-half of those in Darom and all in the Negev would receive distilled water, then 47,000 dunums deligated to citrus production are involved in the dilution process. No information is given on other crops, but if the countrywide ratios of citrus to non-citrus are assumed for these two regions, then an additional 75,000 dunums of chloride-sensitive crops are subject to the dilution process.

Now how much will these crops use of total irrigation volumes after 1975? Mundlak\(^2\) estimates that fruit orchards will increase by 140,000 dunums, and other crops by from 213,000 to 413,000 dunums between 1965 and 1975, and will use water at the rate of 550 CM/dunum.

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2 Mundlak, Yair, Long-Term Projections of Supply and Demand for Agricultural Products in Israel, Op. cit.
This increase in plantings -- mostly in the South --
will take \( Q_{11} = 292 \) MCM in 1975.\(^1\)

The estimate of \( Q \), the plant water required to maintain
the salt balance short of damage, depends upon the concentrations
found hazardous in the South. Chloride danger, related to soil
texture, is greater in heavy soils. (If there is a hard-pan
layer -- called Nazzaz in Israel -- then drainage is difficult
and the hazard is greatest.)\(^2\) It is greatest in "Sensitive
Stocks": about one-half of the citrus is reported to be planted
on sensitive root stocks, i.e., 16,000 dunums in Darom and
15,000 in Negev. If 24,000 of these dunums is in heavy or medium
soil, then the quantity of dilute water \( Q_{n1} = (24,000)(550) =
13,200 \) MCM. If 50 per cent of the additional 140,000 dunums

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\(^1\) Assuming the now-planted 122,000 dunums take 550 CM/dunum
at 66 MCM, and that the 411,000 additional dunums take 226
MCM. The projected supplies for the region are 280 MCM with 52
MCM for municipal use. Then the 118 MCM of output from a water
plant would fill the gap between 292 MCM and 228 MCM.

\(^2\) The following indicates the distribution of soil types in Darom
and Negev:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Darom</th>
<th>Negev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>16.6</td>
<td>15.1</td>
</tr>
<tr>
<td>Light</td>
<td>8.8</td>
<td>28.1</td>
</tr>
<tr>
<td>Medium</td>
<td>4.4</td>
<td>48.4</td>
</tr>
<tr>
<td>Heavy</td>
<td>70.2</td>
<td>8.4</td>
</tr>
</tbody>
</table>

Ministry of Agriculture - Water Commissioner's Office.
Tel Aviv, May, 1964.
are in sensitive rootstocks on medium soils, then \( Q_{m2} = 19,250 \) MCM.  

The change in gross value of output with respect to change in chloride concentration \( \frac{\partial Pq}{\partial K} \) is the last independent variable to be estimated. Very little direct information on this variable is available. But damage is thought to be cumulative in time: a tree might do fairly well for a few years, but, as chlorides accumulate in the tissue, damage continues to increase. If damage were to start at \( K = 10.0 \) m.e.q./liter, then the citrus root probably would be dead at \( K = 15.0 \) m.e.q./liter after a period of time long enough to limit damage to between 0.1\( Pq^* \) and 0.2\( Pq^* \) where \( Pq^* \) is the gross crop value.  

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1. On heavy soils, for the non-sensitive rootstocks, \( K = 350 \) p.p.m.; this would be outside the limits of expected values of \( K_i \). On light soils \( K_i \) is estimated by the Salinity Survey at 430; so again no damage would be expected.

2. G. Pincock communication January 22, 1967) Pincock used 90 per cent yield at 2.8 millimhos per cm and 50 per cent yield at 4.0 millimhos per cm. Converting to m.e.q. chlorides using the factor 2.2 for TDS/Chlorides gives the value 0.04 \( Pq \), but the damage is not necessarily due to chlorides (although this is likely).

reports the 1975 projected value of citrus and other fruit at 558 million I \$ and estimates the water consumption at 513 MCM, so that \( P_q = (558/513)100 = 109 \) Agorot/CM. Then a conservative estimate of \( \delta(PQ)/\delta K \) is 10 per cent of 109 Agorot/CM or 10.9 Agorot/CM.

From Equations (1) to (3), then

For \( \gamma_1 \), \( \gamma_a = 280(2.2)(340)/(280 + 118) = 526 \) p.p.m.

\( K_{d1} = (640)(4) + (2560(2560 - 2(340))(2.2)^{1/2} = 4,210 \) p.p.m.

\( K_{d2} = 2560 + (2560(2560 - 2(526))^{1/2} = 4,540 \) p.p.m.

\( \Delta Q_i = Q_{11}[4,210(4,530-526) - 4,530(4,210-748)]/4,210(4,530-526) \)

\[ = 0.0710 Q_{11} \]

\( \gamma_1 = \Delta Q_1(P-C)q/Q_S = 0.0710(280-52-13.2-19.3)(19.7)/118 = 2.32 \) Agorots/CM

\( \gamma_{21} = (0.10)(109)(3.0/35.5)(13.2)/398 = 0.03 \) Agorots/CM

\( \gamma_{22} = (0.10)(109)(3.4/35.5)(19.3)/398 = 0.05 \) Agorots/CM

\( \gamma_1 + \gamma_{21} + \gamma_{22} = 2.4 \) Agorots/CM

Federal Water Pollution Control Administration has underway a comprehensive study of salt damage in the Colorado River Basin. For the Lower Main Stem Region their unpublished estimate, based on U.S. Regional Salinity Laboratory Data and projections of the economy indicate that the total damage to agriculture under 1980 conditions for salinity values of 526 p.p.m. TDS and 748 p.p.m. (corresponding to the effect of the desalting plant on water in South Israel) to be $0.5 million and $1.8 million annually. Gross agricultural production is estimated at $291.6 million per annum; the amount of water used, 433,000 million gallons (1,640 MCM). The value of distilled water for dilution under these conditions would be 0.72c/1000 gallons. Based on 1960 economic levels, the value would be only about 25 per cent of the above. This information results from conservations with Russell Freeman, FWPCA, Denver, Colorado, January 19, 1967, and with Dr. Glade Pincock, January 22, 1967. This information indicates that the estimates for Israel may be quite generous.
The relatively low value results in part from the small amount of citrus which would be affected. Even if $\Delta Pq/\Delta K$ were doubled, however, and the areas susceptible increased appreciably, the gains from dilution would not exceed 3 Agorots/CM.

There is additional value for industrial and municipal use from the non-saline water. Within the dilution area an increase of 52 MCM for industrial and municipal use by 1975 has been forecast. Benefits of reduced salt are many -- either soap may be saved or softening costs reduced, or industrial treatment costs in various processes may be reduced. Assuming it is desirable to reduce hardness to 85 p.p.m. for either industrial or domestic use, and that needs for special process water beyond this standard will be met by the industries concerned, it may cost about 0.1¢ per thousand gallons or 0.08 Agorots/CM to reduce hardness by one part per million.

The value would then be equal to this value of 52 MCM times the .08 Agoret times the amount of hardness. General information on the ion distribution of typical Israeli waters is

The text on the page is not legible due to the quality of the image. It appears to be a page from a book or a report, but the content cannot be accurately transcribed.
not available; however, if Haifa is typical, about 250 p.p.m. or one-third of TDS is the present level so that the change in hardness equals

\[ H = \frac{(748 - 526)}{3} = 74 \text{ p.p.m.} \]

and the saving would be

\[ (52)(0.08)(74)/118 = 2.6 \text{ Agorots/CM.} \]

The total value of dilution is thus 2.4 plus 3.3, or approximately 5.7 Agorot/CM or -- at present exchange rates -- $1.9 million per annum after 1975.

Three Economy-Wide Benefits from Desalting

The effects from adding this new technology are not limited to those on agriculture. There are potential changes in all of the operating policies of the national water carrier, and in the long range social development plan of the country itself. There are alleged to be world-wide gains from the resulting progress in development of new and important technology. But these gains can scarcely be measured; by their nature they are not valued in markets nor have they begun to be realized. As a first experiment, however, in showing their existence, hypotheses are formed here of their magnitude. The first is the social value of "safe yield", the second of technological progress in this plant, the third of new water as a means for achieving the social aims in spreading the population over the countryside.

Additional "safe yield". Israel's natural water supply is highly variable. Aaharon Weiner\(^1\) of Tahal, the National Water

\(^1\) At Tiberias, December 20, 1966.
Carrier, has stated that the usable supplies vary from about 500 MCM to 2,500 MCM annually, with an average of 1,500 MCM. But using Lake Tiberias and ground water storage, Israel can maintain an essentially firm flow from variable surface flow because of their extremely large storage capacity. There may be long term cycles, five to several tens of years, where this will not be the case. Then, with a buildup of ground water reserves or of storage in Tiberias, one would expect irrigation to expand at the margin utilizing non-perennial crops, and the reverse to occur as reserves decrease.

In that case, a supply of desalted water will not change substantially the operational risk at the margin. A desalting plant operating as a base-load plant does not provide additional insurance. To have insurance value, the plant would have to be operated intermittently to make up sporadic deficiencies in natural runoff. Standby operation would substitute for a reservoir -- a use for an Israeli plant which is not now contemplated.

The Value of Research From the point of view of both United States companies as the contractors and the Government of Israel as the purchaser, a plant similar to that in the Kaiser Study would be interesting in and of itself because it would contain some new features. There is to be an initial experiment in the construction of large plants, with the 150-MGD plant of the Metropolitan Water District of Southern California. The
Israeli plant would follow this experiment, but would not repeat it. As shown in Table 2, many of the salient characteristics of the plant would differ from MWD.

The most important difference arises from particular characteristics of the Mediterranean as the input water supply. This sea water is warmer and saltier than the Pacific, so that energy and water plant capital requirements both can differ from those for a Pacific plant.

Other differences occur in the means of coupling the water plant to the energy source and in the modulation of the water plant. The 25-MGD trains in the Kaiser case are larger than the 5-MGD trains now in operation but smaller than the 50-MGD trains of the MWD plant; modulation is in 31 stages rather than 53 for MWD, and it involves four parallel streams per train rather than one. The connection of the water plant to the energy source -- at least in Kaiser -- is by means of straight back-pressure coupling, whereas the MWD design has a condensing turbogenerator in parallel with a back-pressure turbogenerator coupled to the distillation plant.

If some particular characteristics of the Israeli design are shown to result in specific cost reductions, regardless of the experienced level of total costs in this plant, then all of the plants that follow can copy these particular characteristics. The succeeding cost savings should be attributable to the original Israeli design as benefits from that design.
# TABLE 2

## ENGINEERING CHARACTERISTICS OF PROPOSED DESALTING PLANTS

<table>
<thead>
<tr>
<th>1. Capacity, mgd</th>
<th>100</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Power, MW</td>
<td>200</td>
<td>1624/355</td>
</tr>
<tr>
<td>3. Brine Temperature</td>
<td>220/235</td>
<td>250</td>
</tr>
<tr>
<td>4. No. Stages</td>
<td>31</td>
<td>53</td>
</tr>
<tr>
<td>5. Performance ratio</td>
<td>10.3</td>
<td>10.6</td>
</tr>
<tr>
<td>6. Trains</td>
<td>4-25 mgd ea.</td>
<td>3-50 mgd ea.</td>
</tr>
<tr>
<td>7. Parallel streams/trains</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>8. Brine Flow, #/Hr/Ft of width</td>
<td>$1.0 \times 10^6$</td>
<td>$0.373 \times 10^6$</td>
</tr>
<tr>
<td>9. Temp Stm to brine htr, °F</td>
<td>240</td>
<td>258</td>
</tr>
<tr>
<td>10. Design water temp, °F</td>
<td>70</td>
<td>61</td>
</tr>
<tr>
<td>11. Plant operating factor, %</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>12. Tube velocity, fps</td>
<td>6.0</td>
<td>6.5</td>
</tr>
<tr>
<td>13. Flashing range, °F</td>
<td>138/153</td>
<td>189</td>
</tr>
<tr>
<td>14. Concentration factor</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>15. Tubing in recovery stgs</td>
<td>$7/8 \times 20$ BWG 90/10 CuNi</td>
<td>$3/4 \times 19$ BWG 70/30 CuNi</td>
</tr>
<tr>
<td>16. Plant life, yrs.</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>17. No. of recycle pumps/train</td>
<td>2 + 1 stby - 12 total</td>
<td>2 - 6 total</td>
</tr>
<tr>
<td>18. Capacity recycle pump, gpm</td>
<td>72,5000 vs 219' TDH</td>
<td>115,000 vs 225&quot; TDH</td>
</tr>
<tr>
<td>19. Recycle pump horsepower</td>
<td>5000</td>
<td>8000</td>
</tr>
<tr>
<td>20. Salinity sea water, ppm</td>
<td>38,600</td>
<td>34,000</td>
</tr>
<tr>
<td>21. No. brine htrs</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>22. Distillate temp, °F</td>
<td>80</td>
<td>78</td>
</tr>
<tr>
<td>23. Recycle ratio, #brine/#product</td>
<td>8.34</td>
<td>6.9</td>
</tr>
<tr>
<td>24. Sea water intake</td>
<td>submarine pipe (1400')</td>
<td>Intake structure</td>
</tr>
</tbody>
</table>

Source: Office of Saline Water, Department of the Interior.
The question is whether future cost savings can be predicted to follow from these departures in the Kaiser design. The first departure, use of Mediterranean sea water, should demonstrate experimentally the effects on costs of variations in parameter values. But this departure adds little more to our knowledge of reactions to sea water conditions than a single point estimate. Computer sensitivity analysis, in contrast, can add a range of less accurate but more diverse estimates of the effects of parametric variation. Unless the Mediterranean conditions are more "general" than those in the Pacific, which one would not expect, and the particular steam temperatures and capital specifications can be used elsewhere, then there is no basis for predicting measurable and general cost savings from trying the parameters appropriate to this location.

Modulation in the two large scale design plants is mostly a matter of arranging blocs of production units. The Kaiser module is based on four submodules of 6-1/4 MGD each, while the MWD design plant arranges almost the same-sized submodule in three groups of four each to make up the 50-MGD train. Then the only research gain comes from changing the arrangements of the modules; these cost savings may be substantial in some cases, because the experienced "downtime" of a train may be much less with the newer configuration; but
it should be realized that any such gains would have to balance against costs of another kind. The arrangement of more sub-modules per train allows cost savings from using larger pumps, but it implies that more plant capacity will be out if a single pump or a single part of the flow system breaks down. Greater risk of downtime, in other words, accompanies lower design costs. As a consequence, little can be learned as to relative costliness as a result of the operating experience of the two design plants, since the actual results on downtime could depart from a priori design as a matter of chance. More important, the results would be no more than an expression of risk preference: one plant may have the greater risk and the lower expected costs as a matter of choice of the plant owner; but this is scarcely relevant for deciding design for other plant owners because they might prefer less risk and high expected costs.

The same can be said of the direct back-pressure coupling arrangement without a parallel condensing turbo-generator. The presence of this arrangement implies lower costs and a greater risk of substantial downtime. Actual operating experience tells little about the a priori risk in following this design, since experience can depart from the highest prior probability.

There is then a high degree of specificity of design in the Israeli plant (or at least in the Kaiser version of this plant).
No quantitative estimate of general research gains is really possible under these conditions, but it may be possible to place some boundaries on forecasts. Particular analysts could state that this design is general enough and safe enough to be acceptable in follow-on plants, and that the subsequent cost reductions may exceed \( x \) cents per thousand gallons. But another analyst would have equal right to state that the savings would exceed \( y \) cents per thousand gallons. The following statement reflects a cautiously optimistic point of view, close to the middle of extreme forecasts.

If the conceptual art is reasonably determined by the construction of MWD and a series of plants A, B, C, etc., are built in sequence after MWD, information obtained by operating A might lead to cost savings of \( X \) in B, C, D, etc.. But if A had been foregone, this information would have led to savings of \( X \) first in C. Then the value of new technology from A is only the present worth at time A of the prospective savings to be made at the time of B rather than at the time of C. The savings can be calculated for the Israeli case as plant A, and the other prospective large plants as B and C; the extreme assumption is made that the sequence of construction of the following plants is fixed whether or not A is built.

Relating the capital cost schedule to the three most important technological differences suggested above, the cost of
evaporator bundles and pumping equipment totalling $38 million would be decreased the most. Some savings might also accrue in other costs relating to the desalting plant that total $37.5 million. A reduction of 5 per cent of total costs in the first case and 2-1/2 per cent in the latter seems very generous, especially since Table 2 shows MWD to be more advanced technologically than the Kaiser version in virtually every item. Also a maximum reduction of 5 per cent of the operating costs of $3.5 million seems optimistic. The value of cost savings then is $459,000 per annum. Considering the probability of achieving this level of reduction to be no more than 1/4, it is hard to argue for a value in excess of about $500 thousand each year for prospective technological advancement over a thirty year plant lifetime.

Water for Achieving Social Goals. There are political and cultural reasons for national allotments of capital and the settlement of workers into dispersed agriculture in Israel. The land has to be settled in order to hold the frontiers of the country, and it should be settled, according to the "national will" of the 1960's, as part of the new way of life of an involuntarily migrant and oppressed people. The addition of distilled water in the South and West may make it possible to do so without extremely burdensome social costs (or losses in not choosing the best use of resources).
Extreme hardship would result from Kibbutzim in the Southwest if they produced output not worth at least the costs of the scarcest resource. This resource is water; the farms with value of output not covering water costs would not meet minimum requirements, but those offering returns over and above this amount would produce a social dividend. The resources other than water can be looked on -- as a matter of policy -- as having no alternative value. The social value of output from adding desalted water would be 2 to 12 cents per thousand gallons -- at the mean value, $1.8 million per annum and the high value, $3.6 million -- if Negev production covered total costs (or PL + PN + PK at Zero alternative worth would imply gain equal to gross value of product rather than merely net value of product). This is an estimate of the money equivalent to the extra political value of water.

A second estimate has been constructed of the value product from the politically fixed resources in the Southern desert. Raanan Weitz of the Jewish Agency argues that "mobility of water out of Southern agriculture would imply abandonment of villages ... This implies radical changes in the social structure which are not reflected in the marginal analysis." The alternative is

more water -- close to 100 MGD -- for farms in the Besor region that have fixed resources in keeping with national policy for maintaining agriculture. The output is forecast to be worth 224 Million I $ in the near future, with net value product of 53 million I $ or $15 million each year.\(^1\) There are no source materials to verify these estimates -- Weitz claims to have collected the data from personal observation of farms in that region -- but labor and capital resources seem to have been not much greater than for the average farm in Yaron's system of optimal distribution of such resources. There is no indication that any wage payments were removed before calculation of net value product so that either the value of product from water alone is overstated or farm labor has no opportunity cost. Then, as a forecast of 1975 value product of additional water, Weitz's estimates are imperfect: too much water is added to farm resources in one region, and too little is paid to (self-employed) labor. But this case study does provide an indication that additional water supply for production units likely to be favored for social or political reasons results in output whose social value may be more than shown from pure economic organization of resources.

The two studies together would seem to suggest that total x value may be $3 million per annum greater than shown by the value

\(^1\) Ibid., Appendices 2, 12.
of production and that in dilution. The political value of water, in a plan favoring defense and production in the South, is an additional value and merits measurement within the government in ways more concrete than those used in a first attempt here.

A Summary View of Value

The high and low forecasts of dollar returns from desalting have come from diverse sources, and have been contrived using a wide variety of methods. The most important returns come, of course, from the additional output from water. The assumed prices for this output, and the assumed productivity of agriculture at the time that distilled water is inserted in the system, set the general magnitude of revenues and, ultimately, the rates of return from building desalting plants. Changes in these assumptions most sharply affect the final assessment of benefits and costs.

In such circumstances, the only recourse is in not relying too heavily on first estimates. This study should be redone before 1975, if 1975 is the year for beginning construction. The first results were obtained by methods as diverse as supply-demand forecasting, general equilibrium programming analysis, and case-by-case studies of particular farms; the differences from method are not substantial. They can be and most importantly should be adjusted, however, as more complete and accurate information is obtained on 1970's prices of farm products and on changes in farm productivity.
The general returns to the agricultural sector from de-
salted water are between $7.5 million and $8.6 million the first
year of plant operation (as in Table 3). The returns to the
economy are not as substantial -- ranging from zero to $3.5 million.
But these are more imprecisely estimated: quite arbitrary assump-
tions had to be made in each case in order to obtain any esti-
mate at all. The estimates shown (in Table 3) are most likely
within $1 million of the actual returns, and do not depend on
duplicative or compounding errors in method. They determine in
good part this first assessment of benefits and costs, as the
next chapter shows.

**TABLE 3: RETURNS FROM A 100 MGD DESALTING PLANT**

<table>
<thead>
<tr>
<th>Source of returns</th>
<th>1975 net revenues ($ millions)</th>
<th>Annual rate of increase in revenues 1976-2005 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>additional agricultural</td>
<td></td>
<td></td>
</tr>
<tr>
<td>output (high)</td>
<td>6.7</td>
<td>3.5</td>
</tr>
<tr>
<td>output (low)</td>
<td>5.6</td>
<td>2.5</td>
</tr>
<tr>
<td>dilutant (high and low)</td>
<td>1.9</td>
<td>0.0</td>
</tr>
<tr>
<td>additional safe yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(high and low)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>additional research output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(high and low)</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>dispersal of population</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(high)</td>
<td>3.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Source: Summarized from the Text.
6. **THE COST OF WATER AND ITS VALUE TO THE ISRAELI ECONOMY**

The construction of an energy and water-electricity producing facility of the magnitude proposed in the Kaiser and Technion studies would have a significant impact on the Israeli economy. Such is a two edged sword: the value of the outputs generated directly or indirectly from the desalted water is indeed great, but the costs may be of such a magnitude as to bring about a significant slowdown of development in other parts of this economy. Benefits may not exceed costs, when both are put against the measuring rod of alternative returns on investment; the test here is the calculation of "the rate of return" -- that rate of discount equating the construction costs with the stream of net returns -- and then comparing this with returns on other projects.

**Investment and Growth**

Capital inflow sufficient to construct the water plant would have to be at least $20 million for each of the five years during which the facility was being constructed. The construction of the energy producing plant with an accompanying turbo-generator would account for another $20 million per annum. This capital accumulation would take place, most likely, within the context of a full employment economy growing at a rapid rate. Rates of growth of personal consumption -- the ultimate utility -- should be close to 7 per cent per annum. But the country can be expected to move to a growth path of 7 per cent additional output each year with stability of price and employment only under particular
conditions. The first condition is that full employment be restored by eradication of deficient demand encountered in 1966-1967 in the construction and other sectors. The second is that capital inflow not be diverted from most productive uses in order to construct particularly glamorous projects.

The addition of $40 million per annum to capital resources flowing into the country for five years could increase annual per capital consumption by as much as .4 per cent. This is substantial when compared with growth in other parts of the world from development grants and loans. But the gain can only be realized if the capital is invested in the most productive uses of such funds. For the water plant to be a substantial gain for the economy, then it must be the most productive investment. For this to be the case, the water plant should show that the total value of water output is roughly comparable to the total cost of the resources.

Investment in Desalting or in Surface Water Systems

A first test of the productiveness of this investment is whether or not alternative investments in water facilities could produce the same safe yield at lower cost. Safe yield

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1 This is a fairly general prediction; for one example it follows from the sophisticated analytical detail of the econometric model of Israel constructed by Michael Bruno in "A Programming Model for Israel" in I. Adelmann, ed. Development Theory and Design.

2 This is shown, for one, in M. Bruno, op. cit. Figure 1.
could be increased in either one of two ways: (1) by adding to ground water utilization equipment or to the means for capturing surface runoff; (2) by reducing wastage, especially in irrigation or in municipal industrial applications.

As far as the first is concerned, there is some indication that all substantial ground or surface supplies are already being tapped. The discussion of surface water supplies in the Kaiser Study indicates that there are opportunities to add to existing sources, but only if additional salinity can be tolerated. The hydrographic charts show that all of the known or suspected large volumes of low salinity ground water have been or are to be tapped before 1970 -- at least within the present boundaries of the country. If the West bank of the Jordan were to be added to the territory under Israeli control, then exploration might prove out new sources. But these cannot be counted on at the present time.

Certainly some water could be diverted from "wastage" -- from evaporation in irrigation or unused drainage in the cities -- but there is no indication that such diversion results in substantial additions to supplies. The Israelis seem conscious of gains from conservation; they have restrictive quota systems for water in agriculture, which are buttressed by sharp increases in prices for supplies beyond the quota. The quotas are small, and there is no indication that there is much excess water in the quota to be wasted: although climatic differences do not allow
comparisons of consumptive use in United States and Israel agriculture, comparisons of municipal water use indicate that eastern United States per capita consumption in 1954 was close to 106 gallons per day while per capita consumption in Israel, even by the highest income class, did not exceed 45 gallons per day. There is some indication that measures can be taken -- the present program in Israel for installing water-conserving bathroom equipment is evidence that improvements are possible -- but there seems to be no fundamental attack possible on present usage rates. The alternatives to desalting are obscure, but most likely limited, as far as producing a large volume of water is concerned.

Investment in Desalting or in Industry and Trade

The issue is whether this is the best possible investment when compared with non-water investments in industry and trade. The economics of the issue are found in comparisons of rates of return, where the rate of return in water equates the value of the water to its cost.

The value to this economy of desalting investment is the net marginal product of the water and the extra values of reduced system salinity. Based on the economic growth projected for Israeli agriculture in the 1970-75 period, the field crops produced with the additional water are worth $5.6 million per annum or, more optimistically, $6.7 million per annum at the start; they increase from 2.5 per cent to 3.5 per cent each year. The increment of value from the introduction of salt-free water into the
system may exceed $1.9 million each year, but not by a great deal.
At the production margin, there is no change in climatic variation
due to the additional safe yield from a base load desalting
facility, so that the sometimes-claimed insurance value is nil.
The research value of this plant is equivalent to $0.5 million
each year. But these estimates assume perfect mobility of re-
sources so that the inputs are available wherever the margin
appears. Departures from this assumption take place in Israel;
indeed, any additional water may well go to locations in the South
and East where there is an excess of other productive elements
already installed for social and political reasons. In these
areas with fixed resources but little water, the productive value
of water may be $3 million more than shown in the previous esti-
mates. Thus the initial value of desalted water is estimated to
be $8 million or, optimistically, $12.1 million per annum.

The costs of water to compare with value range widely, de-
pending on the technology used and the prices of capital and fuel
actually experienced in the 1970's. The technologies vary widely,
from those in contemporary fossil fuel energy systems to advanced
gas reactors; but they are typified by the four design studies of
energy and water systems, with costs as in Table 1. Each design
study offered a range of costs given possible changes in input
factor prices from those now prevailing. The costs in design
study "i" given factor prices "j" for year "t" are forecast at $C_{ij}^t$.
The "low costs" are $C_{il}^t$, made up of the low estimate in the "range
of reasonable estimates" in Table 1, while "expected costs" are shown by the second and third columns, and "high costs" are shown by the highest estimate in the range. Costs in the first three years are primarily construction costs and thereafter are operation expenses; as a result, \( t \) in \( C^i_t \) runs from 1 to 33 given the generally assumed thirty-year plant lifetime. With four design studies, \( j \) runs from one to four, and there are in all twelve cost schedules.\(^1\)

The rates of return can be projected very roughly from the low and high measures of value and the schedules of costs. These rates in each comparison are defined as \( r \), that internal rate of return which reduces the series \( \sum_t (R^1_t)^{i_j} - C^i_t \) to zero where \( R^1_t \) is the low measure of value and \( R^2_t \) is the high or "optimistic" measure. The rates provide an assessment of net gains from the project; the twenty-four estimates -- twelve for all the cost schedules with the low measure of value, twelve with the high measure -- provide for all of the reasonable possibilities of adding more to future revenue product than the immediate costs of resources. They can be put against the presumed net gains of

\[^{1}\] In this first attempt at comparing values and costs, each cost schedule will be given equal weight. That is, the twelve schedule estimates make up a forecast distribution in which each is given the same subjective probability of occurrence.
investment elsewhere in the economy.¹

TABLE 4: RATES OF RETURN ON DESALTING IN ISRAEL

<table>
<thead>
<tr>
<th>probability of ( r &lt; r^* )</th>
<th>the internal rate of return ( r^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>.05</td>
<td>0</td>
</tr>
<tr>
<td>.25</td>
<td>1</td>
</tr>
<tr>
<td>.50</td>
<td>3</td>
</tr>
<tr>
<td>.75</td>
<td>6</td>
</tr>
<tr>
<td>.95</td>
<td>7</td>
</tr>
</tbody>
</table>

Source: values of \( r \), as calculated from:

\[
\sum (R^{1,2}_t - C^{i,j}_t) / (1 + r)^t = 0
\]

for estimates of \( R, C \) as described in the text. Detailed calculations are shown in Table 4.

¹ The internal rate of return is widely known to have serious drawbacks: it is ambiguous (sometimes there are two plausible values of \( r \) for the same net income stream) and misleading (by showing a higher rate for the first of two projects which, when compared with the second, may be less preferred at some relevant interest charges). Cf. Jack Hirshleifer, "On the theory of the Optimal Investment Division" Journal of Political Economy (August 1958). But other measures of investment worth -- particularly the ratio of the present discounted values of \( R^{1,2}_t \) and \( C^{i,j}_t \) -- require knowledge of the social rate of interest or cost of capital. No such knowledge is available. The studies of capital cost summarized above can greatly assist in finding first estimates of the interest charges during construction, but they cannot bear the weight of a benefit-cost analysis.
The forecast rates are subject to great uncertainty, but quite generally are low. The set is summarized in Table 4 to be mostly between zero and seven per cent, centering on one per cent for low measures of value and six per cent for the high or "optimistic" measures. That is, if agriculture proves relatively unproductive, the returns on desalting should center on one per cent while returns on abundant and high priced crops from the desalted water should center on six per cent. One is no more likely than the other; the expectation for returns is the average of the twenty-four calculated rates or four per cent.

These are low returns when compared with those from alternative projects with this capital base. The closest alternative might be to redesign the dual purpose plant to use the common energy source for more electricity and less water output. This tradeoff of water would increase the marginal and average value products from distillation -- after centering the reduced supplies on the high value and salt sensitive crops -- while only slightly decreasing the (expanding) industrial value products from more electricity. Returns of less than eight per cent would be foregone in water for those greater than that in electricity.\footnote{1}{Given that, as is now foreseen, the marginal net revenues on further expansion of industrial uses are no less than eighty per cent of the average net revenues now realized on sales of electricity.}
Conclusions from Costs, Revenues, and Rates of Return

Given the design preconditions set out above and scale of water output close to 100 MGD, the nature and extent of investment in this project have to be carefully defined if the economy is to realize its full growth potential. Capital has to be available exclusively for this project on terms or interest charges that do not fall outside the range of results shown in Table 3. Otherwise the project should be abandoned as indefensible on (measurable) economic and social grounds.

If the design "ground rules" are not required, the decision may well extend beyond "go" and "no go" in the next few years. A wide variety of plant designs can be undertaken, based on nuclear and non-nuclear energy, and calling for a wide range of ratios of water-to-power outputs.

The first of the open questions should be on the source of energy. No single fuel source has a clear and commanding lead in forecast costs and rates of return. As Table 5 indicates, the forecast rates greatly overlap with the nuclear plants (Kaiser I and Technion I) offering only slightly lower forecast rates than the fossil fuel plants (Kaiser II and Technion II, with five of the six rates of return above six per cent, but with only five of the nine returns below two per cent). Changes in fuel costs could be substantial -- as shown above -- and, if they are to be taken advantage of, the choice of fuel burning equipment should take place shortly before or during the period
TABLE 5: DETAILED CALCULATIONS OF RATES OF RETURN

<table>
<thead>
<tr>
<th>Design Study</th>
<th>Cost Estimate</th>
<th>Value Estimate</th>
<th>Calculated Internal Rate of Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaiser II</td>
<td>high</td>
<td>low</td>
<td>0.4</td>
</tr>
<tr>
<td>Kaiser I</td>
<td>expected</td>
<td>low</td>
<td>0.4</td>
</tr>
<tr>
<td>Technion I</td>
<td>high</td>
<td>low</td>
<td>0.7</td>
</tr>
<tr>
<td>Kaiser II</td>
<td>expected</td>
<td>low</td>
<td>0.9</td>
</tr>
<tr>
<td>Technion II</td>
<td>high</td>
<td>low</td>
<td>0.9</td>
</tr>
<tr>
<td>Kaiser I</td>
<td>high</td>
<td>low</td>
<td>1.0</td>
</tr>
<tr>
<td>Kaiser I</td>
<td>low</td>
<td>low</td>
<td>1.1</td>
</tr>
<tr>
<td>Technion I</td>
<td>expected</td>
<td>low</td>
<td>1.1</td>
</tr>
<tr>
<td>Technion II</td>
<td>expected</td>
<td>low</td>
<td>1.6</td>
</tr>
<tr>
<td>Kaiser II</td>
<td>low</td>
<td>low</td>
<td>2.4</td>
</tr>
<tr>
<td>Technion II</td>
<td>low</td>
<td>low</td>
<td>2.7</td>
</tr>
<tr>
<td>Technion I</td>
<td>low</td>
<td>low</td>
<td>3.4</td>
</tr>
<tr>
<td>Kaiser I</td>
<td>high</td>
<td>high</td>
<td>5.0</td>
</tr>
<tr>
<td>Technion II</td>
<td>high</td>
<td>high</td>
<td>5.2</td>
</tr>
<tr>
<td>Kaiser I</td>
<td>expected</td>
<td>high</td>
<td>5.3</td>
</tr>
<tr>
<td>Kaiser II</td>
<td>high</td>
<td>high</td>
<td>5.5</td>
</tr>
<tr>
<td>Kaiser I</td>
<td>low</td>
<td>high</td>
<td>5.8</td>
</tr>
<tr>
<td>Technion I</td>
<td>high</td>
<td>high</td>
<td>6.0</td>
</tr>
<tr>
<td>Kaiser I</td>
<td>expected</td>
<td>high</td>
<td>6.1</td>
</tr>
<tr>
<td>Technion II</td>
<td>low</td>
<td>high</td>
<td>6.1</td>
</tr>
<tr>
<td>Technion I</td>
<td>expected</td>
<td>high</td>
<td>6.7</td>
</tr>
<tr>
<td>Technion II</td>
<td>low</td>
<td>high</td>
<td>7.1</td>
</tr>
<tr>
<td>Kaiser II</td>
<td>low</td>
<td>high</td>
<td>7.2</td>
</tr>
<tr>
<td>Technion I</td>
<td>low</td>
<td>high</td>
<td>8.6</td>
</tr>
</tbody>
</table>
in which the plant's final design is laid out. Early decisions that a particular energy source is to be used -- such as a nuclear reactor -- would distort the optimization process and increase the cost of resources to this economy.

The second open question has to be the size of water and fuel outputs. The forecast rates of return on 100 MGD, when produced with capacity for 200 MW to 300 MW of electricity, range from zero to seven per cent. A smaller plant could only promise higher returns if carefully designed to place the right amount of distilled water to reduce salinity effects and increase crop outputs. Resources would be released for use in meeting now-unforeseen increases in industrial demands for electricity. The lesson from this study of large scale desalting may well be that smaller scale plants are promising ventures for further analysis and research.
Date

Due

DEC 31

MAY 29

AUG 7

Lib-26-67