**The Armand Hammer Fund for Economic Cooperation in the Middle East**

# WATER DESALINATION AND THE RED SEA-DEAD SEA CANAL

02-1992

Pinchas Glueckstern and Gideon Fishelson

Tel Aviv University
April 1992

# THE ARMAND HAMMER FUND FOR ECONOMIC COOPERATION IN THE MIDDLE EAST

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The programme of the Armand Hammer Fund for Economic Cooperation in the Middle East was conceived and formulated in a series of meetings held during 1980 between the late Dr. Armand Hammer, Chaiman of Occidental Petroleum Corporation, and Professor Haim Ben–Shahar, then President of Tel–Aviv University. The project was made possible by a grant provided by the late Dr. Armand Hammer and with the help of his friends, colleagues and community leaders in Los Angeles.

The future will undoubtedly prove the great and important value of the visionary and historical vision represented by the Armand Hammer Fund for Economic Cooperation in the Middle East.

President Chaim Herzog at the Opening Ceremony of the Armand Hammer Conference, June 1986

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## *Preview*

The present study by Glueckstern and Fishelson examines "other benefits" from a canal that links the Red Sea with the Dead Sea, thus transferring sea water from the former to the latter in order to stop the latter from drying up. The term "other benefits" implies benefits in addition to those obtained directly from the survival of the Dead Sea which will be likely by virtue of its level being raised again to 395 meters, as it was 20 years ago. The other main benefits we have in mind are derived from water desalination and from the generation of electricity, in the above order of importance. The desalinated water will be used in the Jordan Valley and the Arava and, as much as possible, on the two sides of the Israeli-Jordanian border to raise high value, mainly winter crops, for export.

We advocate the Red Sea-Dead Sea project rather than the Mediterranean-Dead Sea project on the grounds that the former is a true binational project between Israel and Jordan. The binational nature of the project is exhibited in all the aspects of the project in terms of sharing the various benefits incurred along the route from the Red Sea to the Dead Sea and then from raising the level of the Dead Sea, as well as the sharing of the desalinated water, and the electricity that is generated. In this sense the project can be justifiably defined as a regional project and could thus enjoy preferred financial terms such as lower interest rates and a longer period of grace. Needless to say, the two by-products of the project—the desalinated water and electricity—are in very short supply in the area where they will be produced. They can also be conveyed out of the area into adjacent areas that are also in need of water and electricity.

I have to admit that my initial estimates regarding the cost of desalination, using the favorable topographic conditions, was of up to 40 cents per cubic meter (not including the capital costs of the canal). However, the findings were less encouraging. At present the state of the preferred technology for desalination—Reverse Osmosis—and prices of inputs that cost ranges between 50 to 60 cents per cubic meter. Yet, while researching the topic, it became evident that improving the technology of reverse osmosis, which is quite likely, and a decline in the price of the membranes, which is even more likely, would lower the desalination costs by at least 20%. Furthermore, these events could take place within the construction period—a decade and a half.

The study was initiated by the Armand Hammer Fund. The Steering Committee of the Fund, headed by Professor Haim Ben-Shahar, followed the study and encouraged it. We are grateful to the Fund for its helpful aid.

Professor Gideon Fishelson
Scientific Coordinator
The Armand Hammer Fund

## *Introduction*

The idea of linking the Dead Sea with the Mediterranean Sea via a canal already appears in the writings of Herzl in 1902 (*Altneuland*). At the beginning of the twentieth century, the intention behind this idea was to generate electricity. This would then have provided a relatively low cost energy resource for the growing economy of the new nation. Promotion of the idea of the canal was resumed by Professor Loudermilk (1944). He also considered the generation of electricity to be the main benefit to be gained from the canal.

The revival of the idea in the last twenty years is for other reasons, most important of which is the monotonous decline of the height of the Dead Sea. Large water projects—Israeli and Jordanian—have lowered the annual flow of water into the Dead Sea over the past thirty years by approximately two-thirds. The level of the Dead Sea in the early 1960s was approximately -395m. Currently the level is approximately -401m. Since the diversion of water continues and becomes more intensive over time (relative to the water that still remains), the level of the Dead Sea will continue to decline. Hence, when considering the supplementary water canal one should actually think about a minimal flow and a maximal flow. The minimal flow corresponds to sustaining the Dead Sea at its current level. The maximal flow corresponds to raising the level back to -395m.

The two basic economic justifications for any project that fits into the minimal-maximal range are:

1. To lower the operation costs of the potash extraction facilities at the southern end of the Dead Sea.
2. To save the tourist facilities along the Dead Sea.

Thus, while considering the various options for sustaining and raising the level of the Dead Sea, the following matters should be taken into account:

1. Operation costs of the potash extraction operation.
2. Tourist facilities on the shore line.
3. Potential damage to agricultural land.
4. Possible flooding of roads, bridges, and various facilities along the shore line.

These four factors, as well as the benefits of a canal are relevant for Israel and for Jordan. Accordingly, any project intended to affect the level of the Dead Sea should be treated as a binational project which is of great interest to both Israel and Jordan.

The main difference between the present study and those conducted in the past (to which we refer below) is that we propose to exploit the differential of levels between the external seas and the Dead Sea for water desalination using the reverse osmosis technology. The study should be viewed as a conceptual framework. We have spared the reader the detailed technological equations that are related to pressure, quantities of water that can be forced through the membranes, calculations of energy needed and energy balance. The interested reader can find them in Glueckstern (1982).

The products of the Red Sea-Dead Sea Canal project will be shared by Israel and Jordan. This holds for both the water and the electricity. Regarding the former, it is not mere fancy to expect that the shortage of water in Amman could be replenished indirectly from this project.

## *PART I: The Red Sea - Dead Sea Canal*

### A. *Water Sources for the Dead Sea*

In order to sustain the present level of the Dead Sea and to then raise its level once again to -395m. large inexhaustible sources of water are needed. Such sources are unavailable in the immediate vicinity. The closest sources are the Mediterranean Sea -- approximately 100 km to the west—and the Red Sea—approximately 200 km to the south. Correspondingly, the traditional proposals (starting with Herzl in 1902) only considered the short distant source, the Mediterranean Sea. Three alternative routes were proposed for the use of this source—the Jezreel Valley Route, the Palmachim Route, and the Katife Route. Each of these three routes has its advantages and disadvantages, evident in varying degrees for each alternative. These advantages and disadvantages are outlined below:

1. The benefits in terms of the generation of electricity due to the height differentials of the final water fall.
2. The benefits of using the transferred water as cooling water for power plants along the route.
3. The benefit of using the transformed water for various economic activities along the route.
4. The benefits from solar ponds.
5. Differential construction costs.
6. Differential environmental damages and potential ecological damages.

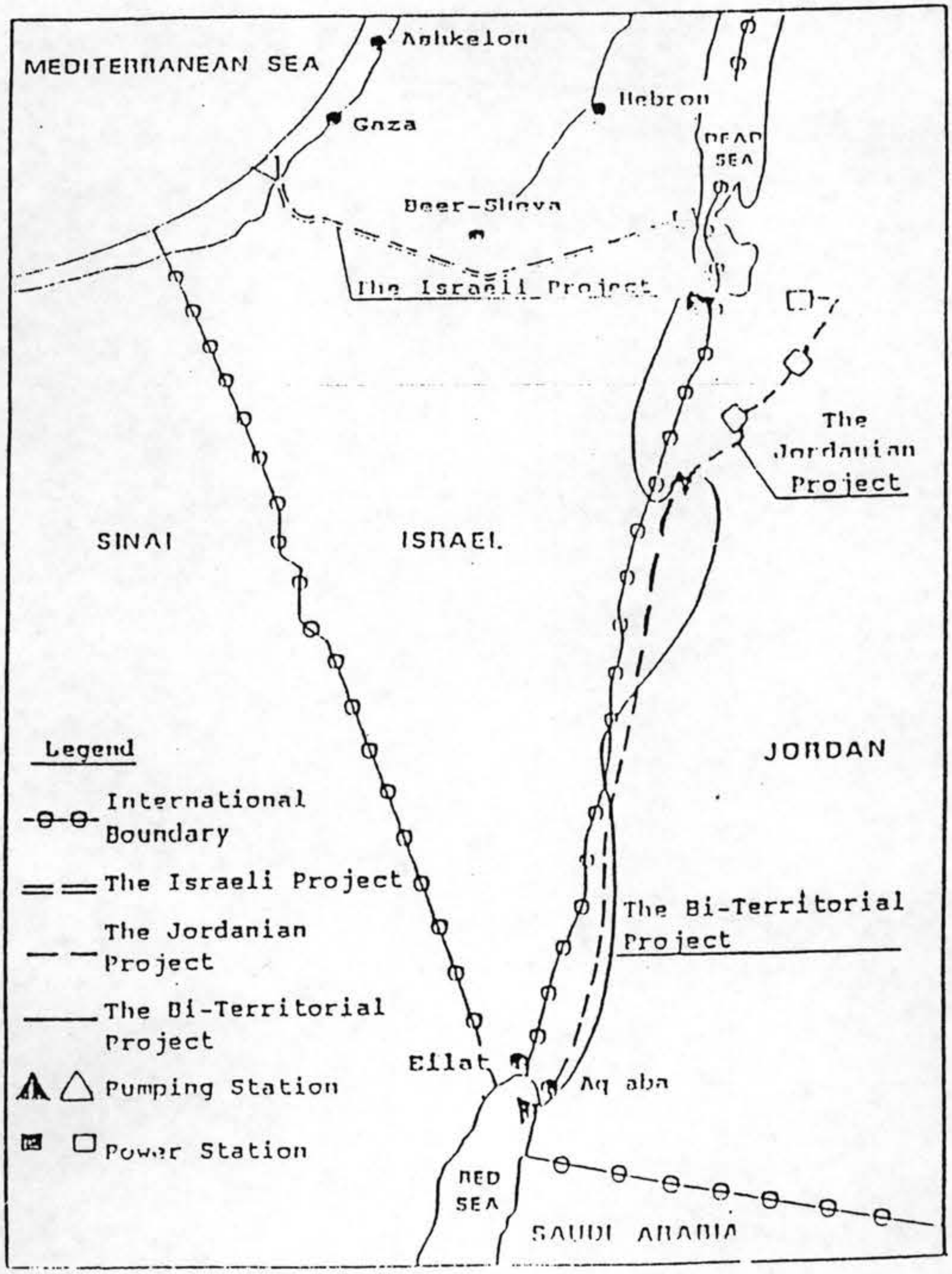
These points considered, the Neaman Committee decided on the Katife Route. In 1984 there was a symbolic initiation of construction, but this is all the progress that has been made to date.

The Red Sea—Dead Sea canal was proposed more recently (also in a study by Harza, 1978, a U.S. consulting company). The Red Sea-Dead Sea project we refer to in this study differs from the Harza project. The Harza project was designed under the constraint that the canal will be entirely within Jordanian territory. Once this constraint is removed, a better solution can be reached. The project we refer to allows the canal to cross the political borders between Israel and Jordan. Thus, from a purely technical-economic point of view, this project is the optimal one in the Red Sea-Dead Sea framework. Its main disadvantages are its relative length (about 220 km vs. 100 km compared to the Katife Route) and the need to raise the intake water by the 220 meters compared to only 100 meters in the Katife variant. There is also a lower height differential (370m vs. 430m). However, the implementation of this proposal would constitute a significant regional water project (see Map 1).

As indicated below, this option would actually enjoy some of the advantages to a greater extent than the option of the Katife Route. Its main advantage is that it would be a joint Israeli-Jordanian project not only at the end point—the Dead Sea, but along the entire route starting at the Red Sea and ending at the Dead Sea.

As noted above, historically the main advantage of the project was considered to be the generation of electricity, in particular the emphasis was on peak load electricity. The value of the generated electricity depends upon the alternative costs of generating this electricity. The latter depends mainly upon the prices of the various fuels (oil, coal). The electricity generated by the hydro-power also has the advantage of being a

## Map 1: Proposed Two-Seas Project



clean non-polluting source of energy. Previous attempts at cost-benefit analysis of the Canal project that considered this electricity showed only very marginal net benefits. The benefits became more positive as the electricity was assigned a higher price and the interest on the investment was lower (approached zero). Yet, given the large absolute investment that is needed, the justification of the whole project remained questionable.

In this study the emphasis is on water desalination. The growing scarcity of water on the one hand and improving technological feasibility of utilizing the water level differential for water desalination on the other, yields the expectation that the cost-benefit analysis with the desalination variant will result in significant net benefits. In addition, positive benefits will accrue along the route from the Red Sea to the Dead Sea, even when the level of the Dead Sea is kept at its present level (they might be higher when the level is raised since more water will be transferred through the canal). Needless to say that the calculated results depend upon the values assigned to the desalinated water. Since this study is not aimed at the determination of these values, the end point of the study is the determination of the desalination costs per cubic meter of water. Hence, the contribution of the desalination option to the benefits equals the value of a unit of desalinated water less the average costs of desalination, multiplied by the quantity that is desalinated.

The following section looks at the Red Sea-Dead Sea Canal. We briefly discuss its characteristics, the implied costs, and the potential benefits along the route. This section is based heavily on studies by Kally. We supplement these findings with data from Halperin and Gordin (1990) which are specific to marine agriculture in the area between the Red Sea and the Dead Sea that is designed to be the route of the Red Sea-Dead Sea Canal.

The aspects of reverse osmosis desalination are presented in the second following section. The calculations there treat the Red Sea-Dead Sea Canal as a given project.

## *B. The Red Sea-Dead Sea Canal—Initial Economic Considerations*

Given the geographic flexibility of the canal (no political border constraints) one can design it to be optimal from the net benefits point of view. However, the design should also follow the mode of joint control of the operation and sharing of the benefits. The suggested canal starts at the Red Sea. The water is raised to +220m and transferred along open canals and tunnels to the Dead Sea. The first optimal section of the canal is unique. Then there are some alternative routes with different locations of hydroelectric plants. The planning is sufficiently flexible to allow for each state to have its own hydro-plants. This however does not assure optimality in terms of total net benefits. Hence, there could be some additional cost savings. A similar argument holds when water desalination is the main benefit. One can design separate by state desalination plants, or an optimal one, the output of which will be shared.

Alternative projects were designed by TAHAL following the models of the lowest cost route subject to joint control on operation and electricity generation. The projects were designed for two capacities 50 $m^3$/sec and 30 $m^3$/sec. As already noted in this study our emphasis is on water desalination. Hence, part of the transferred water will be diverted from the Dead Sea to other usages; thus the annual quantities of 1.9 billion $m^3$/year over the first twenty years—the filling-up stage—and the 1.2 billion $m^3$/year—the water level balancing stage, should be increased by the quantity of the desalinated water. This addition is marginal given the above quantities, and its marginal costs relative to the project's construction costs are negligible. On the other hand, there would be more water to be used in the marine agriculture and tourist facilities along the route of the canal in the Arava Valley which need water mainly for circulation. However part of the water that is to be circulated would evaporate (approximately 3500 m3/year/dunam). The water that would evaporate is already included in the totals of 1.9 and 1.2 billion m3/year. Yet this water—which evaporates while utilized in the economic activities along the route have to be charged with the marginal costs which depend upon the distance transferred. The range of these marginal costs is 3-4 cents/$m^3$, for a range of distances from 70 to 200 km. Kally calculated the benefits per dunam of marine agriculture to be about $7000 per year. The benefits per dunam of a lake for purposes of tourism is not calculated, given the many unknowns that are involved.

Disregarding the hydro part of the project one finds that the lowest construction costs for the system supplying 30 $m^3$/second is about 540 million dollars (1988 prices) and that of supplying 50 $m^3$/second about 730 million dollars. One has to add about 10 percent to these figures for administrative costs. Hence, the total will range from about 600 million dollars to about 800 million dollars.

The above figures should be used as a base upon which interest and depreciation have to be charged, and from their investment the various benefits—not including those of the desalinated water are obtained. In previous versions of Between Seas Canals studies, e.g. Kally (1988), various hydro-electric plants were suggested, the benefits from which were derived from the electricity (peak) generated. The total investment reached a level of 1400 million dollars. In this study, the benefits from the hydro-plants are partly replaced by benefits from desalination plants. Yet, as described below, most of the hydro-project can remain and its benefits should be added to those from the desalination project. In the following section, we present in detail the technology of reverse osmosis when employed within the framework of the Red Sea-Dead Sea canal.[1]

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[1] For a more technical study on desalination see Arad and Glueckstern, 1981. For a specific analysis on reverse osmosis see Glueckstern, 1984.

## *Part II: Combining Desalination Plants with the Red Sea-Dead Sea Canal*

### A. *General*

One of the important and promising benefits of this Two Seas Canal Project is the desalination of sea water on a large scale for the purpose of providing water of high quality to the Dead Sea area and Southern Arava region.

The most widely accepted technologies for desalination of sea water today are based on a process of distillation and a process of reverse osmosis. The reverse osmosis process can take advantage of hydrostatic pressure as part of the energy required for the desalination process, and is therefore suitable for being combined with the Two Seas Canal.

Currently, an initial study has been done using four alternatives: two which do not take advantage of hydrostatic pressure and draw on the source canal of the Two Seas Canal for the water which feeds into them, and two which take advantage of hydrostatic pressure by receiving their feeding water from the upper reservoir of the hydroelectric plant.

A plant with an output of 200,000 $m^3$ per day (66 million $m^3$ per year) was placed in each of the alternatives, while the design of desalination units is based on the technology of desalination plants operating in different places around the world.

The main aims of this study were:

a. To define the main alternatives for desalination of sea water in combination with the Two Seas Canal.

b. To evaluate the investments and costs of the water desalinated in a large plant, versus capital and electricity costs.

c. To conduct the sensitivity analysis and estimate the potential for cost reduction.

## *B. Defining the Alternatives that Have Been Considered*

Alternative A1 - A conventional plant (does not use hydrostatic pressure) that receives the feeding water from the outlet canal of the hydroelectric plant (see Diagram 1).

Alternative A2 - A plant that receives the feed water from the outlet canal of the hydroelectric plant and raises them to an upper reservoir during the off-peak hours of the electric system (similar to a pumped storage plant) and uses hydrostatic pressure to power the desalination process (see Diagram 2).

Alternative B1 - A combined plant with the Mediterranean Sea-Dead Sea Canal, where the upper reservoir is at a height of 430 meters above the desalination plant (Figures of the Israeli canal on the Katife-Massada Route (Ma'ale Yair) (2,3) (see Diagram 3).

Alternative B2 - A combined plant with the Red Sea-Dead Sea Canal, where the upper reservoir is at a height of approximately 350 meters above the desalination plant (the Sodom station in the proposal for a biterritorial seas plant).

## *C. Basic Assumptions*

As stated above, the design of the desalination units was based upon proven technology for commercial desalination plants. This is not the case for the infrastructure, especially with respect to the whole issue of merging with a Two Seas Canal. Moreover, with regard to different components of the desalination plant, at this stage there is still uncertainty regarding planning factors that are dependent upon environmental conditions (cleanliness of the sea water, for example). Therefore, the economic calculation was done with two sets of techno-economic assumptions: a high estimate—based on conservative assumptions regarding environmental conditions and the design of the desalination units; and a low estimate—based on comfortable environmental conditions and certain improvements in the engineering design of the desalination plants.

For the alternatives in which the feeding waters come from the upper reservoir of the hydroelectric plant (B1 and B2), the marginal cost for enlarging the canal was calculated, and the cost sharing of pumping water to the upper reservoir was taken into account.

The costs of water production were calculated for discount rates of 0 to 6 percent and to electricity prices of 6 to 10 cents per kWh.

### D. *Preliminary Design*

Preliminary designs were made for each of the alternatives defined. This included:

a. Calculation of the flows, the pressures and the energy consumption of the process.

b. Calculation of design and cost data of the major plant equipment (membranes, pressure tanks, pumps, motors, energy recovery turbines, etc.).

c. Calculation of the major design and cost data for the infrastructure (site area requirement, buildings, seawater intake, drinking water pretreatment etc.).

The major design data for the desalination units and the infrastructure are summarized in Table 2.

## E. *Estimate of Investments and Desalinated Water Costs*

The estimates of the investments and desalinated water costs for the different alternatives, based on the basic assumptions specified in Table 1 and on the design data specified in Table 2 are summarized in Table 3 (Investments) and Table 4 (Desalination Costs).

Average values of the low and the high estimates of the investments and the desalinated water costs for several values of discount rate (real interest) and electricity, prices are summarized in Table 5.

## F. *Sensitivity Analysis*

The influence of the following changes on the average cost of desalinated water were examined:

a. plant size (an output of 50,000 and 400,000 $m^3$ per day).

b. investment in infrastructure and indirect expenses (according to the high and the low estimate).

c. operation and maintenance (excluding cost of membrane replacement).

d. specific energy consumption.

e. membrane replacement cost (the rate of replacement).

f. reduced membrane prices.

g. higher efficiencies of process pumps.

The effect of the size of the plant on the specific investments (for a unit of output) and on the cost of desalinated water are summarized in Table 6. The effect of the changes in items b through e is based upon the data and assumptions used for cost estimations according to the low and the high estimates (Table 4).

The influence of membrane prices was evaluated by assuming a 50 percent price reduction, compared to current market prices of proven membrane types. It should be noted, that some of less proven new membrane types can be bought at that price.

The present design was based on the use of standard pumps and turbines operating with a 80-85 percent efficiency. It is quite possible that in especially large plants non-standard pumps can be used having operating efficiencies around 90%. The sensitivity analysis for changes b to g were done for alternatives A1 and B2, and are summarized in Table 7.

## *G. Discussion and Analysis of the Results*

### *(a) Alternative A1*

This alternative considers a conventional reverse osmosis plant that desalinates Red Sea water or Mediterranean Sea water which are brought by the Two Seas Canal to the Dead Sea area. The sea water is pumped to the desalination plant from the outlet canal of the hydro-electric plant after all of the advantages (except maintaining the level of the Dead Sea) have already been utilized. From the fundamental and economic point of view, this alternative is identical to a plant located adjacent to a power plant near the shore of the Mediterranean Sea or the Red Sea.

The inclusive investment in a plant for an output of 200,000 $m^3$ per day (66 million $m^3$/year) is estimated at 160 to 200 million dollars. The cost of the water, when the price of electricity is 6 cents per kWh, is estimated to be approximately 66 cents per $m^3$ when the real interest is 6 percent and approximately 54 cents per $m^3$, when the interest is zero (see Table 5).

*(b) Alternative A2*

This alternative consider a reverse osmosis plant which utilizes a pumped reservoir for lowering the energy cost by using cheap electricity supplied at off-peak hours. By placing the reservoir at a height of approximately 400 meters above the reverse osmosis plant, it is possible to get all of the required energy for the process by hydrostatic pressure (the energy required to increase the pressure up to 70 atm, which is the added energy received from the turbines for the membrane operating pressure, is supplied by the energy recovery turbine—see Diagram 2).

The investment in a plant of this kind is greater and is estimated to be 225 million dollars. The cost of the desalinated water, where the price of electricity is 6 cents per KWh and the relationship between the price of electricity at off-peak, and the average price was assumed to be 60 percent, is estimated to be approximately 64 cents per $m^3$, when the real interest is 6 percent annually, and approximately 48 cents per $m^3$ when the interest is zero. This alternative is attractive where there is suitable topography, and where the interest on the investment capital is low.

*(c) Alternative B1*

This alternative considers a reverse osmosis plant that is combined with the Mediterranean Sea-Dead Sea Two Seas Canal, and utilizes the hydrostatic pressure of approximately 430 meters.

The investment in this plant is lower by approximately 8 percent than the regular plant (Alternative A1). However, taking into consideration the additional amount required to enlarge the canal, the overall investment will increase by approximately 4 percent. The investment in the plant for an output of 200,000 $m^3$ per day is estimated at 147 to 185 million dollars and the cost increment for enlarging the canal is 14 to 31 million dollars. The major advantage of this alternative is the rate of energy consumption (about half of that consumed in a regular plant), and therefore, the desalinated water is attained at a significantly lower cost. At a price of 6 cents per KWh for electricity, the cost of water is estimated at approximately 54 cents per $m^3$, when the real interest is 6 percent and at approximately 42 cents per $m^3$ when the interest is zero.

*(d) Alternative B2*

This alternative considers a reverse osmosis plant that is combined with the Red Sea-Dead Sea Two Seas Canal, and utilizes hydrostatic pressure of approximately 300 meters. In this case the energy advantage is lesser (approximately 35 percent of the energy consumed in a regular plant), and therefore the decrease in price is also smaller.

The investment in the plant for output of 200,000 $m^3$ per day (66 million $m^3$ annually) is estimated at 152 to 191 million dollars, and the cost increment for enlarging the canal at 10 to 22 million dollars. The cost of the desalinated water, when the price of electricity is 6 cents per KWh is estimated at approximately 58 cents per $m^3$, when the real interest is 6 percent annually, and at approximately 45 cents per $m^3$ when the interest is zero.

### *(e) The Influence of the Size of the Plant (Table 6)*

Except for Alternative B2 which considers a desalination plant with a pumped storage, the influence of lessening the output to 50,000 $m^3$ per day (approximately 16 million $m^3$ per year) and increasing the output to 400,000 $m^3$ per day (132 million $m^3$ per year) is relatively moderate. The increased specific-investment in the small plant is approximately 10 percent (25 percent in Alternative A2) and the decrease in the case of the large plant is only approximately 5 percent (approximately 10 percent in Alternative A2). The increase in the cost of the desalination in the small plant is approximately 7 percent to 10 percent (16 percent to 18 percent in Alternative A2) and the decrease in the large plant is only 2 percent to 4 percent (6 percent in Alternative A2).

### *(f) Potential Cost Reductions (Table 7)*

From a close examination of Table 7 one sees that the hidden potential for a decrease in price that lies in the realizing of the low estimation of the costs, sums up to approximately 13 percent in Alternative A1 and approximately 15 percent in Alternative B2. For both of them, the greatest potential for cost reduction is hidden in the lowering of expenses for replacing membranes. The realization of all the cost differences, between the average cost and that arrived at with the low estimate, would amount to a decrease in price of approximately 10 percent in Alternative A1 and by approximately 15 percent in Alternative B2. With the addition of the price drop following the use of pumps with higher efficiencies and cheaper membranes (50 percent of the present commercial price), the overall price drop could come to approximately 20 percent for Alternative B2. There are now, already, signs of this—that the market expansion and the competition among more manufacturers will lower the prices of the membranes, and at least some of the potential for a decrease in price will be realized in the next few years.

### *(g) Costs' Comparison with Other Desalination Methods*

The most common methods of sea water desalination in large quantities are: reverse osmosis and distillation plants combined with power stations. In international tenders that were offered recently in different places around the world, for plants with outputs of several tens of thousands of $m^3$ per day, more of the proposals that were chosen were for plants operating by the reverse osmosis method than for any other method. According to figures published recently, the water costs in three reverse osmosis plants for sea water desalination with relatively large outputs (15,000 $m^3$ per day in Malta, 36,000 $m^3$ per day in Las Palmas, 56,800 $m^3$ per day in Jedda) were 0.98 to 1.16 dollars per $m^3$. These costs which were calculated at an interest rate of 10 percent and at an electricity price of 5 cents per KWh, were lower than those published for plants operating by other desalination methods. Nonetheless, in very large plants—with hundreds of thousands of $m^3$ per day—especially multi-effect distillation (MED) plants planned to be combined with coal power stations in Israel, the cost is likely to be considerably lower.

It is not possible to determine which of the two methods—MED combined with central power stations (dual-purpose plants) or reverse osmosis plants—is preferable for the desalination of very large quantities of sea water, without conducting a comprehensive feasibility study, including general design for a defined site. It is reasonable to assume that the differences in costs will be small, and it may be assumed that for the alternatives of reverse osmosis plants combined with a Two Seas Canal (Alternatives B1 and B2, and perhaps even A2) there are significant economic advantages in comparison with other desalination plants operating according to any other desalination method.

## H. *Summary and Conclusions—Reverse Osmosis*

(a) Bringing Mediterranean Sea water or Red Sea water to the area of the Dead Sea will allow for desalination of sea water for enhancement of the water supply in the area. In that context, the possibility of combining with the Two Seas Canal while using the reverse osmosis method was examined. This option is considered without interfering with the other advantages of the Two Seas Canal.

(b) Three basic possibilities were evaluated:

1. A desalination plant obtaining sea water from the outlet canal of the hydroelectric station.
2. Same as above, coupled with a pumped storage plant to utilize cheap electrical energy during off-peak hours.
3. Two alternatives of receiving sea water from the upper reservoir of the hydroelectric plant, such that part of the energy required for desalination will come from the hydrostatic pressure that results from the difference in water levels.

(c) For each of the alternatives examined, no conflict of usage between the production of electricity and the production of water occurs. For the first two alternatives, the sea water feeding into the desalination plant has already utilized the entire electricity production potential. For the other two alternatives the concentrated waters are returned to the upper reservoir, and thus the electricity production potential is in no way diminished.

(d) The cost of the desalination in the first case above (Alternative A1), represents the estimated cost in a large plant operating according to the reverse osmosis method and located adjacent to a thermal power plant (near the Mediterranean Sea or the Red Sea), or near the hydroelectric plant that will be erected as part of the Two Seas Canal project. At a real interest rate of 6 percent, the cost of desalinated water in this plant is estimated to add up to a sum of 60 to 75 cents per $m^3$. The overall investment for putting up a plant with an output of 200,000 $m^3$ per day (approximately 66 million $m^3$ per year) is estimated to be 160 to 200 million dollars (approximately 2.5 to 3.0 dollars per $m^3$ per year).

(e) Combining a desalination plant with the Two Seas Canal while utilizing the hydrostatic pressure as part of the energy required for desalination (Alternatives B1 and B2), allows for a significant decline in energy consumption (up to 50 percent). As a result, the cost of the desalinated water will be as much as 20 percent lower.

(f) An additional large cost reduction may result if the project will be awarded special financing terms. Assuming low nominal interest such that the real interest will be close to zero, the subsequent cost of desalinated water will be less than half a dollar per $m^3$, and under certain conditions, where it becomes possible to realize a large portion of the other potential cost reductions—less than 40 cents per $m^3$.

(g) Under particularly comfortable financing terms, there is also room to consider the possibility of putting up a large desalination plant based on a pumped storage plant (Alternative A2).

(h) The size of the plant does not have a great influence on the cost of the desalinated water. Doubling the output from 200,000 to 400,000 $m^3$ per day will only lower costs by insignificant percentages. The biggest size influence is attained when the desalination plant is based on a pumped storage plant (Alternative A).

(i) It must be taken into account that all the results in this study are based on a pre-feasibility study, and therefore they should be seen as indicative only. More credible results, with a more limited sphere of uncertainty, can only be reached after a complete feasibility study, based on a general design for a specific site.

## *PART III: The Red-Dead Seas Canal - General Conclusion*

Looking at the small scale canal—30 $m^3$ per second—project, charging the project with annual capital costs of 6 percent (interest and depreciation) and adding maintenance costs implies an annual cost of 50 million dollars. If we deduct from these annual costs the annual net benefits of marine agriculture (10,000 dunam) and tourism—approximately 40 million dollars—the amount to be charged to the desalination plant (disregarding entirely the electric part) is at most 10 million dollars. If one divides this sum by the 66 million $m^3$ of desalinated water, the result is 15 cents per $m^3$. One also has to add the conveyance costs for the extra water from the Red Sea to the Dead Sea. This amounts to another 5 cents per $m^3$. Following the previous chapter, at capital costs of 6% annually, this means an average cost per $m^3$ of desalinated water of 80 cents. One should recall that these costs embody the construction costs for the project of sustaining the level of the Dead Sea at -401m., while the desalination project is a marginal addition to the Red-Dead Seas Canal. Hence changing the desalination part with a proportional share of the costs is, in principle, not justified. Even the small scale project, 30 $m^3$/second, implies building a project that transfers about a billion cubic meters of water per year, out of which the desalination part would circulate about 100 million $m^3$. Hence the interest and depreciation costs that amount to 15 cents per cubic meter of desalinated water, is an exaggeration. Thus, all that one needs in order to justify the project is to be convinced that the (average) marginal benefits per $m^3$ of desalinated water in the Dead Sea region is close to 60 cents per $m^3$. Furthermore, if one considers technological improvements and cost declines in the production of the membranes, then even at the 6% capital costs, the 50 cents/m$^3$ would be the upper limit.

The desalination project we have recommended is relatively small compared to the entire project of the Red Sea-Dead Sea Canal, even in its smallest scale. Hence, the desalination project can be folded several times even at the low-scale canal project and certainly at the large-scale canal project—50 m$^3$/second, i.e. about 1.6 billion m$^3$/year.

## *References*

1. N. Arad and P. Glueckstern. Desalination: A Review of Technology and Cost Estimates. Dan Yaron, (ed.), *Salinity in Irrigation and Water Resources.* NY: Marcel Dekker (1981).
2. P. Glueckstern. "Preliminary Considerations of Combining a Large Reverse Osmosis Plant with the Mediterranean-Dead Sea Project". *Desalination*, 40: 143-156. Amsterdam: Elsevier Scientific Publishing Company (1982).
3. A. Halprin and H. Gordin. Economic Aspects of R&D of Marine Agriculture in Israel. Unpublished (Hebrew) (1990).
4. Israel Electric Corporation. Mediterranean-Dead Sea Project - Engineering Feasibility and Cost Benefit Analysis. Haifa (1978).
5. E. Kally. A Biterritorial Seas Project - A Basic Report. Government of Israel: Ministry of Energy and Infrastructure (Hebrew 1988).
6. E. Kally. The Non-Hydroelectric Benefits of the Arava Two Seas Project. Government of Israel: Ministry of Energy and Infrastructure (Hebrew, 1990).
7. W.C. Loudermilk. *Palestine Land of Promise.* London (1944).
8. Steering Committee of the Mediterranean-Dead Sea Project. Publication issued on the Project (1981).

## Table 1 - Summary of Basic Assumptions for the Calculations of the Different Alternatives

---

1. General Design Data

| | |
|---|---|
| - Working days at full capacity | 330 |
| - Salt content of the sea water mg/1 | 42,000 |
| - Average temperature of the sea water, °C | 22 |

2. Engineering Design Data

2.1 Type of membranes - 8" dia. spiral wound.

2.2 Number of membranes in a single pressure tank: 6.

2.3 Output of desalinated water from a basic desalination unit: 10,000 $m^3$ per day.

2.4 Feedwater recovery: 35%.

2.5 Work pressure of the membranes: up to 70 atm.

2.6 Efficiency of pumping equipment --
pumps of 300 $m^3$: 80%.
pumps of 600 $m^3$: 83%.

2.7 Turbines for energy recovery: identical to pumps.

2.8 All other design data are summarized in Table 2.

3. Economic Data

3.1 Price of membranes: according to commercial offers.

3.2 Price of equipment: according to commercial offers and/or international publications.

3.3 Calculation of direct expenses: excepting desalination units, all of the other components were calculated according to two estimates (see Table 3):

(a) high - based on existing plants and/or commercial offers and the assumption of not particularly convenient site conditions.

(b) low - based on more advanced technology and the assumption of comfortable site conditions.

3.4 Indirect expenses (as percent of the direct expenses) calculated according to the following specifications:

| | | low estimate | high estimate |
|---|---|---|---|
| (a) | planning, administration and supervision, interest during construction, and general expenses | 20.3 | 33.3 |
| (b) | contingency | 12.5 | 20.0 |
| | | 32.8 | 53.3 |

3.5 The relationship between the price of electricity during off-peak hours and the average price: 0.6.

3.6 Number of operators and maintenance personnel in the plant:
low estimate - 30
high estimate - 40

3.7 Annual expenses for spare parts and maintenance materials: 2% of the direct investment, excluding membranes.

3.8 Rate of membrane replacement:
high estimate - 2% per month
low estimate - 1% per month

Table 2 - Summary of Design Data

| Alternative | | A-1 | A-2 | B-1 | B-2 |
|---|---|---|---|---|---|
| 1. | Output of desalinated water, $m^3$/day | 200,00 | 200,000 | 200,000 | 200,000 |
| 2. | Type of sea water, mg/1,<br>°C | 42,000<br>22 | 42,000<br>22 | 42,000<br>22 | 42,000<br>22 |
| 3. | Desalination process, reverse osmosis (R.O.) | (R.O.) | (R.O.) | (R.O.) | (R.O.) |
| 4. | Number of desalination units | 20 | 20 | 20 | 20 |
| 5. | Type of membrane, spiral wound 8" diameter | 8" s.w. | 8" s.w. | 8" s.w. | 8" s.w. |
| 6. | Feedwater recovery, % | 35 | 35 | 35 | 35 |
| 7. | Number of membranes per desalination unit | 1,302 | 1,302 | 1,302 | 1,302 |
| 8. | Number of membranes per pressure vessel | 6 | 6 | 6 | 6 |
| 9. | Number of pressure vessels per desalination unit | 217 | 217 | 217 | 217 |
| 10. | Pressure at entrance to membranes, atm | 70.0 | 70.0 | 70.0 | 70.0 |
| 11. | Pressure at entrance to process pump, atm | 1.0 | 41.5 | 41.2 | 27.8 |
| 12. | Pressure increase of process pump, atm | 69.0 | 28.5 | 28.8 | 42.2 |
| 13. | Number of process pumps (and power recovery turbines) per desalination unit | 4 | 2 | 2 | 2 |
| 14. | Process pump flow, $m^3$/hr | 300 | 600 | 600 | 600 |
| 15. | Efficiency of Process pump, % | 80 | 83 | 83 | 83 |
| 16. | Process pump power, kw | 704 | 560 | 566 | 930 |
| 17. | Pressure drop until the entrance to the turbine, atm | 4.0 | 4.0 | 4.0 | 4.0 |
| 18. | Pressure at the exit from the turbine, atm | 1.0 | 1.0 | 44.7 | 31.2 |
| 19. | Difference of pressure on the turbine, atm | 65.0 | 65.0 | 21.3 | 34.8 |
| 20. | Efficiency of the turbine for energy recovery, % | 80 | 83 | 83 | 83 |
| 21. | Flow | 195 | 390 | 390 | 390 |
| 22. | Power of single power recovery turbine, kw | 276 | 560 | 188 | 306 |
| 23. | Consumption of electrical power of a pump-turbine, kw | 446 | --- | 394 | 545 |
| 24. | Total hourly supply of feedwater to the plant in $m^3$ | 24,000 | 48,000* | 24,000 | 24,000 |
| 25. | Number of feedwater supply pumps | 5 | 5 | --- | --- |
| 26. | Pressure of feedwater pumps, atm | 3.0 | 42.0 | --- | --- |
| 27. | Efficiency of feedwater pumps + motor, % | 85.0 | 85.0 | --- | --- |
| 28. | Feedwater pump power capacity, kw | 460 | 12,900* | --- | --- |
| 29. | Average active capacity of auxiliary services, kw | 500 | 800 | 800 | 800 |
| 30. | Total power during off-peak hours only, kw | --- | 64,500 | --- | --- |
| 31. | Total power capacity in the plant, kw | 38,480 | 65,300 | 16,560 | 22,600 |
| 32. | Specific energy consumption, kWh/$m^3$ | 4.62 | 3.97 | 1.99 | 2.71 |
| 33. | Consumption at all hours of the day, kWh/$m^3$ | 4.62 | 0.10 | 1.99** | 2.71*** |
| 34. | Consumption at off-peak hours only, kWh/$m^3$ | --- | 3.87 | --- | --- |
| 35. | Feedwater stages | 2 | 2 | 2 | 2 |
| 36. | Total filtration area, $m^2$ | 4,800 | 4,800 | 4,800 | 4,800 |
| 37. | Area of main building, $m^3$ | 5,000 | 5,000 | 5,000 | 5,000 |
| 38. | Area required for the plant, $10^3.m^2$ | 30 | 30 | 30**** | 30 |
| 39. | Annual operating days | 330 | 330 | 330 | 330 |
| 40. | Annual output, $10^6$ $m^3$ | 66 | 66 | 66 | 66 |

* Reservoir pumped during 12 hours of the day.

** Does not include participation in pumping in the Seas Canal (approximately 0.4 kWh/$m^3$).

*** Does not include participation in pumping in the Seas Canal (approximately 0.3 kWh/$m^3$).

**** Does not include area of pumped storage system.

Table 3 - Summary of Direct and Indirect Investments (estimates)

| Alternative | A-1 | | A-2 | | B-1 | | B-2 | |
|---|---|---|---|---|---|---|---|---|
| Estimate | Low | High | Low | High | Low | High | Low | High |
| Investments in thousands of dollars | | | | | | | | |
| 1. Infrastructure (site development, buildings, tanks, foundations, and electrical connections) | 6,500 | 8,000 | 5,500 | 8,000 | 5,500 | 7,000 | 6,500 | 8,000 |
| 2. Filtration of sea water (feedwater pre-treatment) | 10,000 | 15,000 | 10,000 | 15,000 | 10,000 | 15,000 | 10,000 | 15,000 |
| 3. Desalination units, including assembly | 102,000 | 102,000 | 87,800 | 87,800 | 87,200 | 87,200 | 91,200 | 91,200 |
| 4. Sea water intake | 1,500 | 2,500 | * | * | * | * | * | * |
| 5. Other investments | --- | --- | 63,500** | 77,500** | 6,000*** | 8,500*** | 5,000*** | 7,500*** |
| 6. Total direct investments | 120,000 | 127,500 | 167,800 | 188,300 | 108,700 | 117,700 | 112,700 | 121,700 |
| 7. Indirect investments | 39,360 | 67,700 | 55,040 | 99,990 | 35,650 | 62,500 | 36,970 | 64,620 |
| 8. Spare parts | 2,500 | 5,000 | 3,200 | 6,400 | 2,500 | 5,000 | 2,500 | 5,000 |
| 9. Total investments | 161,860 | 200,200 | 226,040 | 294,690 | 146,850 | 185,200 | 152,170 | 191,320 |
| 10. Participation in expanding the canal | --- | --- | --- | --- | 13,800 | 31,000 | 9,700 | 21,700 |
| Specific Investment, $\$/m^3$ per day | | | | | | | | |
| 11. Without participation in expanding canal | 809 | 1,001 | 1,130 | 1,473 | 734 | 926 | 761 | 957 |
| 12. With participation in expanding canal | 809 | 1,001 | 1,130 | 1,473 | 803 | 1,081 | 809 | 1,065 |

* Included in 5

** Pumped storage plant

*** Pressure pipe

Table 4 - Summary of Specific Investments, Specific Energy Consumption, Operational Expenses, and Desalinated Water Costs vs. Interest Rates

| Alternative | | A-1 | | A-2 | | B-1 | | B-2 | |
|---|---|---|---|---|---|---|---|---|---|
| Estimate | | Low | High | Low | High | Low | High | Low | High |
| 1. | Specific investment in membranes, $\$/m^3$-year | 0.59 | 0.59 | 0.59 | 0.59 | 0.59 | 0.59 | 0.59 | 0.59 |
| 2. | Direct specific investment, except for membranes | 1.23 | 1.34 | 1.95 | 2.26 | 1.06 | 1.19 | 1.12 | 1.25 |
| 3. | Specific investment, except for membranes, including participation in expanding the canal | 1.83 | 2.44 | 2.83 | 3.87 | 1.85 | 2.68 | 1.88 | 2.66 |
| 4. | Specific energy consumption, kWh/$m^3$ | | | | | | | | |
| | - during all hours of the day | 4.2 | 4.6 | 0.1 | 0.1 | 2.2 | 2.4 | 2.7 | 3.0 |
| | - during off-peak hours only | -- | -- | 3.6 | 3.9 | -- | -- | -- | -- |
| | - compounded according to average price* | 4.2 | 4.6 | 2.3 | 2.4 | 2.2 | 2.4 | 2.7 | 3.0 |
| 5. | Number of operators and maintenance personnel | 30 | 40 | 30 | 40 | 30 | 40 | 30 | 40 |
| 6. | Cost of operation and maintenance, cents/$m^3$: | | | | | | | | |
| | - Personnel | 2.0 | 2.7 | 2.0 | 2.7 | 2.0 | 2.7 | 2.0 | 2.7 |
| | - Chemicals | 4.0 | 6.0 | 4.0 | 6.0 | 4.0 | 6.0 | 4.0 | 6.0 |
| | - Spare parts and maintenance materials | 2.5 | 2.7 | 3.9 | 4.5 | 2.1 | 2.4 | 2.2 | 2.5 |
| | - Membrane replacement | 7.1 | 14.2 | 7.1 | 14.2 | 7.1 | 14.2 | 7.1 | 14.2 |
| | - Total, not including energy | 15.6 | 25.6 | 17.0 | 27.4 | 15.2 | 25.3 | 15.3 | 25.4 |
| | - Energy | 25.2 | 27.6 | 13.5 | 14.4 | 13.2 | 14.4 | 16.2 | 18.0 |
| | - Total including energy | 40.8 | 53.2 | 30.5 | 41.8 | 28.4 | 39.7 | 31.5 | 43.4 |
| 7. | Cost of the capital component, cents/$m^3$ | | | | | | | | |
| | - where interest is: 0% annually | 6.2 | 8.1 | 9.4 | 12.9 | 6.2 | 8.9 | 6.3 | 8.6 |
| | 3% annually | 11.3 | 14.2 | 16.2 | 21.5 | 11.2 | 15.4 | 11.4 | 17.1 |
| | 6% annually | 17.1 | 21.3 | 24.1 | 31.7 | 17.0 | 23.0 | 17.2 | 22.9 |
| 8. | Total cost of desalinated water, cents/$m^3$ where interest is: | | | | | | | | |
| | - 0% annually | | | | | | | | |
| | - 3% annually | 47.0 | 61.3 | 39.9 | 55.5 | 34.6 | 48.6 | 37.8 | 52.0 |
| | - 6% annually | 52.0 | 67.4 | 46.7 | 64.1 | 39.6 | 55.1 | 42.9 | 60.5 |
| | | 57.9 | 74.5 | 54.6 | 73.5 | 45.4 | 62.7 | 48.7 | 66.3 |

* 6.0 cents/kWh

Table 5 - Average Values of Investments, Energy Consumption, Operation Expenses, and Cost of Desalinated Water vs. Price of Capital and Price of Electricity

| Alternative | A—1 | | | A—2 | | | B—1 | | | B—2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Values of Economic Parameters | Average Value | Difference (1) % | Index (2) % | Average Value | Difference (1) % | Index (2) % | Average Value | Difference (1) % | Index (2) % | Average Value | Difference (1) % | Index (2) % |
| 1. Specific investment, | | | | | | | | | | | | |
| $\$/m^3$ - daily (3) | 905 | | | 1302 | | | 830 | | | 856 | | |
| $\$/m^3$ - annually (3) | 2.74 | 10 | Basic | 3.94 | 13 | 144 | 2.52 | 11 | 92 | 2.59 | 11 | 95 |
| $\$/m^3$ - annually (4) | 2.74 | 10 | | 3.94 | 13 | 144 | 2.86 | 15 | 104 | 2.86 | 14 | 104 |
| 2. Specific energy consumption, kWh/$m^3$ | | | | | | | | | | | | |
| during all hours of the day | 4.40 | | | 0.10 | | | 2.30 | | | 2.85 | | |
| during off-peak hours only | -- | | | 3.85 | | | -- | | | -- | | |
| compounded according to average price (5) | 4.40 | 5 | Basic | 2.30 | 4 | 52 | 2.30 | 4 | 52 | 2.85 | 5 | 65 |
| 3. Operation costs, not including energy, cents/$m^3$ | 20.60 | 24 | Basic | 22.20 | 23 | 108 | 20.30 | 25 | 99 | 20.40 | 25 | 99 |
| a. Where the price of electricity is: 6.0 cents/kWh | | | | | | | | | | | | |
| and interest is: 0% annually | 54.20 | 13 | Basic | 47.70 | 16 | 88 | 41.60 | 17 | 77 | 44.90 | 16 | 83 |
| 6% annually | 66.20 | 13 | Basic | 64.10 | 15 | 97 | 54.10 | 16 | 82 | 57.50 | 15 | 87 |
| b. Where the price of electricity is: 10.0 cents/kWh | | | | | | | | | | | | |
| and interest is: 0% annually | 71.80 | 11 | Basic | 56.90 | 14 | 79 | 50.90 | 16 | 71 | 56.30 | 14 | 78 |
| 6% annually | 83.80 | 11 | Basic | 73.30 | 13 | 87 | 63.00 | 15 | 75 | 68.90 | 14 | 82 |

(1) The difference (±) from the average in percentages of the high and low estimates.

(2) In comparison to the basic alternative (A-1).

(3) Not including participation in the investment to expand the canal.

(4) Including participation in the investment to expand the canal.

(5) Assuming that the price during off-peak is 60% of the average price.

**Table 6 - The Influence of the Size of the Desalination Plant on Investments and the Cost of Desalinated Water**

(index in % in comparison to the plant of reference—200,000 $m^3$ daily)

| Alternate | A—1 | | A—2 | | B—1 | | B—2 | |
|---|---|---|---|---|---|---|---|---|
| Output, thousands of $m^3$-daily | 50 | 400 | 50 | 400 | 50 | 400 | 50 | 400 |
| Specific investment, $/$m^3$-daily | 108 | 97 | 125 | 91 | 111 | 95 | 111 | 95 |
| Cost of desalinated water:<br>(price of electricity = 6 cents/kWh) | | | | | | | | |
| interest on the capital = 6% | 107 | 97 | 116 | 94 | 110 | 96 | 109 | 97 |
| Interest on the capital = 0% | 107 | 98 | 118 | 94 | 110 | 96 | 109 | 97 |

**Table 7 - Potential for Lowering the Price by Realizing the Low Estimate and Realizing an Additional Price Drop by Using Improved Pumps and Decreasing the Cost of Replacing Membranes***

| Alternative | A—1 | | | B—2 | | |
|---|---|---|---|---|---|---|
| | Potential Price Drop Cents/m3 | Average Cost Cents/m3 | % | Potential Price Drop Cents/m3 | Average Cost Cents/m3 | % |
| 1. Cost of desalinated water | -- | 66.2 | 100.0 | -- | 57.5 | 100.0 |
| 2. Lowering price by realizing the low estimate: | | | | | | |
| 2.1 Capital expenses | 2.1 | | 3.2 | 2.9 | | 5.0 |
| 2.2 Energy expenses | 1.2 | | 1.8 | 0.9 | | 1.6 |
| 2.3 Membrane replacement expenses | 3.5 | | 5.3 | 3.5 | | 6.1 |
| 2.4 Operation and maintenance expenses not including membranes | 1.5 | | 2.3 | 1.5 | | 2.6 |
| 2.5 Total price drop by realizing the low estimate. | 8.3 | | 12.6 | 8.8 | | 15.3 |
| 3. Additional price drop beyond the low estimate: | | | | | | |
| 3.1 Use of pumps with improved efficiency (90%) | 1.4 | | 2.1 | 0.8 | | 1.4 |
| 3.2 Decreasing the cost of membrane replacement (50%) | 3.5 | | 5.3 | 3.5 | | 6.1 |
| 3.3 Total additional price drop | 4.9 | | 7.4 | 4.3 | | 7.5 |
| 4. Total potential lowering of price (clauses 2.5 + 3.3) | 13.2 | | 20.0 | 13.1 | | 22.8 |
| 5. Cost of desalinated water realizing entire potential for lowering the price | | 53.0 | 80.1 | | 44.4 | 77.2 |

* With real interest of 6% annually and energy price of 6 cents/kWh.

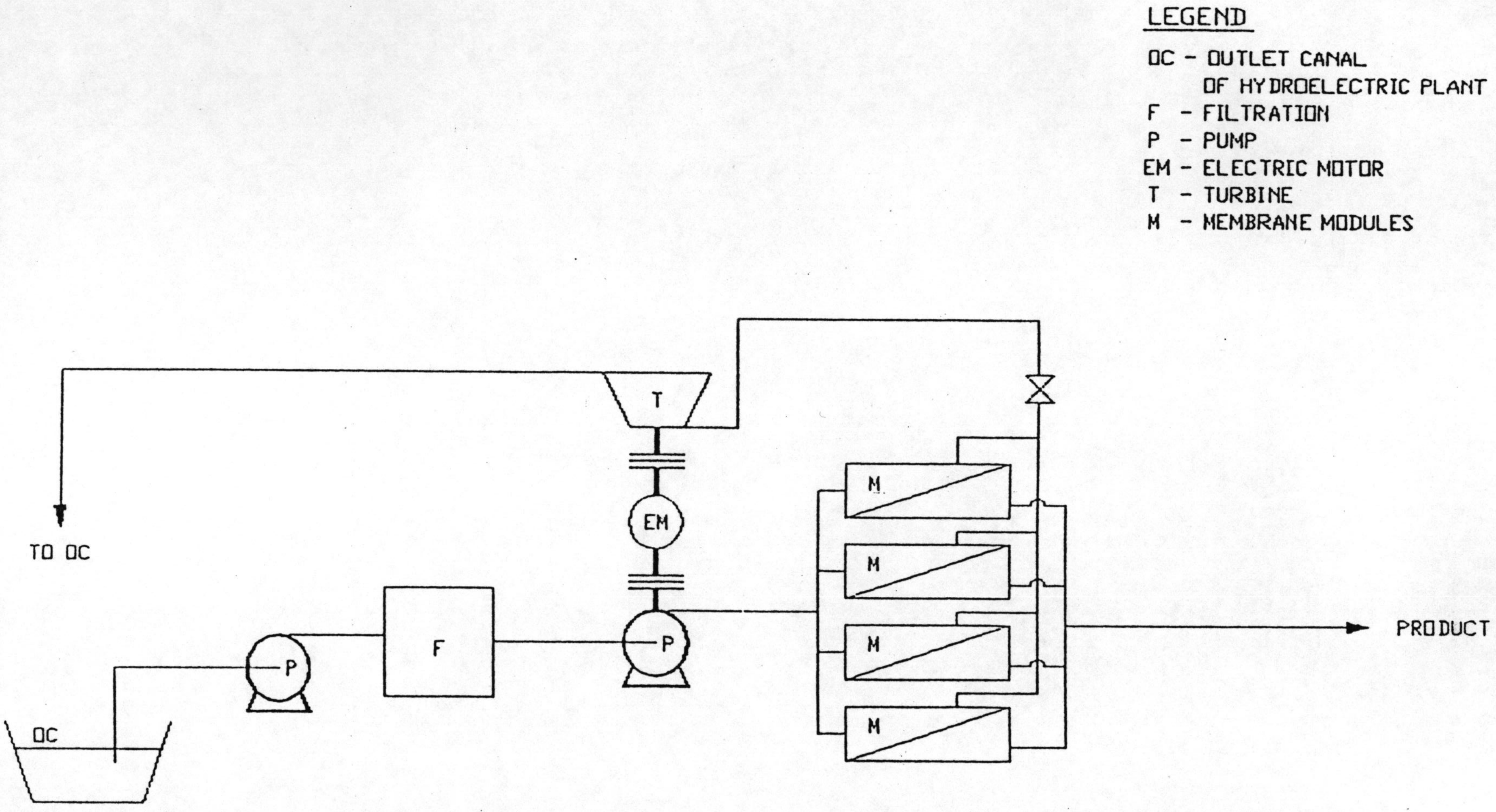

DIAGRAM 1: CONNECTION SCHEME OF CONVENTIONAL REVERSE OSMOSIS DESALTING PLANT RECEIVING FEEDWATER FROM THE OUTLET CANAL OF THE HYDROELECTRIC PLANT (ALTERNATIVE A1)

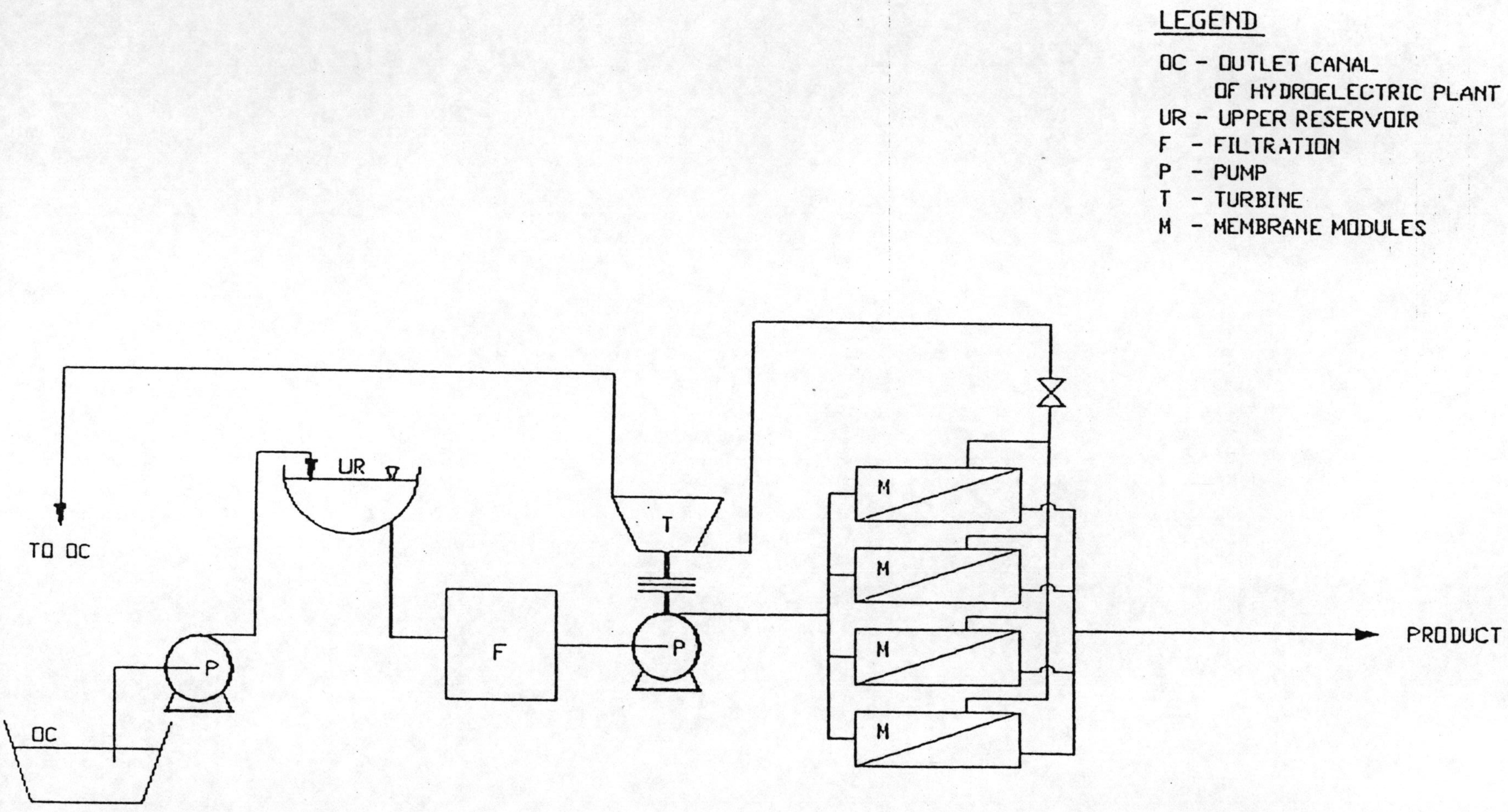

DIAGRAM 2: CONNECTION SCHEME OF REVERSE OSMOSIS DESALTING PLANT (USING HYDROSTATIC PRESSURE) IN CONJUNCTION WITH A PUMPED STORAGE SYSTEM RECEIVING FEEDWATER FROM OUTLET CANAL OF THE HYDROELECTRIC PLANT (ALTERNATIVE A2)

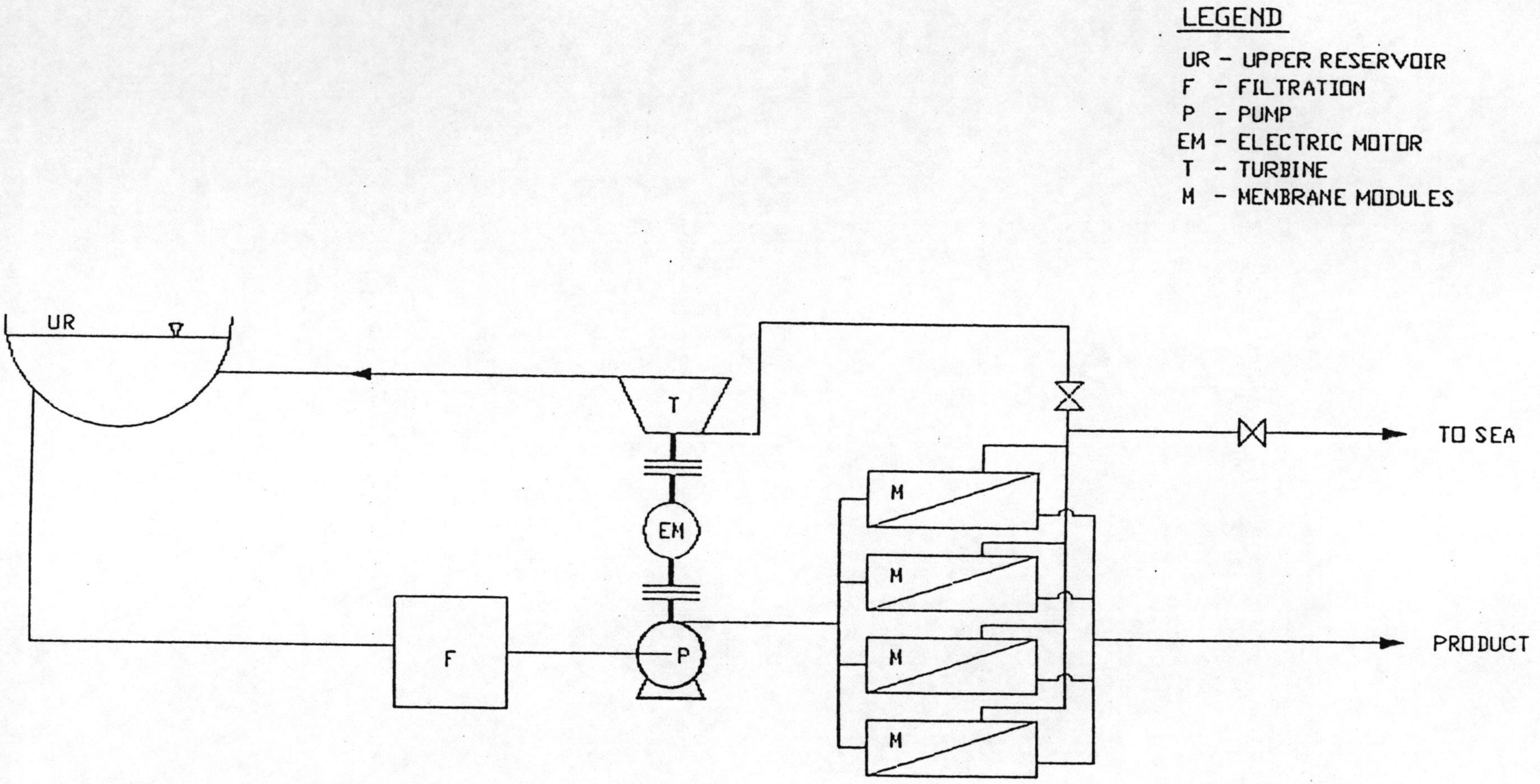

DIAGRAM 3: CONNECTION SCEME OF A CONJUNCTIVE HYDRO-ELECTRIC REVERSE OSMOSIS PLANT
(ALTERNATIVE B1 OR B2)

## ooks

- Ruth Arad, Zeev Hirsch and Alfred Tovias,
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  1983, MacMillan, for the Trade Policy Research Center, London.

- Haim Ben–Shahar, Gideon Fishelson, Zeev Hirsch,
  Economic Cooperation and Middle East Peace,
  1989, Weidenfeld and Nicolson, U.K.

- Gideon Fishelson, (ed.),
  Economic Cooperation in the Middle East,
  1989, Westview Press, Boulder, Colorado.

- Elisha Kally,
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- Elisha Kally,
  Water and Peace,
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