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Desalting Seawater and Brackish Water: Cost Update, 1979

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DESALTING SEAWATER AND BRACKISH WATER: COST UPDATE, 1979

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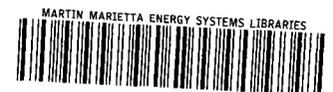
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FOREWORD

This study was prepared by Larson & Associates, Limited, under contract with the Nuclear Division of Union Carbide Corporation acting in behalf of the U.S. Department of Energy. The section on Distillation was prepared by Mr. Gordon Leitner of Leitner and Associates, Inc. The Project Officer was Mr. Sherman Reed, whose guidance and support is gratefully acknowledged.

During the course of this study, visits were made to a number of desalting equipment manufacturers, and input was received from a number of consultants and A & E firms. The helpful assistance provided by all who contributed to this report is gratefully acknowledged.

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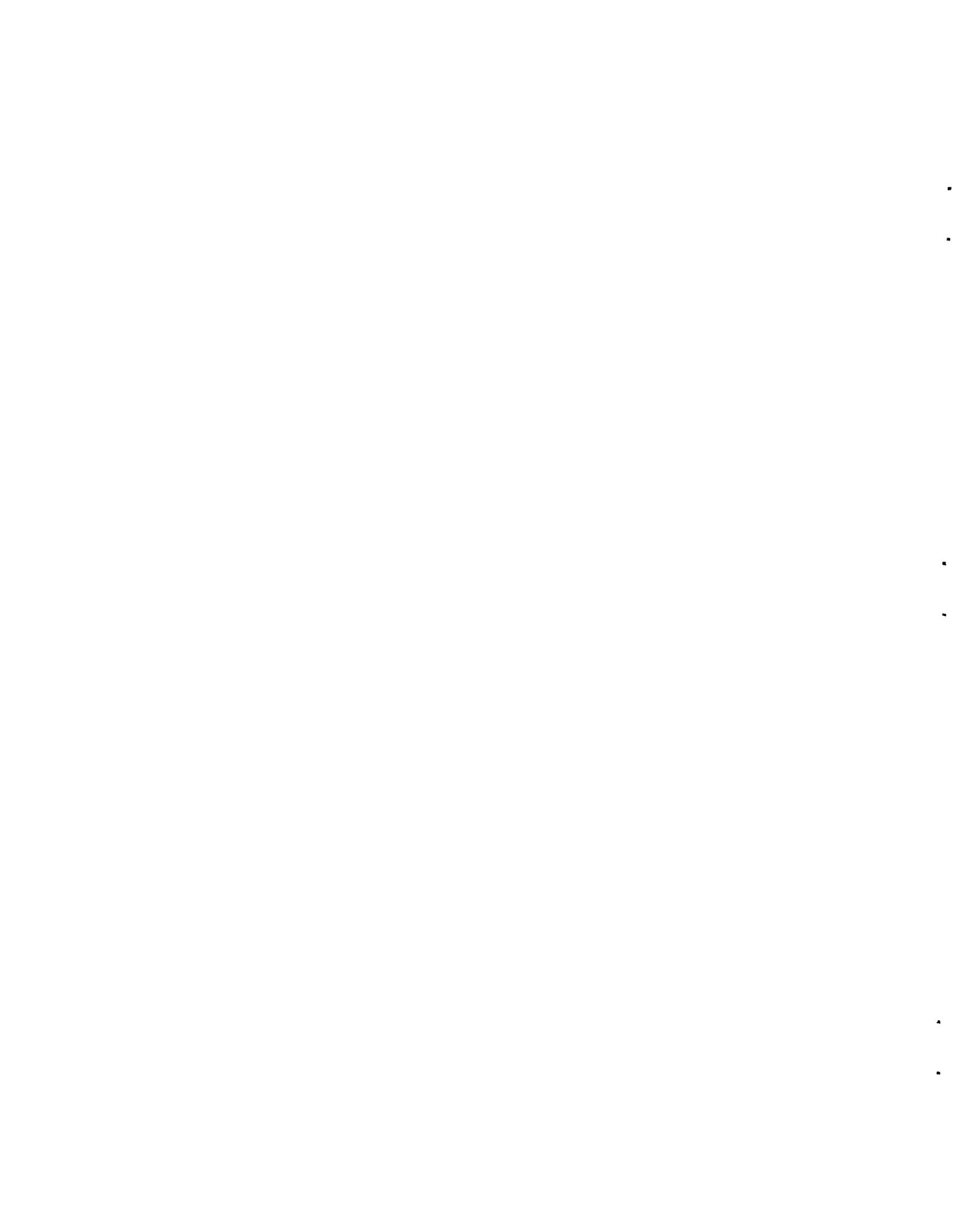
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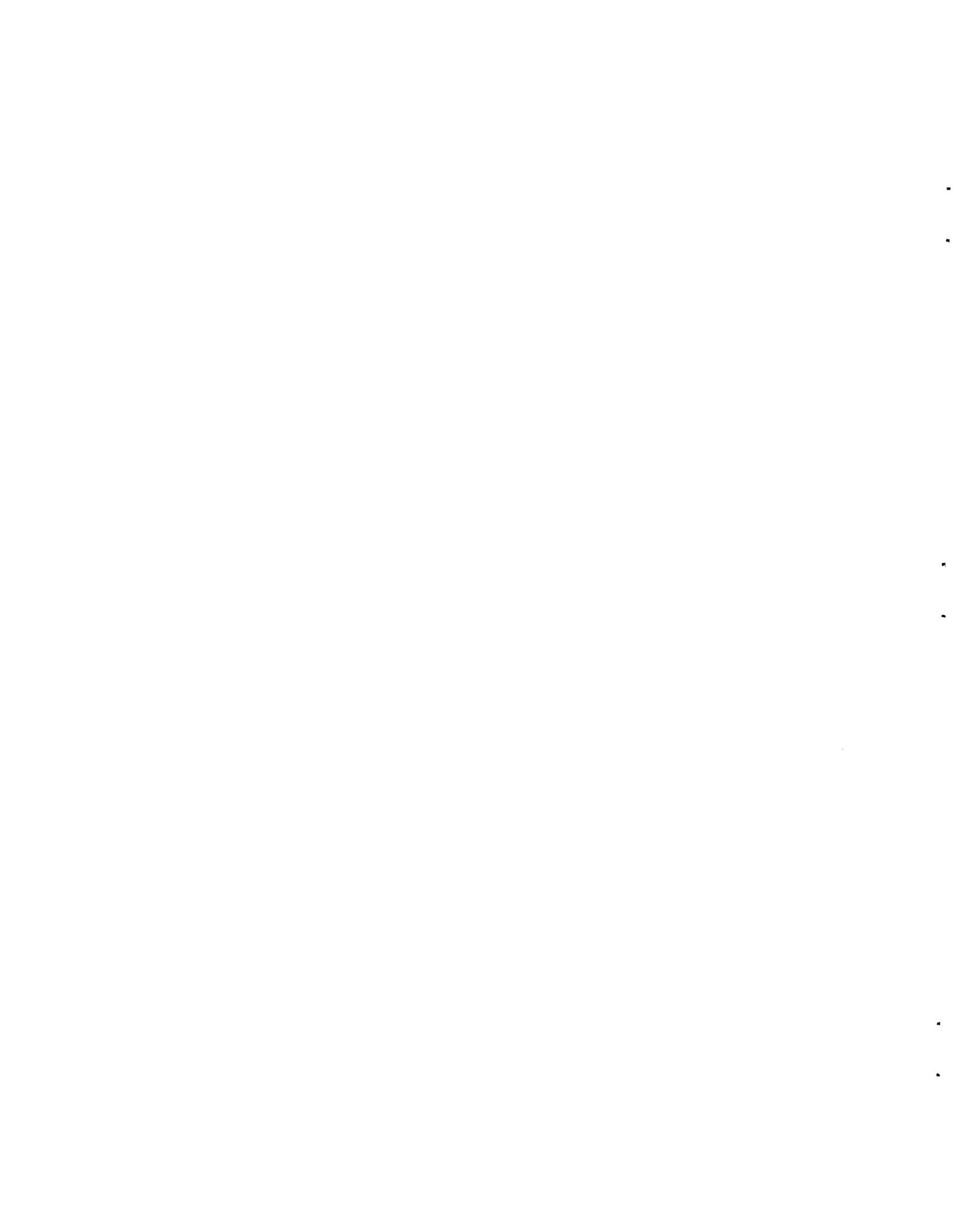
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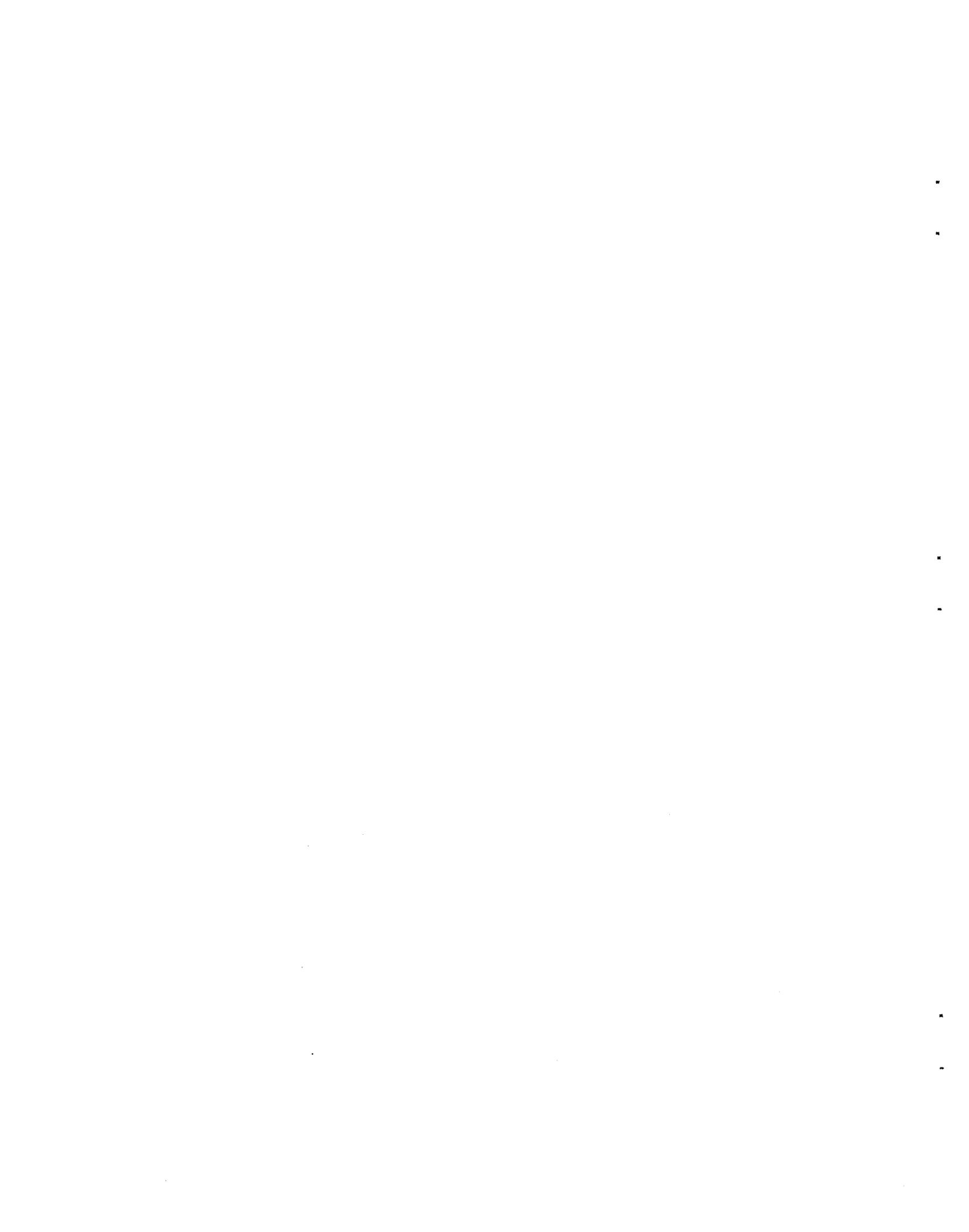
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ABSTRACT

This report updates and expands on the scope of data presented in ORNL/TM-5926, published in November 1977. Since the previous report, overall plant equipment costs have increased approximately 7%/yr and the costs of civil works and switchgear have increased at an annual rate of 7-8%. Operation and maintenance costs have increased about 7%/yr.

On average, the cost of desalting seawater by distillation has increased 25-30%. On a comparable basis, both electro dialysis and reverse osmosis costs have increased from 15-30% depending on plant size and feedwater composition.

1. INTRODUCTION AND SUMMARY

1.1 Introduction

Approximately two years ago, and also four 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 electro dialysis 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.

This report updates ORNL/TM-5926 by estimating product water costs based upon first quarter 1978 installed equipment costs, a level fixed charge rate, and energy and site development costs which are current. In the earlier reports, the costs for the distillation processes included all site development costs, intake, and outfalls, etc., while the costs for reverse osmosis and electro dialysis did not. The scope of this report has been expanded to include this information for all three systems. Each cost element is considered separately and the assumptions given, so that the reader may make the appropriate adjustment to relate the costs presented to his particular case.

1.2 Summary

The cost data given in the original report reflected the rapid increases in the cost of fuel and the marked escalation in equipment costs and interest rates on borrowed capital during the three years prior to 1976. The previous update indicated that the cost of fuels and equipment continued to rise. That trend has continued during the past two years as reflected in this current report.

Overall plant equipment costs have increased about 7% per year, while the cost of switchgear and civil works has gone up at an annual rate of about 7-8%. Operation and maintenance costs have increased approximately 7%/yr. On the average, the cost of desalting seawater by distillation has increased 25-30%. A more detailed analysis of both reverse osmosis and electrodialysis shows that when all cost inputs are considered, the water costs for these two processes have increased from 15-30% also.

2. BASIS FOR COST ESTIMATES

2.1 Financial Parameters

All cost estimates are based upon first quarter 1979 dollars. Utility financing, with a plant life expectancy of thirty years was used. A levelized fixed charge rate of 16.5% was used in all calculations. A rate of 9.5% 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 9.5% 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 A & E fee equal to 16% of the direct and other indirect capital costs has also been included. These rates and fees are 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

As shown in Fig. 1, the average cost of fuel used for electrical generation has continued to increase, with oil and gas prices escalating the most sharply. As a result steam costs have continued to rise (Fig. 2) accordingly.

For the distillation systems, it was assumed that electricity would be generated on-site using steam from boilers fired with oil, high sulfur coal, or nuclear steam from a dual-purpose electric station. Steam and electric costs were based upon the values shown in Table B.

For the membrane plants, it was assumed that operation would be based upon electricity purchased from a utility at an uninterruptible commercial rate of 2.5¢/kWhr. 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 5 MGD in operation in the continental United States.

TABLE A
CHEMICAL COSTS

| Chemical | Unit Cost | |
|--------------------------|-----------|-------|
| | \$/kg | \$/lb |
| Antifoam | 2.14 | 0.97 |
| Sulphuric acid (100%) | 0.48 | 0.22 |
| Polyphosphate | 3.40 | 1.55 |
| Sodium hexametaphosphate | 0.64 | 0.29 |
| Potassium permanganate | 1.26 | 0.58 |
| Caustic (NaOH) | 0.40 | 0.18 |
| Sodium sulfite | 0.12 | 0.05 |
| Chlorine | 0.25 | 0.11 |

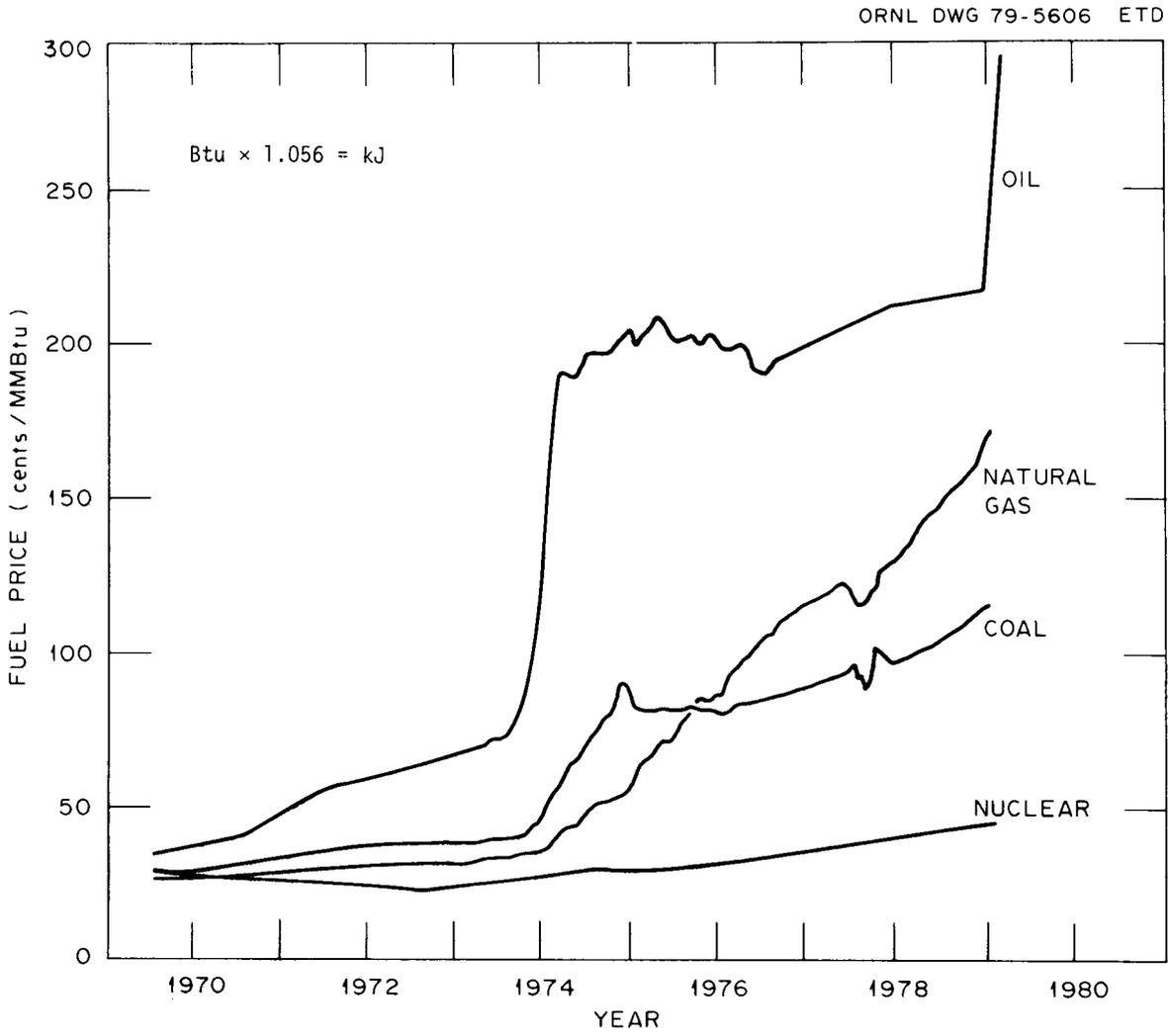


Fig. 1. Average costs of fuels used for electrical generation in the United States.

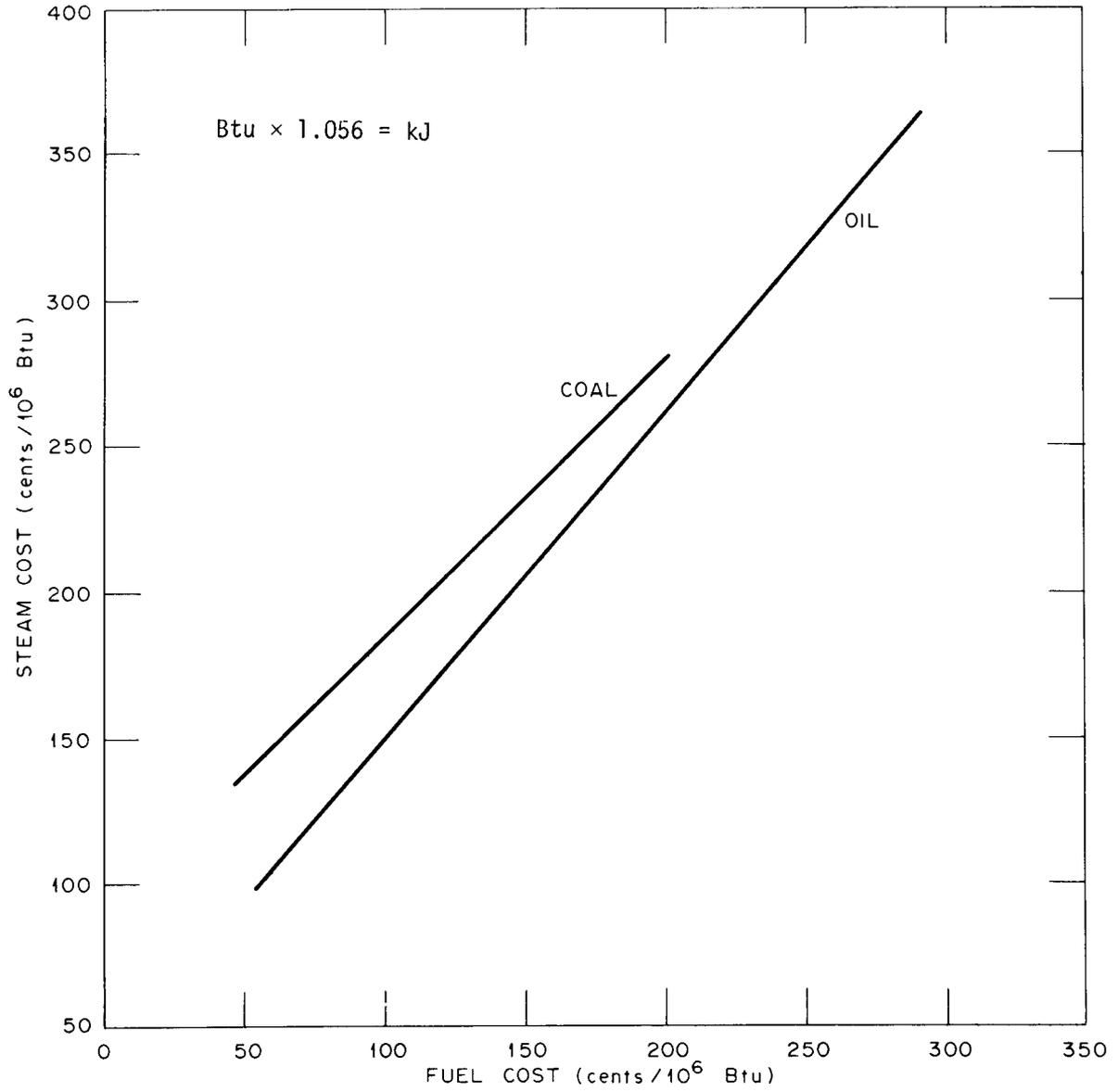


Fig. 2. Effect of fuel cost on steam costs.

TABLE B
ENERGY COSTS

| Fuel Cost | Steam Conditions and Cost | Electric Cost Mills/kwhr |
|--|--|-----------------------------|
| Oil - \$2.20/10 ⁶ Btu (\$13.20/bbl, 6 x 10 ⁶ Btu/bbl) | Prime, 538°C (1000°F) - \$3.62/10 ⁶ Btu 129°C (265°F) - \$0.93/10 ⁶ Btu 93°C (200°F) - \$0.62/10 ⁶ Btu | 36.0 |
| Coal - \$1.05/10 ⁶ Btu (high sulfur, 11,900 Btu/lb @ \$25.00/ton) | Prime, 538°C - \$3.53/10 ⁶ Btu* 129°C - \$0.95/10 ⁶ Btu 93°C - \$0.61/10 ⁶ Btu | 34.4 |
| Coal - \$1.47/10 ⁶ Btu (low sulfur, 8500 Btu/lb @ \$25.00/ton) | Prime, 538°C - \$3.28/10 ⁶ Btu 129°C - \$0.89/10 ⁶ Btu 93°C - \$0.56/10 ⁶ Btu | 33.5 |
| Nuclear (1200 MW PWR) dual purpose** (\$0.40/10 ⁶ Btu) | Prime, 274°C (525°F) - \$2.48/10 ⁶ Btu 129°C - \$0.81/10 ⁶ Btu 93°C - \$0.51/10 ⁶ Btu | 25.8 |

* Includes stack gas scrubbers.

** Capital and O&M costs based on technical assessment guide, EPRI PS-866-SR, Electric Power Research Institute (June 1978) escalated by 8% to January 1, 1979 dollars.

2.8 Membrane Replacement Costs

Membrane replacement costs for electro dialysis systems are based upon the assumption that 20% of the capital cost is membrane, and that a membrane lifetime of seven and one-half years is achieved.

Membrane replacement costs for brackish water reverse osmosis systems are based upon current (first quarter 1979) quantity pricing, and an assumed three year lifetime.

Membrane replacement costs for seawater reverse osmosis systems are estimated at three times the brackish water membrane replacement cost.

2.9 System Costs/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 could be 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. The Appendix contains a series of tables which provide details of each cost contributing item.

3.1 Seawater Desalting by Distillation

The cost of product water using vertical tube evaporators (VTEs) and multistage flash evaporators (MSFs) using acid feed treatment as a function of plant size and type of fuel is presented in Fig. 3. It should be noted that the cost for vertical tube evaporators is probably comparable to the costs for horizontal tube, spray film, multiple effect. For small plants, 3785 m³/day (1 MGD), costs from a high of \$1.69/m³ (\$6.41/1000 gal) using an MSF plant in combination with an oil-fired or coal-fired boiler, to a low of \$1.45/m³ (\$5.49/1000 gal) using a VTE plant and nuclear power. At the largest plant size considered, 378,500 m³/day (100 MGD), product water costs range from \$0.75/m³ (\$2.85/1000 gal) for MSF plants using boilers fired with oil as fuel, down to a low of \$0.57/m³ (\$2.15/1000 gal) for VTE plants with a steam generator using nuclear fuel.

Water costs estimated for small 3785 to 18,925 m³/day (1 and 5 MGD) MSF plants operating at lower temperature 88-91°C (190-195°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 \$1.78/m³ (\$6.73/1000 gal) from the 3785 m³/day (1 MGD) plant using oil or high-sulfur coal as boiler fuel. The lowest cost water, \$1.37/m³ (\$5.20/1000 gal) was from the five plants using nuclear power. For a distillation plant, the tubes represent about 15% of the cost. During the two-year period covered by this report, the cost of copper nickel tubes has increased 25%. This increase is reflected in the distillation plant cost shown in Tables A-1, A-2, and A-3.

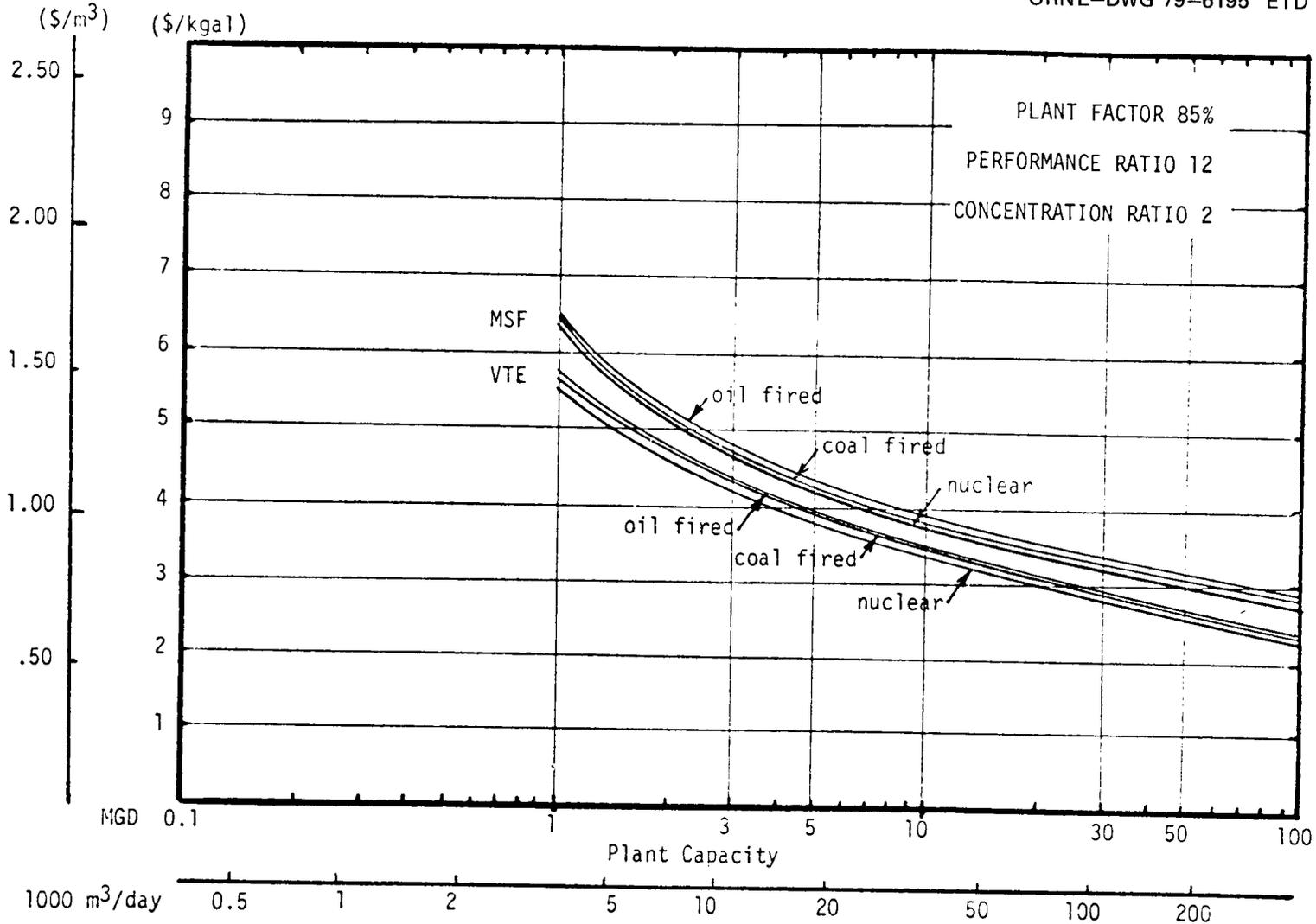


Fig. 3. Water costs — seawater desalting by distillation.

Seawater distillation costs are shown in the report for unit capacities of from 3785 m³/day (1 MGD) through 378,500 m³/day (100 MGD). It should be noted the capital cost data, which represents about 65% of the calculated cost of water, is limited in accuracy by the situation in the U.S. marketplace. For example:

1. The largest single distillation units, of all types in operation today, have a capacity of only 35,958 m³/day (9.5 MGD) (ref. 1), as compared with the estimates in this report which cover unit capacities up through 378,500 m³/day (100 MGD). The U.S. and Saudi Arabia have contracted to prepare a design concept for a 189,250 m³/day (50 MGD) flash distillation unit. However, the results of this study will not be available until late 1979 or 1980.
2. While the report limits its scope to cost of distillation plants in the U.S., no distillation plants within the size range covered by the report have been built in the U.S. since the last update report. Bids were taken in 1978 by the Virgin Islands Water and Power Authority for three 4731 m³/day (1.25 MGD) distillation units, but as of the writing of this report, the award is still awaiting final approval to proceed.
3. There are only two U.S. manufacturers of seawater distillation units with capability to build plants of 3785 m³/day (1 MGD) or above. The other U.S. manufacturers have withdrawn from the market.
4. Whereas VTE plants (including horizontal tube multieffect) reflect the lowest costs, no plants of this type and in the size range covered by this report have been built during the period covered by this report.

In contrast to previous ORNL reports, this report includes a cost estimate for an additional plant capacity, 9462 m³/day (2.5 MGD). This information was added to permit comparison with data presented in ref. 2, which includes a rather thorough cost study for this unit capacity. The two cost estimates are quite close in terms of total estimated cost and total annual cost.

Another reference¹ also offers some interesting comparisons. This paper reviews some worldwide distillation plant costs based on bidding by international companies for distillation plant projects in the Middle East and Far East during the past two years. Here again the capital costs are quite close in comparison to those calculated in this update report.

Reference 3 identifies thirty-seven potential sites in the U.S. for a water desalting demonstration plant. Fourteen are on a seacoast or island and could employ a distillation plant such as described in this report.

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. There are currently in excess of 38,750 m³/day (10 MGD) of capacity either under construction or in operation. The two largest systems include a 12,112 m³/day (3.2 MGD) spiral wound system in Jeddah, Saudi Arabia, and a 3785 m³/day (1 MGD) hollow fine-fiber system in Venezuela.

The costs of desalting seawater by reverse osmosis have been presented in the past two Oak Ridge reports, but the basis used was different from that used for the distillation systems. The earlier costs did not take full cognizance of some of the site-related costs, nor did they include the indirect capital costs. The costs developed and reported in this section do include those costs. However, in order that a direct comparison can be made between this report and the last, Table A-10 which has the same basis as the earlier reports, is included in the Appendix.

Figures 4, 5, and 6 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 6 (Seawater Desalting by Reverse Osmosis) then is directly comparable to Fig. 1 (Seawater Desalting by Distillation).

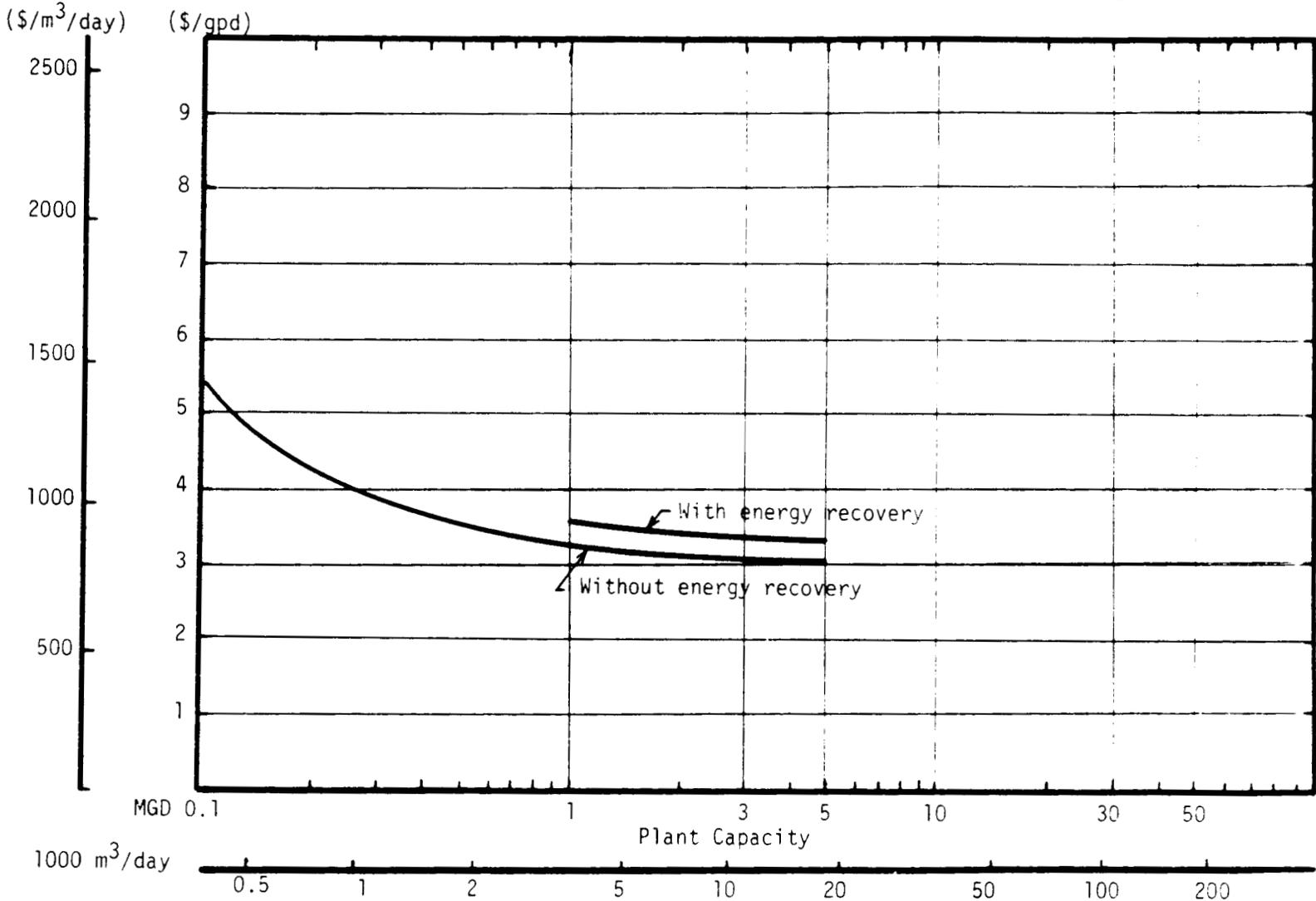


Fig. 4. Capital equipment cost - seawater desalting by reverse osmosis.

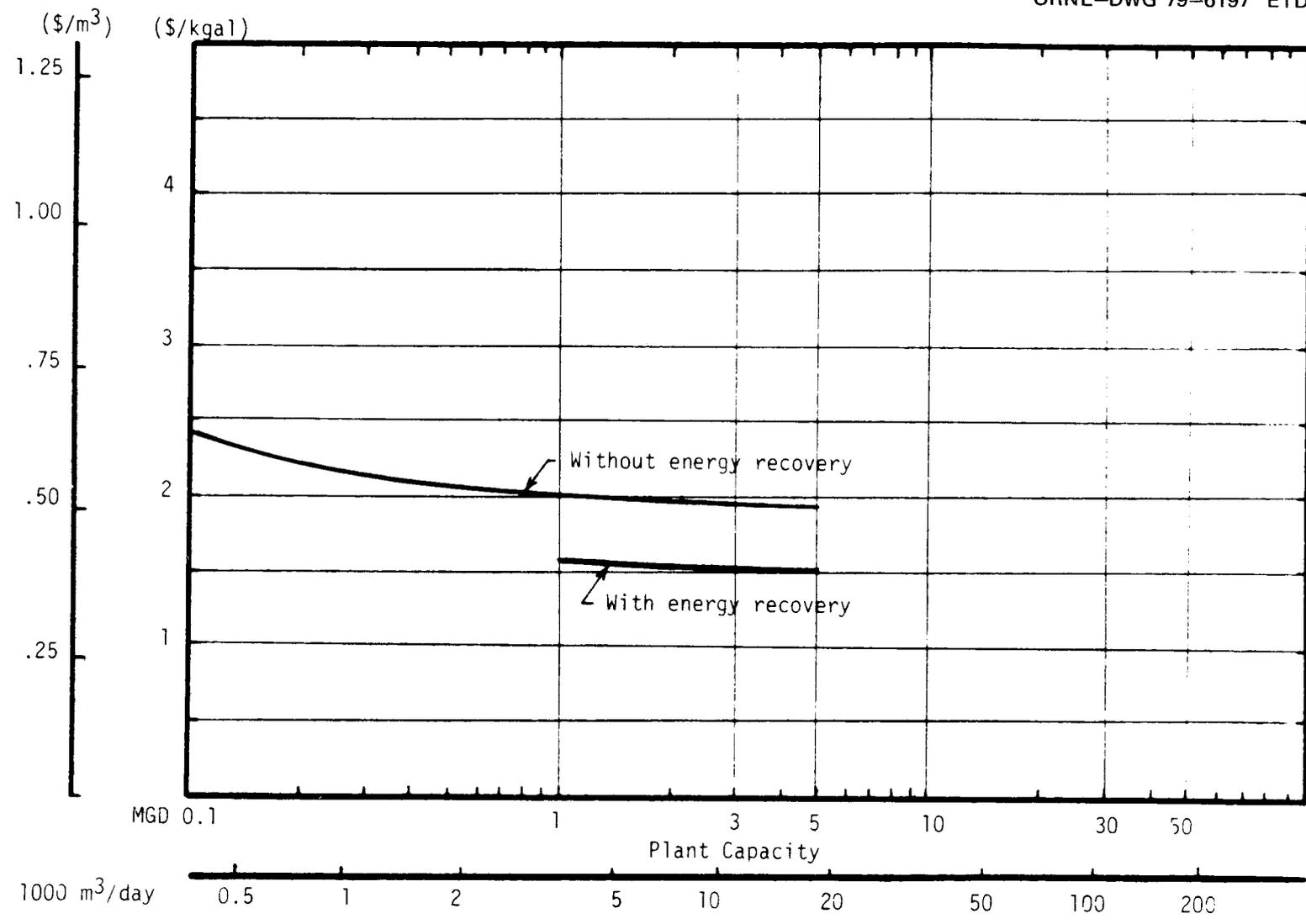


Fig. 5. Operating costs - seawater desalting by reverse osmosis.

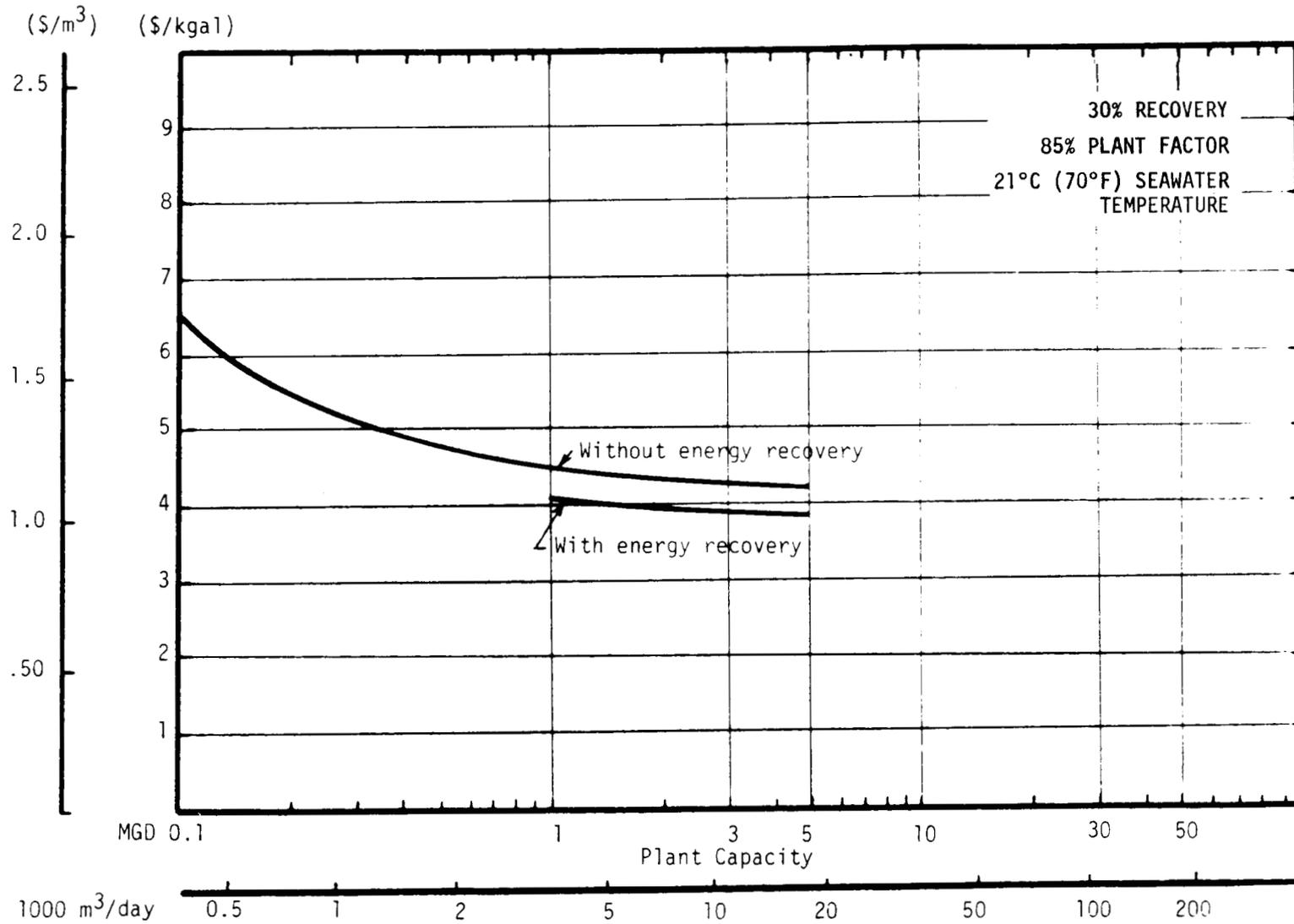


Fig. 6. Water cost - seawater desalting by reverse osmosis.

Figure 4 shows that the capital costs for seawater reverse osmosis systems ranges from approximately \$1,453/m³/day (\$5.50/gpd) to \$798/m³/day (\$3.02/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.

Figure 5 shows that the operating costs for seawater reverse osmosis systems vary from approximately \$0.62/m³ (\$2.36/1000 gal) to \$0.51/m³ (\$1.95/1000 gal) across the size range of 380/m³/day (0.1 MGD) to 18,925 m³/day (5 MGD). It should be noted that these operating costs are based upon an electrical energy usage of 10 kWhr/m³ (38 kWhr/1000 gal). If energy recovery were incorporated into the system, the electrical usage would drop to 5.28 kWhr/m³ (20 kWhr/1000 gal). This would result in a savings in operating cost of \$0.12/m³ (\$0.45/1000 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 3785 m³/day (1 MGD) or larger.

Figure 6 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 are seen to vary from \$1.73/m³ (\$6.54/1000 gal) at the small system end to \$1.14/m³ (\$4.31/1000 gal) for larger systems. As with Fig. 5, 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%.

3.3 Brackish Water Desalting by Reverse Osmosis

As with the desalting of seawater, the costs presented in earlier reports for the desalting of brackish water by reverse osmosis did not include all of the costs. Table A-11 in the Appendix was developed on the same basis as the earlier reports, and is included to provide a direct comparison. The data presented below takes full cognizance of all costs, and so is on the same basis as the preceding two sections.

Figures 7, 8, and 9 have been prepared to show the equipment cost (exclusive of site costs or indirect capital costs), the system operating costs (exclusive of the capital charges), and the water cost, including all of the cost inputs. These data have been developed based upon a feedwater with a salinity in the range of 2000-5000 ppm total dissolved solids.

Figure 7 shows that the capital cost for brackish water-reverse osmosis systems varies from \$225/m³/day (\$0.85/gpd) for a 3785 m³/day (1 MGD) system to \$135/m³/day (\$0.51/gpd) for a 94,625 m³/day (25 MGD) system. Figure 8 shows that the operating costs vary from \$0.18/m³ (\$0.67/1000 gal) to \$0.15/m³ (\$0.55/1000 gal) across the same range of sizes.

Figure 9 shows the water costs for brackish water desalting by reverse osmosis. These include not only the pure operation costs from Fig. 8, but also a capital charge based upon both the equipment cost and the other site and installation related costs. Water costs are seen to vary from \$0.36/m³ (\$1.37/1000 gal) to \$0.25/m³ (\$0.95/1000 gal) across the 3785-94,625 m³/day (1-25 MGD) size range.

3.4 Brackish Water Desalting by Electrodialysis

As has been noted in the previous cost studies, the cost of converting brackish waters to potable quality by electrodialysis is highly sensitive to feedwater composition. The costs which are presented here are based upon the four different feedwater 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, a three-stage system for waters number 2 and 4, and a two-stage system for water number 3. All systems operate in the recovery range from 78 to 87%, and each is designed to produce a product water with a salinity less than 500 ppm. In earlier studies, a three-stage system was used on water number 1; the primary electrodialysis equipment supplier, however, recommended that we use a four-stage system for this report. As with seawater and brackish water desalting by reverse osmosis,

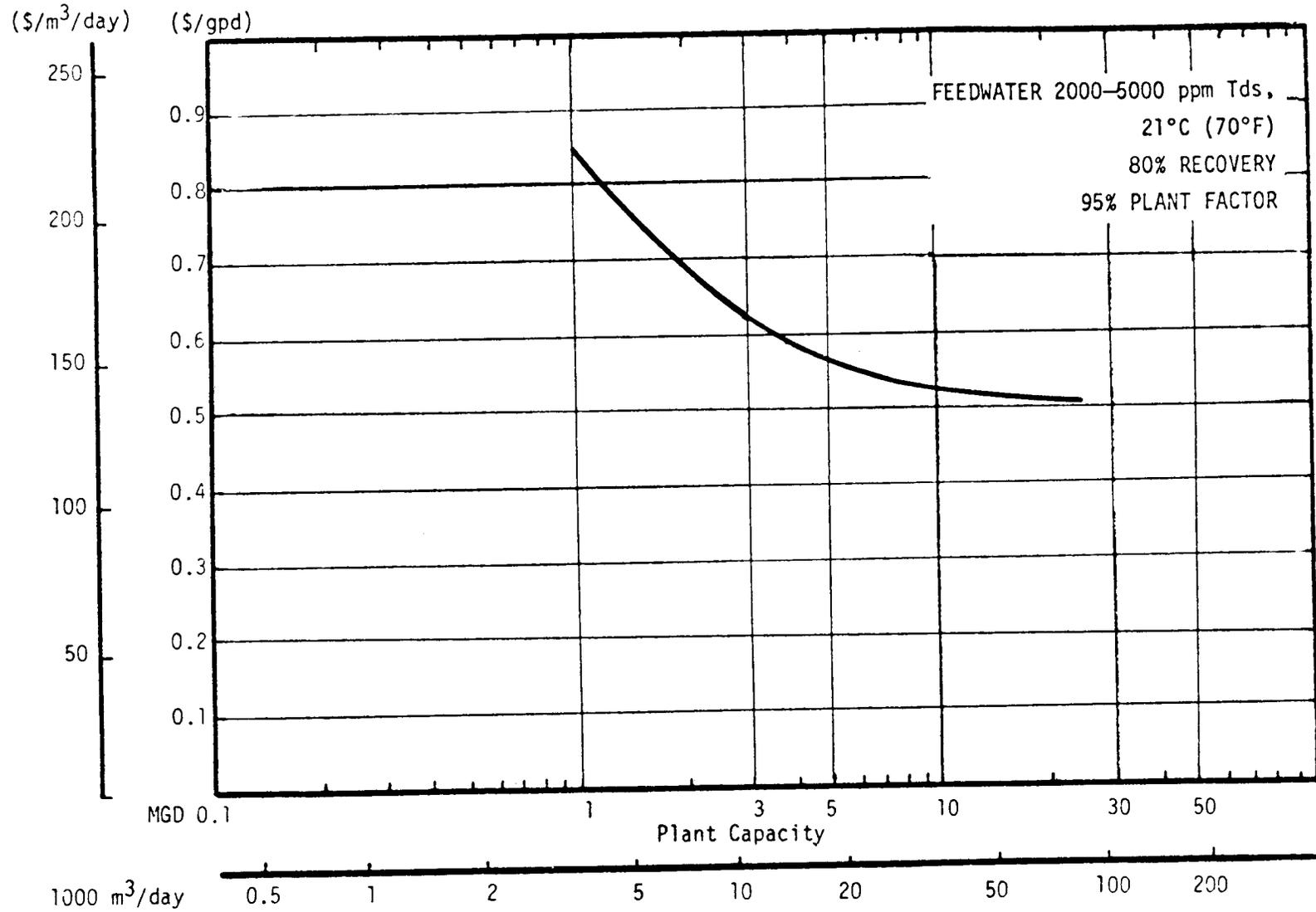


Fig. 7. Capital equipment cost — brackish water desalting by reverse osmosis.

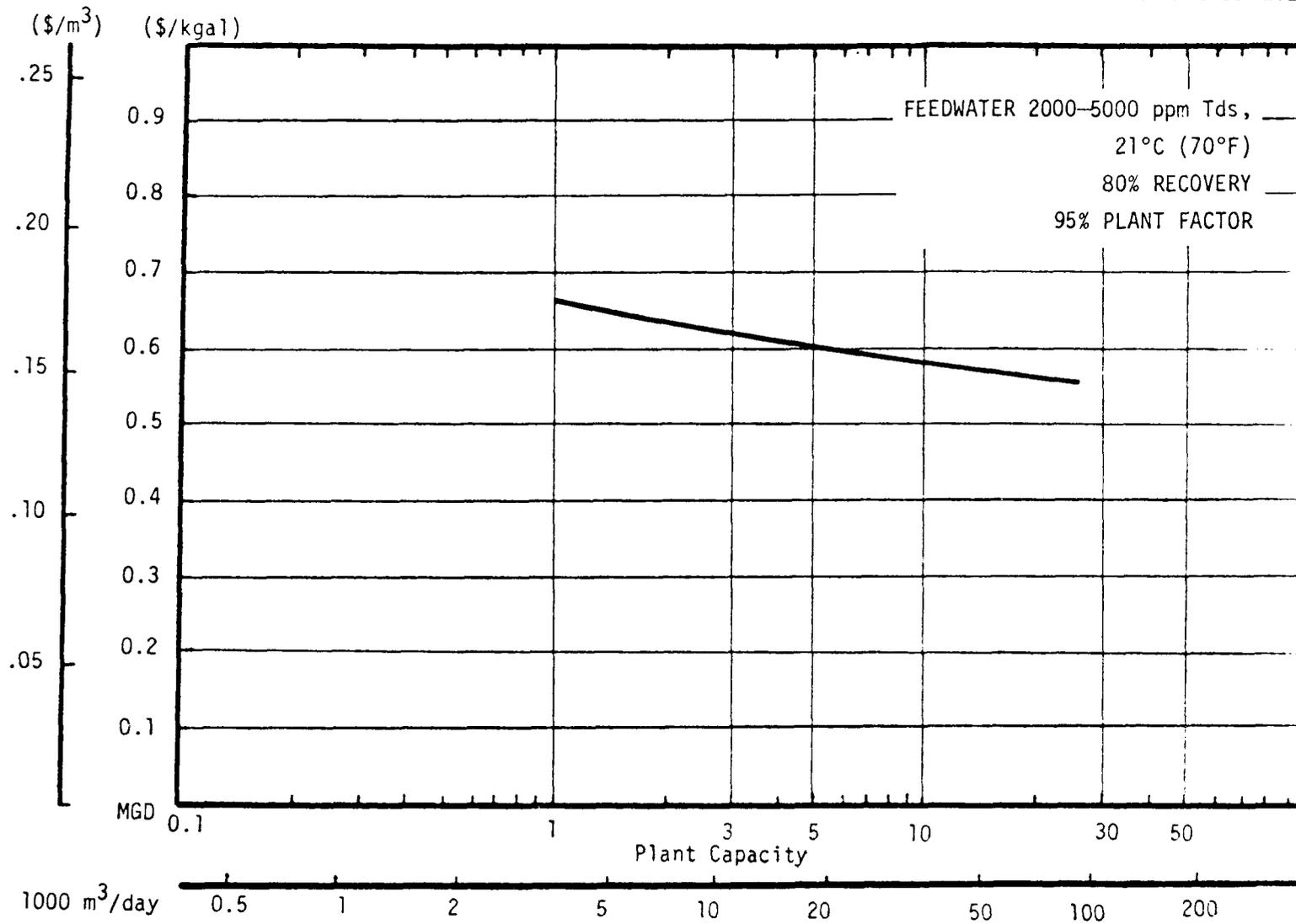


Fig. 8. Operating cost — brackish water desalting by reverse osmosis.

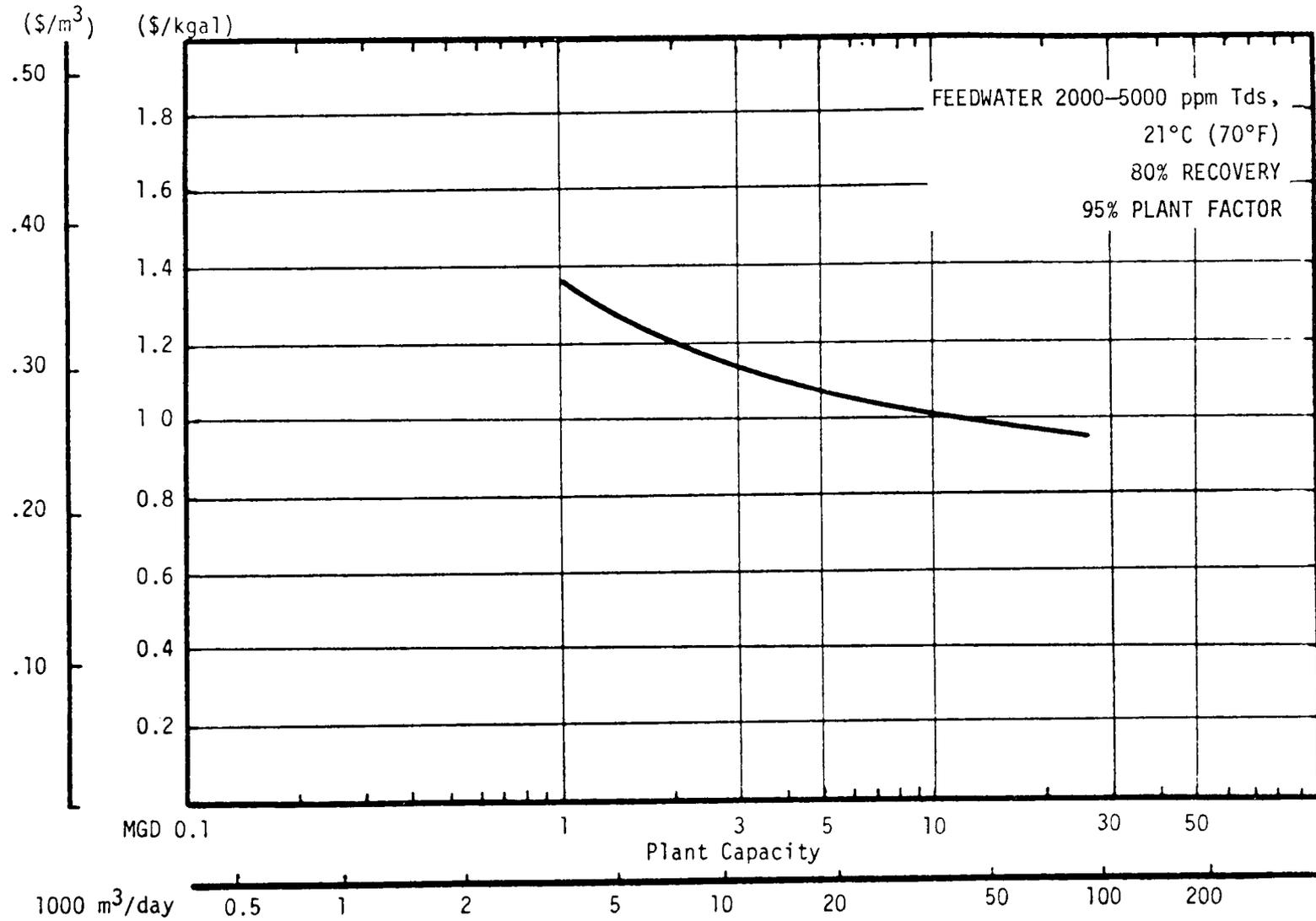


Fig. 9. Water cost - brackish water desalting by reverse osmosis.

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 | 1,054 | 1,450 |
| Sulfate (SO ₄) | 1,943 | 900 | 115 | 590 |
| Bicarbonate (HCO ₃) | 473 | 357 | 78 | 210 |
| Hardness as CaCO ₃ | 590 | 1,073 | 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 | 3,648 | 1,800 | 2,076 | 3,475 |
| pH | 7.6 | 7.9 | 8.1 | 7.3 |
| Temperature, °F | 70" | 70° | 70° | 70° |
| Organics (Chemical Oxygen Demand) | 10 | 7.9 | | 7 |

the earlier two reports did not include all costs. Tables A-10-A-15 in the Appendix were prepared on the earlier basis to provide a direct comparison.

Three figures are presented here for electrodialysis – one showing capital equipment costs (exclusive of site related costs); one showing operating costs (exclusive of capital charges); and one showing overall water costs (including all inputs). Each one of the figures includes a curve for systems operating on each of the four waters.

Figure 10 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 \$274/m³/day (\$1.04/gpd) for a small four-stage system, to a minimum of \$148/m³/day (\$0.56/gpd) for a large two-stage system.

Figure 11 shows the operating cost for systems operating on these four waters. It is seen that the costs range from \$0.16/m³ (\$0.50/1000 gal) for a small four-stage system on a difficult water to \$0.08/m³ (\$0.30/1000 gal) for a large two-stage system on a relatively easy water.

Finally, Fig. 12 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 are seen to vary from a low of \$0.19/m³ (\$0.71/1000 gal) to a high of \$0.35/m³ (\$1.32/1000 gal).

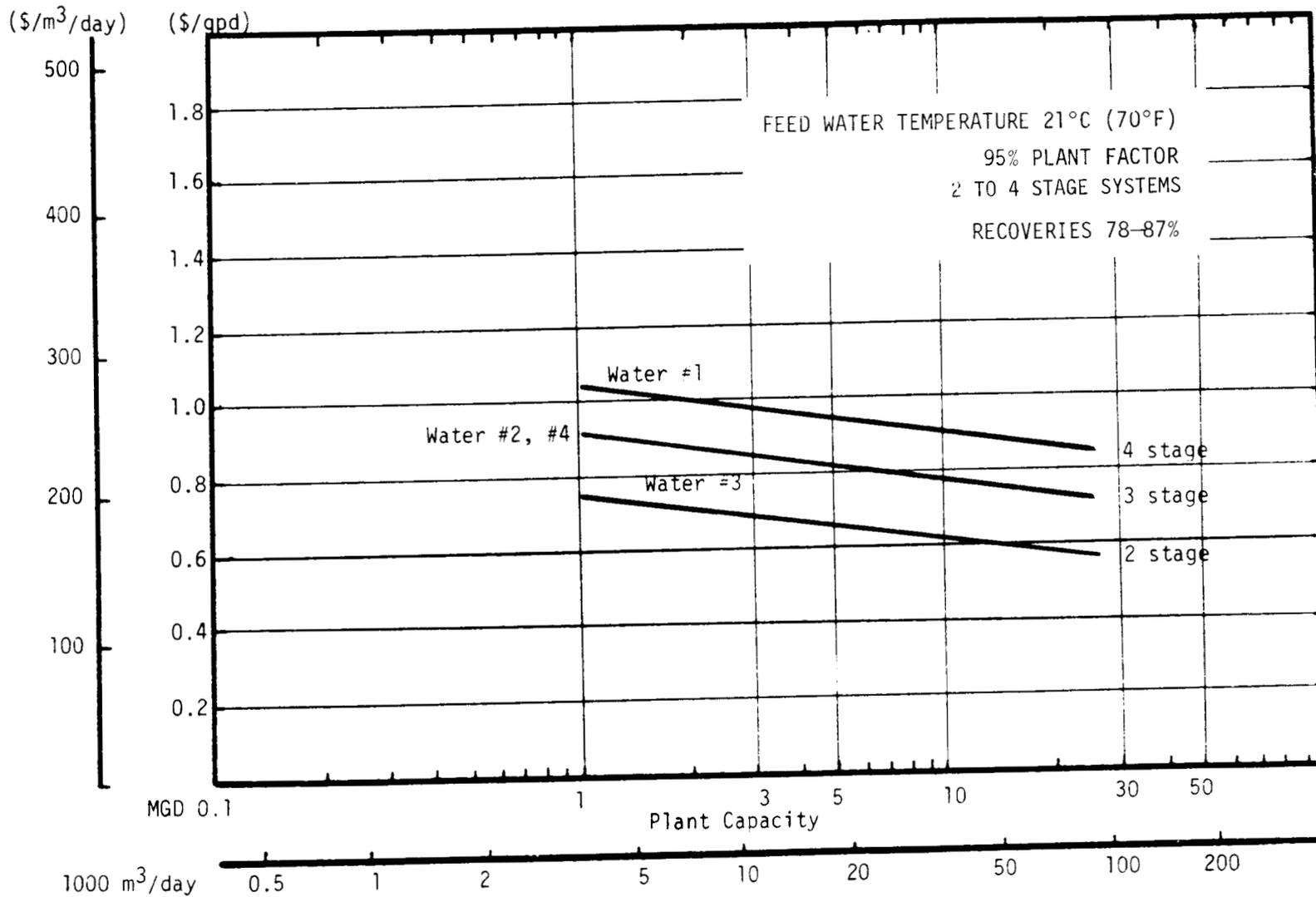


Fig. 10. Brackish water desalting by electro dialysis.

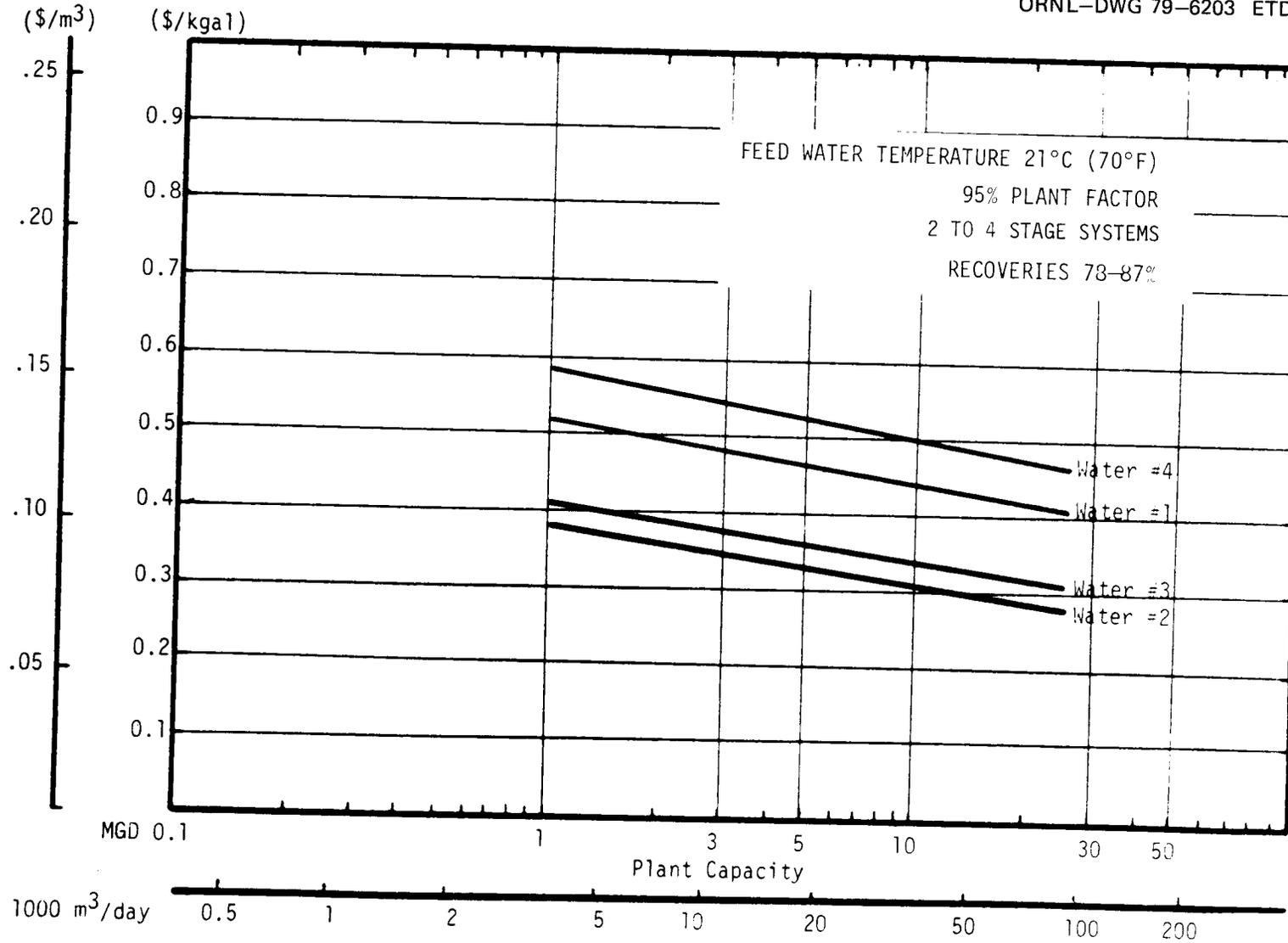


Fig. 11. Operating cost — brackish water desalting by electrodialysis.

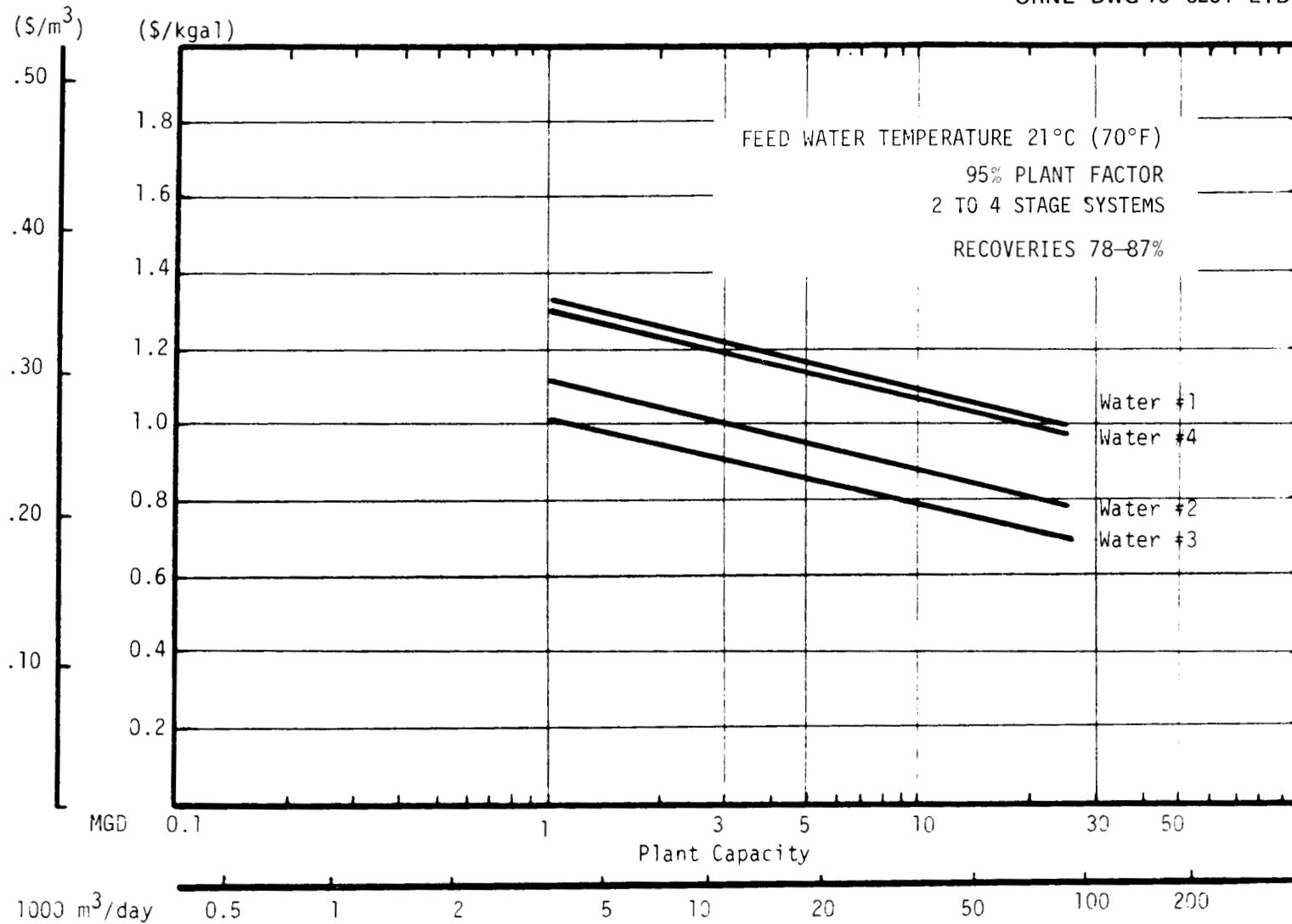


Fig. 12. Water cost - brackish water desalting by electro dialysis.

REFERENCES

1. F. C. Wood, "Review Paper on the Status of Desalting," Twelfth Congress of International Water Supply Association, Kyoto, Japan, October 1978.
2. O. J. Morin and S. R. Latour, "Cost Comparison of Reverse Osmosis and Multi-Stage Flash Seawater Desalination," NWSIA Journal, Volume 6, Number 1, January 1979.
3. "Evaluation of Technical Material and Information for Potential Desalting Demonstration Plants," OWRT Contract 14-34-0001-8705, December 1978. Boyle Engineering Corporation.



APPENDIX

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 first quarter 1979 input, and all are based upon 1979 dollars.

Tables A-1-A-9 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.

Tables A-10-A-15 are structured in a manner identical with the two past ORNL cost reports [ORNL/TM-5926 and ORNL/TM-5070 (rev.)]. These tables are also based upon first quarter 1979 costs and use 1979 dollars. They are included in order to provide a direct comparison with the earlier ORNL reports.

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
(FIRST QUARTER - 1979)

| ITEM | PLANT CAPACITY (mgd) | | | | | | |
|--|----------------------|---------|---------|---------|---------|---------|-----------|
| | 1 | 2.5 | 5 | 10 | 25 | 50 | 100 |
| Construction Period, Months | 18 | 20 | 20 | 24 | 36 | 36 | 42 |
| Land Req'd.-Acres | 2 | 3 | 3 | 4 | 11 | 13 | 23 |
| Ft. 2 | 87,000 | 130,500 | 130,500 | 174,000 | 478,500 | 565,500 | 1,000,000 |
| DIRECT CAPITAL COSTS | | | | | | | |
| Site Development & Common Facilities, | | | | | | | |
| Grading, Roads, Fencing, Gate, | | | | | | | |
| Service Buildings, Etc. | 250 | 480 | 710 | 1,133 | 1,992 | 3,244 | 4,955 |
| Intake & Outfall Systems | 221 | 398 | 575 | 920 | 1,619 | 2,639 | 4,038 |
| Electrical Utilities & Switchgear | 125 | 285 | 444 | 880 | 2,076 | 4,279 | 8,433 |
| Cranes | 0 | 2 | 4 | 4 | 6 | 7 | 35 |
| SUBTOTAL | 596 | 1,165 | 1,733 | 2,937 | 5,693 | 10,169 | 17,461 |
| MSF Distillation Plant | 4,676 | 9,000 | 16,138 | 28,013 | 54,809 | 97,438 | 164,429 |
| TOTAL DIRECT CAPITAL COSTS | 5,272 | 10,165 | 17,871 | 30,950 | 60,502 | 107,607 | 181,890 |
| INDIRECT COSTS | | | | | | | |
| Interest During Construction | 333 | 713 | 1,278 | 2,661 | 7,810 | 13,884 | 27,328 |
| Project Management, Overhead, and Profit | 1,977 | 3,812 | 6,701 | 11,803 | 24,370 | 43,525 | 74,602 |
| SUBTOTAL | 2,310 | 4,525 | 7,979 | 13,464 | 32,180 | 57,409 | 101,930 |
| Working Capital | 379 | 734 | 1,292 | 2,221 | 4,634 | 8,251 | 14,191 |
| Contingency | 796 | 1,542 | 2,714 | 4,664 | 9,732 | 17,327 | 29,801 |
| TOTAL CAPITAL COST | 8,757 | 16,966 | 29,856 | 51,299 | 107,048 | 190,594 | 327,812 |
| Capital Cost \$/GPD | 8.76 | 6.79 | 5.97 | 5.13 | 4.28 | 3.81 | 3.27 |
| ANNUAL OPERATION & MAINTENANCE COST | | | | | | | |
| Fixed Charges @ 16.5% | 1,445 | 2,799 | 4,926 | 8,464 | 17,663 | 31,448 | 54,089 |
| O & M Labor | 143 | 160 | 183 | 343 | 572 | 787 | 1,467 |
| General & Administration Charges (40% of Labor) | 57 | 62 | 73 | 137 | 229 | 315 | 587 |
| Supplies & Maintenance Materials | 30 | 45 | 72 | 133 | 333 | 655 | 1,273 |
| Chemicals | 48 | 140 | 240 | 481 | 1,204 | 2,409 | 4,818 |
| ANNUAL COSTS EXCLUSIVE OF ENERGY | 1,723 | 3,206 | 5,494 | 9,558 | 20,001 | 35,614 | 62,234 |
| I. OIL FIRED BOILER | | | | | | | |
| Steam @ \$0.98/MMBTU | 211 | 527 | 1,054 | 2,113 | 5,280 | 10,560 | 21,121 |
| Electricity @ 34.4 Mils/KW hr. | 52 | 130 | 266 | 518 | 1,334 | 2,667 | 5,337 |
| TOTAL ANNUAL O & M COST | 1,986 | 3,863 | 6,814 | 12,189 | 26,615 | 48,841 | 88,694 |
| Cost of Water \$/KGAL. | 6.41 | 4.98 | 4.44 | 3.93 | 3.43 | 3.15 | 2.86 |
| II. COAL FIRED BOILER | | | | | | | |
| A. High Sulfur Coal | | | | | | | |
| Steam @ 0.95/MMBTU | 204 | 510 | 1,022 | 2,047 | 5,117 | 10,237 | 20,473 |
| Electricity @ 36 Mils/KW hr. | 55 | 137 | 279 | 541 | 1,396 | 2,791 | 5,585 |
| TOTAL ANNUAL O & M COST | 1,982 | 3,853 | 6,795 | 12,146 | 26,514 | 48,642 | 88,292 |
| Cost of Water \$/KGAL. | 6.39 | 4.97 | 4.38 | 3.92 | 3.42 | 3.14 | 2.85 |
| B. Low Sulfur Coal | | | | | | | |
| Steam @ 0.89/MMBTU | 192 | 480 | 956 | 1,918 | 4,794 | 9,589 | 19,180 |
| Electricity @ 33.5 Mils/KW hr. | 51 | 127 | 259 | 503 | 1,299 | 2,599 | 5,196 |
| TOTAL ANNUAL O & M COST | 1,966 | 3,813 | 6,709 | 11,979 | 26,094 | 47,802 | 86,610 |
| Cost of Water \$/KGAL. | 6.34 | 4.92 | 4.33 | 3.86 | 3.37 | 3.08 | 2.79 |
| III. DUAL-PURPOSE STATION, NUCLEAR | | | | | | | |
| Steam @ 0.81/MMBTU | 174 | 435 | 871 | 1,746 | 4,363 | 8,728 | 17,456 |
| Electricity @ 40 Mils/KW hr. | 60 | 150 | 309 | 601 | 1,550 | 3,101 | 6,205 |
| TOTAL ANNUAL O & M COST | 1,957 | 3,791 | 6,674 | 11,905 | 25,914 | 47,443 | 85,895 |
| Cost of Water \$/KGAL. | 6.31 | 4.89 | 4.30 | 3.84 | 3.34 | 3.06 | 2.77 |

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
POLYPHOSPHATE FEED TREATMENT:
PERFORMANCE RATIO = 10: 90°C (194°F) MAX. BRINE TEMPERATURE,
85% PLANT FACTOR
ALL COSTS IN THOUSANDS OF DOLLARS
(FIRST QUARTER - 1979)

| ITEM | PLANT CAPACITY (mgd) | |
|--|----------------------|---------------|
| | 1 | 5 |
| Construction Period, Months | 18 | 20 |
| Land Req'd.-Acres | 2 | 3 |
| Ft. ² | | |
| DIRECT CAPITAL COSTS | | |
| Site Development & Common Facilities, Grading, Roads, Fencing, Gate, Service Buildings, Etc. | 250 | 710 |
| Intake & Outfall Systems | 221 | 575 |
| Electrical Utilities & Switchgear | 125 | 444 |
| Cranes | 0 | 4 |
| SUBTOTAL | 596 | 1,733 |
| MSF Distillation Plant | 5,053 | 21,172 |
| TOTAL DIRECT CAPITAL COSTS | 5,649 | 22,905 |
| INDIRECT COSTS | | |
| Interest During Construction | 402 | 1,806 |
| Project Management, Overhead, and Profit | 2,118 | 8,589 |
| SUBTOTAL | 2,520 | 10,395 |
| Working Capital | 110 | 320 |
| Contingency | 847 | 3,436 |
| TOTAL CAPITAL COST | 9,126 | 37,056 |
| Capital Cost \$/GPD | 9.13 | 7.41 |
| ANNUAL OPERATION & MAINTENANCE COST | | |
| Fixed Charges @ 16.5% | 1,506 | 6,114 |
| O & M Labor | 143 | 183 |
| General & Administration Charges (40% of Labor) | 57 | 73 |
| Supplies & Maintenance Materials | 30 | 72 |
| Chemicals | 56 | 286 |
| ANNUAL COSTS EXCLUSIVE OF ENERGY | 1,792 | 6,728 |
| I. OIL FIRED BOILER | | |
| Steam @ \$0.62/MMBTU | 160 | 802 |
| Electricity @ 34.4 Mils/KW hr. | 135 | 579 |
| TOTAL ANNUAL O & M COST | 2,087 | 8,109 |
| Cost of Water \$/KGAL. | 6.73 | 5.23 |
| II. COAL FIRED BOILER | | |
| A. High Sulfur Coal | | |
| Steam @ 0.61/MMBTU | 158 | 788 |
| Electricity @ 36 Mils/KW hr. | 141 | 605 |
| TOTAL ANNUAL O & M COST | 2,091 | 8,121 |
| Cost of Water \$/KGAL. | 6.73 | 5.23 |
| B. Low Sulfur Coal | | |
| Steam @ 0.56/MMBTU | 145 | 724 |
| Electricity @ 33.5 Mils/KW hr. | 130 | 564 |
| TOTAL ANNUAL O & M COST | 2,067 | 8,016 |
| Cost of Water \$/KGAL. | 6.66 | 5.16 |
| III. DUAL-PURPOSE STATION, NUCLEAR | | |
| Steam @ 0.51/MMBTU | 132 | 660 |
| Electricity @ 40 Mils/KW hr. | 157 | 674 |
| TOTAL ANNUAL O & M COST | 2,081 | 8,062 |
| Cost of Water \$/KGAL. | 6.71 | 5.20 |

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
 (FIRST QUARTER - 1979)

| ITEM | PLANT CAPACITY (mgd) | | | | | |
|--|----------------------|---------------|---------------|---------------|----------------|----------------|
| | 1 | 5 | 10 | 25 | 50 | 100 |
| Construction Period, Months | 18 | 20 | 24 | 36 | 40 | 44 |
| Land Req'd.-Acres | 2 | 3 | 4 | 7 | 10 | 18 |
| Ft. ² | | | | | | |
| DIRECT CAPITAL COSTS | | | | | | |
| Site Development & Common Facilities, Grading, Roads, Fencing, Gate, Service Buildings, Etc. | 250 | 710 | 1,138 | 1,992 | 3,244 | 4,955 |
| Intake & Outfall Systems | 221 | 575 | 920 | 1,619 | 2,639 | 4,038 |
| Electrical Utilities & Switchgear | 123 | 408 | 754 | 1,824 | 3,650 | 7,049 |
| Cranes | 0 | 4 | 4 | 6 | 7 | 35 |
| SUBTOTAL | 594 | 1,697 | 2,816 | 5,441 | 9,540 | 16,077 |
| VTE Distillation Plant | 4,140 | 14,737 | 25,577 | 50,242 | 77,778 | 121,799 |
| TOTAL DIRECT CAPITAL COSTS | 4,734 | 16,434 | 28,393 | 55,683 | 87,318 | 137,876 |
| INDIRECT COSTS | | | | | | |
| Interest During Construction | 295 | 1,167 | 2,430 | 7,134 | 12,289 | 21,193 |
| Project Management, Overhead, and Profit | 1,764 | 6,133 | 10,767 | 22,243 | 35,334 | 56,991 |
| SUBTOTAL | 2,059 | 7,300 | 13,197 | 29,377 | 47,623 | 78,184 |
| Working Capital | 340 | 822 | 1,420 | 2,784 | 4,366 | 6,894 |
| Contingency | 713 | 2,456 | 4,301 | 8,784 | 13,931 | 22,295 |
| TOTAL CAPITAL COST | 7,846 | 27,012 | 47,311 | 96,628 | 153,228 | 245,249 |
| Capital Cost \$/GPD | 7.85 | 5.40 | 4.73 | 3.86 | 3.06 | 2.45 |
| ANNUAL OPERATION & MAINTENANCE COST | | | | | | |
| Fixed Charges @ 16.5% | 1,295 | 4,457 | 7,806 | 15,944 | 25,283 | 40,466 |
| O & M Labor | 143 | 183 | 343 | 572 | 787 | 1,467 |
| General & Administration Charges (40% of Labor) | 57 | 73 | 137 | 229 | 315 | 587 |
| Supplies & Maintenance Materials | 30 | 72 | 133 | 333 | 655 | 1,273 |
| Chemicals | 35 | 176 | 354 | 886 | 1,772 | 3,546 |
| ANNUAL COSTS EXCLUSIVE OF ENERGY | 1,560 | 4,961 | 8,773 | 17,964 | 28,812 | 47,339 |
| I. OIL FIRED BOILER | | | | | | |
| Steam @ \$0.98/MMBTU | 211 | 1,054 | 2,113 | 5,280 | 10,560 | 21,121 |
| Electricity @ 34.4 Mils/KW hr. | 17 | 81 | 161 | 404 | 808 | 1,616 |
| TOTAL ANNUAL O & M COST | 1,788 | 6,096 | 11,047 | 23,648 | 40,180 | 70,076 |
| Cost of Water \$/KGAL. | 5.77 | 3.93 | 3.56 | 3.05 | 2.59 | 2.26 |
| II. COAL FIRED BOILER | | | | | | |
| A. High Sulfur Coal | | | | | | |
| Steam @ 0.95/MMBTU | 204 | 1,022 | 2,047 | 5,117 | 10,237 | 20,473 |
| Electricity @ 36 Mils/KW hr. | 17 | 84 | 169 | 423 | 846 | 1,691 |
| TOTAL ANNUAL O & M COST | 1,781 | 6,067 | 10,989 | 23,504 | 39,895 | 69,503 |
| Cost of Water \$/KGAL. | 5.75 | 3.91 | 3.54 | 3.03 | 2.57 | 2.24 |
| B. Low Sulfur Coal | | | | | | |
| Steam @ 0.89/MMBTU | 192 | 956 | 1,918 | 4,794 | 9,589 | 19,180 |
| Electricity @ 33.5 Mils/KW hr. | 16 | 78 | 157 | 392 | 787 | 1,574 |
| TOTAL ANNUAL O & M COST | 1,768 | 5,995 | 10,848 | 23,150 | 39,188 | 68,093 |
| Cost of Water \$/KGAL. | 5.70 | 3.87 | 3.50 | 2.99 | 2.53 | 2.20 |
| III. DUAL-PURPOSE STATION, NUCLEAR | | | | | | |
| Steam @ 0.81/MMBTU | 174 | 871 | 1,746 | 4,363 | 8,728 | 17,456 |
| Electricity @ 40 Mils/KW hr. | 18 | 93 | 186 | 469 | 939 | 1,879 |
| TOTAL ANNUAL O & M COST | 1,752 | 5,925 | 10,705 | 22,796 | 38,479 | 66,674 |
| Cost of Water \$/KGAL. | 5.65 | 3.82 | 3.45 | 2.94 | 2.48 | 2.15 |

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 SEAWATER DESALTING COSTS* — REVERSE OSMOSIS
 FEEDWATER: SEAWATER (35,000 ppm Tds), TEMPERATURE 21°C (70°F)
 30% RECOVERY, 85% PLANT FACTOR

| Cost Items | Plant Capacity (MGD) | | | | |
|---|-------------------------|-------|---------|----------|----------|
| | .01 | .1 | 1 | 3 | 5 |
| Construction Period (Months) | 6 | 6 | 12 | 15 | 18 |
| <u>Direct Capital Costs</u> | (\$ × 10 ³) | | | | |
| 1. Installed Equipment Cost | 55 | 525 | 3,190 | 9,240 | 15,125 |
| 2. Site Development | 5 | 20 | 125 | 225 | 375 |
| 3. Intake and Outfall System | 5 | 30 | 221 | 425 | 575 |
| 4. Electric Utilities & Switchgear | 10 | 55 | 316 | 700 | 990 |
| Total Direct Capital Cost | 75 | 630 | 3,852 | 10,590 | 17,065 |
| <u>Indirect Capital Costs</u> | | | | | |
| 5. Interest during construction & startup | 1.3 | 12.5 | 151.5 | 548.6 | 1,077.6 |
| 6. Working Capital | 3.8 | 31.5 | 192.6 | 529.2 | 853.2 |
| 7. Contingency - A & E Fee | 13.2 | 111.2 | 692.3 | 1,925.2 | 3,134.3 |
| TOTAL CAPITAL COST | 93.3 | 785.2 | 4,888.4 | 13,593.0 | 22,130.1 |
| <u>Operating Costs (Annual)</u> | | | | | |
| 8. Operating & Maintenance Labor | 4.5 | 9.0 | 27.5 | 52.5 | 77.5 |
| 9. G & A @ 40% | 1.8 | 3.6 | 11.0 | 21.0 | 31.0 |
| 10. Chemicals | 1.0 | 9.7 | 97.0 | 291.1 | 485.2 |
| 11. Filters | 0.2 | 1.7 | 17.2 | 52.0 | 86.5 |
| 12. Other Materials | 0.2 | 2.4 | 14.5 | 42.0 | 68.8 |
| 13. Electricity @ 2.5¢/kwhr | 2.9 | 29.5 | 294.5 | 883.5 | 1,472.5 |
| 14. Membrane Replacement | 1.8 | 17.3 | 161.0 | 481.0 | 801.0 |
| TOTAL OPERATING COSTS | 12.4 | 73.2 | 622.7 | 1,823.1 | 3,022.5 |
| 15. Fixed Charge @ 16.5% | 15.4 | 129.6 | 806.6 | 2,242.8 | 3,651.5 |
| TOTAL ANNUAL COST | 27.8 | 202.8 | 1,429.3 | 4,065.9 | 6,674.0 |
| Cost of Water, \$/kgal | 8.96 | 6.54 | 4.61 | 4.37 | 4.31 |

* All costs in 1979 first quarter dollars.

TABLE A-5 BRACKISH WATER DESALTING COSTS* — REVERSE OSMOSIS

FEEDWATER: 2000-5000 ppm Tds, TEMPERATURE 21°C (70°F)

80% RECOVERY, 95% PLANT FACTOR

| Cost Items | Plant Capacity (MGD) | | | | |
|---|----------------------|---------|---------|---------|----------|
| | 1 | 3 | 5 | 10 | 25 |
| Construction Period (Months) | 9 | 12 | 15 | 20 | 24 |
| <u>Direct Capital Costs</u> | (\$ × 10) | | | | |
| 1. Installed Equipment Cost | 851.0 | 2,020.0 | 2,820.0 | 5,270.0 | 12,810.0 |
| 2. Site Development | 125.0 | 225.0 | 375.0 | 450.0 | 675.0 |
| 3. Intake and Outfall System | 75.0 | 180.0 | 250.0 | 400.0 | 800.0 |
| 4. Electric Utilities & Switchgear | 125.0 | 316.0 | 444.0 | 755.0 | 1,600.0 |
| Total Direct Capital Costs | 1,176.0 | 2,741.0 | 3,889.0 | 6,875.0 | 15,885.0 |
| <u>Indirect Capital Costs</u> | | | | | |
| 5. Interest during construction & startup | 30.3 | 95.9 | 167.4 | 417.2 | 1,217.0 |
| 6. Working Capital | 58.8 | 137.0 | 194.4 | 343.8 | 794.2 |
| 7. Contingency - A & E Fee | 202.4 | 475.0 | 678.7 | 1,218.2 | 2,863.4 |
| TOTAL CAPITAL COST | 1,467.5 | 3,448.9 | 4,929.5 | 8,854.2 | 20,751.6 |
| <u>Operating Costs (Annual)</u> | | | | | |
| 8. Operating and Maintenance Labor | 27.5 | 52.5 | 77.5 | 140.0 | 140.0 |
| 9. G & A @ 40% | 11.0 | 21.0 | 31.0 | 56.0 | 56.0 |
| 10. Chemicals | 42.0 | 126.1 | 210.2 | 420.4 | 1,050.9 |
| 11. Cartridge Filters | 6.9 | 20.8 | 34.6 | 69.2 | 173.0 |
| 12. Other Materials | 4.0 | 9.6 | 13.4 | 25.1 | 61.0 |
| 13. Electricity @ 2.5¢/kwhr | 86.5 | 259.5 | 432.5 | 865.0 | 2,162.5 |
| 14. Membrane Replacement | 55.6 | 150.0 | 240.0 | 459.9 | 1,140.0 |
| TOTAL OPERATING COSTS | 233.5 | 639.5 | 1,039.2 | 2,035.6 | 4,783.4 |
| 15. Fixed Charge @ 16.5% | 242.1 | 569.1 | 813.4 | 1,460.9 | 3,425.3 |
| TOTAL ANNUAL COST | 475.6 | 1,208.6 | 1,852.6 | 3,496.5 | 8,208.7 |
| Cost of Water, \$/kgal | 1.37 | 1.16 | 1.07 | 1.01 | 0.95 |

* All costs in 1979 first quarter dollars.

TABLE A-6 BRACKISH WATER DESALTING COSTS* - 1 MGD ELECTRODIALYSIS
 FEEDWATER TEMPERATURE 21°C (70°F)
 95% PLANT FACTOR

| Item | Feedwater Type | | | |
|---|-------------------------|---------|---------|---------|
| | 1 | 2 | 3 | 4 |
| Construction Period (Months) | 6 | 6 | 6 | 6 |
| <u>Direct Capital Cost</u> | (\$ × 10 ³) | | | |
| 1. Installed Equipment Cost | 1,040 | 920 | 740 | 920 |
| 2. Site Development | 125 | 125 | 125 | 125 |
| 3. Intakes and Outfalls | 75 | 75 | 75 | 75 |
| 4. Electric Utilities and Switchgear | 125 | 80 | 80 | 125 |
| Total Direct Capital Cost | 1,365 | 1,200 | 1,020 | 1,245 |
| <u>Indirect Capital Cost</u> | | | | |
| 5. Interest during construction & startup | 24.7 | 21.8 | 17.6 | 21.8 |
| 6. Working Capital | 68.2 | 60.0 | 51.0 | 62.2 |
| 7. Contingency - A & E Fee | 233.3 | 206.1 | 174.2 | 212.6 |
| TOTAL CAPITAL COST | 1,691.2 | 1,488.9 | 1,262.8 | 1,541.6 |
| <u>Operating Costs (Annual)</u> | | | | |
| 8. Operating and Maintenance Labor | 27.5 | 27.5 | 27.5 | 27.5 |
| 9. G & A @ 40% | 11.0 | 11.0 | 11.0 | 11.0 |
| 10. Chemicals | 3.5 | 3.5 | 3.5 | 3.5 |
| 11. Filters | 10.4 | 10.4 | 10.4 | 10.4 |
| 12. Other Materials | 5.2 | 4.6 | 3.7 | 4.6 |
| 13. Electricity @ 2.5¢/kwhr | 95.2 | 53.6 | 64.9 | 119.4 |
| 14. Membrane Replacement | 27.8 | 24.6 | 19.8 | 24.6 |
| TOTAL OPERATING COSTS | 180.6 | 135.2 | 140.8 | 201.0 |
| 15. Fixed Charge @ 16.5% | 279.0 | 245.3 | 208.4 | 254.4 |
| TOTAL ANNUAL COST | 459.6 | 380.5 | 349.2 | 455.4 |
| Water Cost, \$/kgal | 1.32 | 1.10 | 1.00 | 1.31 |

* All costs in 1979 first quarter dollars.

TABLE A-7 BRACKISH WATER DESALTING COSTS* — 5 MGD ELECTRODIALYSIS
 FEEDWATER TEMPERATURE 21°C (70°F)
 95% PLANT FACTOR

| Item | Feedwater Type | | | |
|---|-------------------------|---------|---------|---------|
| | 1 | 2 | 3 | 4 |
| Construction Period (Months) | 15 | 15 | 15 | 15 |
| <u>Direct Capital Cost</u> | (\$ × 10 ³) | | | |
| 1. Installed Equipment Cost | 4,770 | 4,140 | 3,330 | 4,140 |
| 2. Site Development | 375 | 375 | 375 | 375 |
| 3. Intakes and Outfalls | 250 | 250 | 250 | 250 |
| 4. Electric Utilities and Switchgear | 444 | 285 | 285 | 444 |
| Total Direct Capital Cost | 5,839 | 5,050 | 4,240 | 5,209 |
| <u>Indirect Capital Cost</u> | | | | |
| 5. Interest during construction & startup | 282.9 | 245.5 | 197.5 | 245.5 |
| 6. Working Capital | 291.9 | 252.5 | 212.0 | 260.4 |
| 7. Contingency - A & E Fee | 1,026.2 | 887.7 | 743.9 | 914.4 |
| TOTAL CAPITAL COST | 7,440.0 | 6,435.7 | 5,393.4 | 6,629.3 |
| <u>Operating Costs (Annual)</u> | | | | |
| 8. Operating and Maintenance Labor | 77.5 | 77.5 | 77.5 | 77.5 |
| 9. G & A @ 40% | 31.0 | 31.0 | 31.0 | 31.0 |
| 10. Chemicals | 17.5 | 17.5 | 17.5 | 17.5 |
| 11. Filters | 52.0 | 52.0 | 52.0 | 52.0 |
| 12. Other Materials | 23.8 | 20.7 | 16.7 | 20.7 |
| 13. Electricity @ 2.5¢/kwhr | 475.8 | 268.2 | 324.4 | 596.8 |
| 14. Membrane Replacement | 127.4 | 110.5 | 89.0 | 110.5 |
| TOTAL OPERATING COSTS | 805.0 | 577.4 | 608.1 | 906.0 |
| 15. Fixed Charge @ 16.5% | 1,227.6 | 1,061.9 | 883.9 | 1,093.8 |
| TOTAL ANNUAL COST | 2,032.6 | 1,639.3 | 1,498.0 | 1,998.8 |
| Water Cost, \$/kgal | 1.17 | 0.94 | 0.86 | 1.15 |

* All costs in 1979 first quarter dollars.

TABLE A-8 BRACKISH WATER DESALTING COSTS* — 10 MGD ELECTRODIALYSIS
 FEEDWATER TEMPERATURE 21°C (70°F)
 95% PLANT FACTOR

| Item | Feedwater Type | | | |
|---|-------------------------|----------|---------|----------|
| | 1 | 2 | 3 | 4 |
| Construction Period (Months) | 20 | 20 | 20 | 20 |
| <u>Direct Capital Cost</u> | (\$ × 10 ³) | | | |
| 1. Installed Equipment Cost | 9,070 | 7,820 | 6,290 | 7,820 |
| 2. Site Development | 450 | 450 | 450 | 450 |
| 3. Intakes and Outfalls | 400 | 400 | 400 | 400 |
| 4. Electric Utilities and Switchgear | 755 | 485 | 485 | 755 |
| Total Direct Capital Cost | 10,675 | 9,155 | 7,625 | 9,425 |
| <u>Indirect Capital Cost</u> | | | | |
| 5. Interest during construction & startup | 718.3 | 619.3 | 498.1 | 619.3 |
| 6. Working Capital | 533.8 | 457.8 | 381.2 | 471.2 |
| 7. Contingency - A & E Fee | 1,908.3 | 1,637.1 | 1,360.7 | 1,682.5 |
| TOTAL CAPITAL COST | 13,835.4 | 11,869.2 | 9,865.0 | 12,198.0 |
| <u>Operating Costs (Annual)</u> | | | | |
| 8. Operating and Maintenance Labor | 140.0 | 140.0 | 140.0 | 140.0 |
| 9. G & A @ 40% | 56.0 | 56.0 | 56.0 | 56.0 |
| 10. Chemicals | 35.0 | 35.0 | 35.0 | 35.0 |
| 11. Filters | 105.0 | 105.0 | 105.0 | 105.0 |
| 12. Other Materials | 45.4 | 39.1 | 31.4 | 39.1 |
| 13. Electricity @ 2.5¢/kwhr | 951.5 | 536.3 | 648.8 | 1,193.7 |
| 14. Membrane Replacement | 242.2 | 208.8 | 167.9 | 208.8 |
| TOTAL OPERATING COSTS | 1,575.1 | 1,120.2 | 1,184.1 | 1,777.6 |
| 15. Fixed Charge @ 16.5% | 2,282.8 | 1,958.4 | 1,627.7 | 2,012.7 |
| TOTAL ANNUAL COST | 3,857.9 | 3,078.6 | 2,811.8 | 3,790.3 |
| Water Cost, \$/kgal | 1.11 | 0.89 | 0.81 | 1.09 |

* All costs in 1979 first quarter dollars.

TABLE A-9 BRACKISH WATER DESALTING COSTS* — 25 MGD ELECTRODIALYSIS
 FEEDWATER TEMPERATURE 21°C (70°F)
 95% PLANT FACTOR

| Item | Feedwater Type | | | |
|---|-------------------------|----------------|----------------|----------------|
| | 1 | 2 | 3 | 4 |
| Construction Period (Months) | 24 | 24 | 24 | 24 |
| <u>Direct Capital Cost</u> | (\$ × 10 ³) | | | |
| 1. Installed Equipment Cost | 20,600 | 17,480 | 14,060 | 17,480 |
| 2. Site Development | 675 | 675 | 675 | 675 |
| 3. Intakes and Outfalls | 800 | 800 | 800 | 800 |
| 4. Electric Utilities and Switchgear | <u>1,600</u> | <u>1,025</u> | <u>1,025</u> | <u>1,600</u> |
| Total Direct Capital Cost | 23,675 | 19,980 | 16,560 | 20,555 |
| <u>Indirect Capital Cost</u> | | | | |
| 5. Interest during construction & startup | 1,957.0 | 1,660.6 | 1,335.7 | 1,660.6 |
| 6. Working Capital | 1,183.8 | 990.0 | 820.0 | 1,027.8 |
| 7. Contingency - A & E Fee | <u>4,290.5</u> | <u>3,622.3</u> | <u>2,994.5</u> | <u>3,718.9</u> |
| TOTAL CAPITAL COST | 31,106.3 | 26,261.9 | 21,710.2 | 26,962.3 |
| <u>Operating Costs (Annual)</u> | | | | |
| 8. Operating and Maintenance Labor | 140.0 | 140.0 | 140.0 | 140.0 |
| 9. G & A @ 40% | 56.0 | 56.0 | 56.0 | 56.0 |
| 10. Chemicals | 87.5 | 87.5 | 87.5 | 87.5 |
| 11. Filters | 262.5 | 262.5 | 262.5 | 262.5 |
| 12. Other Materials | 103.0 | 87.4 | 70.3 | 87.4 |
| 13. Electricity @ 2.5¢/kwhr | 2,378.8 | 1,340.8 | 1,621.8 | 2,984.2 |
| 14. Membrane Replacement | <u>550.0</u> | <u>466.7</u> | <u>375.4</u> | <u>466.7</u> |
| TOTAL OPERATING COSTS | 3,577.8 | 2,440.9 | 2,613.5 | 4,084.3 |
| 15. Fixed Charge @ 16.5% | <u>5,132.5</u> | <u>4,333.2</u> | <u>3,582.2</u> | <u>4,448.8</u> |
| TOTAL ANNUAL COST | 8,710.3 | 6,774.1 | 6,195.7 | 8,533.1 |
| Water Cost, \$/kgal | 1.00 | 0.78 | 0.71 | 0.98 |

* All costs in 1979 first quarter dollars.

TABLE A-10 REVERSE OSMOSIS ANNUAL OPERATION AND MAINTENANCE COST
 FEEDWATER: SEAWATER ($\approx 35,000$ ppm Tds), TEMPERATURE 21°C (70°F)
 30% RECOVERY, 85% PLANT FACTOR
 ALL COSTS IN DOLLARS (FIRST-QUARTER 1979)
 (Old Basis)

| Cost Items | Plant Capacity (MGD) | | | | |
|---------------------------------|----------------------|-------------|-------------------------|--------------|--------------|
| | .01 | .1 | 1 | 3 | 5 |
| Installed Capital Cost* x 1,000 | | | (\$ × 10 ³) | | |
| Equipment | 55 | 525 | 3,190 | 9,420 | 15,125 |
| Intake & Outfalls | <u>5</u> | <u>30</u> | <u>221</u> | <u>425</u> | <u>575</u> |
| TOTAL | 60 | 555 | 3,411 | 9,665 | 15,700 |
| ANNUAL O & M COSTS, x \$1,000 | | | | | |
| Fixed Charge @ 16.5% | 9.9 | 91.2 | 562.8 | 1,594.7 | 2,590.5 |
| Operating & Maintenance Labor | 4.5 | 9.0 | 27.5 | 52.5 | 77.5 |
| G & A on Labor (40%) | 1.8 | 3.6 | 11.0 | 21.0 | 31.0 |
| Chemicals | 1.0 | 9.7 | 97.0 | 291.1 | 435.2 |
| Cartridge Filters | 0.2 | 1.7 | 17.2 | 52.0 | 86.5 |
| Other Materials & Supplies | 0.2 | 2.4 | 14.5 | 42.0 | 68.8 |
| Electricity @ 2.5¢/kwhr | 2.9 | 29.5 | 294.5 | 883.5 | 1,472.5 |
| Membrane replacement | <u>1.8</u> | <u>17.3</u> | <u>161.0</u> | <u>481.0</u> | <u>801.0</u> |
| TOTAL O & M COST | 22.3 | 164.4 | 1,185.5 | 3,417.8 | 5,613.0 |
| Cost of Water, \$/kgal | 7.20 | 5.30 | 3.83 | 3.68 | 3.61 |

* Installed cost (in 1979 first-quarter dollars) includes overhead, profit, interest during construction (9.5%), and all startup expenses and operator training. Does not include cost of feedwater or brine-disposal wells, land or site preparation.

TABLE A-11 REVERSE OSMOSIS PLANTS ANNUAL OPERATION AND MAINTENANCE COST
 FEEDWATER: 2000-5000 ppm Tds, TEMPERATURE 21°C (70°F)
 80% RECOVERY, 95% PLANT FACTOR
 ALL COSTS IN DOLLARS (FIRST-QUARTER 1979)
 (Old Basis)

| Cost Items | Plant Capacity (MGD) | | | | |
|-----------------------------------|----------------------|---------|-------------------------|---------|----------|
| | 1 | 3 | 5 | 10 | 25 |
| | | | (\$ × 10 ³) | | |
| Installed Capital Cost* x \$1,000 | 851.0 | 2,020.0 | 2,820.0 | 5,270.0 | 12,810.0 |
| ANNUAL O & M COSTS, x \$1,000 | | | | | |
| Fixed Charge @ 16.5% | 140.4 | 333.3 | 465.3 | 869.6 | 2,113.6 |
| Operating & maintenance labor | 27.5 | 52.5 | 77.5 | 140.0 | 140.0 |
| G & A on Labor (40%) | 11.0 | 21.0 | 31.0 | 56.0 | 56.0 |
| Chemicals | 42.0 | 126.1 | 210.2 | 420.4 | 1,050.9 |
| Cartridge filters | 6.9 | 20.8 | 34.6 | 69.2 | 173.0 |
| Other materials and supplies | 4.0 | 9.6 | 13.4 | 25.1 | 61.0 |
| Electricity @ 2.5¢/kwhr | 86.5 | 259.5 | 432.5 | 865.0 | 2,162.5 |
| Membrane Replacement | 55.6 | 150.0 | 240.0 | 459.9 | 1,140.0 |
| Total Annual O & M Cost | 373.9 | 972.8 | 1,504.5 | 2,905.2 | 6,897.0 |
| Cost of Water, \$/Kgal | 1.08 | 0.94 | 0.87 | 0.84 | 0.80 |

* Installed cost (in 1979 first quarter dollars) includes overhead, profit, interest during construction (9.5%), and all startup expenses and operator training. Does not include cost of feedwater or brine-disposal wells, land or site preparation.

TABLE A-12 ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE*
 FEEDWATER TEMPERATURE 21°C (70°F), 95% PLANT FACTOR
 (Old Basis)

| Items | Plant Size - 1 MGD | | | |
|--|--------------------|-------|-------|-------|
| | Feedwater Type | | | |
| | 1 | 2 | 3 | 4 |
| Water Recovery (%) | 87.0 | 77.5 | 79.0 | 87.0 |
| Product purity (ppm Tds) | 420 | 420 | 420 | 420 |
| Stages | 4 | 3 | 2 | 3 |
| Plant capital cost ⁽¹⁾ , \$ x 10 ⁶ | 1.04 | .92 | .74 | .92 |
| ANNUAL COST, \$ x 10 ³ | | | | |
| Fixed charges @ 16.5% | 171.6 | 151.8 | 122.1 | 151.8 |
| Operating & maintenance labor | 27.5 | 27.5 | 27.5 | 27.5 |
| G & A on Labor (40%) | 11.0 | 11.0 | 11.0 | 11.0 |
| Chemicals ⁽²⁾ | 3.5 | 3.5 | 3.5 | 3.5 |
| Cartridge filters | 10.4 | 10.4 | 10.4 | 10.4 |
| Other materials & supplies | 5.2 | 4.6 | 3.7 | 4.6 |
| Electricity @ 2.5¢/kwhr | 95.2 | 53.6 | 64.9 | 119.4 |
| Membrane Replacement | 27.8 | 24.6 | 19.8 | 24.6 |
| Total Annual Cost | 352.2 | 287.0 | 262.9 | 352.8 |
| Water Cost, \$/kgal | 1.02 | 0.83 | 0.76 | 1.02 |

* All Costs in 1979 first quarter dollars.

- (1) Installed cost (in 1979 first quarter dollars) includes overhead, profit, interest during construction (9.5%), and all startup expenses and operator training. Does not include cost of feedwater or brine-disposal wells, land or site preparation.
- (2) Chemical costs are for cleaning.

TABLE A-13 ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE*
 FEEDWATER TEMPERATURE 21°C (70°F), 95% PLANT FACTOR
 (Old Basis)

| Items | Plant Size — 5 MGD | | | |
|--|--------------------|--------------|-------------|--------------|
| | Feedwater Type | | | |
| | 1 | 2 | 3 | 4 |
| Water Recovery (%) | 87.0 | 77.5 | 79.0 | 87.0 |
| Product purity (ppm Tds) | 420 | 420 | 420 | 420 |
| Stages | 4 | 3 | 2 | 3 |
| Plant capital cost ⁽¹⁾ , \$ x 10 ⁶ | 4.77 | 4.14 | 3.33 | 4.14 |
| ANNUAL COST, \$ x 10 ³ | | | | |
| Fixed charges @ 16.5% | 786.2 | 683.1 | 549.4 | 683.1 |
| Operating & maintenance labor | 77.5 | 77.5 | 77.5 | 77.5 |
| G & A on Labor (40%) | 31.0 | 31.0 | 31.0 | 31.0 |
| Chemicals ⁽²⁾ | 17.5 | 17.5 | 17.5 | 17.5 |
| Cartridge filters | 52.0 | 52.0 | 52.0 | 52.0 |
| Other materials & supplies | 23.8 | 20.7 | 16.7 | 20.7 |
| Electricity @ 2.5¢/kwhr | 475.8 | 268.2 | 324.4 | 596.8 |
| Membrane Replacement | <u>127.4</u> | <u>110.5</u> | <u>89.0</u> | <u>110.5</u> |
| Total Annual Cost | 1,591.2 | 1,260.5 | 1,157.5 | 1,589.1 |
| Water Cost, \$/kgal | 0.92 | 0.73 | 0.67 | 0.92 |

* All costs in 1979 first quarter dollars.

(1) Installed cost (in 1979 first quarter dollars) includes overhead, profit, interest during construction (9.5%), and all startup expenses and operator training. Does not include cost of feedwater or brine-disposal wells, land or site preparation.

(2) Chemical costs are for cleaning.

TABLE A-14 ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE*
 FEEDWATER TEMPERATURE 21°C (70°F), 95% PLANT FACTOR
 (Old Basis)

| Items | Plant Size -- 10 MGD | | | |
|--|----------------------|--------------|--------------|--------------|
| | Feedwater Type | | | |
| | 1 | 2 | 3 | 4 |
| Water Recovery (%) | 87.0 | 77.5 | 79.0 | 87.0 |
| Product purity (ppm Tds) | 420 | 420 | 420 | 420 |
| Stages | 4 | 3 | 2 | 3 |
| Plant capital cost ⁽¹⁾ , \$ x 10 ⁶ | 9.07 | 7.82 | 6.29 | 7.82 |
| ANNUAL COST, \$ x 10 ³ | | | | |
| Fixed charges @ 16.5% | 1,496.6 | 1,290.3 | 1,037.8 | 1,290.3 |
| Operating & maintenance labor | 140.0 | 140.0 | 140.0 | 140.0 |
| G & A on Labor (40%) | 56.0 | 56.0 | 56.0 | 56.0 |
| Chemicals ⁽²⁾ | 35.0 | 35.0 | 35.0 | 35.0 |
| Cartridge filters | 105.0 | 105.0 | 105.0 | 105.0 |
| Other materials & supplies | 45.4 | 39.1 | 31.4 | 39.1 |
| Electricity @ 2.5¢/kwhr | 951.5 | 536.3 | 648.8 | 1,193.7 |
| Membrane Replacement | <u>242.2</u> | <u>208.8</u> | <u>167.9</u> | <u>208.8</u> |
| Total Annual Cost | 3,071.7 | 2,410.5 | 2,221.9 | 3,067.9 |
| Water Cost, \$/kgal | 0.89 | 0.70 | 0.64 | 0.89 |

* All costs in 1979 first quarter dollars.

(1) Installed cost (in 1979 first quarter dollars) includes overhead, profit, interest during construction (9.5%), and all startup expenses and operator training. Does not include cost of feedwater or brine-disposal wells, land or site preparation.

(2) Chemical costs are for cleaning.

TABLE A-15 ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE*
 FEEDWATER TEMPERATURE 21°C (70°F), 95% PLANT FACTOR
 (Old Basis)

| Items | Plant Size — 25 MGD | | | |
|--|---------------------|---------|---------|---------|
| | Feedwater Type | | | |
| | 1 | 2 | 3 | 4 |
| Water Recovery (%) | 87.0 | 77.5 | 79.0 | 87.0 |
| Product purity (ppm Tds) | 420 | 420 | 420 | 420 |
| Stages | 4 | 3 | 2 | 3 |
| Plant capital cost ⁽¹⁾ , \$ x 10 ⁶ | 20.60 | 17.48 | 14.06 | 17.48 |
| ANNUAL COST, \$ x 10 ³ | | | | |
| Fixed charges @ 16.5% | 3,399.8 | 2,884.2 | 2,319.9 | 2,884.2 |
| Operating & maintenance labor | 140.0 | 140.0 | 140.0 | 140.0 |
| G & A on Labor (40%) | 56.0 | 56.0 | 56.0 | 56.0 |
| Chemicals ⁽²⁾ | 87.5 | 87.5 | 87.5 | 87.5 |
| Cartridge filters | 262.5 | 262.5 | 262.5 | 262.5 |
| Other materials & supplies | 103.0 | 87.4 | 70.3 | 87.4 |
| Electricity @ 2.5¢/kwhr | 2,378.8 | 1,340.8 | 1,621.8 | 2,984.2 |
| Membrane Replacement | 550.0 | 466.7 | 375.4 | 466.7 |
| Total Annual Cost | 6,977.6 | 5,325.1 | 4,933.4 | 6,968.5 |
| Water Cost, \$/kgal | 0.80 | 0.62 | 0.57 | 0.80 |

* All costs in 1979 first quarter dollars.

(1) Installed cost (in 1979 first quarter dollars) includes overhead, profit, interest during construction (9.5%), and all startup expenses and operator training. Does not include cost of feedwater or brine-disposal wells, land or site preparation.

(2) Chemical costs are for cleaning.

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