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Desalting Seawater and Brackish Waters: 1981 Cost Update

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Engineering Technology Division

DESALTING SEAWATER AND BRACKISH WATERS: 1981 COST UPDATE

Prepared by

S. A. Reed
for
Office of Water Research and Technology
U. S. Department of the Interior
Washington, D.C. 20240

Date Published - August 1982

Prepared by the
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Oak Ridge, Tennessee 38930
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UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

FOREWORD

This report was prepared for the Office of Water Research and Technology, U.S. Department of the Interior. The Project Manager was Melvin E. Mattson, whose guidance and support is gratefully acknowledged.

The capital, operation, and maintenance costs presented in this report for the membrane processes were compiled by T. J. Larson Associates under contract with the Nuclear Division of Union Carbide Corporation. Corresponding data for the section on distillation systems was compiled by Mr. Gordon Leitner of Leitner and Associates, Inc.

During the course of this study, input was received from a number of equipment manufacturers, consultants, and architect and engineering (A&E) firms. The helpful assistance provided by all who contributed to this report is gratefully acknowledged. We wish to especially acknowledge the help of William E. Katz, Ionics, Inc., who assisted in optimizing the electrodialysis equipment flowsheets for treating the various feedwaters discussed in Sect. 3.5 of this report.

All of us in the desalting community were stunned and saddened by the untimely death of Ted Larson on December 24, 1981. We who had the good fortune to know and work with Ted will always remember him for his numerous contributions to the advancement of membrane desalination technology.

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DESALTING SEAWATER AND BRACKISH WATERS: 1981 COST UPDATE

S. A. Reed

ABSTRACT

This is the fourth in a series of desalting cost update reports. Cost data are reported for desalting seawater by various distillation systems and by reverse osmosis. Costs of desalting four brackish waters, representative of those found in the United States by both reverse osmosis and electrodialysis are also given. Cost data are presented parametrically as a function of energy cost and plant size.

The cost of desalting seawater by distillation has increased by 40% during the past two years, while desalting by reverse osmosis has increased by about 36% during the same period. Brackish water desalting by reverse osmosis has only increased by about 12%, and brackish water desalting by electrodialysis is up by 40%. Again, the continued increase in energy costs has had a major impact on all desalination systems.

1. INTRODUCTION AND SUMMARY

1.1 Introduction

Approximately two years ago, four years ago, and also six years ago, cost data were obtained from U.S. manufacturers of desalting equipment. These data were used to estimate the cost of conversion of seawater by commercial distillation and reverse osmosis systems; and brackish waters by reverse osmosis and electrodialysis systems. The first study was published in January 1976 as an Oak Ridge National Laboratory Report, ORNL/TM-5070 (Rev.). The second report, ORNL/TM-5926, which updated the first was published in November 1977. The third, ORNL/TM-6912, which was the second update, was published in August 1979.

This report updates ORNL/TM-6912 by estimating product water costs based upon second quarter 1981 installed equipment costs, a level fixed charge rate, and energy and site development costs which are current. The water costs for all processes include all site development costs, intakes and outfalls, etc. Each cost element is considered separately and the assumptions are given so that the reader may make the appropriate adjustments to relate the costs presented to his or her particular case.

1.2 Summary

The cost data given in the prior reports reflected the rapid increases in the cost of fuel and the marked escalation in equipment costs and interest rates on borrowed capital during the 1970s. The trend of increasing costs continued in most areas during the past two years, as reflected in this current report.

The cost of civil works and switchgear has continued to rise at 7 to 9% per year, and overall plant equipment costs for distillation systems have increased at an annual rate of about 12%. It is interesting to note that the cost of reverse osmosis equipment has remained relatively constant during 1979 and 1980, primarily due to increased competition. This cost stability, however, has been more than offset by a doubling of the electrical energy costs, and in the case of seawater reverse osmosis, a doubling in the membrane replacement cost, as well. Capital costs for electrodialysis systems have increased about 12% per year, and operation and maintenance costs are up 50% or more due primarily to a doubling in electrical energy costs.

The net result of the above items is that the cost of desalting seawater by distillation has increased by 40% during the past two years, while desalting by reverse osmosis has increased by about 36% during the same period. Brackish water desalting by reverse osmosis has only increased by about 12%, and brackish water desalting by electrodialysis is up by 40%.

2. BASIS FOR COST ESTIMATES

2.1 Financial Parameters

All cost estimates are based upon second quarter 1981 dollars. Utility financing, with a plant life expectancy of 30 years was used. A levelized fixed charge rate of 18% was used in all calculations. A rate of 11% was used for interest during construction.

2.2 Capital Costs

Capital cost estimates exclude certain site specific costs, such as those for the purchase of land and for the storage or distribution of the final product water from the system. Costs have been included for site development, the civil work associated with the establishment of well fields and brine disposal or the installation of intakes and outfalls, as required, and the provision of the necessary electrical switchgear. These costs will vary with the site selected, but are included here for completeness. The reference cases are based upon the assumption that the system would be installed in a continental U.S. location at a site which does not have intakes, outfalls, or brine disposal, and which requires some, but not extensive site development work.

2.3 Indirect Capital Costs

As noted above, an interest rate of 11% on capital has been assumed during the construction period. Working capital was assumed to be 5% of the total direct capital cost. A contingency and architect and engineering (A&E) fee equal to 16% of the direct and other indirect capital costs has also been included. These rates and fees are considered realistic and appropriate for construction programs at this time.

2.4 Plant Load Factor

A plant load factor of 85% has been assumed for all seawater systems, and 95% for brackish water systems. These plant factors are representative of today's state-of-the-art.

2.5 Chemical Costs

Chemical treatment costs were computed using unit prices shown in Table A.

It is recognized that treatment costs will vary with feedwater characteristics, the process employed, and the system recovery. The treatment costs listed herein are based upon the feedwater composition analyses and ranges indicated, and are considered to be typical.

2.6 Energy Costs

For the distillation systems, it was assumed that electricity would be generated on-site using steam from boilers fired with oil, high sulphur coal, low sulphur coal, or nuclear steam from a dual purpose electric station. Steam and electric costs were based upon the values shown in Table B. (A further breakdown of these costs is shown in Appendix B.)

For the membrane plants, it was assumed that operation would be based upon electricity purchased from a utility at an uninterruptable commercial rate of 5¢/kWh. This is an average of the current commercial rates in areas where membrane plants might find use in the United States.

2.7 Labor Costs

The costs of operating and maintenance labor are based upon input from equipment suppliers and end users. These costs are representative of the current practice for systems up to 18,925 m^3/d (5 MGD) in operation in the continental United States.

2.8 Membrane Replacement

Membrane replacement costs for electrodialysis systems are based upon the manufacturer's price for membrane, and a membrane lifetime of seven and one-half years.

Membrane replacement costs for brackish water reverse osmosis systems are based upon current (second quarter 1981) quantity pricing, and an

Table A. Chemical costs

Chemical	Unit cost	
	\$/kg	\$/lb
Antifoam	2.31	1.05
Sulphuric acid (100%)	0.53	0.24
Polyphosphate	3.98	1.81
Sodium hexametaphosphate	0.70	0.32
Potassium permanganate	1.43	0.65
Caustic (NaOH)	0.46	0.21
Sodium sulfite	0.13	0.06
Chlorine	0.30	0.14

Table B. Energy costs

Fuel cost	Steam conditions and cost	Electric cost mils/kWh
Oil – \$5.50/10^6 Btu (\$32.00/bbl, 5.8 x 10^6 Btu/bbl)	Prime, 538°C (1000°F) \$8.98/10^6 kJ (\$8.50/10^6 Btu)	75.0
	129°C (265°F) – \$2.43/10^6 kJ 93°C (200°F) – \$1.54/10^6 kJ	
Coal – \$1.90/10^6 Btu (high sulfur, 12,900 Btu/lb @ \$45.00/ton)	Prime, 538°C – \$5.70/10^6 kJ[a] (\$5.40/10^6 Btu)	53.4
	129°C – \$1.53/10^6 kJ 93°C – \$0.98/10^6 kJ	
Coal – \$2.30/10^6 Btu (low sulfur, 8,040 Btu/lb @ \$37.00/ton)	Prime, 538°C – \$5.40/10^6 kJ[a] (\$5.11/10^6 Btu)	53.2
	129°C – \$1.47/10^6 kJ 93°C – \$0.92/10^6 kJ	
Nuclear (1200 MW PWR) dual purpose (\$0.70/10^6 Btu)	Prime, 274°C (525°F – \$4.91/10^6 kJ (\$4.65/10^6 Btu)	49.3
	129°C – \$1.60/10^6 kJ 93°C – \$1.01/10^6 kJ	

[a]Includes stack gas scrubbers.

assumed three-year lifetime, although there is increasing evidence that five-year lifetimes can be achieved in well operated systems.

Membrane replacement costs based on five-year life time for seawater reverse osmosis systems are estimated at current pricing for Dupont B-10 membrane replacement cost. The Dupont B-10 was chosen as a standard because at this time it dominates the market in the size ranges of interest.

2.9 System Costs and Operating Costs

System costs and operating costs were obtained by direct contact with original equipment manufacturers, membrane suppliers, consultants, the U.S. Government, major A&E firms, etc. All recent references which deal with either capital or operating costs of any of the three processes were reviewed in detail to ensure proper cognizance was taken of each cost contributing factor.

3. DESALTING COSTS

The following sections present the cost of conversion of water by distillation, reverse osmosis, and electrodialysis. The body of the report contains only a few figures showing the results of the analysis. Appendix A contains a series of tables which provide details of each cost contributing item.

3.1 Seawater Desalting by Distillation

The cost of product water as a function of plant size and type of fuel is presented in Fig. 1 for vertical tube evaporators (VTEs) and multistage flash evaporators (MSFs) using acid feed treatment. For small plants, 3785 m^3/d (1 MGD), costs range from a high of \$2.35/m^3 (\$8.90/1000 gal) using an MSF plant in combination with an oil-fired or coal-fired boiler, to a low of \$1.93/m^3 (\$7.31/1000 gal) using a VTE plant with coal-fired boilers. At the largest plant size considered, 378,500 m^3/d (100 MGD), product water costs range from \$1.45/m^3 (\$5.40/1000 gal) for MSF plants using an oil-fired boiler and acid treated feed, down to a low of \$1.11/m^3 (\$4.18/1000 gal) for VTE plants using coal-fired boilers.

Water costs estimated for small 3,785 to 18,925 m^3/d (1 to 5 MGD) MSF plants operating at lower temperature 88 to 91°C (190 to 195°F), using 93°C (200°F) steam to the brine heater and threshold scale treatment, followed a similar but higher trend. The maximum cost of water is \$2.66/m^3 (\$10.05/1000 gal) for the 3785 m^3/d (1 MGD) plant using oil as boiler fuel. The lowest calculated water costs are those for the MED plants utilizing low temperature steam and aluminum alloy heat transfer surface; \$1.82/m^3 at 3785 m^3/d (1 MGD) to \$1.15/m^3 at 37,850 m^3/d (10 MGD) using subituminous coal-fired boilers and \$2.03/m^3 and \$1.31/m^3 for the same respective sizes when utilizing oil-fired boilers.

Seawater distillation costs are shown in this report for unit capacities of from 1,890 m^3/d (0.5 MGD) through 378,500 m^3/d (100 MGD). Several comments are worthy of note:

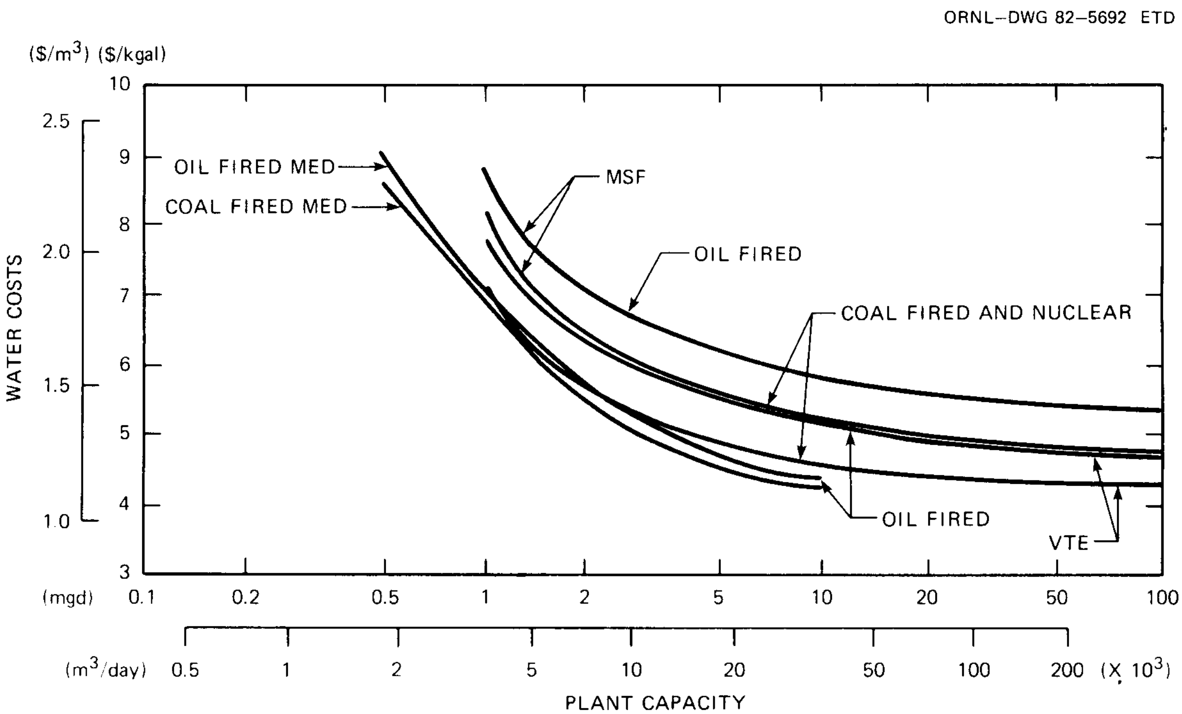

Fig. 1. Water cost — seawater desalting by distillation.

1. While this report is limited to costs of distillation plants built and installed in the continental U.S., no distillation plants within the size range covered by the report have been built and installed in the United States within the past ten years. Three 4732 m^3/d plants were started up in the Virgin Islands in 1980 and 1981. These are discussed on the following page.

2. Because of the almost total absence of distillation plant building activity in the United States, this report necessarily draws upon data from installations in other parts of the world and from estimates based on best available information.

3. Whereas multi-effect distillation (MED) plants [VTE and horizontal tube multi effect (HTME)] produce the lowest cost water using a distillation process, it is surprising to note there have been very few of these plants built. This is no doubt in large part due to the predominant experience with MSF plants and an overall reluctance to build a multi-million dollar plant without similar long term experience. Perhaps due to the increasing competition brought about by seawater reverse osmosis, we can expect to see increasing development activity, using the VTE or HTME process, either alone or in combination with MSF in the coming years.

For this present cost update, a curve has been added (Fig. 2) showing estimated capital equipment costs versus capacity for distillation plants installed in a continental U.S. location. The costs are for plant equipment including civil works and all indirect costs such as interest and project management. The need for such a curve became apparent when a review of the literature revealed so little information on distillation plant capital costs. Published costs for distillation plants that have been built are often not relevant (with one exception) because they are for plants built and installed outside the United States, and because they are likely to include costs for such nonplant components as pipelines, reservoirs, housing complexes, auxiliary power plants, etc.

The curve (Fig. 2) was developed in lieu of merely adding inflation to the cost figures in the previous reports because, over the past several

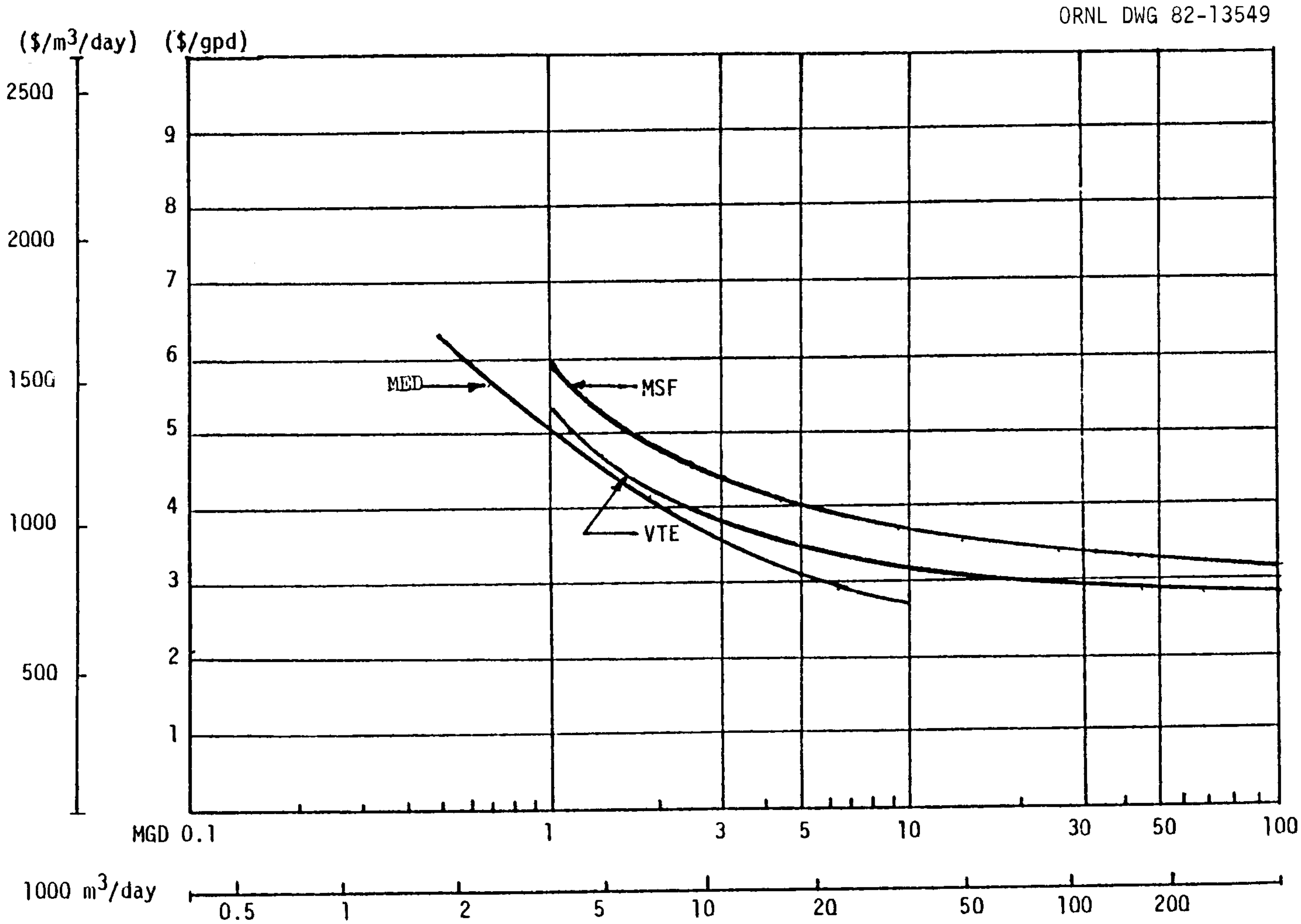

Fig. 2. Capital equipment cost — seawater desalting by distillation.

years there has been an increase in the true cost of distillation plants. As noted by F. C. Wood[1] "...because of improved specifications and higher performance ratios, the increase (in costs) is greater than those of capital goods generally..." The "improved specifications" mainly call for more extensive use of nonferrous materials such as titanium, copper/nickel, and stainless steel, as dictated by field experience.

Sources for data for the curve, in addition to Ref. 1, include the following:

- Reference 2. Birket and Newton, provides an excellent summary of 68 distillation plants operating in 25 locations which include details on heat transfer surface for each of the plants. The amount of surface in a MSF plant is relatively constant for a given gain ratio,* and the cost per pound is relatively unchanged with capacity. By using the data from this report and by using current costs for tubing, a larger component for costs could be fixed for each size of plant for the gain ratio used in this report.
- Reference 3. Hornburg and Jamjoon provide a breakdown of tender prices for a 2270 m^3/d (600,000 GPD) MSF plant, and this data point correlates with Fig. 2.
- Reference 4. Hoffman provides a total installed price for three 4732 m^3/d horizontal tubed, falling film multiple effect distillation (MED) plants. The plants utilize low pressure steam 0.24 MPa (38 psi) in a thermocompressor. The rated gain ratio is 10 to 1. Reported capital costs are approximately \$1057/m^3/d (\$4 per GPD). These plants are equipped with aluminum condensers. The life of aluminum alloy in this environment is yet to be demonstrated in the United States. The point on the cost curve is based on 90/10 Cu:ni alloy.

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*Gain ratio (or performance ratio, PR) = 0.43 kg product water/MJ of steam used (1 lb/1000 Btu).

The MED process employing aluminum alloy heat transfer tubing has been developed under a ten-year Joint United States/Israel Desalination Program which will culminate with a test demonstration of a 18,170 m^3/d plant currently being constructed at Ashdod, Israel. As noted above, Israel Desalination Engineering, Ltd. has recently brought on stream three 4732 m^3/d plants, based on this design, in the Virgin Islands.

Total water costs, including capital costs, are shown in Appendix A (Tables A-1 through A-4). These changes in capital costs that have occurred since the 1979 Cost Update result from the changes shown in Fig. 2, which include the effect of inflation, and from the higher current rates of interest during construction.

Energy costs have increased at an accelerating rate. Since the 1979 Cost Update, increase for produced steam costs are estimated as follows:

	Fuel (% increase in cost)			
	Oil	Bituminous coal	Sub-bituminous coal	Nuclear
Steam conditions 129°C (265°F) and 93°C (200°F)	234	152	156	187

Similarly the cost of electric power used in the report has increased about 55% since the 1979 report.

The energy cost factor will have a profound impact on the design of future distillation plants, most likely leading to higher gain ratios and more complicated and elaborate process schemes.

3.2 Seawater Desalting by Reverse Osmosis

Significant progress in the desalting of seawater by reverse osmosis has been made since the last Cost Update was completed. Currently, there are ~78,000 m^3/d (20 MGD) of capacity either under construction or in operation. The largest systems include a 12,000 m^3/d (3.2 MGD) spiral wound system in Jeddah, Saudi Arabia; a 12,000 m^3/d (3.0 MGD) hollow fine fiber system at Key West, Florida; and a 7,300 m^3/d (1.9 MGD) hollow fine fiber system in Venezuela.

Figures 3, 4, and 5 have been prepared to show the equipment cost (exclusive of site costs or indirect capital costs), the system operating costs (exclusive of the capital charge), and finally the water cost which includes all of the various costs. Figure 5 (Seawater Desalting by Reverse Osmosis) then is directly comparable to Fig. 1 (Seawater Desalting by Distillation).

Figure 3 shows that the capital equipment cost for seawater reverse osmosis systems ranges from approximately \$1450/m³/d (\$5.40/gpd) to \$800/m³/d (\$3.00/gpd) of installed capacity. These values are based upon equipment prices in the United States, and do include installation...but do not include any other site related costs. It is worthy of note that except for very small systems, the capital cost of seawater reverse osmosis systems has remained almost unchanged for the past two years. A major contributory factor to the price stability has been strong price competition among the equipment suppliers.

Figure 4 shows that the operating costs for seawater reverse osmosis systems vary from approximately \$1.45/m³ (\$5.51/1000 gal) to \$0.85/m³ (\$3.27/1000 gal) across the size range of 380 m³/d (0.1 MGD) to 19,000 m³/d (5 MGD). It should be noted that these operating costs are based upon an electrical energy usage of 10 kWh/m³ (38 kWh/1000 gal). If energy recovery were incorporated into the system, the electrical usage would drop to no more than 5.3 kWh/m³ (20 kWh/1000 gal). At current pricing, this would result in a savings in operating cost of \$0.24/m³ (\$0.90/1000 gal). This savings is almost equal to the membrane replacement cost. An additional line has been drawn on Fig. 4 to show the impact of energy recovery on systems of 3800 m³/d (1 MGD) or larger. There is an increasing move among equipment suppliers to incorporate energy recovery devices within large reverse osmosis systems to reduce water costs. This is clearly the trend of the future.

It should be noted that the use of 10 kWh/m³ (38 kWh/1000 gal) as the basis for calculating energy costs is a conservative assumption. Energy usage is primarily a function of combined pump and motor efficiency

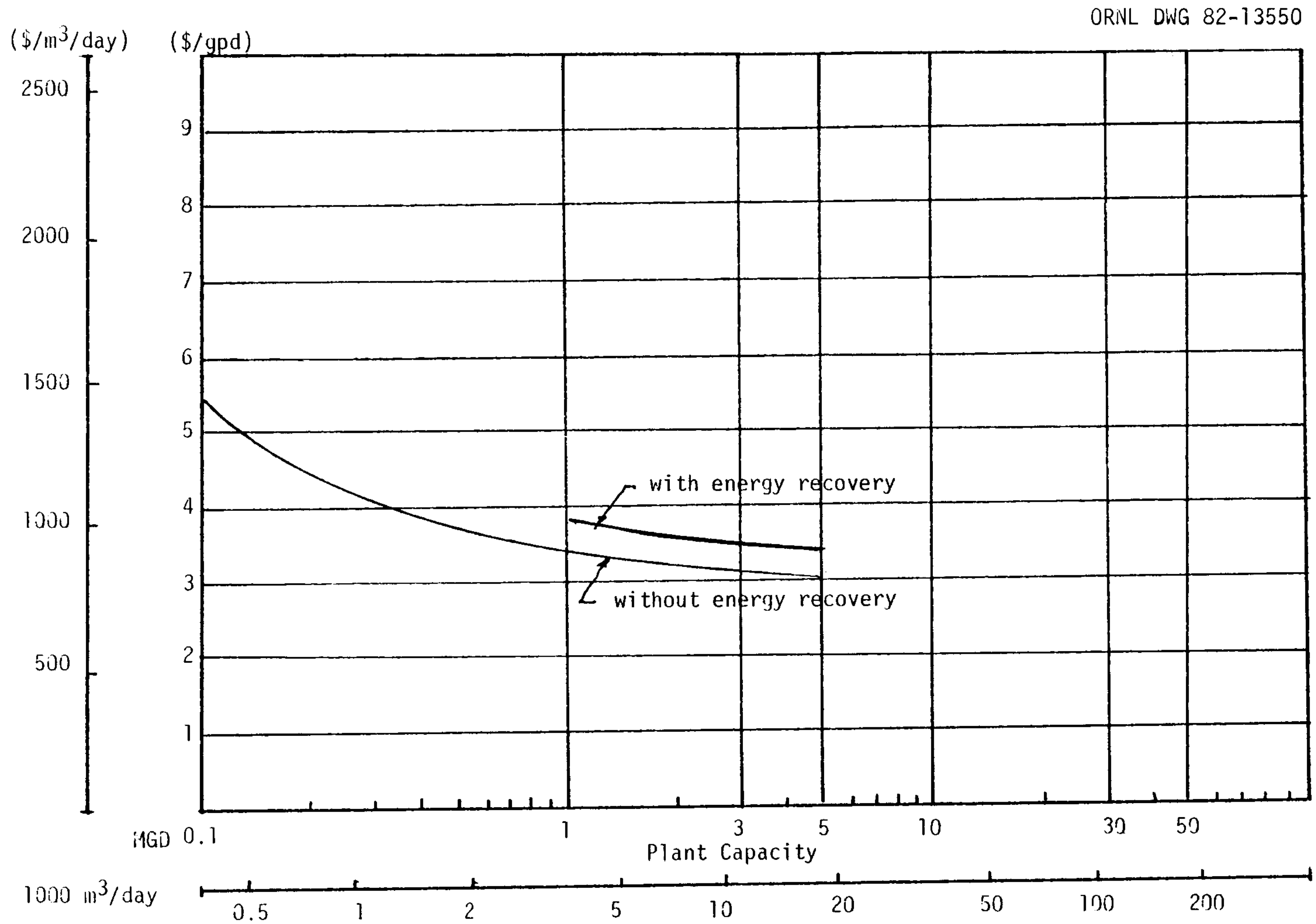

Fig. 3. Capital equipment cost — seawater desalting by reverse osmosis.

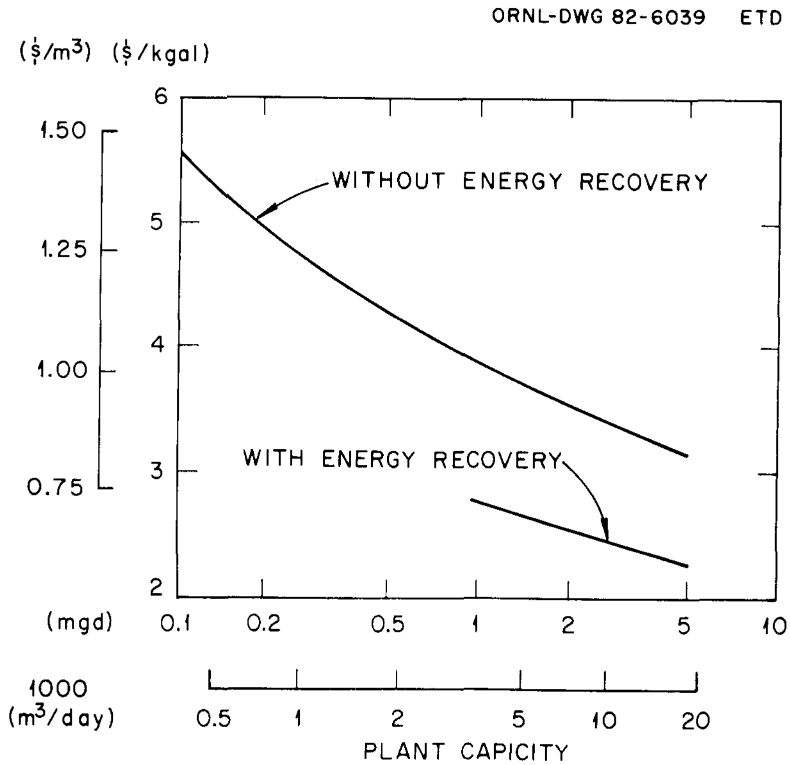

Fig. 4. Operating costs — seawater desalting by reverse osmosis.

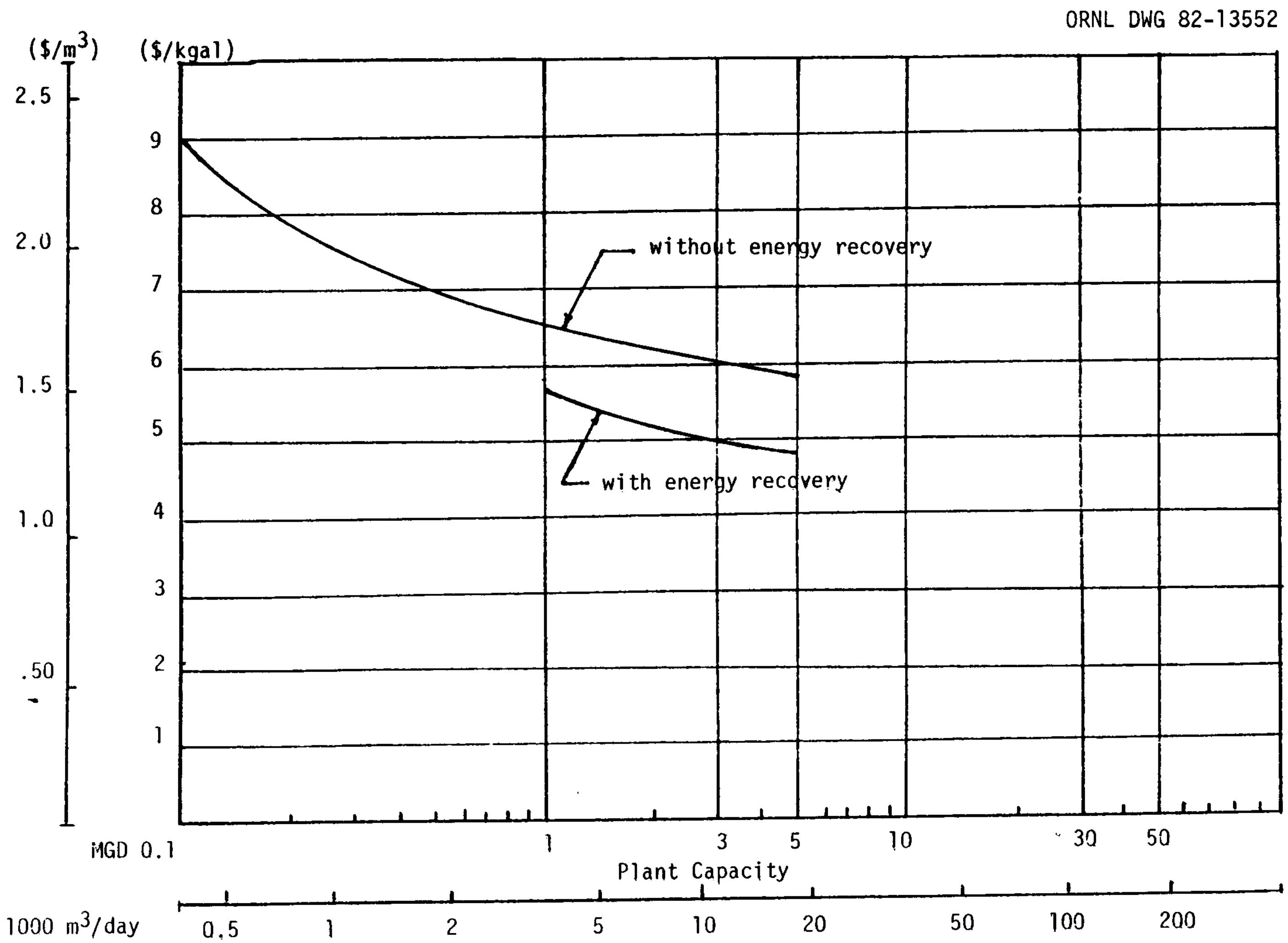

Fig. 5. Water cost — seawater desalting by reverse osmosis.

and will vary depending on plant size and other factors. Moreover, for small capacity plants of 378 m^3/d (100,000 gpd) or less, positive displacement pumps, of high efficiency could be readily substituted.

The major increase in operating cost since the last report is attributable to two items: electrical energy cost, and membrane replacement cost. The cost of electrical energy has doubled – from 2.5¢/kWh to 5.0¢/kWh – over the past two years. This item alone has increased water costs by nearly \$0.26/m^3 (\$1.00/1000 gal).

When the preceding report was prepared two years ago, it appeared that spiral wound seawater reverse osmosis membranes offered significant cost advantages, vis-a-vis membrane replacement, over hollow fine fibers (HFF). Accordingly, the spiral pricing was used. Except for very small systems, the development of the seawater market has been dominated by Dupont's B-10 HFF permeators during the past two years. It seemed appropriate then to use the current membrane replacement cost for Dupont B-10 permeators for this report. These costs are roughly double the projected spiral replacement costs which were shown in the last report. If the spirals ultimately demonstrate their economic promise, membrane replacement costs will decrease proportionately.

Figure 5 shows the water costs for seawater desalting by reverse osmosis. These include not only the operating costs, but also a capital charge based upon equipment costs and other costs associated with the site and the installation. Water costs for seawater desalting by reverse osmosis vary from 2.39/m^3 (\$9.04/1000 gal) at the small system end to \$1.54/m^3 (\$5.82/1000 gal) for larger systems. As with Fig. 4, an additional line has been drawn on the figure to show the salutary impact of energy recovery. In calculating these savings, it was assumed that an energy recovery device would increase the equipment cost by 10%. This assumption is considered to be conservative.

3.3 Seawater Desalting by Electrodialysis and Freezing

Desalting seawater by electrodialysis and freezing are in an advanced state of development and one or both methods may become commercial within the next few years.

With regard to electrodialysis, the Japanese are known to have been working on the development of seawater desalting by electrodialysis for a number of years. There are reported to be a number of successful installations in Japan, but little economic or operating data has yet been made available. In addition, at least one U.S. manufacturer (Ionics) has been doing development work in this area which shows promise of future success.

"Two different freezing methods are being actively investigated. Both methods employ a secondary refrigerant with indirect freezing. They differ in that one is based on use of a vacuum while the second operates at atmospheric pressure. A few small units, based on the vacuum freezing method, have already been sold commercially."

"No information on seawater desalting by electrodialysis or freezing is included herein, but it is important to note that the next revision to this report should investigate both areas thoroughly; and if sufficient progress has been made, an analysis should be included at that time."

3.4 Brackish Water Desalting by Reverse Osmosis

Figures 6, 7, and 8 have been prepared to show, respectively, the equipment cost (exclusive of site costs or indirect costs), the system operating costs (exclusive of the capital charges), and the water cost, including all of the cost inputs. The data have been developed based upon a feed-water with a salinity in the range of 2000 to 5000 ppm total dissolved solids.

Figure 6 shows that the capital cost for brackish water reverse osmosis systems varies from \$160/m^3/d (\$0.60/gpd) for a 3,800 m^3/d (1 MGD) system to \$130/m^3/d (\$0.50/gpd) for a 95,000 m^3/d (25 MGD) system. The trend of price stability observed with seawater reverse osmosis system has also been maintained for brackish water reverse osmosis systems — the effect of competition has counterbalanced inflation.

Figure 7 shows that the operating costs vary from \$0.24/m^3 (\$0.91/1000 gal) to \$0.18/m^3 (\$0.68/1000 gal) over the same range of sizes. The

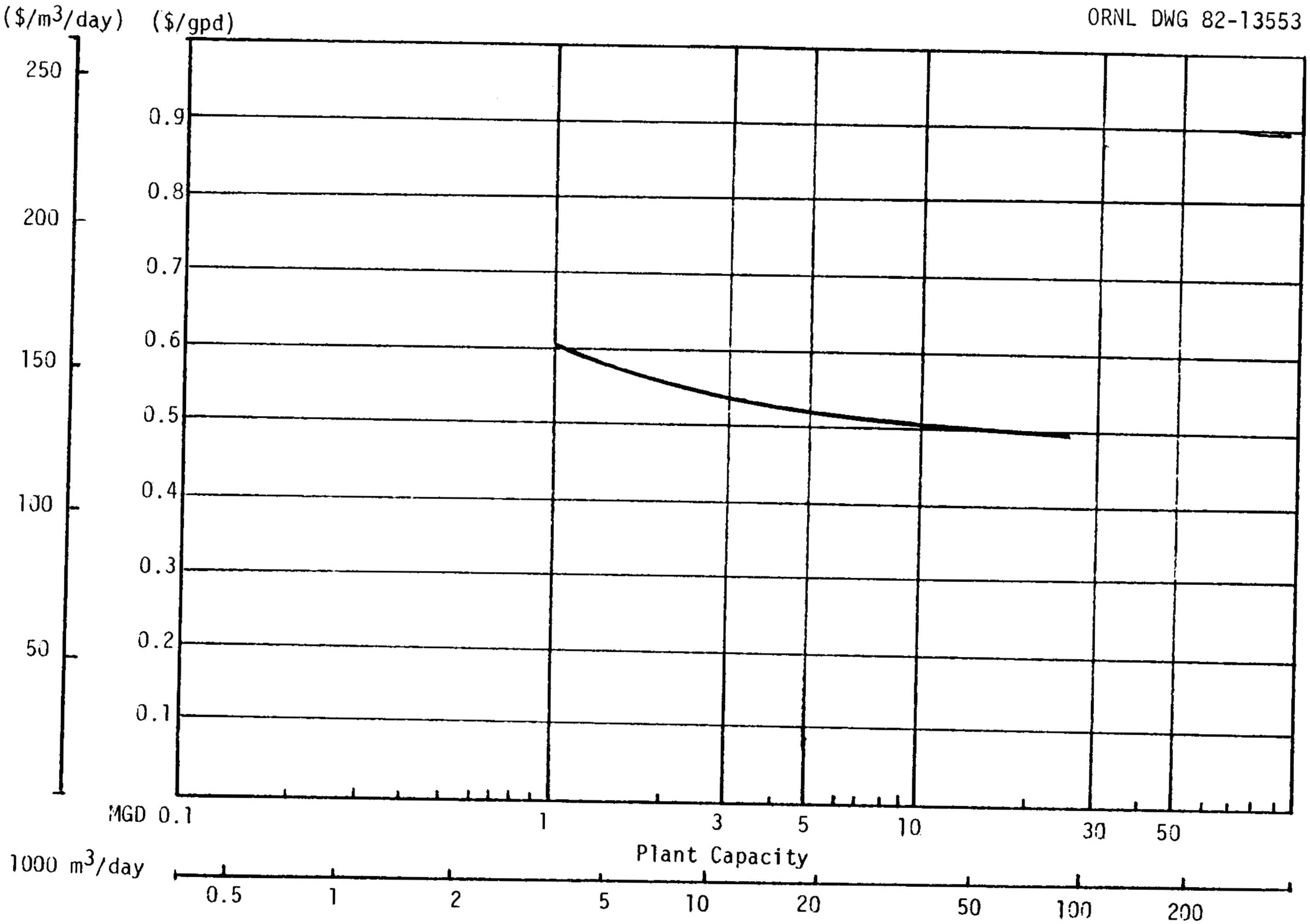

Fig. 6. Capital equipment cost — brackish water desalting by reverse osmosis.

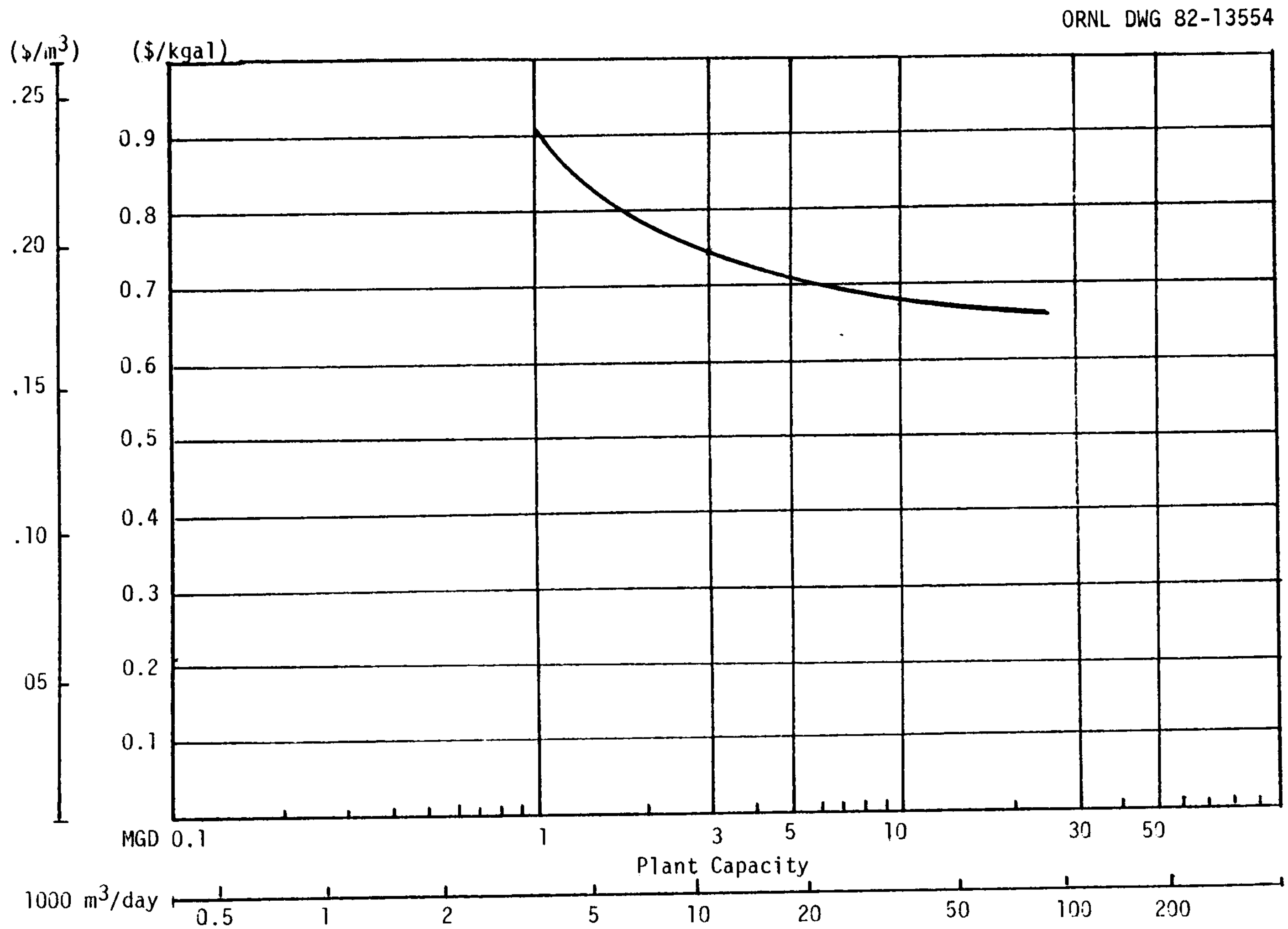

Fig. 7. Operating cost — brackish water desalting by reverse osmosis.

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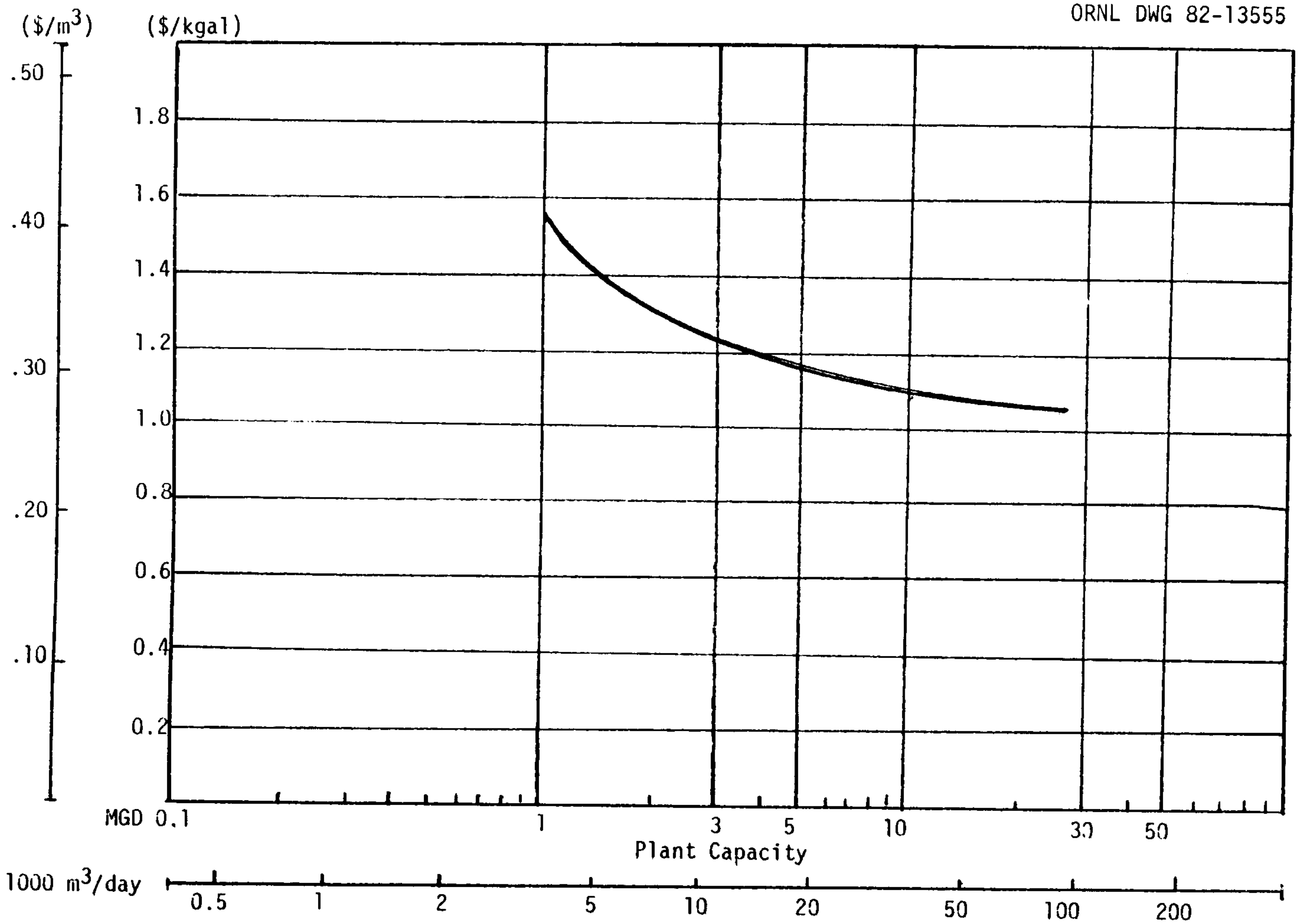

Fig. 8. Water cost — brackish water desalting by reverse osmosis.

primary area of cost increase since the last report has been in the area of electrical energy cost, which has doubled. Energy recovery is not nearly as important in brackish water systems as in seawater because brackish water plants operate at much higher recoveries at lower pressures than seawater systems. A typical pressure used for brackish water desalting is 400 psi. In contrast, operating pressures for seawater plants currently range from 800 to 1000 psi. A major future trend for potential cost reduction in the brackish water area would appear to be centered on new low pressure (i.e., 250 psi maximum) membranes under development.

Figure 8 shows the water costs for brackish water desalting by reverse osmosis. These include not only the pure operation costs from Fig. 7, but also a capital charge based upon both the equipment cost and the other site and installation related costs. Water costs vary from \$0.40/m^3 (\$1.54/1000 gal) to \$0.29/m^3 (\$1.11/1000 gal) across the 3,800 to 95,000 m^3/d (1 to 25 MGD) size range.

In presenting costs for brackish water desalting by reverse osmosis in previous reports, two important simplifying assumptions have been utilized: (1) that reverse osmosis desalting costs do not vary in the range of 2000 to 5000 parts per million; and (2) that a recovery of 80% can be achieved by reverse osmosis in this range. The facts are that an 80% recovery system operating on 5000 ppm feedwater will require nominally either 20% more membrane area, or 20% more pump discharge pressure to produce the same output as a system operating on a 2000 ppm feed. In generating the capital and operating cost data for this report, we have elected to increase the pump discharge pressure to the point where it will accommodate a 5000 ppm feed. This is reflected in the energy cost. Under these circumstances, the energy costs for a system operating on a 2000 ppm feed are conservative by about 20%.

With regard to recovery, it is clear that not all waters are capable of being processed to a level of 80% recovery without a major pretreatment system to preclude calcium sulfate or silica scaling. One would either have to operate at lower recoveries with the attendant higher costs of intake, outfall, brine disposal, and chemical treatment, or face the addition of much more extensive pretreatment. For example, of the four waters listed in Table C as typical brackish waters used to calculate the cost of desalting by electrodialysis, the safe achievable recoveries for reverse osmosis (without pre-softening) are ∿70%, 65%, 85%, and 75%, respectively.

The above comments notwithstanding, we have again elected to assume that 80% recovery is achievable for desalting by reverse osmosis. So as not to unfairly burden the case for electrodialysis, we have made the same assumption, so that filtration costs, chemical costs, cost of intakes and outfalls, etc., for both systems are all based upon recoveries in this range. In fact, a review of the cost breakdowns in the Appendix shows that the chemical costs for reverse osmosis systems are estimated much more conservatively than those for electrodialysis.

3.5 Brackish Water Desalting by Electrodialysis

The electrodialysis reversal (EDR) configuration of electrodialysis is now the dominant form of electrodialysis, having accounted for virtually all new electrodialysis water desalting installations in the past four years. The figures given in this section are for EDR equipment. The cost of converting brackish waters to fresh by EDR is a function of total dissolved solids, water composition, temperature, and other factors. The ability of the EDR process to achieve high recoveries on high silica or calcium sulfate waters yields significant economic benefits. The costs which are presented here are based upon the four different feed water compositions shown in Table C. The compositions generally represent the range of waters found throughout the United States.

A four-stage electrodialysis system has been selected to treat water number 1, two-stages for water 3, and three-stages for waters 2 and 4. All systems operate in the recovery range of 80 to 87% and each is designed to produce a product water of 500 parts per million total dissolved solids (TDS).

Three figures are presented here for electrodialysis — one showing capital equipment costs (exclusive of site related costs); one showing

Table C. Chemical compositions of typical brackish waters

Chemical composition (ppm)	Brackish waters			
	No. 1	No. 2	No. 3	No. 4
Sodium, Na	886	125	630	900
Calcium, Ca	118	316	116	250
Magnesium, MG	72	69	15	70
Chloride, Cl	131	67	1054	1450
Sulfate, SO_4	1943	900	115	590
Bicarbonate, HCO_3	473	357	78	210
Hardness as $CaCO_3$	590	1073	354	912
Manganese, Mn	1	0.10	Nil	0.1
Fluoride, F			2	
Iron, Fe	2	1.0	0	0.4
Potassium, K	16	13	0	5
Nitrate, NO_3	6.3	19	9	1
Silicate, SiO_3			17	
Total dissolved solids	3648	1800	2076	3475
pH	7.6	7.9	8.1	7.3
Temperature, °F	70	70	70	70
Organics, chemical oxygen demand	10	7.9		7

operating costs (exclusive of capital charges); and one showing overall water costs, including all inputs. Each of the figures includes a curve for systems operating on each of the four waters.

Figure 9 shows that the capital cost for electrodialysis increases as the number of stages increases. It also shows that the costs vary from a maximum of \$330/m³/d (\$1.25/gpd) for a small four-stage system, to a minimum of \$195/m³/d (\$0.74/gpd) for a large two-stage system.

Figure 10 shows the operating cost for systems operating on these four waters. Costs range from \$0.22/m³ (\$0.84/1000 gal) for a small four-stage system on a difficult water to \$0.11/m³ (\$0.41/1000 gal) for a large two-stage system on a relatively easy water.

Finally, Figure 11 shows the water costs for brackish water desalting by electrodialysis. These include not only the pure operating costs, but also a capital charge based upon all other inputs. Water costs vary from a low of \$0.26/m³ (\$0.98/1000 gal) to a high of \$0.45/m³ (\$1.69/1000 gal).

The roughly 40% increase in water costs over those published in ORNL/TM-6912 is primarily attributable to two factors: (1) the increased capital cost resulting from conversion to the more reliable, versatile, and energy efficient EDR system: and (2) a doubling in specific electrical energy costs. As noted above, the EDR system has dominated the recent electrodialysis marketplace because of its many operational advantages.

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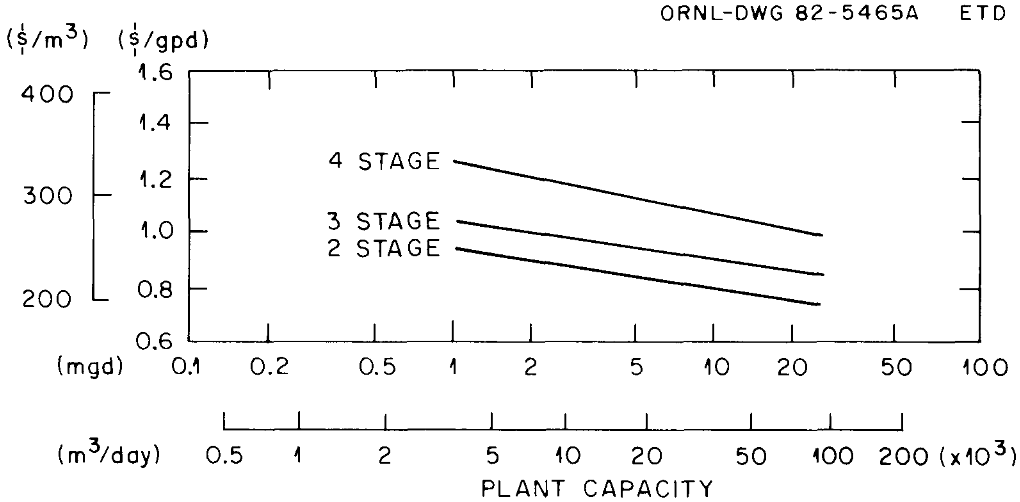

Fig. 9 CAPITAL COST - BRACKISH WATER DESALTING BY ELECTRODIALYSIS

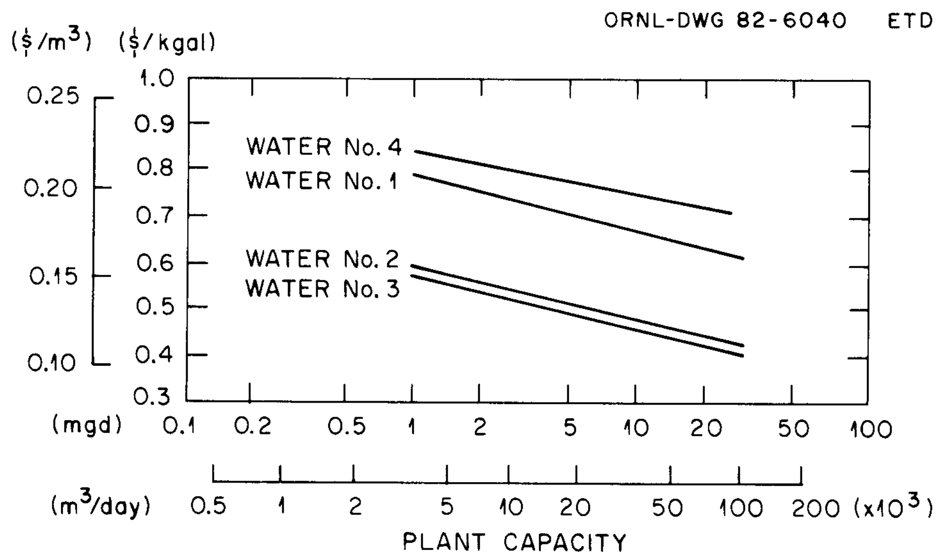

Fig. 10. Operating cost — brackish water desalting by electrodialysis.

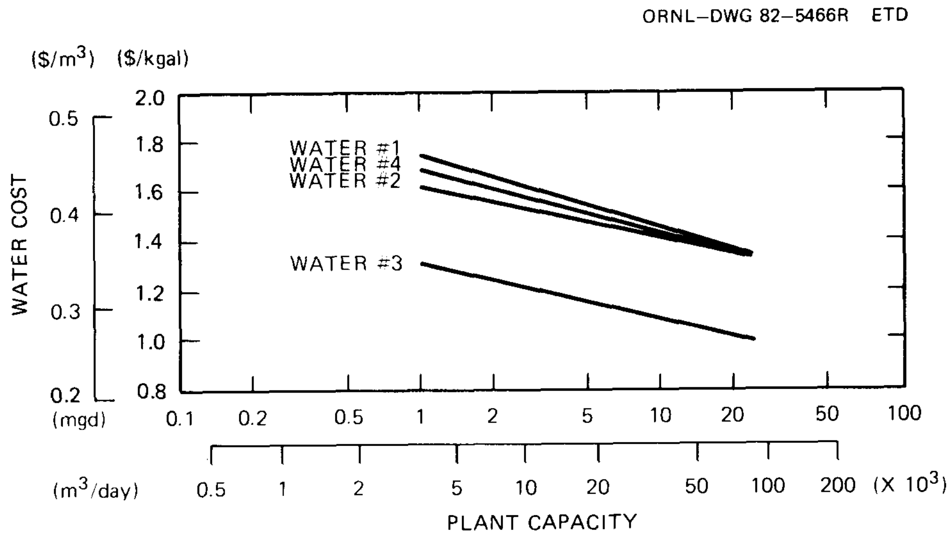

Fig. 11. Water cost — brackish water desalting by electrodialysis.

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APPENDIX A

This appendix consists of a series of tables which show the breakdown of all direct and indirect capital costs, operating costs, and water costs for desalting seawater and brackish water by distillation, reverse osmosis, and electrodialysis, as appropriate. All costs are based upon current second quarter 1981 input, and all are based upon 1981 dollars.

Tables A-1 through A-10 show all cost contributing items. As such, these tables are directly comparable with one another. The assumptions regarding interest rates, working capital, chemical costs, energy costs, membrane replacement, etc., are included in the body of the basic report. In this way, the cost figures can be adjusted to suit a particular case at the option of the user.

Table A.1. Costs of desalting seawater in multistage flash seawater distillation plants acid-treated feed: performance ratio = 12; concentration ratio = 2 85% plant factor all costs in thousands of dollars

[2nd quarter (1981)]

Item	Plant capacity $[m^3/d \times 10^3$ (MGD)]						
	3.8 (1)	9.5 (2.5)	19.0 (5)	37.9 (10)	94.6 (25)	189.3 (50)	378.5 (100)
Construction period, months	18	20	20	24	36	36	42
Land required, $m^2 \times 10^3$	8.1	12	12	16	44.5	52.6	93.1
$Ft^2 \times 10^3$	87	130	130	174	478.5	565.5	1,000
Direct capital costs[a]							
Site development and common facilities, grading, roads, fencing, gate, service buildings, etc.	285	547	809	1,292	2,271	3,698	5,649
Intake and outfall systems	252	454	656	1,048	1,846	3,008	4,603
Electrical utilities and switchgear	143	325	506	1,025	2,418	4,985	9,824
Cranes	0	3	5	5	8	9	35
Subtotal	680	1,329	1,976	3,370	6,543	11,700	20,111
MSF distillation plant	5,344	10,000	17,750	33,000	77,500	147,500	290,000
Total direct capital costs	6,024	11,329	19,726	36,370	84,043	159,200	310,111
Indirect costs							
Interest during construction	497	1,038	1,808	4,331	13,867	26,268	59,696
Project management, overhead and profit	2,259	4,248	7,397	13,639	31,516	59,700	116,291
Subtotal	2,756	5,286	9,205	17,970	45,383	85,968	175,987
Working capital	439	532	1,926	2,738	4,142	7,845	15,555
Contingency	904	1,699	2,959	5,455	12,606	23,880	46,517
Total capital cost	10,123	18,846	33,816	62,533	146,174	276,893	548,170
Capital cost $/GPD	10.12	7.54	6.76	6.25	5.85	5.54	5.48
Annual operation and maintenance cost							
Fixed charges at 18%	1,822	3,392	5,907	11,256	26,311	49,840	98,671
O&M labor	170	190	218	408	681	936	1,746
General and administrative charges (40% of labor)	68	76	87	163	272	374	698
Supplies and maintenance materials	36	54	86	158	396	779	1,515
Chemicals	57	167	286	572	1,433	2,867	5,733
Annual costs exclusive of energy	2,153	3,879	6,584	12,557	29,093	54,796	108,363
Oil-fired boiler							
Steam at $2.30/MMBtu	495	1,238	2,475	4,950	12,375	24,750	49,500
Electricity at 75 Mils/kWh	113	282	565	1,130	2,825	5,650	11,300
Total annual O&M cost	2,761	5,399	9,624	18,637	44,293	85,196	169,163
Cost of water $/m³ ($/kgal)	2.37 (8.90)	1.86 (6.96)	1.65 (6.20)	1.61 (5.95)	1.52 (5.71)	1.46 (5.49)	1.45 (5.45)
Coal-fired boiler							
Bituminous coal	(8.90)	(6.96)	(6.20)	(5.95)	(5.71)	(5.49)	(5.45)
Steam at $1.45/MMBtu	311	777	1,555	3,110	7,775	15,550	31,100
Electricity at 53.4 Mils/kWh	82	205	410	820	2,050	4,100	8,200
Total annual O&M cost	2,546	4,861	8,549	16,305	38,918	74,446	147,663
Cost of water $/m³ ($/kgal)	2.19	1.67	1.47	1.40	1.34	1.28	1.27
Sub-bituminous coal	(8.20)	(6.26)	(5.51)	(5.26)	(5.02)	(4.80)	(4.76)
Steam at $1.39/MMBtu	300	750	1,500	3,000	7,500	15,000	30,000
Electricity at 53.2 Mils/kWh	81	202	405	810	2,025	4,050	8,100
Total annual O&M cost	2,534	4,831	8,489	16,185	38,618	73,846	146,463
Cost of water $/m³ ($/kgal)	2.18	1.66	1.46	1.39	1.33	1.27	1.26
Dual purpose station, nuclear	(8.17)	(6.23)	(5.47)	(5.22	(4.98)	(4.76)	(4.72)
Steam at $1.52/MMBtu	327	817	1,635	3,270	8,175	16,350	32,700
Electricity at 49.3 Mils/kWh	74	185	370	740	1,850	3,700	7,400
Total annual O&M cost	2,554	4,881	8,589	16,385	39,118	74,846	148,463
Cost of water $/m³ ($/kgal)	2.20 (8.23)	1.68 (6.29)	1.53 (5.57)	1.41 (5.28)	1.34 (5.04)	1.29 (4.84)	1.28 (4.79)

[a]Does not include cost of land. Includes inspection, manufacturer's overhead and profit on shop-fabricated equipment installed on site. Electric power generated on site.

Table A.2. Costs of desalting seawater in multistage flash seawater distillation plants; non-acid feed treatment: performance ratio = 10; 90°C (194°F) MAX brine temperature, 85% plant factor all costs in thousands of dollars

[2nd quarter (1981)]

Item	Plant capacity ($m^3/d \times 10^3$) 3.8	189.3
Construction period, months	18	20
Land required, $m^2 \times 10^3$	8.1	12
Ft²	87,000	130,500
Direct capital costs[a]		
Site development and common facilities, grading, roads, fencing, gate, service buildings, etc.	285	809
Intake and outfall systems	252	656
Electrical utilities and switchgear	143	506
Cranes	0	5
Subtotal	680	1,976
VTE or H.T.M.E. distillation plant	5,760	24,200
Total direct capital costs	6,440	26,176
Indirect costs		
Interest during construction	532	2,159
Project management, overhead and profit	2,419	9,816
Subtotal	2,951	11,975
Working capital	127	515
Contingency	967	3,926
Total capital cost	10,485	42,592
Capital cost $/GPD	10.49	8.52
Annual operation and maintenance cost		
Fixed charges at 18%	1,889	7,667
O&M labor	170	218
General and administrative charges (40% of labor)	68	87
Supplies and maintenance materials	36	86
Chemicals	67	340
Annual costs exclusive of energy	2,230	8,398
Oil-fired boiler		
Steam at $2.30/MMBtu	594	2,970
Electricity at 75 Mils/kWh	294	1,262
Total annual O&M cost	3,118	12,630
Cost of water $/m³ ($/kgal)	2.68 (10.05)	2.17 (8.14)
Coal-fired boiler		
Bituminous coal		
Steam at $1.45/MMBtu	376	1,878
Electricity at 53.4 Mils/kWh	208	894
Total annual O&M cost	2,814	11,170
Cost of water $/m³ ($/kgal)	2.42	1.92
Sub-bituminous coal	(9.07)	(7.20)
Steam at $1.39/MMBtu	360	1,798
Electricity at 53.2 Mils/kWh	206	896
Total annual O&M cost	2,796	11,092
Cost of water $/m³ ($/kgal)	2.40	1.91
Dual purpose station, nuclear	(9.01)	(7.15)
Steam at $1.52/MMBtu	393	1,967
Electricity at 49.3 Mils/kWh	193	831
Total annual O&M cost	2,816	11,196
Cost of water $/m³ ($/kgal)	2.42 (9.08)	1.93 (7.22)

[a]Does not include cost of land. Includes inspection, manufacturer's overhead and profit on shop-fabricated equipment installed on site. Electric power generated on site.

Table A.3. Costs of desalting seawater in vertical tube seawater distillation plants acid-treated feed: performance ratio = 12; concentration ratio = 2 85% plant factor all costs in thousands of dollars

[2nd quarter (1981)]

Item	Plant capacity (m^3/d x 10^3)					
	3.8	18.9	37.9	94.6	189.3	378.5
Construction period, months	18	20	24	36	40	42
Land required, m^2 x 10^3	8	12	16	28	40	72
Ft^2 x 10^3	87	130	174	304	435	783
Direct capital costs[a]						
Site development and common facilities, grading, roads, fencing, gate, service buildings, etc.	285	809	1,297	2,271	3,698	5,649
Intake and outfall systems	252	655	1,049	1,846	3,008	4,603
Electrical utilities and switchgear	140	465	860	2,079	4,161	8,036
Cranes	0	5	5	7	8	41
Subtotal	677	1,934	3,211	6,203	10,875	18,329
VTE or H.T.M.E. distillation plant	4,720	16,000	29,700	69,750	132,500	261,000
Total direct capital costs	5,397	17,934	32,911	75,953	143,375	279,329
Indirect costs						
Interest during construction	445	1,644	3,620	12,532	26,285	53,771
Project management, overhead and profit	2,024	6,725	12,342	28,482	53,766	104,748
Subtotal	2,469	8,369	15,962	41,014	80,051	158,519
Working capital	360	842	1,514	3,743	7,150	14,011
Contingency	809	2,690	4,937	11,393	21,506	41,899
Total capital cost	9,035	29,835	55,324	132,103	252,082	493,758
Capital cost $/GPD	9.03	5.97	5.53	5.28	5.04	4.94
Annual operation and maintenance cost						
Fixed charges at 18%	1,626	5,370	9,967	23,779	45,375	88,876
O&M labor	170	218	408	681	936	1,746
General and administrative charges (40% of labor)	68	87	163	272	374	698
Supplies and maintenance materials	36	86	158	396	779	1,515
Chemicals	42	209	421	1,054	2,109	4,220
Annual costs exclusive of energy	1,942	5,970	11,117	26,182	49,573	97,055
Oil-fired boiler						
Steam at $2.30/MMBtu	495	2,475	4,950	12,375	24,750	49,500
Electricity at 75 Mils/kWh	37	177	351	881	1,762	3,523
Total annual O&M cost	2,474	8,622	16,418	39,438	76,085	150,078
Cost of water $/$m^3$ ($/kgal)	2.13 (7.97)	1.48 (5.56)	1.41 (5.29)	1.36 (5.08)	1.31 (4.90)	1.29 (4.84)
Coal-fired boiler						
Bituminous coal						
Steam at $1.45/MMBtu	311	1,515	3,110	7,775	15,550	31,100
Electricity at 53.4 Mils/kWh	25	124	251	627	1,255	2,508
Total annual O&M cost	2,278	7,609	14,478	34,584	66,378	130,663
Cost of water $/$m^3$ ($/kgal)	1.96	1.31	1.25	1.19	1.14	1.12
Sub-bituminous coal	(7.34)	(4.91)	(4.67)	(4.46)	(4.28)	(4.21)
Steam at $1.39/MMBtu	300	1,500	3,000	7,500	15,000	30,000
Electricity at 53.2 Mils/kWh	25	124	250	622	1,250	2,500
Total annual O&M cost	2,267	7,594	14,367	34,304	65,823	129,555
Cost of water $/$m^3$ ($/kgal)	1.96 (7.31)	1.31 (4.90)	1.24 (4.63)	1.18 (4.42)	1.13 (4.24)	1.11 (4.18)
Dual purpose station, nuclear						
Steam at $1.52/MMBtu	327	1,635	3,270	8,175	16,350	32,700
Electricity at 49.3 Mils/kWh	22	115	229	578	1,157	2,316
Total annual O&M cost	2,291	7,720	14,616	34,935	67,080	132,071
Cost of water $/$m^3$ ($/kgal)	1.97 (7.38)	1.33 (4.98)	1.26 (4.71)	1.20 (4.50)	1.15 (4.32)	1.14 (4.26)

[a]Does not include cost of land. Includes inspection, manufacturer's overhead and profit on shop-fabricated equipment installed on site. Electric power generated on site.

Table A.4. Costs of desalting seawater in M.E.D. aluminum-tubed seawater distillation plants non-acid feed treatment[a]

Item	Plant capacity ($m^3/d \times 10^3$)				
	1.9	3.8	7.6	19.0	37.9
Construction period, months	7	7	9	18	20
Land required, $m^2 \times 10^3$	1.63	2.84	4.86	10.2	17.2
$Ft^2 \times 10^3$	17.5	30.5	52.3	109.0	185.0
Direct capital costs[b]					
Site development and common facilities, grading, roads, fencing, gate, service buildings, etc.	210	260	350	530	850
Intake and outfall systems	300	450	650	850	1,250
Electrical utilities and switchgear	120	200	350	500	1,000
Cranes	0	0	0	5	5
Subtotal	630	910	1,350	1,885	3,105
M.E.D. Distillation Plant	2.500	4.200	7.000	13,500	25,000
Total direct capital costs	3,130	5,110	8,350	15,385	28,105
Indirect costs					
Interest during construction	100	164	344	1,265	2,577
Project management, overhead and profit	1,174	1,916	3,131	5,773	10,539
Subtotal	1,274	2,080	3,475	7,038	13,116
Working capital	55	89	149	303	564
Contingency	454	741	1,218	2,310	4,235
Total capital cost	4,913	8,020	13,192	25,046	46,020
Capital cost $/GPD	9.83	8.02	6.60	5.01	4.60
Annual operation and maintenance cost					
Fixed charges at 18%	884	1,444	2,376	4,508	8,284
O&M labor	130	155	155	180	180
General and administrative charges (40% of labor)	52	62	62	72	72
Supplies and maintenance materials	50	84	140	270	500
Chemicals	14	28	56	140	280
Annual costs exclusive of energy	1,130	1,773	2,788	5,170	9,316
Oil-fired boiler					
Steam at $2.30/MMBtu	223	446	892	2,230	4,460
Electricity at 75 Mils/kWh	70	140	280	700	1,400
Total annual O&M cost	1,423	2,359	3,960	8,100	15,176
Cost of water $/m³ ($/kgal)	2.18 (9.18)	2.03 (7.60)	1.70 (6.37)	1.39 (5.22)	1.31 (4.90)
Coal-fired boiler					
Bituminous coal					
Steam at $1.45/MMBtu	157	313	626	1565	3130
Electricity at 53.4 Mils/kWh	50	100	200	500	1,000
Total annual O&M cost	1,337	2,186	3,604	7,235	13,446
Sub-bituminous coal					
Steam at $1.39/MMBtu	151	300	600	1,500	3,000
Electricity at 53.2 Mils/kWh	49.8	99.6	199	498	996
Total annual O&M cost	1,331	2,173	3,587	7,168	13,312
Cost of water $/m³ ($/kgal)	2.29 (8.58)	1.82 (7.00)	1.54 (5.78)	1.23 (4.62)	1.15 (4.29)
Cost of water $/m³ ($/kgal)	2.30 (8.63)	1.88 (7.05)	1.55 (5.80)	1.25 (4.67)	1.16 (4.34)
Dual purpose (heat consumption)[c]					
Temperature at turbine °F	167.9	169.4	169.4	150	170.8
Performance ratio	8.4	8.4	8.4	6.2	10.6
$\times 10^6$ Btu/year	130	260	520	1,930	2,400

[a]Performance ratio – 12, 75°C (167°F) maximum Brine temperature, 85% plant factor All costs in thousands of dollars (2nd quarter – 1981)

[b]Does not include cost of land. Includes inspection, manufacturer's overhead and profit on shop-fabricated equipment installed on site. Electric power generated on site.

[c]Cost of water should be calculated according to steam cost.

Table A.5. Seawater desalting costs[a] – Reverse osmosis: feedwater seawater (35,000 ppm TDS); 30% recovery; 85% plant factor; Temperature 70°F

	Plant capacity ($m^3/d \times 10^3$)				
	0.038	0.38	3.8	11.4	18.9
Construction period (months)	6	6	9	12	12
Direct capital costs ($1000)					
1. Installed equipment cost	70	550	3,500	9,600	15,000
2. Site development	6	23	142	256	428
3. Intake and outfall system	6	34	248	476	644
4. Electric utilities and switchgear	12	66	380	840	1,188
Total direct capital cost	94	673	4,270	11,172	17,260
Indirect capital costs ($1000)					
5. Interest during construction and startup	1.9	15.1	144.2	528.0	825.0
6. Working capital	4.7	33.6	213.5	558.6	863.0
7. Contingency – A&E fee	16.1	115.5	740.4	1,961.4	3,031.7
Total capital cost	116.7	837.2	5,368.1	14,220.0	21,979.7
Operating costs (annual) ($1000)					
8. Operating and maintenance labor	4.0	15.0	85.0	125.0	145.0
9. G&A at 40% of O&M	1.6	6.0	34.0	50.0	58.0
10. Chemicals	0.6	5.6	49.6	130.3	217.2
11. Filters	0.6	4.6	31.0	93.0	155.0
12. Other materials	0.7	5.5	35.0	96.0	150.0
13. Electricity at 5¢/kWh	5.9	58.9	589.5	1,768.4	2,947.4
14. Membrane replacement	3.7	34.1	310.2	837.7	1,396.1
Total operating costs	17.1	129.7	1,134.3	3,100.4	5,068.7
15. Fixed charge at 18%	21.0	150.7	966.2	2,559.6	3,956.3
Total annual cost	38.1	280.4	2,100.5	5,660.0	9,025.0
Cost of water, $/m³ ($/kgal)	3.28 (12.28)	2.41 (9.04)	1.81 (6.77)	1.62 (6.08)	1.54 (5.82)

[a]All costs in 1981 second quarter dollars.

Table A.6. Brackish water desalting costs[a] – Reverse osmosis: feedwater 2000–5000 ppm TDS; 80% recovery; 95% plant factor; temperature 70°F

	Plant capacity ($m^3/d \times 10^3$)				
	3.8	11.4	18.9	37.9	94.6
Construction period (months)	6	9	9	12	15
Direct capital costs ($1000)					
1. Installed equipment cost	600.0	1,650.0	2,600.0	5,000.0	12,500.0
2. Site development	142.0	256.0	428.0	513.0	770.0
3. Intake and outfall system	84.0	201.6	280.0	448.0	896.0
4. Electric utilities and switchgear	150.0	379.2	532.8	906.0	1,920.0
Total direct capital cost	976.0	2,486.8	3,840.8	6,967.0	16,086.0
Indirect capital costs ($1000)					
5. Interest during construction and startup	16.5	68.1	107.2	275.0	859.4
6. Working capital	48.8	124.3	192.0	343.4	804.3
7. Contingency – A&E fee	166.6	428.7	662.4	1,197.7	2,840.0
Total capital cost	1,207.9	3,107.9	4,802.4	8,683.1	20,589.7
Operating costs (annual) ($1000)					
8. Operating and maintenance labor	42.5	52.5	85.0	105.0	135.0
9. G&A at 40% of O&M	17.0	21.0	34.0	42.0	54.0
10. Chemicals	37.2	93.1	124.1	248.2	620.5
11. Cartridge filters	15.5	37.2	62.0	93.1	232.0
12. Other materials	3.0	8.2	13.0	25.0	62.5
13. Electricity at 5 ¢/kWhr	138.7	416.1	693.5	1,387.0	3,650.0
14. Membrane replacement	62.1	158.2	232.7	465.4	1,163.4
Total operating costs	316.0	786.3	1,244.3	2,365.7	5,917.4
15. Fixed charge at 18%	217.4	559.4	864.4	1,562.9	3,706.1
Total annual cost	533.4	1,345.7	2,108.7	3,928.6	9,623.5
Cost of water, $/m³ ($/kgal)	0.41 (1.54)	0.34 (1.29)	0.33 (1.22)	0.30 (1.13)	0.30 (1.11)

[a] All costs in 1981 second quarter dollars.

Table A.7. Brackish water desalting costs[a] – electrodialysis – 3.8 x 10^3 m^3/d feedwater temperature 70°F, 95% plant factor

	Feedwater type			
	1	2	3	4
Construction period (months)	6	6	6	6
Direct capital costs ($1000)				
1. Installed equipment cost	1,250.0	1,250.0	940.0	1,060.0
2. Site development	142.0	142.0	142.0	142.0
3. Intake and outfall system	84.0	84.0	84.0	84.0
4. Electric utilities and switchgear	150.0	150.0	96.0	150.0
Total direct capital cost	1,626.0	1,626.0	1,262.0	1,436.0
Indirect capital costs ($1000)				
5. Interest during construction and startup	34.4	34.4	25.8	29.2
6. Working capital	81.3	81.3	53.0	71.8
7. Contingency – A&E fee	278.7	278.7	214.5	245.4
Total capital cost	2,020.4	2,020.4	1,555.3	1,782.4
Operating costs (annual) ($1000)				
8. Operating and maintenance labor	42.5	42.5	42.5	42.5
9. G&A at 40% of O&M	17.0	17.0	17.0	17.0
10. Chemicals	10.5	10.5	7.0	7.0
11. Filters	15.5	15.5	15.5	15.5
12. Other materials	5.2	5.2	3.7	4.6
13. Electricity at 5¢/kWh	145.1	79.7	95.8	178.6
14. Membrane replacement	37.0	37.0	18.5	27.8
Total operating costs	272.8	207.4	200.0	293.0
15. Fixed charge at 18%	363.7	363.7	279.6	320.5
Total annual cost	636.5	571.1	479.6	613.5
Cost of water, $/$m^3$ ($/kgal)	0.48 (1.69)	0.44 (1.65)	0.36 (1.38)	0.48 (1.77)

[a]All costs in 1981 second quarter dollars.

Table A.8. Brackish water desalting costs[a] – electrodialysis – 18.9 x 10^3 m^3/d feedwater temperature 70°F, 95% plant factor

	Feedwater type			
	1	2	3	4
Construction period (months)	9	9	9	9
Direct capital costs ($1000)				
1. Installed equipment cost	5,733.0	5,733.0	4,299.0	4,873.0
2. Site development	428.0	428.0	428.0	428.0
3. Intake and outfall system	280.0	280.0	280.0	280.0
4. Electric utilities and switchgear	532.0	532.0	341.0	532.0
Total direct capital cost	6,973.0	6,973.0	5,348.0	6,113.0
Indirect capital costs ($1000)				
5. Interest during construction and startup	236.5	236.5	177.3	201.0
6. Working capital	348.6	348.6	267.4	305.6
7. Contingency – A&E fee	1,209.3	1,209.3	926.8	1,059.1
Total capital cost	8,767.4	8,767.4	6,719.5	7,678.7
Operating costs (annual) ($1000)				
8. Operating and maintenance labor	85.0	85.0	85.0	85.0
9. G&A at 40% of O&M	34.0	34.0	34.0	34.0
10. Chemicals	52.5	52.5	35.0	35.0
11. Filters	62.0	62.0	62.0	62.0
12. Other materials	23.8	23.8	16.7	20.7
13. Electricity at 5¢/kWh	725.4	398.5	479.0	892.9
14. Membrane replacement	185.0	185.0	92.5	139.0
Total operating costs	1,167.7	840.8	804.2	1,268.6
15. Fixed charge at 18%	1,578.1	1,578.1	1,209.5	1,382.2
Total annual cost	2,745.8	2,438.9	2,013.7	2,650.8
Cost of water, $/$m^3$ ($/kgal)	0.42 (1.58)	0.38 (1.42)	0.31 (1.16)	0.40 (1.53)

[a]All costs in 1981 second quarter dollars.

Table A.9. Brackish water desalting costs[a] – electrodialysis – 37.9×10^3 m³/d feedwater temperature 70°F, 95% plant factor

	Feedwater type			
	1	2	3	4
Construction period (months)	12	12	12	12
Direct capital costs ($1000)				
1. Installed equipment cost	10,901.0	10,901.0	8,175.8	9,265.8
2. Site development	513.0	513.0	513.0	513.0
3. Intake and outfall system	448.0	448.0	448.0	448.0
4. Electric utilities and switchgear	906.0	906.0	582.0	906.0
Total direct capital cost	12,768.0	12,768.0	9,718.8	11,132.8
Indirect capital costs ($1000)				
5. Interest during construction and startup	599.6	599.6	449.7	509.6
6. Working capital	638.4	638.4	485.9	556.6
7. Contingency – A&E fee	2,240.9	2,240.9	1,704.7	1,951.8
Total capital cost	16,246.9	16,246.9	12,359.1	14,150.8
Operating costs (annual) ($1000)				
8. Operating and maintenance labor	105.0	105.0	105.0	105.0
9. G&A at 40% of O&M	42.0	42.0	42.0	42.0
10. Chemicals	105.0	105.0	70.0	70.0
11. Filters	93.1	93.1	93.1	93.1
12. Other materials	45.4	45.4	31.4	39.1
13. Electricity at 5¢/kWh	1,450.8	797.0	958.0	1,785.7
14. Membrane replacement	370.0	370.0	185.0	278.0
Total operating costs	2,211.3	1,557.5	1,484.5	2,412.9
15. Fixed charge at 18%	2,924.4	2,924.4	2,224.6	2,547.1
Total annual cost	5,135.7	4,481.9	3,709.1	4,960.0
Cost of water, \$/m³ (\$/kgal)	0.39 (1.48)	0.35 (1.30)	0.28 (1.07)	0.38 (1.43)

[a]All costs in 1981 second quarter dollars.

Table A.10. Brackish water desalting costs[a] – electrodialysis – 94.6 x 10^3 m^3/d feedwater temperature 70°F, 95% plant factor

	Feedwater type			
	1	2	3	4
Construction period (months)	15	15	15	15
Direct capital costs ($1000)				
1. Installed equipment cost	24,760.0	24,760.0	18,570.0	21,046.0
2. Site development	770.0	770.0	770.0	770.0
3. Intake and outfall system	896.0	896.0	896.0	896.0
4. Electric utilities and switchgear	1,920.0	1,920.0	1,230.0	1,920.0
Total direct capital cost	28,346.0	28,346.0	21,466.0	24,632.0
Indirect capital costs ($1000)				
5. Interest during construction and startup	1,702.2	1,702.2	1,276.7	1,446.9
6. Working capital	1,417.3	1,417.3	1,073.3	1,231.6
7. Contingency – A&E fee	5,034.5	5,034.5	3,810.6	4,370.0
Total capital cost	36,500.0	36,500.0	27,626.7	31,680.5
Operating costs (annual) ($1000)				
8. Operating and maintenance labor	135.0	135.0	135.0	135.0
9. G&A at 40% of O&M	54.0	54.0	54.0	54.0
10. Chemicals	262.5	262.5	175.0	175.0
11. Filters	232.0	232.0	232.0	232.0
12. Other materials	103.0	103.0	70.3	87.4
13. Electricity at 5¢/kWh	3,683.3	1,992.5	2,395.0	4,464.3
14. Membrane replacement	925.0	925.0	462.5	695.0
Total operating costs	5,394.8	3,704.0	3,523.8	5,842.7
15. Fixed charge at 18%	6,570.0	6,570.0	4,972.8	5,702.5
Total annual cost	11,964.8	10,274.0	8,496.6	11,545.2
Cost of water, $/m³ ($/kgal)	0.36 (1.38)	0.32 (1.18)	0.26 (0.98)	0.35 (1.33)

[a]All costs in 1981 second quarter dollars.

APPENDIX B

The Engineering Analysis Section of the ORNL Engineering Technology Division estimated the cost of prime steam and electricity for mid-1981 from new nuclear, coal and oil-fired plants located on the Gulf Coast. Table B.1 shows technical and economic parameters used in the analysis. The capital costs are for a plant coming into operation in mid-1981. These costs are based on recent cost models received from United Engineers and Constructors in the case of the coal and nuclear plants. Both coal plants have flue-gas desulphurization (FGD) systems. The investment cost estimate for the oil-fired plant is based on the cost of plants recently completed or nearing completion. Nuclear fuel costs are based on current price levels for the cost components. The oil price is approximately market for No. 6 oil. The coal prices were derived from recent delivery prices of coal in the Gulf area.

The power generation costs are given in Table B.2. The values shown represent costs from a new plant and therefore do not reflect the average cost of energy from the entire grid.

The Engineering Analysis Section also maintains a data file on the historic cost of fuels used by electric utilities throughout the United States. The average cost of fuels for U.S. electric utilities is shown in Fig. B.1 for 1970–1982. Note that this is not the same as the values presented in Table B.1 for plants located on the Gulf Coast.

Table B.1. Technical and economic parameters

Plant size, MW(e)	
Nuclear	1 x 1200
Coal	2 x 600
Oil	2 x 600
Location	Gulf coast
Capacity factor, %	70
Heat rates, Btu/kW(e)	
Nuclear	10,600
Bituminous coal fired plant	9,900
Sub-bituminous coal fired plant	10,400
Oil fired plant	9,200
Year of plant startup	Mid-1981
Fixed charge rate on capital, %	18
Capital investment, \$/kW(e)	
Nuclear	1,250
Bituminous coal	930
Sub-bituminous coal	860
Oil	750
Fuel prices, \$/10^6 Btu	
Oil (\$/Bbl)	5.50 (32)
Bituminous coal (\$/ton)	1.90 (46)
Sub-bituminous coal (\$/ton)	2.30 (37)
Nuclear	0.70

Table B.2. Power generation costs (mills/kWh)

	Oil	Bituminous coal	Sub-bituminous coal	Nuclear
Capital investment	22.0	27.3	25.2	36.7
O&M	2.5	7.3	4.1	5.2
Fuel	50.5	18.8	23.9	7.4
Total				
Mills/kWh	75.0	53.4	53.2	49.3
\$/GJ	8.98	5.70	5.40	4.91
\$/10^6 Btu	8.50	5.40	5.11	4.65

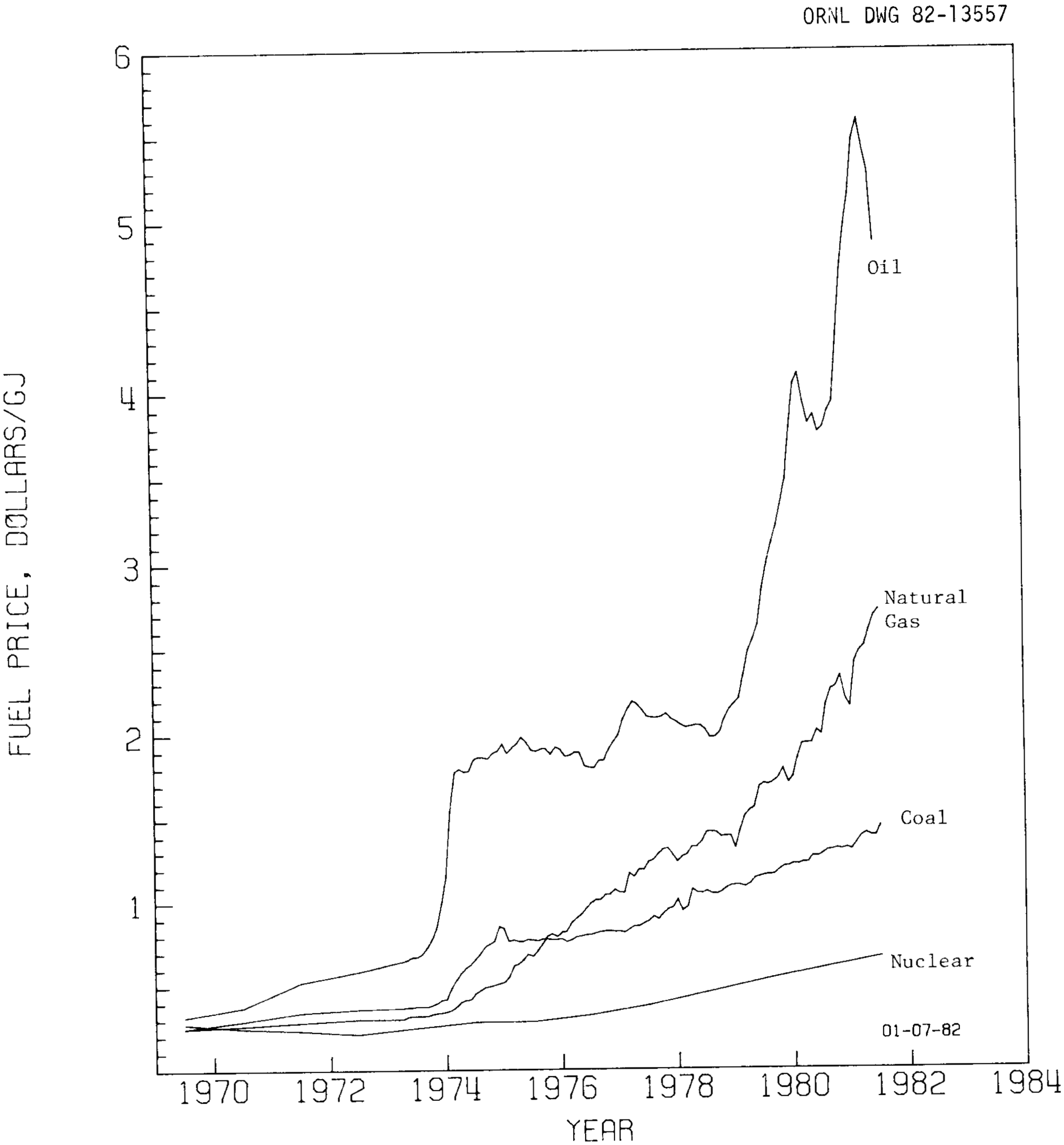

Fig. B-1. Utility fossil fuel costs.

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