Desalted Seawater for Agriculture: Is It Economic?

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In the past decade, there has been mounting advocacy of desalting seawater for use in commercial agriculture in various locations of the world, especially in the Middle East. The process, it is contended, is both technically and economically feasible, or soon will be, and its application on a large scale can produce additional volumes of food at competitive prices—the desert will blossom like the rose—and at a profit.

Although research on desalting techniques had proceeded for many years in the Interior Department's Office of Saline Water supported by modest funds, and the Atomic Energy Commission had been exploring the role that nuclear energy might play in desalting, the entire matter suddenly acquired international interest after the 6-day Israeli-Arab war in June 1967.

Within days after the war, the London *Times* published two letters recommending desalting schemes in the Middle East. A detailed letter from Edmund de Rothschild suggested three nuclear desalting installations in Israel, Jordan, and the Gaza Strip, respectively. This provoked comments and questions in the House of Commons, which generally approved the idea or at least further exploration of it. On this side of the Atlantic the U.S. Senate in December 1967 passed Resolution 155 without a dissenting vote. It says in part:

> Whereas the greatest bar to a long-term settlement of the differences between the Arab and Israeli people is the chronic shortage of fresh water, useful work, and an adequate food supply; and
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> Whereas the United States now has available the technology and the resources to alleviate these shortages and to provide a base for peaceful cooperation between the countries involved:
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> Now, therefore, be it
>
> Resolved, that it is the sense of the Senate that the prompt design, construction, and operation of nuclear desalting plants will provide large quantities of fresh water to both Arab and Israeli territories and, thereby, will result in
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> 1) new jobs for many refugees;
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> 2) an enormous increase in the agricultural productivity of existing wastelands;
>
> 3) a broad base for cooperation between the Israeli and Arab governments; and
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> 4) a further demonstration of the United States efforts to find peaceful solutions to areas of conflict . . .

The resolution was a direct descendant of the "Strauss-Eisenhower Plan," a proposal by former AEC Chairman Lewis Strauss for which he obtained Eisenhower's backing. The proposal gained its greatest popularity through an article written by Eisenhower (*1*), which, with reference to the Middle East, states the proposition in its most optimistic form:

> Now it looks as if we are on the threshold of a new breakthrough—the atomic desalting of sea water in vast quantities for making the desert lands of this earth bloom for human need . . . Since we now know that the cost of desalting water drops sharply and progressively as the size of the installation increases, it is probable that sweet water produced by these huge plants would cost not more than 15 cents per 1000 gallons—and possibly considerably less . . . There is every reason to suppose that it could be a successful, self-sustaining business enterprise, whose revenue would derive from the sale of its products—water and electricity—to the users . . . The purpose . . . is . . . to promote peace in a deeply troubled area of the world through a new cooperative venture among nations.

These and other basic documents, including Strauss' memorandum outlining the proposal, have provided not only a flood of newspaper stories and magazine articles, but have also accelerated government-sponsored efforts. Of the engineering studies, two are directed specifically to foreign areas. Following President Johnson's meeting with Israel Prime Minister Levi Eshkol in June 1964, the Kaiser company was commissioned to make an engineering study of the feasibility of seawater desalting in Israel (*2*). The Oak Ridge National Laboratory has produced a report on nuclear energy centers and agro-industrial complexes to be established in various arid areas of the world (*3*). The tone of these two reports is cautiously optimistic, but a more careful review of their assumptions leads to quite opposite conclusions (*4*). Others have written uninhibitedly—as if sweet water were already flowing into the desert at low costs (*5*).

The Kaiser study was specifically concerned with a desalting plant in Israel; the contemplated location of the plant was on the Mediterranean seashore about 9 kilometers south of Ashdod. The power plant would be a nuclear steam-generating facility using a conventional light-water nuclear reactor with a thermal rating of 1250 megawatts. Essentially all of the steam generated in the reactor passes through the generator without condensation; the steam exhausted from the turbine is condensed in the shell side of the brine heaters of the desalting plant. The evaporator structures consist of heat recovery stages, heat reject, and heat reject-deaerator stages. A multiple seawater intake structure would be located 450 meters offshore and 7 meters deep. An outfall facility would consist of a buried concrete box culvert with transition to an open channel beyond the desalting plant limits. The plant would have a capacity of 100 million gallons of desalted water daily; a plant operating factor of 85 percent is assumed. The generator would produce 200 megawatts salable electrical power at an estimated price of 5.3 mills per kilowatt-hour and an 85 percent power plant operating factor. Total capital costs are estimated from \$187 to \$210 million, depending upon interest rate. Annual operating costs vary from \$16.8 to \$28.7 million, for interest rates of 1.9 percent and 8.0 percent, respectively. Crediting power sales against total costs, water costs per 1000 gallons—conceived as the residual costs—range from 28.6 cents if interest is calculated at 1.9 percent to 67.0 cents if the interest is 8.0 percent. Several variations in structure and methods of operation are possible without major effect upon water cost.

The Oak Ridge proposal is for a major nuclear energy center, with industrial and agro-industrial complexes, as well as desalting works. It was conceived to be broadly suitable for several

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locations in the world, subject to specific site planning and adaptation. The proposal is based upon technologies expected to be developed over the next decade or two, not upon technologies tested and in application today—and that reason makes it less suitable for rigorous review since at *some* time in the future costs of both power and water production will presumably be lower than they are now. "Near-term" light-water reactors and "far-term" advanced breeder reactors were considered as well as near- and far-term desalting equipment; a number of alternative layouts were included, with industrial electrical power ranging mostly from 1585 to 2070 megawatts. Most of the designs would produce 1 billion gallons of desalted water daily. Investment costs in the nuclear plant and desalting works would range from $1.5 to $2.0 billion for most designs. Various industrial processes, producing metals or chemicals and using large amounts of electricity, are considered. Alternative costs are estimated, with different interest rates and other cost factors. A highly advanced type of agriculture is assumed. The Oak Ridge complex would produce ten times as much water as the Kaiser proposal, at a cost at "near-term" technology of 17 cents per 1000 gallons at 5 percent interest, 24 cents at 10 percent interest, and 32 cents at 15 percent interest and about one-third lower at "far-term" technology. As pointed out in the report, these values are arbitrary, since the complexes are conceived as closed economies. They represent the incremental cost of adding one unit of water to an existing plant. But, in the size class here contemplated, these incremental costs will approximate the average cost sufficiently to stand as surrogates.

Currently, a second stage of research, which includes the outlook for marketing the expected increase in output, has been undertaken at Oak Ridge to adapt the general design specifically to conditions as they exist in a number of locations in the Middle East.

Our purpose in this article is to explore the economic feasibility of desalting seawater on a large scale for commercial agriculture in regions of extremely low rainfall. In preparation of the material on desalting costs we have made extensive use of the analysis by Paul Wolfowitz (*6*) of the University of Chicago and a report by W. E. Hoehn of the RAND Corporation (*7*).

Little will be said here of the political aspects of such ventures except to note that we see no reason to believe that the desalting of seawater in the Middle East would have the peacemaking effects that have been claimed for it. The struggles between Israel and its neighbors have not been over freshwater, and even where water has been at issue, as in the case of the Jordan River, the differences could be resolved readily if there were peace in the Middle East, or at least an atmosphere in which negotiations were possible. Indeed, in 1955 these differences were resolved on a technical level, but formal agreement was frustrated by political antagonism (*8*).

Desalting Seawater for Large-Scale Commercial Agriculture

Any program to desalt seawater for use in agriculture involves three closely interrelated components: (i) a source of energy; (ii) a process for producing sweet water out of seawater; and (iii) means for transporting the water, at the right time, to the place of its application for the growth of crops.

Each component is essential, and any part can set a technical or economic limit to the whole process. Much has been written about the first two components, but very little about the third.

Numerous sources of energy and methods of desalting exist, but we shall focus entirely upon nuclear power as the energy source and upon evaporation as the desalting method.

No persuasive case can be made for a preferred energy source. Indeed, one might simply stipulate a given cost of energy, from whatever source is locally most advantageous, and concentrate attention on the other two components. We are analyzing nuclear rather than fossil-fuel energy only because the proposals that have received most notice have been based on nuclear energy. First, the atom attracts both attention and funds. Second, there is a large well-funded atomic research establishment, certainly in the United States, staffed with imaginative and highly skilled thinkers who do not shrink from the novel and spectacular. Third, the larger the proposed installation, the greater the advantage of nuclear energy. And fourth, there are arid areas in the vicinity of seacoasts that are remote from other fuel sources and to which nuclear energy may offer less expensive access to the new technology of sweet water production. For these and perhaps other reasons the packages offered so far have contained nuclear energy as the energy source.

Regarding desalting, it may safely be assumed that current technology offers no more feasible way to obtain freshwater from the sea on a large scale. Even the so-called "far-off," 20-years-in-the-future, technology used in the more favorable of the two Oak Ridge variants is based on evaporation. That a breakthrough—say a very efficient, stiff, membrane—could change the picture goes without saying. But such breakthroughs are not now in view, despite much effort in that direction. Nor would they have a necessary advantageous association with power generation.

In short, we discuss the merits of the programs in the terms chosen by their proponents. Although costs would vary with the location of the plant and other environmental factors, it is possible to consider the problem in general and to reach conclusions which no specific application could significantly change. This is true even for the third component—the conveyance of the water once produced—provided that areas are eliminated which do not have suitable soils, or are too remote from the seacoast, or do not in other ways qualify.

Nuclear Energy

The reputation of nuclear power as a cheap source of energy understandably has reached the desalting field, once it was realized that the addition of power production (from any fuel) to a desalting plant represented a logical combination, wherever raising of steam was part of the desalting process. Nobody now doubts that electricity from nuclear power plants can indeed be fully competitive with that from fossil-fuel plants under certain conditions in certain areas. But it is also true that some of the enthusiasm of recent years was based upon circumstances unlikely to be repeated in this country or to be found at all in less-developed regions of the world. These include the large funds furnished by the government for R&D, and the initial input made by suppliers who quoted highly attractive prices for their generating equipment when it seemed essential to the spread of the new technology. For these and other reasons, some sober criticism has been directed at the evaluation of the outlook for nuclear energy (*7, 9*). This does not cast doubt on its basic competitive position but does question the extent of this advantage. These are major considerations:

1) It will be a year or two before even one U.S. nuclear plant designed to be competitive with fossil-fuel plants has been in operation long enough to establish a performance record that would substantiate expectations. The large scaling-up in size of the equipment ordered for nuclear plants in 1967 and 1968 and the reliance placed in all cost estimates on minimum downtime make this especially significant. What little experience has accumulated from demonstration plants in the United States indicates that the high rates of availability, a *sine qua non* of low power cost assumptions, will not be easy to attain.

2) The cost of nuclear generating equipment for the long run is far from settled. Past reductions in equipment prices by manufacturers have turned out to be more in the nature of initial lures. Costs in 1967 and early 1968 were $30 or more per kilowatt installed above those of 1965 and 1966, allowing for differences in size (*7*). Nor has the trend abated (*10*). Costs of conventional equipment have also risen, but less steeply.

3) There is some uncertainty regarding the future costs of nuclear fuel, once the increased power generation begins to reduce the uranium supply and forces a diversion to higher cost sources of the mineral. But prices of competitive fuels cannot be assumed as constant either, so that uncertainty is the real problem.

4) Nuclear power plants, owing partly to the heavy cost of shielding and containment, require more capital than conventional plants do (*11*). Whenever a portion of the fuel is awaiting enrichment (or being enriched), being fabricated into fuel elements, awaiting loading, or undergoing cooling, it still represents capital investment and thus carries interest charges, no matter whether the utility or the supplier manages the fuel cycle. The recent steep rise in interest rates has been penalizing nuclear more than conventionally fired plants. No one knows whether, to what level and how soon, rates will begin to decline, but while rates are high they blunt the competitive edge of nuclear plants.

In addition to the factors cited which tend to make themselves felt in aggravated form in less-developed countries, there are some elements that apply especially to them.

Economies of Scale

Electric power generation is a classic example of economies of scale: unit cost drops as size of the plant rises. This is especially marked for nuclear power plants, partly because the absolute cost of shielding and containment increases relatively little with reactor size.

Information available for 1967 shows a rise in capital costs per kilowatt capacity from about $130 for plants of 1200 megawatts to about $180 per kilowatt for plants in the 400-megawatt range. This explains why no nuclear power plant smaller than 450 megawatts has been ordered in the United States since 1963, and why the smallest size plant which a utility can now order from a major U.S. supplier is 480 megawatts (*12*).

However, these economies can be realized only when certain other favorable factors are also present. In the less-developed countries they are usually absent. Chief among them are a large market for electricity, that can accommodate a very large plant, and a well-developed power grid.

An engineering rule of thumb calls for reserve capacity equal to at least the largest single generator in the system to assure continued supply when that unit is out. In fact, to keep the system from collapsing in case the nuclear plant trips out, prudent engineers advise against installing in a small isolated system a nuclear plant that is larger than 10 percent of the peak load.

How many countries are there that fulfill the conditions which permit them to benefit from the economies offered by large nuclear reactors? To be competitive with power from conventional sources, ". . . a reactor of 500 Mw, now about the lower limit in size, would . . . have to produce not less than 3.5 billion kwh per year. Presently, there is only a handful of countries outside of North America, Europe, and Oceania that consume that much electric energy per year *altogether*. And, of these, only Argentina, Brazil, Japan, India, North Korea, and the Republic of South Africa consume greatly more" (*13*). Even though power markets will, of course be larger 10 and 20 years from now, it is precisely this circumstance, the "low-demand trap," that has led to the search for an adequate and reliable market, hence the recent work on agro-industrial complexes as built-in consumers.

Availability of Capital

Because nuclear power plants require a large capital outlay per kilowatt of installed capacity, the availability of capital is of great importance. Most of the countries which could best use additional power—and water—are seriously short of capital; alternative investment opportunities exist which can earn interest at much higher rates than are customary in the United States even now. Israel, for instance, permits a legal maximum of 11 percent, and the demand for loans is usually greater than can be supplied at this rate (*14*). Higher rates are paid in various ways. It is certainly doubtful if any country which could use a large desalting project based on nuclear power should count on having to pay less than 10 percent interest per year. If for political or other noneconomic reasons the United States should decide to provide a plant in a country on a subsidized basis, any interest rate could be used in the calculations. Without discussing the merits of subsidization, however, current efforts to portray nuclear desalting as having come or about to come "of age" are based not on subsidized but on market conditions.

Costs of Equipment

Power plant costs would almost surely be higher outside the United States, especially in countries that have been mentioned as candidates for desalting plants (*7*, p. 165). The reasons include costs of shipment of equipment, lack of supporting industries and their production, shortage of national specialists and construction crews, and longer construction time. Only a small portion of these increases might be made up by procurement of some of the equipment from lower cost sources abroad.

Operating Performance

The cost of servicing a nuclear power plant is likely to be higher than in the United States for reasons very similar to those just cited. The intrusion of a highly complex technology into an environment that is not geared to it is bound to result in lessened effectiveness and higher cost of maintenance and operations generally. Although the record of power availability of nuclear plants is anything but good in the few plants that have so far operated in the

United States, it is likely to be poorer in the less-developed areas of the world unless the plant can be run as a virtual enclave, and even then a good record is by no means certain. This is not to say that improvements would not gradually be attained, as they are bound to be attained in the United States. It is reasonable to believe that the economics of nuclear desalting, examined alone, would make the first plant ordered in any less-developed country disproportionately large, and it would be a long time before a second and a third could be built. Thus the initial plant would for years bear the burden and cost of serving both as an economic input and as a training and experimental facility.

We do not wish to appear unduly pessimistic. Not all of the adverse factors need come true, but some are sure to be felt. And there is little in the picture that points to the emergence of unforeseen favorable elements, at least not without consideration of other energy sources. A good deal of what has been said above would not be true of fossil fuels, abundantly available in the Middle East, where vast amounts of natural gas are flared, and where the marginal cost of crude oil is extremely low. Moreover, the economies of scale would be less pronounced and size problems somewhat alleviated.

But for the moment no such proposals have caught the public fancy, although there is no generally valid technical, economic, or other connection between nuclear energy and desalting. Indeed, from the viewpoint of international complications, the association of desalting with nuclear energy probably represents an obstacle rather than an aid to achievement of the economic objectives in some parts of the world. A first indication of change in that direction could be the proposed bill transmitted to the Senate by the Department of the Interior on 17 January 1969, 3 days prior to the Administration changeover. It would authorize U.S. participation in a dual-purpose plant to be erected in Israel. An upper limit of $40 million would be placed on any grant made to help finance the desalting techniques and necessary modifications in the power production of the plant. Financing of the balance as well as the choice of energy source would be determined by the Israeli government.

Efforts to overcome the difficulties briefly described above have taken two forms. One has been to present an optimistic picture of the expected costs of water by making highly favorable assumptions for cost and output factors. The other has been to broaden the scope of operations beyond production of power and water and to test the feasibility of a large agro-industrial complex in which the large volume of electricity that cannot be absorbed by the ordinary demand of the country can find a ready market.

First, Kaiser used plant costs based upon a price schedule that became quickly outmoded, as we have pointed out above, and has led to later revisions (*15*). This would matter less if prices of crops had undergone similar increases, but they have not. Second, interest charges, and fixed charges based upon that interest, are unrealistically low. Even the highest variant has an interest charge of only 8 percent. The assumed downtime for the generating plant is 10 percent, certainly a highly optimistic assumption over the lifetime of the plant (*6*). And since the cost of water is arrived at by deducting from the total costs of the dual plant the income from selling the large amounts of electricity that are not consumed internally, a constant price of that electricity is assumed for the lifetime of the plant. This method discounts the possibility of slowly falling revenue stemming from a declining power-cost level in the economy as a whole. To the extent that the income from electricity sales is maximized, the "cost" of water, as the residual, is minimized.

The Oak Ridge study does make some allowance for higher costs outside of the United States, and sets out a wide range of possible interest rates. But in terms of the Oak Ridge concept, there is no need (and perhaps no basis for doing so) to determine separately the cost of either power or water, since it is the returns for the operation as a whole that measure the profitability of this closed complex.

We shall deal later with the various assumptions, but one needs mentioning here. In both studies joint production economies are reflected in the cost of water. While such a subsidy from one part of joint production to the other may be wholly desirable in a given case, it is apt to mislead those who are interested in the cost of desalted water regardless of its association with power production. In fact, the popular discussion has fastened on precisely the costs of water that have emerged from such studies without awareness that water cost is to a substantial degree a function of the price at which power can be sold. In this connection, the Oak Ridge study straddles the fence. Although its basic concept of an integrated complex renders the costing of either power or water meaningless, it fails to exploit this advantage in a consistent way and presents both costs separately, albeit in a somewhat offhand manner, and, it must be said, to the decided detriment of the entire exercise; for it leads the reader to marvel at the agricultural sector calculations being based predominantly on water at 10 cents per thousand gallons, when the rest of the study clearly spells out that no such water is in the offing, not even in the "far-term" model 20 years hence.

The same phenomenon has turned up in the case of the dual plant in the Los Angeles area, discussed briefly below. Before it was tentatively shelved in mid-'68, the estimated cost of water at the plant had risen from 22 to nearer 40 cents per thousand gallons. But "20 cents per thousand gallons" has left a lasting impression with well-intentioned but ill-informed writers and speakers.

Desalting Process

Much of the uncertainty to which we have drawn attention in the discussion of the energy-producing component is present in aggravated form in the desalting component. Here too, the scale of operations proposed in each instance is greatly in excess of anything that has so far been tried, although in the Kaiser proposal the large capacity is reached by replication of small, basic modules that are only five times the size of anything now in operation.

In each proposal the nuclear power plant and the distillation plant would be closely linked. Anything which led to a shutdown in one would force an early shutdown in the other, although planned maintenance in either process might be carried out during forced shutdowns of the other process. The schedule for a power and distillation plant in the Kaiser proposal calls for a demanding availability of 85 percent jointly, or a downtime of 15 percent. There is little on which to base an appraisal of this assumption. But it may be noted that the Point Loma demonstration plant of the Department of the Interior, prior to its transfer to Guantanamo Bay in Cuba, had an availability of only 70 percent (*6*). Since this was an early plant, one would expect later ones to operate more continuously, if it were not for the type of difficulties that the Point Loma plant experienced. A serious one that the Kaiser plant does not seem to have adequately taken into account was the problem of drawing water out of the ocean. Many materials obstructed the intake pipe—kelp, sand and silt, fish, even large stones. Large and expensive stilling basins must be installed if such difficulties are to be avoided, and one may assume that the type of difficulty will vary from one location to another. "It is evident from our observations both at San Diego and elsewhere," an engineering evaluation states, "that the importance of trouble-free intake systems either does not get through to those responsible for the design of the system or that there exists a tendency to skimp in the design in order to reduce costs" (*16*).

Another unknown is the discharge of hot and bitter brines in volumes 100 times and more than that of existing plants. This could present awkward problems. At the minimum, the discharge point must be removed by considerable distance from the intake point to prevent even partial recirculation of ever saltier water; expensive piping out to sea may be required (*17*). Adverse ecological consequences of dumping these wastes are inevitable. Neither they nor the possible costs of dealing with them have received attention.

Although each report is concerned with the future, some comparison with present plants is sobering. The lowest cost plant operating today (providing water for Key West, Florida) produces water for 83 cents per 1000 gallons, but with a subsidized interest rate loan from the federal government; without it the cost would have been very close to $1 per 1000 gallons. In 1966, two private utilities in Southern California, the City of Los Angeles, and the Metropolitan Water District of Southern California, assisted by funds from the U.S. Department of the Interior and the Atomic Energy Commission, entered into an agreement to build a desalting plant on man-made Bolsa Island in Southern California to serve an urban area with a high demand for both electricity and water. The plant was to produce 150 million gallons of desalted water daily and have a generating capacity of 1.8 million kilowatts of electricity. The originally estimated cost including water conveyance and power transmission was $444 million; by the summer of 1968 estimated costs had escalated to $765 million, owing to a greatly lengthened construction period, increased equipment and interest cost, stricter design criteria, and, one of the smallest items, a 10 percent larger power output. The project is uneconomic at this price, and the proposal in its present form has been shelved.

If desalting of seawater is not economic in Southern California today—where alternative water must be brought long distances at high cost, where electricity surely has a ready market, and where much of the water would not go to agriculture—then where is large-scale desalting of seawater economic? If it is not economic at an interest rate of 3.5 percent, and at the lifetime capacity factor for both water and power of 90 percent, assumed for this venture, then what are the prospects under less generous assumptions?

These recent experiences may not apply to desalting costs in the more distant future, but they are at least sobering. This is particularly true when one attempts to make corrections both for the unrealistically low fixed charges, and especially the interest rate (the Oak Ridge proposal is the most realistic in that respect), and some allowance also for the optimism incorporated into the estimates at various stages. Wolfowitz has tried to make adjustments for the proposed Israeli plant (*6*). Using as his point of departure the lowest estimated cost of 28.6 cents, based on an interest charge of 1.9 percent, he demonstrates persuasively that the likely contingent expenses not included would bring the cost to 40 cents per 1000 gallons at the farm. If adjustment is then made to a more realistic but still modest fixed charge such as 10 percent, the resulting cost of water at the farm would rise to somewhere between 90 cents and $1 per 1000 gallons.

Application of Desalted Seawater to the Land

The third, and most generally neglected, aspect of desalting seawater for use in large-scale agriculture is the conveyance of the water from where it is produced at the edge of the sea to the land, which may be some distance inland and at a much higher elevation. The desalting plants discussed above will produce water in a constant stream (except when shut down for repairs or servicing), but the farmer wants water in a different time sequence during the year. In some way, water must be stored and transported, from one time and place pattern to another, and substantial costs will be incurred in doing so. Much of the discussion of the economics of desalting seawater overlooks this point; someone will compare the costs of water at the plant (usually grossly underestimated) with the value of the water at the farm (usually grossly overestimated).

In an arid region, irrigation water is essential for successful production of most crops, but so are several other inputs. The farmer combines them all into the farm operation program for production of crops and livestock which, in view of prices, costs, and markets, seems to him most likely to produce the greatest net income. The resulting time sequence of irrigation-water use is usually highly seasonal in character, its exact pattern depending upon climatic factors as well as upon choice of crops and methods of crop production. Modifying the farming program to smooth out the seasonal demand somewhat for irrigation water is possible in some areas and under some circumstances, but this modification is very likely to reduce income, sometimes substantially, from the whole farm operation. By and large, for desert and arid areas where desalted water might be used, a markedly seasonal demand for irrigation water is certain, if the farmer is free to choose when he takes water; demand for off-season water may be low.

The problem of storing and conveying water from desalting plant to farm will vary greatly from one location to another, but some generalizations may be made. Desalted water, in excess of immediate need, might be stored in surface reservoirs or underground aquifers located en route or not too distant from the place of either production or application, or in the soil of the farm. In each case, some water—often a great deal—will be lost through evaporation or percolation, or both; water stored in the soil may pick up salt—a great deal in most desert soils. Evaporation in most desert areas is high, often 10 feet or more annually from a water surface. There may be no suitable reservoir site; in any event, dams cost money to build. Soils and aquifers may have a low water-holding capacity or intake rate. Also, some means must be provided for carrying water by large conduits, pipes, or canals from the desalting plant or storage site to the border of each farm. In the United States, this has proven rather costly even when the water source was available by gravity flow. If the arable lands lie at some elevation, pumping costs will be considerable.

In the Kaiser report, the water-conveyance facilities and electrical transmission lines are not included. It is stated that they would add more than 15 percent to the investment. The water cost estimates are based upon 310 days annual operation of the desalting plant but no provision is made for storing this water at times of slack demand and no allowance is made for pumping costs. There are few good surface reservoir sites in Israel. The same limestone formations which allow infiltration of natural precipitation that could later be salvaged as groundwater also are the cause of leaky reservoirs. The most suitable lands in Israel near the proposed desalting plant lie at an elevation of 500 feet or more; pumping costs, even with relatively cheap electricity, would be considerable. The cost of taking desalted water from the plant to the field includes (i) losses in transport; (ii) pumping costs; and (iii) costs of conveyance to the farm, including distribution canals or pipes. By far the greatest of these is likely to be water loss. A 10 percent loss of water would raise the cost of the remaining water by 11 percent, a 20 percent loss by 25 percent, and a 30 percent loss by 43 percent. The more costly the desalting process, the more costly the loss of water in storage or in conveyance.

Pumping costs depend primarily upon lift and distance. Even with high pump efficiency, lifting water requires somewhat more than one kilowatt-hour for each foot of lift for an acre-foot of water (enough water to cover an acre one foot deep, or 326,000 gallons). A 500-foot lift, as would be necessary at the most frequently mentioned Israeli site, would require about 640 kilowatt-hours of electricity; at 5.3 mills per kilowatt-hour, the rate at which the Kaiser report estimates electricity can be disposed of, this would still mean nearly $3.50 per acre-foot for energy; depreciation, maintenance, and interest on pumping equipment would probably add as much again. Finally, there are the costs of construction, maintenance, and operation of a canal or pipe system. The annual cost, including interest on capital, could hardly be less than $3 per acre-foot.

The Kaiser report, on the basis of 8 percent interest on invested capital, arrives at a cost of 67 cents per 1000 gallons at the plant, or $218 per acre-foot. On the basis of the foregoing calculations, an overall loss of water of 10 percent (representing a much higher loss on the volumes actually stored), plus the other costs, would add about $34 per acre-foot to the cost, or 14 percent. If the overall loss were 20 percent, the lost water would add $55 per acre-foot to the cost of the delivered water; with the other costs, total costs incurred between distillation plant and field would be $65, or a 30 percent increase.

If all calculations in the Kaiser report were retained, but the interest rate raised to 12 percent, the costs of desalted water would be in excess of 75 cents per 1000 gallons. If 20 percent were added for conveyance costs and losses, the delivered cost at the farmer's field, on the time schedule he wants the water, rises to 90 cents or more per 1000 gallons.

If one accepts the Oak Ridge calculations, but uses an interest rate of 12 percent, the cost of desalted water at the plant is 28 cents per 1000 gallons; if 20 percent were added for conveyance costs and losses, the delivered price becomes 34 cents; and taking into account all the variables discussed, it seems realistic to count on a delivered cost of at least 40 cents per 1000 gallons, or $130 per acre-foot. It should be noted that some of these additional costs, here incorporated in the cost of irrigation water, are allowed for in various ways in the Oak Ridge scheme under various capital charges of the farm enterprise. Thus, comparisons are difficult because the cost of the water remains unchanged from its cost at the outlet of the desalting plant. But primarily, it is larger size and assumptions of less costly future technology that explain the lower costs of the Oak Ridge study as compared to the Kaiser study.

Value of Irrigation Water

The value of water for irrigation, whatever its source, is affected by many variables—climate, soils, associated inputs such as fertilizer, markets, efficiency of farmers, competition from other producing areas, and many others. Throughout the whole world, water is rarely sold on a market, hence one must estimate "shadow prices" for the irrigation-water supply. It is extremely difficult to determine the *actual* value of irrigation water, but not difficult to say how it should *not* be determined.

First, the value of irrigation water to be developed by the two desalting projects cannot be determined on the basis of what a few farmers could pay to produce a highly specialized crop for a special market. There has been much loose talk about production of "winter vegetables," for instance; aside from the fact that this type of agriculture has never been the gold mine that some think it is, and that competition among producing areas in the future will reduce whatever large profits may have existed in the past (it is hardly legitimate to assume that the advantages of new technology will not be available to other, similarly situated areas), the scale of the Kaiser and Oak Ridge projects preclude this type of agriculture for more than a small fraction of the water to be produced. One hundred million gallons a day for 310 days in the year—85 percent availability—in the Kaiser project, are nearly 100,000 acre-feet annually, or irrigation water for perhaps 35,000 acres of summer crops and much more of winter crops; the Oak Ridge project is ten times as large. Even 35,000 acres is not much less than the total acreage of all vegetables grown annually in Israel, of which only a small fraction are exported. Such an acreage of winter vegetables could not be grown at any single location for the home market and if exported would have disastrous results in terms of prices of products. True, tomatoes—greatly desired as a leading export—are grown in Egypt on some 200,000 acres but exports in 1965 were the equivalent, at prevailing yields, of the harvest from 40 acres! Even in 1960, the best recent export year, exports came from the equivalent of 700 acres. The task of escalating from such levels to those appropriate to the magnitude of the desalting plants is truly overwhelming. Such comparisons and our ignorance concerning the characteristics of the specialty markets lead one to conclude that crop production from large-scale desalting works must be primarily staple, not specialty, crops.

Second, one cannot safely assume that all the increase in value of output resulting from irrigation will, or can be made to, accrue to the irrigation water; this is a trap into which economists around the world have fallen repeatedly. The quality of the labor and the management which will be required under the more intensive irrigation farming will demand, and can get, higher returns than the kind of labor and management which sufficed for the less intensive agriculture that the new irrigation replaced. Moreover, farmers and other landowners the world over have demanded and have secured some part of the increased product resulting from irrigation as a reward for their land. Further, to attract the capital needed for the new irrigated agriculture, adequate rewards must be in prospect, including a generous allowance for risk. Some of the farm programs or budgets prepared for proposed new irrigation seem to show that very large sums can be paid for irrigation water. On closer examination, these have a fatal flaw; if the intended crop production is so profitable that very large sums can be paid for water, then it is profitable enough so that other extensive areas of the world, including those that need not pay high prices for water, can undertake such production—and the estimated price then quickly drops. Furthermore, the costs of other inputs rise rapidly, as the high yields conventionally assumed on irrigated acreage in these studies demand greatly increased applications of fertilizer, pesticides, and so forth, with attendant employment of sophisticated skills and machinery. In irrigated cotton-growing in California, for example, other costs are so high that water costs typically constitute only 10 to 15 percent of total operating cost.

Third, it is easy to develop plans which embody a wholly new order of magnitude in farm efficiency—crop yields much higher than those obtained by farmers in other irrigation projects in the region, fertilizer inputs several times as great as now practiced, new crop varieties that lead to much higher yields, and many others. By comparing irrigation agriculture on this new higher plane of efficiency with nonirrigated agriculture (or even with present irrigation) on the older, lower level of efficiency, some very high values of water can be estimated. Irrigation does indeed open up new production opportunities, but realism is called for in estimating just how much advantage can and will be taken of those opportunities, and how soon. If the new system of agriculture is possible with new irrigation, why is it not feasible with old irrigation? What reason is there to expect that provision of irrigation water will immediately transform a backward, traditional agriculture into a modern or futuristic efficient one?

Fourth, the agro-industrial complex has been offered as an answer to the last question asked. But is it? Such complexes as sketched by their proponents employ currently unknown or untested methods in industry and agriculture, produce for unspecified markets, and appear to justify very high costs for irrigation water. The prime example here is the Oak Ridge project. Although comprehensive in the scope of things to be considered, it tends to assume optimistic outcomes, uses low costs, and fails to allow for unexpected difficulties and costs. Above all, it fails to supply a satisfactory answer to this question: if these great agro-industrial complexes are economically feasible with desalted water, why are they not feasible with natural flow or groundwater? There is nothing magical about desalted water; it is simply water.

The agro-industrial complexes of the Oak Ridge type have been defended on the ground that they would constitute a new order of technology and organization, freed of all the inhibitions of restrictive institutions, cultural values, modes of living, and so forth, which impede agricultural and industrial development in some countries. This is a dubious argument if applied to Australia, Israel, and possibly to Mexico and India. Moreover, this proposal is futuristic plantation philosophy. In many colonies of the world before World War II, there were plantation economies, using outside capital, outside management, and producing for an export market; often they were highly efficient. Most are now liquidated as foreign enterprises; there is little reason to expect that the countries would welcome them back. The very isolation of the proposed agro-industrial complex from the mainstream of the country's culture is its most devastating weakness, regardless of the efficiency it might attain. The Oak Ridge study comments on this by contemplating that the food factory concept "... would appear to be the reverse of agrarian reform programs in many countries. On the other hand, setting up an operation in a sparsely populated area might be effective in avoiding complications of existing social organizations and customs" (*3*, p. 27). One can only comment that it would save even more trouble if one were to select a less difficult geographic, social, and political setting and then find a way of letting the country to be aided share in the fruits of production by assigning to it the plant's net return.

But ignoring these broader-based considerations and insisting only that the large-scale desalting projects planned by Kaiser and Oak Ridge must produce predominantly staple crops, such as grains and cotton, for domestic and export markets, one can judge the economic feasibility from a number of recent American studies that provide estimates of the value of irrigation water for such crops. Since the contemplated farming ventures discussed above are based on highly advanced technologies and must to a large extent be competitive with world market prices, such studies are not as inappropriate a criterion as one might first think.

Young and Martin provide information and analyses to indicate that the value of irrigation water in central Arizona is less than $21 per acre-foot (*18*); Stults, considering the situation in Pinal County, Arizona, makes analyses which imply that the value of the water is about $9 per acre-foot (*19*); Grubb estimated the ability to pay for irrigation water in the High Plains of Texas ranged from $27 to $36 an acre-foot, even in 1990 (*20*); and Brown and McGuire found that the marginal value productivity of irrigation water in Kern County, California, was about $19 per acre-foot (*21*). These are all in fairly good farming areas, where the growing season is rather long, cropping patterns can be rather intensive, and crop yields are relatively high. In irrigated areas where farming is somewhat less intensive, due in part to differences in climate, Hartman and Anderson concluded that the value of supplementary water was from $1.50 to $3 per acre-foot (*22*); and Fullerton found that in a fairly active water-rental area, the price was about $8.75 per acre-foot (*23*). All of these examples involve rather high-level managerial competence (which is more easily hypothesized) unlike that found in some of the countries under study; the same is true of the availability of farm machinery, fertilizer, insecticides, and other inputs. It is important to note that they do not focus on the subsidized price of water, but on what users can afford to pay. Thus they are directly relevant to the hypothetical cost of desalted (or any other) water. Moreover, they escape the frequent criticism that the cost of desalted water should not be compared with the actual price currently paid for water, or that the present price of water is an irrelevant object of comparison, since it must be judged in a multi-purpose use context.

On the basis of this range of American experience, it seems most unlikely that irrigation water delivered to the farm on the schedule the farmer wants it, for the production of staple crops, can attain a value greater than $30 per acre foot (10 cents per 1000 gallons), and a value of $10 per acre foot (3 cents per 1000 gallons) is a much more reasonable planning standard.

The conclusion is inescapable: the full and true costs of the proposed desalting projects, now and for the next 20 years, are at least one whole order of magnitude greater than the value of the water to agriculture. The specifics of both cost and value will vary, depending upon the location of the plant and the myriad of factors associated with that location, upon what desalting costs actually are in practice, upon crop possibilities (costs and markets, especially), and upon other variables. But it is impossible to bring planned costs and prospective values for agriculture together or even close.

Nothing we have said with regard to the prospects for desalting seawater should be construed as an argument against continued research, including the construction of a rather large pilot plant. The Oak Ridge study both merits and needs attentive reading and critical review. Such research must not stop at the farm gate nor bypass the broader implications of such programs with a few passing sentences. There is more involved here than either "truth in advertising," the discovery of a new input, or a new means of fighting hunger. The present mirage may indeed have an oasis within it, and we as a nation have the resources to pursue the matter much further. But let us not delude ourselves or the rest of the world that an early and practical solution is at hand.

References and Notes

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3. *Nuclear Energy Center, Industrial and Agro-Industrial Complexes*, ORNL-4290, UC-80-Reactor Technology (Oak Ridge National Laboratory, Oak Ridge, Tenn., November, 1968). The full report was not available at the time of writing, but has since been published.
4. See our letter to the editor, *Environ. Sci. Technol.* 2, 648 (1968).
5. An example of this sort of writing is an article by V. Nikitopoulos, *Ekistics* **26**, 14 (July 1968), in which the author presents a map showing the land areas of the world which *cannot* be served by desalinated water, namely those more than 1000 kilometers from any ocean.
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7. W. E. Hoehn, *The Economics of Nuclear Reactors for Power and Desalting*, RM-5227-PR/ISA (RAND Corp., Santa Monica, Calif., 1967).
8. G. G. Stevens, *Jordan River Partition* (Hoover Institution on War, Revolution, and Peace, Stanford Univ., Stanford, Calif., 1965).
9. See P. Sporn in *Nuclear Power Economics—1962 through 1967*, report of Joint Committee on Atomic Energy, U.S. Congress (Government Printing Office, Washington, D.C., 1968), p. 2.
10. The Atomic Industry Forum ["The Nuclear Energy Industry—The U.S. Highlights of 1968" (1968), mimeographed] puts the case even more strongly: "The direct costs of constructing nuclear generating plants rose significantly in 1968. From a low in 1966 of about $100 they had increased some 30-40 per cent in 1967, and there seemed to be a strong consensus that this year's increase was also 30-40 per cent. While the costs of comparable fossil-fueled units also rose, the increase was apparently less abrupt."
11. Interestingly, the same is true for the desalting phases. The "far-term" technology (combined flash-vertical-tube) requires more capital than the "near-term" (multistage flash) does.
12. The pessimistic outlook for the emergence of smaller but still low-cost reactors was presented in a paper given at the 1968 World Power Conference in Moscow, and entitled "Prospects for Small- and Medium-Sized Nuclear Reactor Plants," by W. Buenlich and P. H. Kruck (Central Office of World Power Conference, London, England).
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NEWS AND COMMENT

Naval R&D: Conversion Sought for Radiological Defense Lab

Several West Coast University scientists and a bipartisan group of San Francisco Bay area congressmen have been trying to win a reprieve for the Naval Radiological Defense Laboratory, which has been scheduled for "disestablishment" in December.

The object of the campaign is not to win a reversal of the Department of Defense decision, but to delay dispersal of the NRDL staff and instruments so that a new base of federal patronage can be formed and the lab continued at its San Francisco location, preferably as a federal environmental research laboratory.

Congressional critics of the closing have been especially harsh in questioning recent Navy investments in equipment and facilities at NRDL—in particular, a $6-million cyclotron which has been in full service only in the past year. The incident seems likely to provide fuel for the arguments of those who have been demanding more effective government-wide policies on the utilization of federal research facilities.

Nine area congressmen* petitioned Secretary of Defense Melvin Laird to extend the closing date for 6 months to give other federal agencies who might utilize the skills of the NRDL staff time to act. As this was written, no decision by Laird on the request had been made public.

The Department of Defense informed area congressmen on 22 April

* They are William S. Mailliard, a San Francisco Republican who took the lead in the effort; Republicans Paul N. McCloskey, Jr., Don Clausen, and Charles S. Gubser; and Democrats Phillip Burton, Jeffery Cohelan, George P. Miller, Jerome R. Waldie, and Robert L. Leggett.