22
9/4/79
240715

UC-955

ORNL/TM-6912

**Desalting Seawater and Brackish Water:
Cost Update, 1979**

MASTER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$5.25; Microfiche \$3.00

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, contractors, subcontractors, or their employees, makes any warranty, express or implied, nor assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report, nor represents that its use by such third party would not-infringe privately owned rights.

ORNL/TM-6912

Contract No. W-7405-eng-26
Subcontract No. ORNL-11Y-13545V(A)

DESALTING SEAWATER AND BRACKISH WATER: COST UPDATE, 1979

Prepared by

Larson & Associates, Limited
7080 Miramar Road, Suite C
San Diego, California 92121

950 9711

for

Department of Energy
Washington, D.C. 20545

Date Published: August 1979

NOTICE This document contains information of a preliminary nature.
It is subject to revision or correction and therefore does not represent a
final report.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

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.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	vii
LIST OF TABLES	ix
ABSTRACT	1
1. INTRODUCTION AND SUMMARY	1
2. BASIS FOR ESTIMATES	3
3. DESALTING COSTS	10
3.1 Seawater Desalting by Distillation	10
3.2 Seawater Desalting by Reverse Osmosis	13
3.3 Brackish Water Desalting by Reverse Osmosis	17
3.4 Brackish Water Desalting by Electrodialysis	18
APPENDIX	29

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	AVERAGE COST OF FUELS USED FOR ELECTRICAL GENERATION IN THE UNITED STATES	6
2	EFFECT OF FUEL COST ON STEAM COSTS	7
3	WATER COST — SEAWATER DESALTING BY DISTALLATION.....	11
4	CAPITAL EQUIPMENT COST — SEAWATER DESALTING BY REVERSE OSMOSIS	14
5	OPERATING COSTS — SEAWATER DESALTING BY REVERSE OSMOSIS	15
6	WATER COST — SEAWATER DESALTING BY REVERSE OSMOSIS	16
7	CAPITAL EQUIPMENT COST — BRACKISH WATER DESALTING BY REVERSE OSMOSIS	19
8	OPERATING COST — BRACKISH WATER DESALTING BY REVERSE OSMOSIS	20
9	WATER COST — BRACKISH WATER DESALTING BY REVERSE OSMOSIS	21
10	CAPITAL EQUIPMENT COST — BRACKISH WATER DESALTING BY ELECTRODIALYSIS	24
11	OPERATING COST — BRACKISH WATER DESALTING BY ELECTRODIALYSIS	25
12	WATER COST — BRACKISH WATER DESALTING BY ELECTRODIALYSIS	26

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

LIST OF TABLES

<u>Table</u>		<u>Page</u>
A	CHEMICAL COSTS	5
B	ENERGY COSTS	8
C	CHEMICAL COMPOSITIONS OF TYPICAL BRACKISH WATERS	22
A-1	SEAWATER DESALTING COSTS — MSF (ACID TREATMENT)	30
A-2	SEAWATER DESALTING COSTS — MSF (POLYPHOSPHATE TREATMENT)	31
A-3	SEAWATER DESALTING COSTS — VTE (ACID TREATMENT)	32
A-4	SEAWATER DESALTING COSTS — REVERSE OSMOSIS	33
A-5	BRACKISH WATER DESALTING COSTS — REVERSE OSMOSIS	34
A-6	BRACKISH WATER DESALTING COSTS — 1 MGD ELECTRODIALYSIS	35
A-7	BRACKISH WATER DESALTING COSTS — 5 MGD ELECTRODIALYSIS	36
A-8	BRACKISH WATER DESALTING COSTS — 10 MGD ELECTRODIALYSIS	37
A-9	BRACKISH WATER DESALTING COSTS — 25 MGD ELECTRODIALYSIS	38
A-10	REVERSE OSMOSIS ANNUAL OPERATION AND MAINTENANCE COST — SEAWATER (Old Basis)	39
A-11	REVERSE OSMOSIS PLANTS ANNUAL OPERATION AND MAINTENANCE COST — BRACKISH WATER (Old Basis)	40
A-12	ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE — 1 MGD (Old Basis)	41
A-13	ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE — 5 MGD (Old Basis)	42
A-14	ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE — 10 MGD (Old Basis)	43
A-15	ELECTRODIALYSIS ANNUAL OPERATION AND MAINTENANCE EXPENSE — 25 MGD (Old Basis)	44

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 electrodialysis 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 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.

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 electrodialysis 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) - \$0.95/10 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 electrodialysis 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 electrodialysis.

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

Fig. 12. Water cost — brackish water desalting by electrodialysis.

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.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

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	1,613	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 Ft. ²	2	3	4	7	10	18
DIRECT CAPITAL COSTS						
Site Development & Common Facilities, Grading, Roads, Fencing, Gate, Service Buildings, Etc.	250	710	1,138	1,992	3,744	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 @ \$0.90/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	10,227	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	15.4	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	205.1	174.2	212.6
TOTAL CAPITAL COST	1,691.2	1,486.9	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 @ 15.5%	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	1,600	1,025	1,015	1,600
Total Direct Capital Cost	23,675	19,980	16,550	20,555
<u>Indirect Capital Cost</u>				
5. Interest during construction & startup	1,957.0	1,660.5	1,335.7	1,660.6
6. Working Capital	1,183.8	990.0	820.0	1,027.8
7. Contingency - A & E Fee	4,290.5	3,622.3	2,994.5	3,718.9
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	550.0	466.7	375.4	466.7
TOTAL OPERATING COSTS	3,577.8	2,440.9	2,613.5	4,084.3
15. Fixed Charge @ 16.5%	5,132.5	4,333.2	3,582.2	4,448.8
TOTAL ANNUAL COST	8,710.3	6,774.1	6,195.7	8,533.1
Water Cost, \$/kgal	1.00	0.73	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			(\$ $\times 10^3$)		
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 ($\times 10^3$)	10	25
Installed Capital Cost* x \$1,000	851.0	2,020.0	2,320.0	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

40

* 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
 (01d 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	127.4	110.5	89.0	110.5
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.

INTERNAL DISTRIBUTION

1. T. D. Anderson	350. J. L. Rich
2. S. Baron	351. M. W. Rosenthal
3. D. F. Cope	352. M. J. Skinner
4. W. B. Cottrell	353. I. Spiewak
5. J. F. Harvey	354. H. E. Trammell
6. R. F. Hibbs	355. D. B. Trauger
7. R. E. MacPherson	356. J. V. Wilson
8. J. W. Michel	357-358. Central Research Library
9. J. S. Johnson	359. Document Reference Section
10. J. E. Jones	360-361. Laboratory Records
11. M. Levenson	Department
12. H. Postma	362. Laboratory Records, RC
13-349. S. A. Reed	

EXTERNAL DISTRIBUTION

363. D. Linz, DOE, ORO
364. R. Bailie, 38 Pelican Isle, Fort Lauderdale, FL 33301
- 365-464. Walter Barnes, Office of Water Research and Technology,
Washington, DC 20240
465. S. V. Cabibbo, Burns and Roe, Industrial Services Corp.,
P.O. Box 663, Paramus, NJ 07652
466. Harold E. Davis, Water Purification Program, Avco Corp./Avco
System Div., 201 Lowell St., Wilmington, MA 01887
467. R. W. Durante, Westinghouse Electric Corporation, 1801 K. St.,
N.W., Washington, DC 20008
- 468-469. R. H. Evans, Burns and Roe, 1250 Connecticut Ave., N.W.,
Washington, DC 20036
470. W. H. Glaze, Director, Institute of Applied Sciences, North
Texas State University, Denton, TX 76203
471. Robert Glover, Permascops Div., E.I. duPont de Nemours and
Company, 1007 Market St., Wilmington, DE 19898
472. H. Gold, Water Purification Associates, 238 Main St., Cambridge,
MA 02142
473. D. Hornburg, DSS Engineers, 7483 Northwest, 4th St., Fort
Lauderdale, FL 33317
474. Jack Hunter, United Oil Products, 10 UOP Plaza, Des Plains,
IL 60016
475. Thomas E. Kinlin, Product Sales Manager, Heat Transfer Division,
Westinghouse Electric Corp., Lester Branch, A705, P.O. Box 9175,
Philadelphia, PA 19113
476. Neil Kline, Orange County Water District, 10500 Ellis Ave.,
P.O. Box 8300, Fountain Valley, CA 92708
- 477-486. T. J. Larson, 7080 Miramar Road, Suite C, San Diego, CA 92121
487. Manuel Lopez, Jr., 8940 Pembroke Drive, Boise, ID 83704

- 488-490. Sherman C. May, Scientific Development, Bechtel Corporation,
50 Beale St., San Francisco, CA 94105
- 491. D. L. Moen, Heat Transfer Division, Westinghouse Electric Corp.,
Lester Branch, P.O. Box 9175, Philadelphia, PA 19113
- 492. L. Manning Muntzing, LaBoeuf, Lamb, Lieby & MacRae, 1750 N. St.,
N.W., Washington, DC 20036
- 493. J. W. O'Meara, Water Resources Association, 955 L'Enfant Plaza,
North, Suite 1202, Washington, DC 20024
- 494. Wil F. Pergande, President, Mechanical Equipment Company, Inc.,
861 Carondelet Street, New Orleans, LA 70130
- 495. Martin Prochnik, U.S. Department of State, OES/NET/IM,
Washington, DC 20520
- 496. R. H. Rhinesmith, Water Technologies Division, Aqua-Chem, Inc.,
P.O. Box 421, Milwaukee, WI 53201
- 497. Paul J. Shoreder, Fluor Engineers & Constructors, Inc., 3333
Michelson Dr., Irvine, CA 92730
- 498. W. W. Stickney, Resources Conservation Co., P.O. Box 936,
Renton, WA 98055
- 499. Ken Tropmeter, Bureau of Reclamation, Department of the
Interior, P.O. Box 427, Boulder City, NV 89005
- 500. Frank J. Zarambo, Riley-Beard, Inc., P.O. Box 1115, Shreveport,
LA
- 501. Asst. Manager, Energy Research and Development, DOE-OR0
- 502-528. Technical Information Center, Oak Ridge