FIRST UNITED NATIONS DESALINATION PLANT OPERATION SURVEY

UNITED NATIONS

Department of Economic and Social Affairs

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A technical and economic
analysis of the performance
of desalination plants
in operation

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EXPLANATORY NOTES

Certain commonly accepted abbreviations have been used.

References to "dollars", United States dollars, unless otherwise stated.

To convert square feet to square metres, multiply by 0.0929; to convert US gallons to imperial gallons, multiply by 0.83268.

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INTRODUCTION

The first United Nations Desalination Plant Operation Survey is part of the research and studies programme in the field of desalination undertaken by the Resources and Transport Division of the Department of Economic and Social Affairs of the United Nations Secretariat. These studies pay particular attention to the application of desalination technology in developing countries. Among the previous publications in this field reference should be made to Water Desalination in Developing Countries, Water Desalination: Proposals for a Costing Procedure and Related Technical and Economic Considerations, Proceedings of the Interregional Seminar on the Economic Application of Water Desalination and The Design of Water Supply Systems Based on Desalination. [1]

In the course of the United Nations Interregional Seminar on the Economic Application of Water Desalination, which was held at United Nations Headquarters from 22 September to 2 October 1965, participants expressed appreciation of the programme of round-table discussions at which the actual performance of a number of desalination plants already in operation could be reviewed. This provided an opportunity for discussion of the difficulties encountered in plant operation and the remedies applied in each case. Among the recommendations formulated by the participants in the Seminar was the suggestion that the United Nations Secretariat should prepare a basic questionnaire to be sent at regular intervals to authorities charged with the responsibility of operating desalination plants, in order to assemble and maintain up-to-date operational data on desalination plants, which should be published and distributed periodically. Such a publication should be a useful source of information in the field of desalination, particularly for those developing countries that are interested in the application of water desalination.

These recommendations were included in the report of the Secretary-General, "Water desalination with special reference to developments in 1965" (E/4142) [2] and were approved by the Economic and Social Council in resolution 1114 (XL) of 7 March 1966.

The Secretary-General wishes to acknowledge on this occasion the valuable co-operation rendered by the Government of the United Kingdom which, following the recommendations of the Economic and Social Council in resolution 1114 (XL), has provided under a funds-in-trust programme the services of desalination experts to assist the Secretariat in the implementation of its work programme in the field of water desalination.

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[1] United Nations publications, Sales Nos.: 64.II.B.5, 65.II.B.5, 66.II.B.30 and E.68.II.B.20, respectively.

[2] Official Records of the Economic and Social Council, Fortieth Session, Annexes, agenda item 7.

SUMMARY AND CONCLUSIONS

A. Scope of survey

The present survey is the first of a continuing series planned with the objective of compiling a progressive record and analysis of the economic and technological development of desalination plants throughout the world.

The survey includes all plants engaged in commercial production for which it was possible to obtain records of operation throughout 1965. Plants with a capacity of less than 10,000 gallons per day specialized boiler feed-water plants and experimental plants were excluded.

The survey has been made possible through the co-operation of the many authorities responsible for the operation of desalination plants. Data have been obtained from questionnaires completed by these authorities. It should be emphasized, however, that the operating authorities are not necessarily responsible for the interpretation given to these data within this report.

Eighty-seven plants in twenty-one countries were surveyed. Data were obtained on the multi-flash, long-tube vertical, submerged-tube and vapour-compression distillation processes and the electrodialysis process. The total productive capacity of these plants is 24,994,000 gallons per day. Table 1 shows the geographical distribution of the plants; table 2, the capacity distribution; table 3, the year of construction; and table 4, the application.

Multi-flash distillation plants account for more than two-thirds of the total production capacity of plants of all sizes built since 1957 throughout the world.

Table 1

Geographical distribution of plants surveyed, by process

Location	Number of Plants				
	Distillation				
	Multi-flash	Long-tube vertical	Submerged tube	Vapour compression	Electro-dialysis
North America					
United States of America	1	1	-	4	5
South America					
Ecuador	1	-	-	-	-
Peru	-	-	-	1	-
Venezuela	1	-	-	-	-
Caribbean					
Bahamas	1	-	-	2	-
Bermuda	1	-	-	1	-
Cuba	3	-	-	-	-
Leeward Islands	-	-	-	1	-
Netherlands Antilles	3	-	-	-	-
Virgin Islands	2	-	-	-	-
Europe					
Finland	-	-	-	-	1
Gibraltar	2	-	-	-	-
Italy	1	-	-	-	-
Africa					
Libya	3	-	-	-	1
Asia					
Abu Dhabi	1	-	-	-	-
Das Islands	3	-	-	-	-
Kuwait	9	-	28	-	-
Japan	-	-	-	1	-
Pacific					
Marshall Islands	-	-	-	6	-
French Polynesia	-	-	2	-	-
Atlantic					
Ascension Islands	-	-	-	1	-
TOTAL	32	1	30	17	7

Table 2

Plant capacity, by process
(Thousands of U.S. gallons per day)

	Number of plants				
	Distillation				
Capacity range	Multi-flash	Long-tube vertical	Submerged tube	Vapour compression	Electro-dialysis
10-29	-	-	2	11	2
30-99	12	-	-	2	3
100-299	4	-	28	2	1
300-999	9	-	-	1	1
1,000-1,999	7	1	-	1	-
Total number of plants	32	1	30	17	7
Total capacity	17,196	1,000	3,392	2,446	960
Grand total capacity			24,994		

Table 3

Plant construction, by process,
1950-1965

Year	Number of plants				
	Distillation				
	Multi-flash	Long-tube vertical	Submerged tube	Vapour compression	Electro-dialysis
1950	-	-	8	-	-
1951	-	-	-	6	-
1952	-	-	-	-	-
1953	-	-	10	-	-
1954	-	-	-	-	-
1955	-	-	10	4	-
1956	-	-	-	1	-
1957	4	-	-	1	-
1958	1	-	-	-	1
1959	1	-	-	-	1
1960	4	-	-	-	1
1961	2	1	-	-	1
1962	8	-	-	-	1
1963	4	-	2	1	-
1964	6	-	-	3	2
1965	2	-	-	1	-
	32	1	30	17	7

Table 4

Plant application, by process

Application	Number of plants				
	Distillation				
	Multi-flash	Long-tube vertical	Submerged tube	Vapour compression	Electro-dialysis
Water only	9	1	2	16	7
Water and power	20	-	28	-	-
Water and salt	-	-	-	1	-
	29	1	30	17	7

Although sub-merged-tube distillation plants are as numerous as multi-flash units, they account for less than one fifth of the latter group's capacity. Nearly all of the submerged-tube distillation plants were installed in Kuwait between 1950 and 1955, and were built in groups of eight or ten because of technological limitations on unit capacity. By current standards, the submerged-tube distillation process is properly considered obsolete. Indeed, in 1968 - about fifteen years after their construction - the Kuwaiti authorities initiated a programme of scrapping these submerged-tube units.

The inherent limitations of the submerged-tube distillation process have been circumvented in the related long-tube vertical distillation process now being developed to compete with multi-flash distillation. One long-tube vertical distillation plant is included in this survey.

While the vapour-compression distillation process is widely used, it is mainly for small-capacity units.

Electrodialysis, which is a membrane process using electricity for operation, is the only non-distillation process in the survey. At the current time, economic considerations limit the practical application of electrodialysis to brackish-water conversion. The process is more widely used for small plants than is indicated by the data. Although electrodialysis is now rapidly advancing to the stage of widespread commercial application, at the time of the survey the process was still undergoing intensive development towards this larger scale application.

The complementary requirements of high-quality heat for power generation and low-quality heat for distillation lead to the consideration of dual-purpose power/water plants, which offer the possibility of a reduction in over-all cost. Thus, two thirds of the multi-flash distillation plants are integrated with power production, as were all the preceding submerged-tube distillation units.

A unique example of dual-purpose operation is the combination of water production with salt production.

The range and distribution of process types included in the survey provide a useful representation of the practical status of desalination as it existed up to 1965. Predictably, no commercial plants were reported using the reverse osmosis (hyperfiltration) or freezing processes. Future surveys are likely to show a shift in this balance. Indeed by 1968, there had already been a steady advance in the accepted upper limit to the size of multi-flash distillation units, while the near future will undoubtedly see the development of, initially small, commercial reverse-osmosis units and possibly some freezing units. Apart from the intrinsic merits of competing processes, however, local circumstances will continue to play an important part in the selection of particular plant configurations.

B. Major findings

The survey confirms desalination as an entirely viable source of water-supply, at least from the point of view of technical feasibility, under conditions where proper attention is given to the design, construction and operation of both the plant and the water-supply system of which it forms a part. More specifically, it is evident that the design and construction of the plant must be soundly based: adequate operation and maintenance personnel and facilities must be available; and the over-all water-supply system must be so designed that demand can be sustained at all times despite the occasional stoppages to which the desalination plant may be subject and despite seasonal and long-term variations in the pattern of demand. These last considerations result in a reduction in plant load factors to cover maintenance periods and the need for storage or spare desalination capacity to sustain supply during these periods. Similarly, load factors are further reduced by the need to install desalination capacity sufficient to meet seasonal peaks and long-term growth in demand.

In respect of desalination costs, the survey shows the extreme variation between the water costs for different or similar desalination plants operated under various conditions; emphasis is thereby given to the hazards of attempting any generalized statement on these costs. It is evident, however, that the water costs as reported here for actual installations are distributed at a considerably higher level than the cost estimates attached to most published design studies.

The important components of total water costs are: capital and other associated fixed charges; fuel and electricity; labour; maintenance; and chemicals. The factors influencing the capital charges cost component are: the specific investment committed in the plant; the annual interest payable on this investment and the period of amortization of the debt, together with any related capital charges such as insurance or taxes (in total, constituting the annual fixed charges); and the annual production of water over which these fixed charges can be distributed (determined by the plant load factor). It is the variability of these factors which results in the wide range of reported water costs and which, in any particular case, must be specified before a meaningful determination of water cost can be made.

The more detailed findings of the survey are summarized below.

Capital investment

Capital investments for the plants surveyed are shown in chapter 1, table 5. The wide range of specific costs is partly due to the variable degree to which ancillaries and civil work may be included in any contract and the peculiar commercial pressures to which construction bids are subject during the years which precede the stabilization of a world market in any emergent technology.

Despite these factors, the existence of a strong trend towards reducing unit costs in larger plants is firmly established; these economies of scale are well illustrated in table 6.

Capital charges

Capital charges also are discussed in chapter 1. Tables 8, 9 and 11 show the range of interest rates and amortization periods (expected lifetimes) applied to plant investments by the various operating authorities. The sample is strongly biased towards low rates - even zero in one notable example in the Middle East. Plant lifetimes are most frequently assessed at fifteen to twenty years, although these are necessarily forward estimates.

The resulting fixed charges are predominantly within the range of 6-10 per cent per annum.

By contrast, the report (see table 10) recommends that 10 per cent should be considered the minimum rate of fixed charges to be applied under normal economic conditions.

Load factors

The average annual load factor, indicative of the degree to which actual annual water production approaches the level achievable under continuous operation of the plant at its rated capacity, is found to vary significantly between process types. The modern large multi-flash plants have an average annual load factor of 61 per cent; the older submerged-tube units operate at an average annual load factor of 55 per cent; and the vapour-compression distillation and electrodialysis plants have average annual load factors ranging as low as 40 per cent.

Almost half of all the total number of plants operated with annual load factors between 40 per cent and 60 per cent annual load factors and two thirds, between 30 per cent and 70 per cent. (See tables 12, 13 and 14.)

The generally low load factor in the actual operation of most plants illustrates an important departure from the design ideal. While this is partly explained by plant down-time arising from maintenance requirements, of equal importance is the mismatching of plant capacity and water demand, which is inevitable under conditions of seasonal and long-term demand variations. The influence of these two types of demand variations is determined by referring to the peak-month load factor and to the ratio of annual/peak load factor. The peak-month load factor is indicative of the degree to which the plant capacity is fully utilized and hence of the degree to which provision has been made for future long-term growth in demand; the ratio of annual/peak load factor is a simple measure of the seasonal variability of actual demands. (See tables 12, 13 and 14.)

Cost analysis

Water costs

Tables 15 and 16 show total and component water costs for all plants reported. Total costs, which are collated in table 17, show the extreme variability experienced. Significant cost ranges are between $1 and $2 per 1,000 gallons for one third of the plants and between $3 and $4 per 1,000 gallons for another one third of plants. Only 5 per cent of the plants achieved production costs below $1 per 1,000 gallons, while at the other extreme, 5 per cent of the plants had production costs exceeding $20 per 1,000 gallons.

Component costs

The distribution of component costs - capital charges, energy, labour, maintenance and chemicals - is shown in table 19, while the average distributions for the different process types are shown in table 20. The most dominant element is capital charges, which, on average, account for about 35 per cent of the total water cost. This can be attributed to the unusually low load factors mentioned above and suggests an incomplete realization of this factor at the planning stage, resulting in some over-capitalization in plant design.

Energy costs

In the multi-flash distillation plants, energy is the next most significant cost, averaging 26 per cent of the total. In the submerged-tube units, energy represents the unusually low fraction of 10 per cent of the total cost, although this is largely due to somewhat unrepresentative local conditions. Proportionate energy costs are surprisingly low for the vapour-compression and electrodialysis plants.

Labour costs

Labour costs are found to be disturbingly high; on average, they account for about 25 per cent of the total water cost. The subject is discussed in some detail in the report (see chapter 3, section E, and table 30), where it is shown that the continuous manning of a plant with a capacity of 1 million gallons per day at even the low level of one operator per shift can be a significant economic burden. These findings point up the great incentives for more automatic operation of desalination plants, or perhaps more realistically, the advantages of locating desalination units with, say, a power plant so that manpower and other facilities may be shared by the two functions.

Maintenance costs

By far the highest maintenance costs, often exceeding $1 per 1,000 gallons, are found in the smaller plants. Probably of greater interest are maintenance costs in the larger multi-flash units, where costs of the order of $0.10 per 1,000 gallons are experienced. Even at this lower figure, maintenance costs prove to be somewhat higher than the planning estimates provided in many studies.

Dual-purpose plants

Of the thermal distillation plants surveyed, forty-eight are dual-purpose units incorporated with power plants; only twelve are single-purpose plants, including several which are non-typical (see table 21). While the usual practice of taking low-pressure exhaust steam to drive the distillation plant in a dual-purpose installation undoubtedly offers economies, it does demand careful planning of the system to avoid the serious problems arising from a short- or long-term mismatching of power and water demands.

The location of a distillation plant and a power plant on a common site does, however, offer considerable advantages even where such close coupling of the steam-supplies is not practised. These advantages are that the two functions can share the same management, operation and maintenance facilities; in general, the requirements of the two functions are similar in these three respects. For distillation plants of anything but unusually large capacity, it is only on this "shared" basis that the rather specialized management and maintenance requirements, and the part-time operating labour demands, can be met at acceptable cost.

Distillation condenser design

Distallation condenser tube specifications are listed in table 26, the large element of total capital cost attributable to condensers making them of special interest. The recovery section, accounting for the most significant part of the total heat-exchange surface in the high-performance multi-flash units, are most commonly tubed in aluminium brass. There is, however, a growing tendency towards the use of one of the more expensive cupro-nickels in the heat input and rejection stages where more corrosive conditions are encountered. For the same reasons, a cupro-nickel tube material may be employed in the initial recovery stages where the brine first flashes with the release of residual dissolved gases. The great majority of multi-flash plants employ tube diameters of between three-quarters of an inch and one inch; tube thicknesses are almost universally 0.046 to 0.049 inches (18 gauge).

Scale control

For scale control, the majority of plants employ phosphate dosing, which is effective up to temperatures of about 200° F (see table 27). This apparent preference for phosphate dosing, as opposed to acid treatment, which allows operation up to approximately 250° F, is most probably due to two factors: most of the plants were constructed before acid scale-control techniques had been fully developed; and many of the plants are located in areas where acid prices are prohibitively high.

The performance of the phosphate compounds under differing conditions of sea-water feed remains somewhat variable and even unpredictable; excellent performance has been obtained in some areas, while in others there has been a continuing history of problems, e.g., excessive sludge formation. Operating experience of some of the proprietary scale inhibitors recently developed should be awaited with interest.

Water quality and temperature

Product-water qualities and temperatures are given in table 28. A marked difference exists between distillation, which usually yields a product of 50 ppm or better, and electrodialysis, where purities are usually set at about 500 ppm - higher purities being achievable only at increased cost. With the high product purities produced in distillation units, chemical dosing or blending is usually required to ensure that the product is non-corrosive to the distribution system and to improve palatability. Where brackish water is available, this blending can result in a useful increase in water production.

The distillation process does, however, suffer the disadvantage of producing a rather high-temperature product. Actual temperatures are influenced by local sea-water temperatures and the specific plant design. In most cases, distillation product-waters were reported at around 100° F, or higher.

Operational problems

The principal causes of plant shut-down are listed in chapter 3, section F of the report. More than half of the plants reported shut-downs due to the pumps and drives, and, similarly, more than half of the plants reported troubles arising from corrosion. A significant number of plants reported blockages or fouling due to inadequate screening of the sea-water feed.

Over two-thirds of the plants reported scale problems as the cause of shut-downs.

Storage capacity

The storage capacities associated with desalination plants are listed in table 31. Some ambiguity necessarily arises in assigning these storage facilities when a number of plants are located at a common site. Taking into account these multiple-plant complexes, the majority of desalination installations are reported to have storage capacities of between one week and one month of production capacity.

Chapter 1

ECONOMIC ANALYSIS

A. Capital investment

Data on years of construction, unit capacity and specific investment (dollars per gallon per day capacity) are given in table 5. The investment data are collated in terms of plant capacity in table 6.

Table 5

Capital investment, by process

Plant No.	Construction year	Unit capacity (thousands of gallons per day)	Investment (dollars per gallon per day)
		Multi-flash distillation	
27	1958	30.0	7.37
38-40	1962	30.0	1.55
33-34	1962	50.0	4.57
41	1962	50.0	2.40
12	1960	60.0	4.00
30	1964	85.0	2.35
32	1964	94.0	2.37
18	1964	156.0	3.36
42	1959	360.0	1.06
44-47	1957	630.0	1.55
43	1962	720.0	0.85
20-22	1964	750.0	3.31
48-49	1960	1,200.0	0.82
15	1962	1,463.0	1.55
24	1963	1.600.0	0.76
		Long-tube vertical distillation	
2	1961	1,000.0	1.57
		Submerged-tube distillation	
50-57	1950	120.0	1.30

Table 5 (continued)

Plant No.	Construction year	Unit capacity (thousands of gallons per day)	Investment (dollars per gallon per day)	
58-67	1953	120.0	4.13	
68-77	1955	120.0	3.03	
		Vapour-compression distillation		
4-5	1964	14.4	2.85	
23	1965	14.4	3.16	
13	1955	20.0	6.00	
16	1956	21.6	7.36	
17	1955	36.0	5.55	
3	1964	40.0	4.80	
87	1957	103.6	9.56	
19	1955	200.0	2.76	
78	1955	890.0	1.44	
6	1963	1,000.0	1.79	
		Electrodialysis		Feed-water salinity (ppm)
29	1964	13.0	5.77	7,000
8	1959	28.0	3.57	2,650
11	1961	55.0	1.53	5,400
10	1958	70.0	0.86	-
36	1964	100.0	5.60	3,500
7	1962	650.0	0.47	2,300

Table 6

Capital investment and unit capacity, by process

Unit capacity range (thousands of gallons per day)	Investment (dollars per gallon per day)		
	Minimum	Average	Maximum
	Multi-flash distillation		
30-99	1.55	3.23	7.37
100-299	-	3.36	-
300-999	0.85	1.35	1.55 a/
1,000-2,000	0.76	0.99	1.55
	Long-tube vertical distillation		
1,000	-	1.57	-
	Submerged-tube distillation		
120	1.30	3.00	4.13
	Vapour-compression distillation		
10-29	2.85	4.44	7.36
30-99	4.80	5.17	5.55
100-299	-	2.76 b/	-
300-1,000	1.44	1.61	1.79
	Electrodialysis		
10-29	3.57	4.67	5.77
30-99	0.86	1.20	1.53
100-299	-	(5.60)	-
300-999	-	0.47	-

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a/ Excluding plants Nos. 20-22.

b/ Excluding plant No. 87.

The specific investment shows wide variations; and the limited number of data preclude drawing generalized conclusions, but some significant points may be made.

A key factor in specific investment is plant capacity and the marked trend towards reduced specific investment with increasing plant capacity is well illustrated.

In addition to the basic cost of the manufactured plant (dependent upon capacity performance and technological development), the total investment cost depends heavily upon external factors, such as the extent of ancillary investment in feed water and steam supplies, civil-engineering problems and numerous other factors peculiar to individual plants. The over-all significance of these factors is illustrated in the variation of about two to one, or more, in specific investment for plants of similar capacity, even though several extreme cases were excluded from the table. This point emphasizes the need for extreme caution in only one of the many aspects of assessing potential desalination projects without thorough study of the particular circumstances.

Although the progressive reduction of specific investment costs with technological development is largely masked by other factors in the tabulated data, detailed comparison of certain cases is indicative of the trends as is shown in table 7.

Table 7

Progressive reduction of investment, selected plants

Plant No.	Construction year	Unit capacity (thousands of gallons per day)	Specific investment (dollars per gallon per day)
	Case 1. Multi-flash distillation		
42	1959	360	1.06
43	1962	720	0.85
	Case 2. Multi-flash distillation		
44-47	1957	630	1.55
48-49	1960	1,200	0.82
	Case 3. Multi-flash distillation		
48-49	1960	1,200	0.82
43	1962	720	0.85
24	1963	1,600	0.76
	Case 4. Submerged-tube distillation		
58-67	1953	120	4.13
68-77	1955	120	3.03

Case 1 compares successive multi-flash distillation plants at one location and shows a reduction of 20 per cent in three years with doubling of capacity.

Case 2 compares a four-unit multi-flash distillation plant with a subsequent two-unit plant of equal total capacity at the same location and shows a reduction of 47 per cent in three years with doubling of capacity.

Case 3 compares the three lowest investment multi-flash distillation plants in the survey, constructed in different locations but by the same manufacturer. Thus, over a period of two years, the specific investment was maintained for a plant of little more than half the capacity of the earlier plant. The following year a larger plant showed a reduction in specific investment to $0.76 per gallon per day, which is the lowest specific investment for any of the distillation plants covered by this survey.

Case 4 compares the earlier development of submerged-tube distillation. Plants Nos. 58-67, which were built as a group, were followed two years later by a similar group (Nos. 68-77) at the same location at a cost reduction of 27 per cent. It may be very tentatively concluded, therefore, that advances in technology and increased unit capacity have resulted in reducing specific investment by approximately 10 per cent per annum.

The single example of the new long-tube vertical distillation process was built partly for experimental purposes; and the relatively high specific investment cost, compared with that for multi-flash distillation, is not representative of commercial possibilities.

No significant conclusions can be drawn from the few data on the investment costs for vapour-compression and electrodialysis plants. Particular caution must be applied to the costs for electrodialysis plants, as feed-water salinity is a major factor in determining the investment cost for any location.

B. Capital charges

Data on expected plant lifetimes, interest rates and total fixed charges on capital (comprising interest, depreciation, taxes and insurance) are given in table 8.

Table 8

Amortization, by process

Plant No.	Expected life (years)	Interest rate	Fixed charges
		(percentage)	
	Multi-flash distillation		
12	15.0	-	6.7
15	25.0	5.5	9.6
18	15.0	-	1.6
20-22	25.0	2.5	6.4
24	16.7	7.0	9.8
27	10.0	3.0	13.0
30	15.0	6.0	11.0
32	15.0	6.0	10.0
38-40	10.0	10.0	20.0
41	8.0	-	12.5
42	-	-	9.9
43	-	-	9.9
44-47	20.0	0	5.0
48-49	20.0	0	5.0
	Long-tube vertical distillation		
2	20.0	4.0	9.0
	Submerged-tube distillation		
50-57	-	-	3.7[a]
58-67	15.0	0	6.7
68-77	15.0	0	8.3
	Vapour-compression distillation		
3	20.0	4.5	2.7
6	20.0	2.0	6.5
13	20.0	6.0	-
16	20.0	4.0	7.4
17	20.0	4.0	7.4
19	5.0	-	-
23	15.0	2.5	6.8
78	10.0	8.0	-
87	20.0	4.0	7.3
	Electrodialysis		
7	25.0	4.4	6.7
8	10.0	6.0	12.0
29	10.0	6.0	13.3
36	10.0	5.0	18.0

a/ Plant depreciation complete.

Discussion of the complex economic theory of amortization rates is inappropriate to this report, particularly because it is a world-wide survey wherein large variations occur in economic practices, ranging from short amortization periods at high interest rates for plants owned by industrial interests to long amortization periods and low interest rates for plants owned by public interests.

Considering amortization periods in terms of plant lifetime, desalination equipment is, in general, relatively simple and heavily built. The major part of the investment is for items of static construction, which are not subject to wear. While the failure of mechanically operating components poses a threat to indefinite operation, these components may be replaced as necessary since they comprise only a small part of the total investment. The main threat to indefinite operation arises from corrosion, to which the entire plant is subject in varying and somewhat unpredictable degrees. Investment cost is heavily dependent upon provision for corrosion so that plant structural components guaranteed to maintain integrity for twenty years may in practice remain usable for two or three times as long. Alternatively, in exceptional circumstances, unforeseeable localized corrosion problems may recur at intervals of a few years and necessitate attention to some components. The most important aspect of a plant's life is condenser tubing (discussed in detail in chapter 2, section E), which is particularly susceptible to corrosion. The very large number of tubes and the unpredictable statistical frequency of failure result in condenser tube replacement being accepted as a progressive maintenance function, and it is generally accepted that replacement of most of the tubing may be necessary during a ten- or twenty-year service life.

Table 9 shows the predicted lifetimes for the plants surveyed.

Table 9

Planned plant life

Expected life (years)	Number of plants
10	8
15	(25)
20	13
25	5

The high proportion of plants with a fifteen-year lifetime is of limited significance because it includes two large groups of associated plants subject to the same lifetime consideration. A significant number of plants are based on a service life of twenty-five years, which implies a high degree of confidence in corrosion resistance or the acceptance of possible extensive maintenance.

Given the feasibility of operating plants for periods up to twenty-five years, the important question is the economic incentive to do so. Technological advances and the possible introduction of new processes over periods covering decades may result in old plants becoming uneconomic to operate before their practical life is complete. After only approximately fifteen years of service, many of the submerged-tube distillation plants reported in this survey are being replaced by multi-flash distillation plants of greatly superior performance.

Thus, whatever the foreseeable practical lifetime of plants may be, it is important in computing amortization charges to take account of potential economic changes imposed by technological improvements.

Components of fixed charges on capital include: (a) depreciation of investment over the assumed practical or economic lifetime of the plant; (b) the interest rate applicable according to local economic practice; (c) taxes and insurance. Table 10 gives, for comparison, the rates of fixed charges used in normal accounting practice for periods of 15, 20 and 25 years, with interest rates of 4 and 6 per cent plus taxes and insurance, at an assumed 2 per cent on investment.

Table 10

Fixed charges, standard rates
(percentage)

Period (years)	Fixed charges with interest at	
	4 per cent	6 per cent
15	11.0	12.3
20	9.4	10.7
25	8.4	9.8

Thus, fixed charges of at least 10 per cent are necessary to repay capital investment within fifteen to twenty years with interest rates of between 4 and 6 per cent.

Table 11 gives an analysis of the fixed charges for the plants listed in table 8 and shows that few plants carry fixed charges sufficient to repay their investments by normal standards.

Conventional economic criteria are not universally applied; and some countries, Kuwait, for example, charge no interest at all. It must be stressed, however, that realistic evaluation of economics in most countries requires fixed charges of at least 10 per cent.

Table 11

Fixed charges, rates of plants surveyed
(percentage)

Fixed charges	Number of plants
0-1.9	1
2-3.9	9
4-5.9	6
6-7.9	20
8-9.9	15
10-11.9	2
12-13.9	4
14-15.9	-
16-17.9	-
18-19.9	1
20-21.9	3
	61

C. Load factors

A major factor in determining the cost of water produced is the extent to which the plant is used since the fixed charges have to be borne by the quantity of water actually produced. Great importance attaches to the relationship between installed capacity and actual production because several factors operate against full utilization of the plant.

Demand for water is subject to fundamental daily variations for domestic purposes superimposed on seasonal variations, including air-conditioning, irrigation and tourist requirements. Daily variations in water-supply are of little significance - unlike the case of electricity supply - since storage capacity for one or even a few days can be easily provided at little cost. Indeed, short-term storage is very likely to be included in any event to cover periods of interrupted production due to breakdown or scheduled maintenance. Such short-term storage may be associated directly with plants where these are the only source of water supply or, alternatively, may be indirectly provided by conventional water-supply arrangements where desalination provides a supplemental supply. Provision of extended storage capacity capable of absorbing peak seasonal demand is, in general, uneconomic because of the large quantities involved. The problems of economic integration of production and storage capacity are very complex and have been the subject of a separate United Nations study. 1/ The problems of integration of desalination with conventional water supplies are also very complex and have been the subject of detailed study elswhere. 2/

1/ United Nations, The Design of Water-Supply Systems Based on Desalination (United Nations publication, Sales No. E.68.II.B.20).

2/ Water Research Association, Desalination as a Supplement to Conventional Water Supply, II, T.P. 60 (Marlow, England, 1967).

In addition to the variations in demand, there is the problem of the over-all relation of plant capacity to demand. In general, water demand increases progressively over a period of years, and the nature of desalination plant investment is such that plants have to be able to meet such increasing demands over a five- to ten-year period. Thus, a plant is likely to have greater capacity and investment than that required when it is first constructed.

The actual water production which has to bear the fixed investment costs is therefore less than the nominal production capacity of the plant to the extent of the periodic variations in production and the initial over-capacity of the plant.

Data on load factors are shown in table 12. The annual load factor is the total production for the year as a percentage of the rated capacity. It provides a measure of the over-all utilization of the plant.

Table 12

Load factors, by process

(percentage)

Plant No.	Load factor		
	Annual	Peak-month	Annual/peak
	Multi-flash distillation		
1	43	90	48
12	98	-	-
15	42	93	45
18	49	100	49
20-22	91	98	93
24	47	67	70
27	71	-	-
30	57	74	77
32	18	37	49
33-34	36	44	82
35	71	86	83
38-40	18	22	82
41	85	97	88
42	71	88	81
43	93	102	91
44-47	70	87	80
48-49	85	102	84

Table 12 (continued)

Plant No.	Load factor		
	Annual	Peak-month	Annual/peak
	Long-tube vertical distillation		
2	62	106	59
	Submerged-tube distillation		
50-57	65	81	80
58-67	47	71	66
68-77	55	67	82
	Vapour-compression distillation		
3	15	31	48
4-5	39	46	85
6	25	67	37
13	24	84	29
16	19	22	86
17	21	43	49
19	46	-	-
23	31	-	-
78	98	100	98
79-84	48	55	87
87	38	42	91
	Electrodialysis		
7	28	34	82
8	70	74	95
9	63	82	77
10	39	69	57
11	24	46	52
36	34	-	-

The peak-month load factor is the maximum monthly production as a percentage of the rated capacity. It provides a measure of the maximum utilization of the plant.

The annual/peak load factor is the ratio of the average annual production rate to peak monthly production rate. It provides a measure of the consistency of utilization of the plant.

The annual load factor is the dominant factor in dictating the extent to which capital charges can be spread over the total quantity of water produced. This in turn determines the fixed charges element of the water cost. Accordingly, it is the annual load factor that is of primary significance in economic terms. However, the reason that any particular plant may suffer a low annual load factor - resulting in a high water cost - may rest in two quite different types of demand/capacity mismatching. It is the other two load factor indices which identify the source of this mismatching.

A high peak-month load factor indicates the extent to which the plant capacity is justified by demand at some time. Set against a background of annual increases in demand, the peak-month load factor will be relatively low at first and will then increase. Peak-month load factors approaching 100 per cent signal the impending need for further provision of water-supply capability.

Some degree of demand variation within the year is inevitable, and the magnitude of this variation is most simply indicated by the annual/peak load factor. This ratio should approach unity for maximum plant utilization. Low annual/peak load factors, however, indicate basic problems of demand variation.

Such problems of demand variation have no definite trends and may improve or deteriorate in particular countries. Increased industrial activity operating consistently throughout the year will tend to stabilize demand variation. Increased seasonal activity, such as tourism or irrigation, will exaggerate demand variation. These problems of demand variation emphasize the necessity for improved over-all water management techniques for influencing demand and better integration, where appropriate, with conventional water supply and storage.

The load factor data are collated in table 13, and the average values for various types of plants are given in table 14.

Table 13

Collated load factors

(percentage)

Load factor	Number of plants with		
	Annual load factor	Peak-month load factor	Annual/ peak load factor
10 to 19	6	0	0
20 to 29	5	4	1
30 to 39	8	3	1
40 to 49	21	7	6
50 to 59	11	6	3
60 to 69	10	13	10
70 to 79	8	12	3
80 to 89	3	16	42
90 to 99	6	6	7
100 to 109	0	6	0
	78	73	73

Table 14

Average load factors by process

(percentage)

Process	Average load factor		
	Annual	Peak-month	Annual/peak
Multi-flash distillation	61	76	77
Long-tube vertical distillation a/	(62)	(106)	(59)
Submerged-tube distillation	55	72	76
Vapour-compression distillation	40	54	74
Electrodialysis	43	61	73
All processes	53	70	76

a/ One plant only.

The average annual load factor for all plants surveyed is only 53 per cent, with significant differences between processes. The modern large multi-flash plants have an average annual load factor of 61 per cent. The single example of long-tube vertical distillation is not statistically significant because it is an experimental plant whose operating programme is not determined by water demand. The older submerged-tube distillation plants operate at an average annual load factor of 55 per cent, which is significantly less than that for multi-flash distillation plants and is of particular interest as all the submerged-tube distillation plants included in this analysis operate in association with more modern and efficient multi-flash distillation plants, which have, in consequence, been more heavily loaded. The vapour-compression distillation and electrodialysis plants operate with much lower average annual load factors of 40 and 43 per cent. Examination of the data for individual plants shows that this is accounted for largely by relatively small requirements being met by the installation of standardized units. On an over-all basis nearly half of the plants operate with annual load factors of 40-60 per cent, and two thirds have load factors of 30-70 per cent. In spite of the low average annual load factor, however, more than 10 per cent of the plants have annual load factors greater than 80 per cent, and about 8 per cent have load factors equal to or greater than 90 per cent. Most of these plants, moreover, operate in isolation so that very little margin remains to cover increasing demand or interruptions of operation.

As expected peak-month load factors are substantially higher than annual load factors, averaging 70 per cent compared with 53 per cent, more than half of the plants have peak-month load factors in the range of 60-90 per cent. Indeed, 8 per cent of the plants have peak-month load factors in excess of 100 per cent of rated capacity; many of these are the plants previously referred to as having annual load factors above 80 or 90 per cent, thus emphasizing their critical situation with respect to increases in demand or interruptions of production.

The data for annual/peak load factors show that the average annual production rate is only 76 per cent of peak production, with two thirds of the plants averaging between 70 and 90 per cent of peak production. There is some reason to believe, however, that some of the plants only achieve this apparently high degree of uniformity of production by virtue of the fact that they are part of a complex which fails to satisfy the total seasonal peak demand for water. In this sense, it may be unwise to assume that there is necessarily a one-for-one correspondence between production rates and water demands.

The general conclusion that may be drawn suggests that even in ideal circumstances, i.e. where plant capacity exactly matches peak requirements, the annual production averages only about 76 per cent of installed capacity. In practical circumstances, where excess capacity is installed to meet increasing demand over several years, the annual production averages only about 60 per cent of installed capacity even for large individually designed multi-flash distillation plants. The annual utilization of small plants, which are likely to be supplied in standardized units, may be as low as 40 per cent.

D. Cost analysis

Tables 15 and 16 give cost analyses comprising fixed charges (depreciation, interest, taxes and insurance); labour (including overheads), maintenance (including materials), chemicals, fuel, electricity, feed water and, finally total production cost for each plant.

The form of presentation of the data permits the comparison of absolute costs of items, as well as comparisons of the relative significance of component items in the total production costs.

Cursory examination is sufficient to show the extreme variations in the component costs in total water costs, which range from $0.66 per 1,000 gallons to $34.85 per 1,000 gallons. The percentage analysis data show how widely the significance of component costs varies; for example, the proportion of fixed charges ranges from 8.0 to 74.0 per cent; and the proportion of fuel costs ranges from 2.9 to 44.6 per cent of total water costs.

Table 15

Cash analysis of water costs, by process

(Dollars per 1,000 gallons)

Plant No.	Fixed charges	Labour[a]	Maintenance[b]	Chemicals	Fuel	Feed water	Electricity	Total
Multi-flash distillation								
12	.76	.63	.82	.07	1.61[c]	.65	.50	5.04
15	.98	.20	.02	.05	.38	-	.12	1.75
18	.30	1.14	.56	.17	1.30	-	.26	3.73
20-22	.63	.26	.04		.71[c]	-	.04	1.68
24	.43	.21	.07	.00	.34[c]	-	.02	1.07
27	3.70	2.77	.15	.09	3.68	-	.64	11.03
30	1.24	.16	.00	.05	.00	-	.46	1.91
32	3.62	.79	.08	1.11	.13	-	.13	5.85
33-34	-	3.92	2.23	.69	-	-	-	-
38-40	4.69	3.28	1.55		.00	-	.94	10.46
41	.97	2.27	.65	.13	.32	-	.73	5.07
42	.40	1.23	.09	.06	.17[c]	.18	.02	2.15
43	.24	1.23	.09	.06	.17[c]	.18	.02	1.99
44-47	.31	.30	.02	.15	.21[c]	-	.07	1.06
48-49	.13	.17	.11	.12	.12[c]	-	.01	.66
Long-tube vertical distillation								
2	.63	.46	.04	.05	.73	-	.11	2.02
Submerged-tube distillation								
50-57	.24	1.23	.09	.06	.17[c]	.18	.02	1.99
58-67	1.59	1.20	.19	.40	.30[c]	-	.04	3.72
68-77	1.26	.89	.10	.66	.30[c]	-	.05	3.26
Vapour-compression distillation								
3	2.32	3.13	1.31	.09	.59	-	1.54	8.98
6	1.27	.97	.50	.10	.05	-	.92	3.81
13	-	2.14	3.77	.12	.69	-	.87	-
16	7.90	13.51	11.82	.61	1.01	-	Nil	34.85
17	5.36	17.40	8.15	.58	1.05	-	Nil	32.54
19	-	2.10	5.10	.49	2.08	-	.13	-
23	1.92	Nil	.18		.31	-	.19	2.59
79-84	-	3.33	1.03		.16	-	.32	-
87	5.10	7.13	7.27	.60	1.03	-	Nil	21.13
Electrodialysis								
7	.31	.09	.18	.01	Nil	-	.10	.69
8	1.67	.83	.98	.18	Nil	-	.15	3.81
9	-	1.24	.12	.35	Nil	-	.14	-
10	-	4.73	.10		Nil	-	.15	-
11	-	3.50	.79	1.02	Nil	-	.18	-

[a] Including overhead.
[b] Including materials.
[c] Cost of steam.

Table 16

Percentage analysis of water costs, by process

Plant No.	Fixed charges	Labour[a]	Maintenance[b]	Chemicals	Fuel plus electricity	Feed water
			Multi-flash distillation			
12	15.1	12.5	16.2	1.4	41.8	13.0
15	56.0	11.4	1.1	2.9	28.6	-
18	8.0	30.5	15.0	4.6	41.9	-
20-22	37.5	15.5	2.4		44.6	-
24	40.1	19.6	6.5	0.0	33.8	-
27	33.4	25.2	1.4	0.8	39.2	-
30	64.9	8.4	0.0	2.6	24.1	-
32	61.7	13.5	1.4	19.0	4.4	-
38-40	44.8	31.4	14.8		9.0	-
41	19.2	44.7	12.8	2.6	20.7	-
42	18.6	57.2	4.2	2.8	8.8	8.4
43	12.1	61.9	4.5	3.0	9.5	9.0
44-47	29.2	28.3	1.9	14.2	26.4	-
48-49	19.8	25.6	16.6	18.2	19.8	-
			Long-tube vertical distillation			
2	31.2	22.8	2.0	2.5	41.5	-
			Submerged-tube distillation			
50-57	12.1	61.9	4.5	3.0	9.5	9.0
58-67	42.7	32.3	5.1	10.7	9.2	-
68-77	38.6	27.3	3.1	20.3	10.7	-
			Vapour-compression distillation			
3	25.8	34.9	14.6	1.0	23.7	-
6	33.3	25.5	13.1	2.6	25.5	-
16	22.7	38.8	33.9	1.7	2.9	-
17	16.5	53.4	25.1	1.8	3.2	-
23	74.0	0.0	7.0		19.0	-
87	24.1	33.8	34.4	2.8	4.9	-
			Electrodialysis			
7	44.9	13.1	26.1	1.4	14.5	-
8	43.8	21.8	25.8	4.7	3.9	-

---

[a] Including overhead.

[b] Including materials.

Total water costs

The total water production costs are collated in table 17. Only 5 per cent of the plants achieved production costs below $1 per 1,000 gallons, while at the other extreme, 5 per cent of the plants had production costs exceeding $20 per 1,000 gallons. The significant cost ranges are between $1 and $2 per 1,000 gallons for one third of the plants and between $3 and $4 per 1,000 gallons for another one third of the plants.

Since particular interest attaches to the plants producing water at the lowest costs a number of them are detailed in table 18 for comparison.

The lowest cost water ($0.66 per 1,000 gallons) is that produced by multi-flash distillation plants Nos. 48-49. They were built in 1960 and were the first plants to produce over 1 million gallons per day and to have an investment cost below $1 per gallon per day capacity (1.2 million gallons per day each and $0.82 investment per gallon per day). They operate at the very high annual load factor of 85 per cent and with the very low fixed charges rate of 5 per cent. As a result, fixed charges on investment account for only $0.13 of the water cost per 1,000 gallons, though even this is 20 per cent of the total cost. A conventional rate of 10 per cent for fixed charges would increase the water cost to only $0.79 per 1,000 gallons, but the proportion attributable to fixed charges would increase to 33 per cent. The charges for these plants are approximately equally shared by fixed charges, labour, maintenance, chemicals and energy.

Table 17

Water production costs

(Dollars per 1,000 gallons)

Water costs	Number of plants
0- .99	3
1.0-1.99	19
2.0-2.99	3
3.0-3.99	23
4.0-4.99	0
5.0-5.99	3
6.0-6.99	0
7.0-7.99	0
8.0-8.99	1
9.0-9.99	0
10.0-19.99	4
20.0-29.99	1
30.0-39.99	2
	59

Table 18

Cost analyses, selected plants

Plant No.	48-49	7[a]	44-47	24	20-22
Year constructed	1960	1962	1957	1963	1964
Unit capacity (gallons per day)	1,200,000	650,000	630,000	1,600,000	750,000
Investment (dollars per gallon per day)	.82	.47	1.55	.76	3.31
Annual load factor (percentage)	85	28	70	47	91
Fixed charge rate (percentage)	5.0	6.7	5.0	9.8	6.4
		(Dollars per 1,000 gallons)			
Fixed charges	.13	.31	.31	.43	.63
Labour[b]	.17	.09	.30	.21	.26
Maintenance[c]	.11	.18	.02	.07)	.04
Chemicals	.12	.01	.15	.00)	
Fuel plus electricity	.13	.10	.28	.36	.75
Total water cost	.66	.69	1.06	1.07	1.68
		(Percentage)			
Fixed charges	19.8	44.9	29.2	40.1	37.5
Labour[b]	25.6	13.1	28.3	19.6	15.5
Maintenance[c]	16.6	26.1	1.9	6.5)	2.4
Chemicals	18.2	1.4	14.2	)	
Fuel plus electricity	19.8	14.5	26.4	33.8	44.6

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[a] Electrodialysis; the other plants are multi-flash distillation.

[b] Including overhead.

[c] Including materials.

The second lowest cost water, $0.69 per 1,000 gallons, is produced by plant No. 7; this, however, is an electrodialysis plant operating on a brackish water for which costs can be expected to be lower than for distillation. These costs, therefore, cannot be generally compared with the other plants tabulated, all of which use distillation. Nevertheless, the significance of investment is of interest. The inherently lower capital investment for brackish water is reflected in the lowest reported investment cost, $0.47 per gallon per day capacity, but the very low load factor results in a contribution to water cost of $0.31 per 1,000 gallons, equivalent to 45 per cent of the total.

The third lowest water cost, $1.06 per 1,000 gallons, was reported by plants Nos. 44 to 47 which were built on the same site as the lowest cost plants (Nos. 48 and 49), but which were constructed three years earlier. The smaller unit capacity of these earlier plants largely results from the almost doubled unit investment. These older and less efficient plants are operated at a lower load factor, which further increases the fixed charges component of water cost to $0.31 per 1,000 gallons (29 per cent of the total). The operation of four plants, compared with two of the same total capacity, is reflected in almost doubled labour costs, an increase from $0.17 to $0.30 per 1,000 gallons. Inexplicably, the maintenance costs of the older plants are very much lower than those for the plants constructed more recently. For both groups of plants, chemical costs of $0.12 and $0.15 per 1,000 gallons for scale control are relatively high, due to unusually high feed-water salinity and associated problems. The lower efficiency of the older plants is reflected in the more than doubled energy cost, a rise from $0.13 to $0.28 per 1,000 gallons.

The next lowest water cost, $1.07 per 1,000 gallons, is provided by plant No. 24, which is a more recent, larger plant with a lower investment than the plant with the lowest water cost considered first above. In plant No. 24, a low load factor of only 47 per cent and a conventional rate of 9.8 per cent for fixed charges result, however, in the fixed charges component increasing to $0.43 per 1,000 gallons and 40 per cent of the total water cost. The less difficult feed-water salinity conditions are reflected in very much reduced chemical costs for scale control, although the cost is unusually low since minimum scale-control costs are normally expected to be several cents per 1,000 gallons. Energy costs are higher, $0.36 per 1,000 gallons, because the energy is not produced from entirely nominally zero-cost fuel, as it is in the case of the plants previously mentioned.

The next lowest water cost of $1.68 per 1,000 gallons is that of plants Nos. 20-22. Due to special circumstances, the capital investment is exceptionally and atypically high at $3.31 per gallon per day capacity. The very high investment, although partially mitigated by an exceptionally high load factor and a low fixed charges rate, still results in very high fixed charges of $0.63 per 1,000 gallons, 37.5 per cent of the total. The energy costs are also much higher, $0.75 per 1,000 gallons, and reflect the first instance of energy costs derived from market-cost fuel, as compared with zero on low-cost fuel in the previous cases.

The major significance of this limited analysis is to focus attention on the wide variations of the component costs and thereby to emphasize the importance of very careful investigation of all the factors in analysing or forecasting water costs.

E. Distribution of costs

The statistical distribution of component costs is given in table 19, and the average distribution for different processes is given in table 20.

Table 19

Distribution of component costs

Percentage of total water cost	Number of plants				
	Fixed charges	Labour a/	Fuel plus electricity	Maintenance b/	Chemicals
0- 4.9	0	1	5	29	25
5- 9.9	1	1	23	11	0
10-14.9	9	4	11	3	14
15-19.9	6	4	3	4	3
20-24.9	2	2	3	0	10
25-29.9	5	18	6	3	0
30-34.9	3	16	1	2	0
35-39.9	13	1	1	0	0
40-44.9	16	1	6	0	0
45-49.9	0	0	0	0	0
50-54.9	0	1	0	0	0
55-59.9	1	1	0	0	0
60-64.9	2	9	0	0	0
65-69.9	0	0	0	0	0
70-74.9	1	0	0	0	0
	59	59	59	52	52

a/ Including overhead.

b/ Including materials.

Table 20

Average distribution of component costs, by process
(percentage)

Fixed charges	Labour a/	Fuel plus electricity	Maintenance b/	Chemicals
Multi-flash distillation (13 plants)				
33.8	24.4	26.0	6.1	9.7
Long-tube vertical distillation (1 plant)				
31.2	22.8	41.5	2.0	2.5
Submerged-tube distillation (20 plants)				
40.7	29.8	9.9	4.1	15.5
Vapour-compression distillation (5 plants)				
24.5	37.3	12.0	24.2	2.0
Electrodialysis (2 plants)				
44.3	17.5	9.2	25.9	3.1
All processes (41 plants)				
36.5	28.2	16.0	8.2	11.0

a/ Including overhead.

b/ Including materials.

Fixed charges on investment

The dominant factor is clearly the fixed charges on investment, which account, on average, for more than one third of water costs. Indeed, for half of the plants, fixed charges on investment account for between 35 and 45 per cent of water costs.

Labour costs

Of almost equal significance are labour costs, which account, on average, for nearly one third of water costs; for more than half of the plants, labour costs account for between 25 and 35 per cent of water costs. Thus, capital and labour charges together account for nearly two thirds of water costs.

Significance of load factor

Actual expenditure on fixed charges and on labour is determined by installed capacity regardless of utilization since the labour required to operate the plant is essentially the same whether the plant operates at partial capacity or at full capacity. Even periods of complete shutdown for a few days or weeks give very limited possibilities for transferring staff and their costs elsewhere.

The importance of load factor in determining water costs can scarcely be overemphasized. As previously noted (chapter 1, section C), the average annual load factor of all the plants surveyed is only 53 per cent. It is for this reason that the load factor dependent costs of fixed charges and labour account for two thirds of the total water costs. Thus, if plants could be operated at full capacity, the costs attributable to investment and labour would be halved and total water costs reduced by one third. While it is impractical to arrange for operation at full capacity, there is, nevertheless, a considerable economic incentive to make the load factor as high as possible and to take this factor into account in planning desalination installations.

Energy costs

As a consequence of the inflation of fixed charges and labour costs by low utilization, the proportion of costs attributable to energy is small, averaging only 16 per cent. For nearly half of the plants, energy costs account for less than 10 per cent of total water costs, and two thirds of the plants have energy costs of less than 15 per cent of total water costs.

This result is, however, largely due to the predominance of multiple-unit submerged-tube plants in the sample. If these plants are excluded, the majority of the remaining plants have energy cost components of between 20 per cent and 40 per cent.

Maintenance costs

Costs for maintenance (including materials) average 8.2 per cent of total costs. The individual process data given in table 20 show, however, a marked difference between maintenance costs for the generally larger multi-flash, long-tube vertical and submerged-tube distillation plants, compared with those for the generally smaller vapour-compression distillation and electrodialysis plants. In the case of the larger plants, maintenance costs average from 2 to 6 per cent of the total water costs, whereas for the smaller electrodialysis and vapour-compression plants, maintenance costs are closer to 25 per cent of the total water cost.

Reference to table 15 shows that cash maintenance costs are often less than $0.10 per 1,000 gallons of water produced for the larger distillation plants. For electrodialysis plants, where scheduled replacement of membranes was required by the current state of technology, the maintenance cost increases several times. In the case of vapour-compression plants, maintenance costs of several dollars per 1,000 gallons are involved. A major factor in these cases, however, appears to be the cost of manual removal of scale from old and unsophisticated small plants where the costs were borne by relatively small quantities of water product. It is noteworthy that the most recent and largest vapour-compression plant (No. 3) has by far the lowest maintenance cost.

Chemical costs

The average cost of chemicals for scale control (see table 20) amounts to 11 per cent of total water costs, but this figure is distorted by the large number of surveyed plants operating in Kuwait, where scale problems are unusually severe. The individual cost data given in table 15 show that many of the large distillation plants operating outside Kuwait have chemical costs well below $0.10 per 1,000 gallons of water produced, whereas in Kuwait, the costs are higher for multi-flash distillation and much higher for submerged-tube distillation.

F. Dual-purpose applications

Of the multi-flash, long-tube vertical and submerged-tube distillation plants, forty-eight are dual-purpose plants incorporating power production; only twelve are water production only, including several which are atypical. Vapour-compression and electrodialysis plants are normally single-purpose plants; the sole exception is vapour-compression plant No. 78 (Sakito, Japan), which primarily produces salt, with water desalination as a subsidiary function.

Economic and production data for dual-purpose plants are given in table 21.

Table 21

Dual-purpose plant data

		Plant capacity		Total invest-ment (thousands of dollars)	Total annual costs (thousands of dollars)			Annual production	
Plant No.	Year	Water (thousands of United States gallons per day)	Electricity (kilo-watts)		Investment	Operation	Fuel	Water millicns of US gallons	Electricity millicns of kwH
15[a]	1962	1,463	-	6,610	637	322	347	222.9	-
20-22[a]	1964	2,250	15,000	10,860	690	555	638	750.1	75.9
30[a]	1964	85	5,300	-	-	-	-	17.8	26.8
33-34[a]	1962	50	3,000	1,460	-	290	-	13.0	5.0
36[c]	1964	100	525	-	-	-	-	12.5	-
50-57[b]	1950	960	37,500	11,000	692	2,030	708	228.7	192.1
42[a]	1959	360						93.0	
43[a]	1962	720						244.2	
58-67[b]	1953	1,200	33,000	27,400	1,580	1,930	Nil	207.5	164.8
68-77[b]	1955	1,200						241.4	
44-47[a]	1957	2,520						632.1	
48-49[a]	1960	2,400						746.3	

[a] Multi-flash distillation.

[b] Submerged-tube distillation.

[c] Electrodialysis.

The integration of energy supply in the form of steam with power production considerations sets a restriction, in principle, on the selection of maximum brine temperature and thus performance ratio. In practice, this restriction has not been critical because the overriding restriction has tended to be set by scale-control problems. Nevertheless, possible future requirements for greater proportions of water production in relation to power production may lead to the selection of higher maximum brine temperatures.

Important factors in the economics of dual-purpose plants are the load factors for both functions. The allocation of shared costs between power and water production is, in practice, a contentious subject. This is further complicated when load factors are of a low order. Operation of power production is inflexibly dictated by demand, with significant variations on a daily, or even on an hourly, basis. This trend may be alleviated where the power unit is able to operate on base load in an integrated power system, but this may not be always possible in the relatively isolated locations in which desalination plants may frequently be installed. Water-storage capacity can, in principle, permit desalination units to operate at variable loads in step with daily variations in power production. The economic penalty of the increased investment in desalination plant capacity implied by this type of reduced operation is, however, unlikely to be acceptable. A more practical solution lies in the selection of a pass-out turbine where a fairly wide variation in the power/water ratio may be achieved without serious impact on the over-all economics.

Unmatched seasonal variations in demand for water and electricity will probably be prohibitively uneconomic to resolve by water storage unless they could possibly be integrated with conventional water supplies. Alternatively, operation of the water and power units at different load factors will require consideration of the appropriate allocation of common costs. Thus, operation of the water production unit at times when power production is not necessary will require consideration of bearing the entire cost of steam raising.

A further important factor in dual-purpose plant operation is the reduction of labour costs, which have been shown elsewhere to be the second most important item of cost. Water- and power-producing plants require minimal attention over long periods of the day so that in the case of dual-purpose plants, a minimal operation team of one, or perhaps two, men can cover requirements on both aspects of operation, and costs can therefore be shared. Many labour costs can be similarly reduced in dual-purpose operation, and administrative and general service costs can be shared. Supervisory and skilled maintenance staff, whose numbers are usually minimal, may frequently deal with both operating plants, with a consequent sharing of costs.

This ability to share the resources of skilled manpower and maintenance facilities arising from the location of desalination and power installations on a common site may be of even greater importance than the more usually quoted raison d'être of the benefits of a combined source of steam-supply. Experience shows that a distillation plant is a basically simple piece of equipment which should demand little in the way of day-to-day operating requirements. The continued long-term success of its operation does, however, require a more sophisticated level of plant management and maintenance facilities - of a nature closely corresponding to those found on most power-plant sites. The provision of such facilities for a single-purpose (water) plant of anything but unusually large capacity results in a serious inflation of water costs or, more frequently, is regarded as a use of highly specialized and scarce resources which cannot be justified.

Chapter 2

TECHNOLOGY

A. Design of multi-flash distillation plants

A complete analysis of the design characteristics involves complex design calculations beyond the scope of this report; consequently, only the main features will be discussed in general terms.

Two characteristics are of immediate interest to the operator: (a) capital investment, which is largely dependent upon the amount of heat-exchange surface installed - accounting for upwards of 40 per cent of the total cost; thus, high water yield in terms of "gallons per square feet" is related to low capital cost; (b) operating cost, which is basically influenced by energy costs, which are dependent upon performance ratio (quantity of product - desalinated water per unit weight of steam).

Thus, high values of specific water output and performance ratio are mutually desirable for the operator, although they present mutually conflicting problems for the designer. Two main design parameters - the number of stages and the flashing range - are involved in resolving these problems.

Number of stages

In principle, increasing the number of stages permits both the specific water output and the performance ratio to be increased, but the plant design becomes increasingly complex until the consequential additional capital costs involved exceed the savings on heat-transfer surface. In addition, the plant may be more difficult to operate. Therefore, large land-based plants typically have around twenty stages and only in exceptional cases do they have thirty or more stages. In contrast, relatively small shipborne and power-station make-up plants, which are subject to very different criteria, typically have a range of only one or two, up to perhaps five stages.

Flashing range

Increasing the difference between the maximum and minimum temperature also permits the water yield and the performance ratio to be increased. However, the minimum temperature is necessarily dependent upon the ambient water temperature, which, in tropical locations, may significantly affect the optimum choice of temperature. In current practice, the maximum temperature is determined largely by problems of scale control. The commonly used phosphate additives are ineffective at about 200°F, this temperature corresponding reasonably with optimum steam temperatures available in dual-purpose electricity and water plants. Alternatively, subject to careful control to avoid corrosions, acid addition may be used to control scale and is effective up to about 250°F, and even to 300°F or more in the more complex multi-effect, multi-stage flash distillation concepts currently under development. Engineering costs, however, tend to increase more rapidly at higher temperatures, thereby offsetting the gains from increased performance. Thus, maximum temperature is determined mainly by over-all economic, rather than engineering, considerations.

The main design parameters are given in table 22, and illustrate the wide variations possible in selecting values for particular circumstances.

Table 22

Multi-flash distillation design parameters

Plant No.	Year	Unit capacity (thousands of gallons per day	Water yield (gallons per square foot per day)	Actual performance ratio (pounds per 1,000 BTU steam)	Number of stages	Actual flashing range (°F)
1	1965	140	17.4	5.26[a/]	26	130
12	1960	60	11.1	4.68	13	72
18	1964	156	8.3	6.68[b/]	40	95
20	1964	750	8.1	7.51	28	80
21-22	1964	750	9.8	7.51	15	80
24	1963	1,600	18.9	5.95	18	145
25-26	1962	1,710	8.1	7.50	30	90
30	1964	85	12.8	4.68	13	94
37	1963	30	8.6	1.60	2	-
38-40	1962	30	13.1	1.87	6	50
42	1959	360	11.8	3.99	22	70
43	1962	720	11.0	4.83	21	82
41-47	1957	630	5.2	3.15	4	77
48-49	1960	1,200	11.8	5.67	19	92

[a/] Design values.

[b/] Fuel equivalent.

The oldest group of plants Nos. 44-47, built in 1957 with a modest selection of parameters, four stages and a flash range of 77°F, provide a performance ratio of 3.15 and a water yield of 5.2 gallons per square foot.

Plants Nos. 48 and 49 (built on the same site) have many more stages (nineteen) and a flash range increased to 92°F. The performance ratio is nearly doubled, 5.67; and the water yield is more than doubled, 11.8 gallons per square foot.

Plants Nos. 42 and 43 have similar characteristics with smaller performance ratios corresponding to smaller flash ranges.

Plant No. 24, with a comparable number of stages (eighteen) but a very large flash range (145°F), shows a greatly increased water yield of 18.9 gallons per square foot, together with a slight increase in performance ratio to 5.95.

In contrast, plants Nos. 25 and 26, with a very large number of stages (thirty) and a modest flash range (90°F), achieve a very high performance ratio of 7.50 at the expense of a poor water yield of only 8.1 gallons per square foot.

Plant No. 18 shows similar characteristics with an exceptionally large number of stages (forty) and an increased flash range of 95°F, but a decline in performance ratio to 6.68 with a very small improvement in water yield to 8.3 gallons per square foot.

Plants Nos. 12 and 30 each have thirteen stages and a performance ratio of 4.68. Plant No. 12, with a flashing range of 72°F, has a water yield of 11.1 gallons per square foot; plant No. 30, with an increased flashing range of 94°F, has an increased water yield of 12.8 gallons per square foot.

B. Design of long-tube vertical and submerged-tube distillation plants

In the case of long-tube vertical and submerged-tube distillation plants, re-use of latent heat, as possible within the actual temperature range with the constraint that increasing the number of effects reduces the temperature difference between effects, necessitating greater surface areas and thereby reducing water yield per unit of heat-transfer surface.

The few available data are given in table 23 and do not provide any significant comparisons except that between the obsolescent submerged-tube distillation process and the more recent version of long-tube vertical distillation.

The heat-transfer limitations of submerged-tube distillation therefore require temperature driving forces of around 25°F per effect and, for an over-all temperature range of around 75°F, limit the number of effects to three and the performance to little more than two. The use of long-tube vertical distillation with improved heat-transfer characteristics permits the temperature differences to be halved while maintaining the same water yield. Thus, combined with a greater temperature range of 150°F, twelve effects have been utilized to increase the performance ratio five times to 10.9.

Table 23

Long-tube vertical and submerged-tube distillation parameters

Plant No.	Year	Unit capacity (thousands of gallons per day)	Water yield (gallons per square foot per day)	Actual performance ratio (pounds per 1,000 BTU)	Number of effects	Actual performance range (°F)
			Long-tube vertical distillation			
2	1961	1,000	14.1	10.9	12	150
			Submerged-tube distillation			
50-57	1950	120	19.3	2.1	3	65
58-67	1953	120	14.8	2.2	3	75
68-77	1955	120	14.4	2.2	3	86
85-86	1963	16	14.9	-	5	61

C. Design of vapour-comparison distillation plants

The available data are given in table 24. As in other processes, the designer is faced with conflicting requirements of water yield and performance ratio. An important parameter in this process is the operating temperature because the feed-water temperature has to be raised to the operating temperature by heat exchangers, which have to be of the same order of surface area as in the actual distillation unit. The amount of heat-exchange surface can be reduced by working at a low temperature, as is done in one of the plants surveyed; but reducing the operating temperature results in rapid increases in steam and plant volume, and, consequently, increased plant investment. Since performance ratio and water yield are conflicting requirements, a high performance ratio requires a low compression ratio, thereby permitting only a small temperature difference, which leads to large heat-exchange surfaces and a low water yield.

Table 24

Vapour-compression distillation parameters

Plant No.	Year	Unit capacity (thousands of gallons per day)	Water yield (gallons per square foot per day)	Actual performance ratio (pounds per 1,000 BTU fuel)	Number of Evaporators	Brine temperature ($^{\circ}F$)
3	1964	40.0	15.6	10	1	110
4-5	1964	14.4	-	-	1	220
6	1963	1,000.0	9.5	43[a/][b/]	2[c/]	225
13	1955	20.0	11.1	-	2	220
16	1956	21.6	10.9	8	3	210
17	1955	36.0	11.9	8	5	210
19	1955	200.0	-	11[a/]	4	214
23	1965	14.4	9.7	14	-	216
78	1955	895.0	17.2	-	1	218
87	1957	103.6	11.2	8	14	210

a/ Design values.

b/ Thousand BTU electricity.

c/ Two-effect.

D. Design of electrodialysis plants

In the electrodialysis process, the characteristic parameter is the membrane area through which the dissolved solids are extracted. As in the case of the heat-transfer area for distillation processes, the designer has to reconcile the conflicting requirements of high water yield per unit of membrane surface and high performance ratio (usually expressed for this process in terms of energy consumed per unit of water produced so that low figures represent good performance). Technical requirements dictate that the flow shall be subdivided into multiple cells for each stack. For large capacities, it may be necessary also to assemble several stacks in parallel into a single stage. Since electrodialysis, unlike distillation, does not intrinsically provide a total separation of dissolved solids, it may be economically necessary to process the water successively in several stages (continuous operation) in cases where the feed-water salinity is high or the required product salinity is low. Compared with distillation, therefore, more key parameters must be taken into account; the range of values is shown in table 25.

Table 25

Electrodialysis parameters

Plant No.	Year	Unit capacity (thousands of gallons per day)	Water yield (gallons per square feet per day)	Feed-water salinity (parts per million)	Actual performance ratio (kWh per 1,000 gallons)	Cell dimensions (inch x inch)	Cells per stack
7	1962	650	39.4	2,300	12[a]	18 x 40	275
8	1959	28	9.3	2,650	16[a]	18 x 20	150
9	1960	44	11.0	-	-	18 x 20	100
10	1958	70	34.4	-	15	18 x 20	102
11	1961	55	14.7	5,400	-	18 x 20	150
29	1964	13	4.9	7,000	62	16 x 40	300
36	1964	100	8.3	3,500	29[a]	20 x 60	200

[a] Design value.

E. Engineering of distillation heat exchangers

The factors determining the heat-exchange surface area requirements have been discussed in sections A, B and C of this chapter. The engineering problem is to provide that surface at minimum cost compatible with reliable service. The unavoidable hazard of corrosion, of variable and largely unpredictable degree, results in random failures among the very large number of tubes. In view of the large component of capital investment attributable to heat-exchanger costs, the use of lower cost material or thinner tubing will give a significant saving in initial plant cost. This saving, however, has to be balanced against the uncertain possible increases in tube failure, and consequent costs, at some time, perhaps ten or twenty years later. Even the reliability of various materials differs according to circumstances, and it is by no means certain that a high-cost material will be superior to a low-cost material. The engineer is therefore faced with a very difficult decision in selecting tubing material and thickness. As this survey does not include data on tubing failures, a detailed discussion is not possible. However, a recent study of condenser life for many applications, including some desalination plants, has been published elsewhere. 3/

Aluminium brass is the lowest cost material, whereas 90/10 cupro-nickel is 22 per cent more expensive and 70/31 cupro-nickel is 44 per cent more expensive.

Multi-flash distillation

The data in table 26 show that half of the plants used aluminium brass and half of the plants used either of the cupro-nickels for heater and heat-rejection sections. Two thirds of the plants, however, used aluminium brass for the heat-recovery section in which most of the heat-exchange surface is concentrated so that, in practice, the majority of the over-all heat-exchange surface is provided by the least costly aluminium brass. The use of thicknesses ranging from .046 to .049 (18 gauge) is now almost universal. Most of the exceptions represent groups of plants; and, in those cases, the use of particularly thin or thick tubing does not necessarily correspond with high- or low-cost material.

Submerged-tube distillation

The data suggest that the use of the most costly 70/30 cupro-nickel with relatively large thicknesses is almost universal, but allowance must be made for the fact that all twenty-eight plants comprise only three groups and were built between 1950 and 1955 when little experience was available. The two other plants were built in 1963 and used the least costly aluminium brass in the thinnest gauge, albeit for relatively low temperatures, at which corrosion problems are less severe.

3/ E.H. Newton and J.D. Birkett, Survey of Condenser Tube Life in Salt Water Service, US Office of Saline Water, Research and Development Progress report No. 278 (Cambridge, Massachusetts, Arthur D. Little, Inc., 1967).

Long-tube vertical distillation

The single example is a demonstration plant and incorporates a variety of materials in order to compare performance directly.

Vapour-compression distillation

The material used in vapour-compression distillation is about equally divided between aluminium brass and either of the more costly cupro-nickels, with a tendency also to greater thicknesses. It must be noted, however, that operating temperatures, in general, are rather higher for these plants than for most of the other plants in this survey and that corrosion problems are consequently increased. In addition, the higher temperatures preclude the use of phosphate for scale control so that either continuous acid addition or intermittent acid and mechanical cleaning are required. The use of acid to control scale does not necessarily increase corrosion, but it does require close control. Many of the vapour-compression plants in this survey are relatively small and are used only intermittently under circumstances where particularly close control is uneconomic so that more robust construction is appropriate.

Table 26

Condenser tube material and dimensions

Materials	Multi-flash			Submerged tube	Long-tube vertical	Vapour compression
	Heater	Recovery	Rejection			
Aluminium Brass	15	20	13	2)		6
Cupro-Nickel 90/10	6	4	6	-)	1	) 5
Cupro-Nickel 70/30	9	7	9	28)		) -
Cupro-Nickel 50/10	1		1	-	-	-
Monel	-	1	-	-	-	-
	31	32	29	30	1	11

Diameter (inches)	Multi-flash	Submerged tube	Long-tube vertical	Vapour compression
.375	1	-	-	-
.55	-	2	-	-
.625	7	-	-	4
.75	6	10	-	3
.875	5	-	-	1
1.0	12	18	-	8
2.0	-	-	1	1
	31	30	1	17

Thickness (inches)	Multi-flash	Submerged tube	Long-tube vertical	Vapour compression
.035/.039	2	2	-	-
.046/.049	19	18	-	10
.064/.065	3	10	1	6
.080	3	-	-	-
.091	-	-	-	1
	27	30	1	17

Chapter 3

OPERATION

A. Scale control and removal in distillation plants

Two alternative methods of controlling scale deposition are in common use. The method used in the majority of plants (forty-two) in this survey is dosing the feed water with a few ppm of complex phosphates. The alternative method used in twenty of the plants is reducing the pH of the feed by addition of the order of 100 ppm of acid.

Table 27 lists the operating conditions and the scale-control materials used.

The mechanism by which phosphates control scale deposition is not properly understood. It is not effective above 200°F, at which temperature the phosphate complex decomposes. Some plant operators have found, however, that the simple and cheaper phosphates are just as effective as the complex varieties.

The phosphate complexes are usually incorporated with other chemicals into trade-name materials, e.g., Hagevap or P.D.8, whose composition is not publicly known. The simple phosphates are obtained under the trade-name, Calgon. Phosphate-based materials are also marketed under other trade-names, such as AC.1. At the current time, many chemical manufacturers are developing scale-control materials based on phosphates or other chemicals, and some of these new materials are becoming available.

Phosphate-based materials are, in general, effective in preventing or at least retarding the growth of hard-scale deposits, but in some circumstances, as yet undefined, large quantities of soft, sticky sludge accumulate on the heat-transfer surfaces, thereby severely restricting the performance. These sludges can be removed by conventional periodic acid washing or, as in the case of plant No. 15 (Clifton Pier, Bahamas), by periodically circulating slightly oversized soft plastic balls through the heat exchangers to displace the sludge. The additional cost of sludge removal by either method is only about $0.01 per 1,000 gallons.

For temperatures above (and below) 200°F, scale deposition can be completely prevented by acid addition. In areas where acid is available at normal commercial prices, the costs of phosphate and acid methods are similar and may be well below $0.10 per 1,000 gallons (table 15). However, as many desalination plants are located in areas remote from commercial acid, production and the problems of transport may make the use of acid much more expensive than the use of easily transportable phosphate materials. As a consequence, there is a trend in plant design towards limiting the maximum temperature to permit the use of phosphate control materials. In addition, acid treatments require more careful control since overdosing, even temporarily, can cause damage to the plant.

Table 27

Scale, foam and corrosion control, by process

Plant No.	Maximum Brine Temperature ($^{\circ}F$)	Feed-water salinity (ppm)	Scale control	Scale removal	Foam control	Corrosion control
Multi-flash distillation						
1	210	35,000	Sulphuric acid	-	Dow "C"	Nil
12	182	33,000	Hagevap	Hydrochloric acid	a/	Nil
14	221	Sea	Nil	Acid	-	Neoprene
15	190	35,000	Hagevap or Calgon	Taprogge	Hagan Cl	Cathodic protection
18	195	36,000	Hagevap	-	a/	Nil
20-22	195	35,000	Hagevap	Sulphuric acid	a/	Epoxy
24	243	20,000	Sulphuric acid	-	Yes	Monel and rubber
25-26	190	Sea	Hagevap or Calgon	Acid	a/	Rubber
27	198	-	Hagevap	H 400	a/	Nil
30	190	20,000	Calgon	Hydrochloric acid	AL 14	Rubber
32	133	37,000	Aqua-Chem AC 1	-	-	Nil
33-34	200	21,000	Hagevap	-	a/	Cathodic protection
35	225	38,000	Sulphuric acid	-	Nil	Nil
37	170	-	Hagevap	-	a/	Non-ferrous
38-40	160	42,000	Hagevap	Hydrochloric acid	a/	Cathodic protection and epoxy
41	190	39,000	Hagevap	Hydrochloric acid	a/	Cathodic protection and CR paint
42	180	42,000	Hagevap	-	a/	Chlorinated rubber paint

Table 27 (continued)

Scale, foam and corrosion control, by process (continued)

Plant No.	Maximum Brine Temperature (^{o}F)	Feed-water salinity (ppm)	Scale control	Scale removal	Foam control	Corrosion control
Multi-flash distillation (continued)						
43	192	42,000	Hagevap	-	a/	Chlorinated rubber paint
44-47	194	45,000	Hagevap	Acid	a/	Chlorinated rubber paint
48-49	192	45,000	Hagevap	Acid	a/	Chlorinated rubber paint
Long-tube vertical distillation						
2	250	33,000	Sulphuric acid	-		Nil
Multi-effect distillation						
50-57	184	42,000	Hagevap	-	a/	Nil
58-67	180	45,000	Hagevap	Hydrochloric acid	a/	Aluminium and CR paint
68-77	196	45,000	Ferric chloride	Hydrochloric acid	Nil	Nil
85-86	165	-	Hagevap	-	a/	-
Vapour-compression distillation						
3	110	14,000	Sulphuric acid	-	Nil	-
4-5	220	4,000	Sulphuric and hydrochloric	-	Nil	Nil
6	225	15,000	Sulphuric acid	-	Nil	Nil
13	220	35,000	Hydrochloric acid	-	Nil	Nil
16	210	35,000	Nil	Sulphamic acid	Nil	Nil
17	210	35,000	Nil	Sulphamic acid	Nil	Nil

Table 27 (continued)

Scale, foam and corrosion control, by process (continued)

Plant No.	Maximum brine Temperature (^{o}F)	Feed-water salinity (ppm)	Scale control	Scale removal	Foam control	Corrosion control
Vapour-compression distillation (continued)						
19	214	33,000	Hydrochloric acid	-	Nil	Nil
23	216	35,000	Nil	Sodium bisulphate	-	Nil
78	268	36,000	Annydrite seeding	-	Yes	Nil
79-84	104	Sea	Nil	Calcium hypochloride	Nil	Nil
87	210	35,000	Nil	Sulphamic acid	Nil	Nil

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a/ Included in scale-control material.

Most of the plants that do use acid operate at temperatures too high for phosphate materials. The type of acid used is unimportant technically, and the choice is determined by other factors, such as cost, availability and handling. Sulphuric and hydrochloric acid are commonly used. Ferric chloride has the advantage of being solid and consequently less dangerous to handle.

Among the new techniques of scale control being developed is the circulation with the water of finely divided suspended solids, possibly the actual scale materials themselves, on which the scale deposits in preference to fouling the heat-transfer surface. Plant No. 78 (Sakito, Japan) is the only plant in this survey to use this technique. It is, however, known to be used experimentally elsewhere.

For removal of accumulated scale deposits, periodic acid washing is almost universal and successful. In extreme cases, however, mechanical removal is sometimes required.

B. Foam control in distillation plants

Foaming may be accentuated by any of a very large variety of possible trace impurities in the feed water. Consequently, foam-control problems vary according to location. Many foam-control materials that deal with specific problems are commercially available. The proprietory scale-control material, Hagevap, includes a foam-control constituent.

C. Corrosion control in distillation plants

Differences of temperature, mixed materials of construction, scale deposits, water-flow patterns and possible use of acids all interact to give very complex corrosion problems, which differ from plant to plant and are not entirely predictable. Reference has already been made to the problems of condenser-tube material. In addition, careful design is necessary to avoid corrosion arising from water-flow patterns in the tubes and in other components also. Corrosion of specific components or areas is limited by appropriate design on special materials of construction, but general corrosion is restricted to acceptable limits by a variety of coatings or electrical methods. The difficulty is to achieve a satisfactory degree of corrosion control at a realistic cost.

As is shown in table 27, a variety of coating materials are in use, any of which should, ideally, give adequate protection. In practice, however, great problems are encountered in ensuring that such coatings are properly applied in the difficult circumstances of plant construction. Similarly, with electrical methods it is very difficult to ensure uniform protection of the relatively complicated construction of a distillation plant.

In either case, local failures result in corrosion, possibly even to an intensified degree.

D. Comparison of design and operating performance

Water quantity

It is to be expected that some plants, particularly those of new design, or those operating in new circumstances, should encounter difficulties in meeting design specifications when first commissioned, and a few of the plants surveyed did have extended commissioning periods. None of the plants is reported as being unable to produce at full capacity in normal operation, and some have operated significantly above design capacity for extended periods of peak demand, as was shown in the discussion of load factors (chapter 1, section C).

The significance of over-capacity should not be over-emphasized, however, since, in general, design output does not represent an absolute limitation but, rather, an optimum selection of operating conditions which may, if required, be changed. For example, it may be possible, though not necessarily so, to increase significantly the output of distillation plants by supplying additional steam. In phosphate-dosed plants, however, this may accelerate the normal decline in performance due to scale accumulation and necessitate more frequent cleaning.

Water quality

Comparison data for design and actual salinities and temperatures are given in table 28.

In principle, distillation provides a total separation of water from impurities. In practice, however, the evaporation of steam from brine is accompanied by droplets of brine mist which must be removed by demisting equipment before reaching the condensers. Slight variations in plant operation and feed-water conditions have a major effect on the quantity and quality of brine mist which is generated. It is difficult, therefore, to design the demisting equipment for a precise product specification. For many cases of desalination for drinking purposes, the water quality is not critical, compared with the potential performance of distillation. Accordingly, it is usual to instal, at reasonable cost, sufficient demisting equipment to guarantee a conservative purity specification although the actual product quality is considerably better. Thus, many distillation plants produce water containing less than 10 ppm of impurities and few produce water exceeding 30 ppm of impurities.

For drinking purposes, desalinated water is frequently blended with other water to increase the impurity level up to as much as 500 ppm to improve palatability and also to increase the total potable water-supply by up to 10 or 20 per cent with corresponding reduction in cost. However, these factors are not significantly affected by small variations in plant product-water quality.

For such purposes as boiler-water make-up, where very pure water is essential, it is entirely practical and usual to guarantee product-water quality of 1 ppm or less by the installation of extensive demisting equipment with a corresponding increase in investment cost.

Table 28

Product quality, by process

	Product water				
	Salinity (ppm)		Temperature (°F)		
Plant No.	Design	Actual	Design	Actual	Feed-water temperature (°F)
			Multi-flash distillation		
1	500	20	85	80	57-66
12	66 cu	66 cu	110	-	73-80
14	10	10	-	109	85
15	60	5	105	105	75-85
18	6	2	100	85	61-80
20-22	50	30	-	115	81-83
24	1	-	167	174	84-87
25-26	5	5	100	100	80-85
27	4	4	115	115	-
30	10	4	98	96	58-67
32	.2	.3	108	104	50-79
35	6	10	100	94	62-82
38-40	150	30	120	110	75-92
41	20	20	110	110	50-90
42	25	100	180	110	59-87
43	25	10	110	110	59-87
44-47	80	150	120	117	58-90
48-49	100	80	110	100	58-90
			Long-tube vertical distillation		
2	50	10	87	100	61-82
			Submerged-tube distillation		
50-57	85	4	-	110	59-87
58-67	100	5	110	110	58-90
68-77	15	5	110	110	58-90

Table 28 (continued)

Product quality, by process (continued)

Plant No.	Product water: Salinity (ppm) Design	Salinity (ppm) Actual	Temperature (^{o}F) Design	Temperature (^{o}F) Actual	Feed-water temperature (^{o}F)
			Vapour-compression distillation		
3	0	-	90	90	40-60
4-5	2	2	66	66	44-50
6	50	50	100	78	69
13	30	5	150	110	58-61
16	40	10	85	83	77
17	40	10	85	83	77
19	50	6	100	90	66-82
23	5	3	-	100	85
79-84	21	21	104	104	89-94
87	40	30	85	83	77
			Electrodialysis		
7	500	500	-	80	80-90
8	350	400	90	-	75-86
9	1000	855	47	-	45
11	500	500	-	-	90[a]
29	500	650	-	61	32-54
36	500	500	-	-	59-86

[a] Heated water.

Electrodialysis is fundamentally different from distillation in that product quality is directly related to the plant investment and the energy consumed. As a result, water costs depend significantly upon product-water quality. Design specifications therefore correspond directly to requirements, and plants are adjusted to meet specifications closely. As is shown in table 28, water produced by electrodialysis plants contains dissolved solids on the order of 500 ppm, corresponding to potability requirements, compared with less than 30 ppm of dissolved solids from distillation plants.

Product-water temperature

Low product-water temperatures are generally desired by consumers, but these are necessarily related to feed-water temperatures, particularly in distillation processes that involve supplying heat which must be subsequently rejected by heating the product (and waste) water above the temperature of the incoming feed water.

In electrodialysis, the energy input is smaller and the consequent rise in product-water temperature is not so marked as that in distillation processes.

All of the plants listed in table 28 meet the design specification for product temperature, but in many cases this is above 100°F for distillation processes.

Maximum brine temperature and performance ratio

As is shown in table 29, few of the plants actually reach their design maximum temperature, and this short-coming is reflected in a larger energy consumption than was specified. Of the fifty-eight plants compared in table 29, only seven reach or exceed their design performance ratio.

Table 29

Comparison of design and actual brine temperature and performance ratios, by process

Plant No.	Brine temperature (^{o}F)		Performance ratio (pounds per 1,000 BTU steam)	
	Design	Actual	Design	Actual
		Multi-flash distillation		
1	220	210	5.26	-
12	-	182	5.39	4.68
14	221	221	3.67	3.21
18	195	-	6.55	6.68
20-22	195	195	7.09	7.51
24	248	243	6.95	5.95
30	190	190	4.68	4.68
32	153	133	0.92	0.92
33-34	200	200	-	-
35	225	225	-	-
38-40	180	160	1.87	-
41	200	190	-	-
42	180	180	4.73	3.99
43	194	192	6.30	4.83
44-47	200	194	3.36	3.15
48-49	192	192	5.77	5.67
		Long-tube vertical distillation		
2	250	-	12.6	10.9
		Submerged-tube distillation		
50-57	175	184	2.52	2.10
58-67	185	180	2.41	2.21
68-77	196	180	2.41	2.21

Table 29 (continued)

Plant No.	Brine temperature (°F)		Performance ratio (pounds per 1,000 BTU fuel)	
	Design	Actual	Design	Actual
		Vapour-compression distillation		
3	110	110	39	10
4-5	220	220	-	-
6	232	225	44[a]	-
13	215	220	-	-
16	225	210	11	8
17	225	210	11	8
19	219	214	11	-
23	216	216	11	14
78	268	268	-	-
79-84	104	104	39[a]	25[a]
87	225	210	11	8
		Electrodialysis		
			kWh per 1,000 gallons	
29	-	68	70	62

a/ Electrical equivalent.

E. Staff requirements

Data on plant capacity, single or dual-purpose operation and numbers of staff employed on supervision, operation and maintenance are given in table 30. Some inaccuracies possibly occur due to difficulties of classification of staff function.

The high proportion of water cost due to labour charges averaging 28 per cent has been discussed in chapter 1, section E. Examination of the data clearly indicates that such high labour costs are due largely to the difficulty of employing less than one man to perform specific functions.

Considering supervision, it is evident that this function is essentially within the capacity of one man. Several of the plants listed do not formally, allocate any staff to supervision, although this responsibility must be absorbed within the organization. Some plants have indicated the fractional degree of part-time attention required for supervision, and even more plants identify single persons responsible for this function. In the few cases where more than one man is allocated to supervision, there are additional responsibilities, such as the operation of multiple units. For several plants, the supervision is shared in dual-purpose operation; two of these plants are demonstration plants involving supervisory staff not required for normal commercial operation.

In considering operating staff, the key factor is the matter of attention being given twenty-four hours per day, seven days per week. To provide the attention of one man at all times requires a theoretical minimum of three men working in rotation. In practice, four men are usually necessary; and in some countries, five men are employed. Safety regulations also frequently require that men shall not work in isolation. Thus, the provision of minimal operator attention at all times may require four, five, eight or ten employees. The significance of this factor is evident in many of the plants where it is apparent that one or two operators are in constant attendance. The problem of continuous operator attendance is encountered in many industrial operations and is not unique to desalination plants. Typically, the problem is that very little real work is required, but some attention may be required from time to time. Furthermore, the presence of an operator is required to deal with unforeseeable occurrences.

The employment of four men, each costing $5,000 per annum, including overhead, on a 1 million gallon per day plant operating at 80 per cent load factor contributes $0.07 per 1,000 gallons to the cost of water, corresponding to 10 per cent of the water cost from the most economic plant under review. Thus, there is a very strong incentive to reduce the amount of labour continuously involved in plant operation.

Opportunities for sharing minimal labour requirements offer possibilities for significant reduction in labour costs. For example, in plants Nos. 20-22 and Nos. 33-34, the operating staffs are shared between several units and also between water and power production. In plants Nos. 42, 43 and 50-57, the operation of ten desalination plants is covered by only four men. This group of ten plants (Kuwait Oil Co.) is located in an oil refinery, an industry which typically operates on a continuous basis and in which possibilities for minimizing operator attendance have been intensively exploited.

Table 30

Staff employed in plants surveyed, by process

Plant No.	Unit capacity (thousands of gallons)	Single or dual purpose	Number of staff			
			Supervisory	Operating	Maintenance	Total
Multi-flash distillation						
12	60.0	Dual	.1	2.6	1.3	4
15	1,463.0	Dual	-	4	-	4
18	156.0	Single	1	4	2	7
20-22	750.0	Dual	3[a]	19[a]	8[a]	30[a]
24	1,600.0	Single	1	2	-	3
27	30.0	Single	1	3	.5	4.5
32	94.0	Single	-	.5	.5	1
33-34	50.0	Dual	2[a]	10[a]	3[a]	15[a]
35	200.0	Dual	-	1	-	1
38-40	30.0	Single	- .5[a]	8[a]	1[a]	9.5[a]
41	50.0	Single	1	1	-	2
42	360.0	Dual	4[b]	4[b]	6[b]	14[b]
43	720.0					
44-47	630.0	Dual	2[a]	3[a]	8[a]	13[a]
48-49	1,200.0	Dual	2[a]	2[a]	7[a]	11[a]
Long-tube vertical distillation						
2	1,000.0	Single	5	4	5	14
Submerged-tube distillation						
50-57	120.0	Dual	Included in Nos. 42-43 listed above			
58-67	120.0	Dual	2[a]	6[a]	8[a]	16[a]
68-77	120.0	Dual	2[a]	5[a]	8[a]	15[a]

Table 30 (continued)

Plant No.	Unit capacity (thousands of gallons)	Single or dual purpose	Number of staff			
			Supervisory	Operating	Maintenance	Total
			Vapour-compression distillation			
3	40.0	Single	1[c]	3[c]	3[c]	7[c]
4-5	14.4	Single	-	3[a]	-	3[a]
6	1,000.0	Single	3	8	3	14
13	20.0	Single	-	1	1	2
16	21.6	Single	-	1	1	2
17	36.0	Single	1	1	1	3
19	200.0	Single	1	11	2	14
23	14.4	Single	-	-	-	0[d]
78	895.0	Dual	-	-	-	48[e]
79-84	14.4	Single	1[a]	1[a]	1[a]	3[a]
87	103.6	Single	1	4	2	7
			Electrodialysis			
7	650.0	Single	-	1	-	1
8	28.0	Single	1	2	-	3
9	44.0	Single	.1	1.5	.4	2
10	70.0	Single	.1	.5	.4	1
11	55.0	Single	.3	1.5	.5	2.3
29	13.0	Single	-	.5	.2	.7
36	100.0	Single	1	4	1	6

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a/ For all plants (including power plants in dual-purpose operation).

b/ For plants Nos. 42, 43 and 50-57, including power plants.

c/ Part-time.

d/ Temporary staff allocated as required.

e/ Including salt production.

Significantly, for some small plants, such as those installed on armed forces bases, where production is required only intermittently and where large numbers of versatile skilled men are employed for other purposes, it has been possible to allocate and to pay for staff only for the periods of operation.

Notable also is the fact that for the smaller scale of operation of vapour-compression and (for brackish water) electrodialysis plants there is a tendency to have fewer operating staff.

In the case of electrodialysis, little operating machinery is involved, safeguards for automatic shut-down are easily incorporated and little risk is involved in leaving plant unattended overnight.

While vapour-compression plants do involve a large operating machinery content, the "package" nature of many such plants has resulted in the more ready acceptance of less continuous operator attendance.

The significant costs involved in continuous operator attendance on multi-flash and multi-effect plants does focus attention on the economic incentive to endeavour to reduce continuous operating staff.

Maintenance staff show wide variations in numbers. Here, the nature of the problem is different from that of operator requirements. Periods of scheduled maintenance and unscheduled repair require several or more men to deal with plant disassembly, servicing or replacement and reassembly in a reasonably short time. Such periods of work, however, account for only a few weeks in a year. Even intermittent attention for scale removal in plants operating under difficult conditions necessarily occupies only a small fraction of the operating time.

For an isolated plant, the problem of providing a number of maintenance men only when required and avoiding costs of employing men for long periods when not required is difficult to resolve. Again, there are possibilities for significant economies where costs of a maintenance team can be shared among a complex of plants.

F. Operational problems

The principal causes of shut-down in various plants, as reported by operators, are noted below for plants using different processes.

Multi-stage flash distillation

Causes of shut-down of some multi-stage flash distillation plants are:

(a) Plant No. 1: to clean boiler on fireside; boiler feed-pump failures; repairs to internal baffles in flash-chambers; steam-ejector troubles;

(b) Plant No. 12: Corrosion of top and bottom water-box covers (now reduced by internal protection by epoxy points); blockage of condenser by sea shell etc. (planned elimination by filter installation);

(c) Plant No. 15: investigation into corrosion; gas blanketing; sludging of heat-exchanger surfaces;

(d) Plant No. 18: accumulations of seaweed and silt in sea-intake trench and evaporator water-boxes;

(e) Plants Nos. 20-22: adjustment; acid cleaning;

(f) Plant No. 27: tubes fouled from shells and coatings; repair and repack pumps; monthly chemical cleaning of boiler; repairing of leaks; heavy ground swells;

(g) Plant No. 30: problems with air supply to pneumatic controls; tube blockage by detached rubber lining from sea-water feed pipes; inspection of brine recirculating pump for damage due to graphite formation in cast-iron pump casing; periodic (quarterly) cleaning of heater and rejection tubes;

(h) Plant No. 32: cleaning of debris from tube sheets on sea-water side;

(i) Plants Nos. 33-34: failure of sea-water intake pumps;

(j) Plant No. 35: boiler shut-down due to automatic-control failure; brine pump prefabricated wear rings (later modified); leaking brine heater tubes at tube sheets; baffles breaking loose in stages 1-10; corrosion of seal leg, shell of final condenser and stage 1; installation of brine-pumps bypass; relocation of acid in injection to improve pH control and reduce corrosion; modification of boiler level control;

(k) Plants Nos. 38-40: descaling; corrosion of heat-exchanger doors;

(l) Plant No. 41: leaking tubes; brine carry-over due to high level or dislodged demisters; air leaks due to corrosion holes in pipes and fittings; suction problems with brine and distillate pumps; frequent shut-down for acid cleaning (later avoided by on-line acid injection);

(m) Plant No. 43: acid cleaning; air leaks; pump repairs; tube leaks;

(n) Plants Nos. 44-47: periodic removal of debris and sludge from heater tube plates; air leaks; pump mechanical seal failures; motor bearings; acid cleaning;

(o) Plants Nos. 48-49: turbine maintenance and repairs; pump maintenance and repairs (usually mechanical seals); acid cleaning.

Long-tube vertical distillation

For long-tube vertical distillation plants, the principal causes of shut-down are illustrated by the experience of plant No. 2: brine-pump leaks; water-box and heat-exchanger leaks; high-temperature differences in first effect; thermal overload.

Submerged-tube distillation

In plants Nos. 58-67 and 68-77, which use the submerged-tube distillation process, the principal causes of shut-down are: internal condensate and distillate drain-pipe corrosion; air leaks; pump and motor repairs (mainly glands and bearings); acid cleaning.

Vapour-compression distillation

The principal causes of shut-down in various vapour-compression plants are listed below:

(a) Plants Nos. 4-5: deterioration of pipes and tubing;

(b) Plant No. 6: tube plugging due to scale; tubing failure due to corrosion and erosion;

(c) Plants Nos. 16-17 and 87: preventive maintenance scheduled after 168 hours of operation; chemical cleaning scheduled after 450 hours of operation;

(d) Plant No. 23: difficulties with diesel engine; failure of heat exchanger;

(e) Plants Nos. 79-84: acid cleaning; general maintenance.

Electrodialysis

Shut-down is primarily brought about in electrodialysis plants for the following reasons:

(a) Plant No. 8: scale buildup in stacks;

(b) Plant No. 29: leaks in interior stacks; breakdown of components, usually due to corrosion; corrosion of electrical contact surface; deterioration of original membranes by organic pollution; difficulties in obtaining and training personnel;

(c) Plant No. 36: membrane cleaning; leakage; automatic-control failure; abnormal corrosion.

There is naturally a wide variation among the operators of the sixty-one plants listed above as to what they considered of sufficient importance to report, and particular care must be exercised to avoid false comparisons and conclusions about the performance of individual plants. Indeed, for an additional twenty-seven plants no causes of shut-down were reported. This may not necessarily mean that there really were no enforced shut-downs. The causes may have been considered trivial and of little significance in terms of production or may have been regarded as normal maintenance problems.

Predictably, many of the causes of shut-down are unique and indicate isolated short-comings in design or engineering for a particular circumstance. A number of causes of shut-down recur in the reports and merit attention.

Distillation plant pump and drive failures

More than half of the plants (thirty-five) reported pump failures. Another twenty-seven plants reported motor failures, and two plants reported turbine failures. The most frequent causes reported are bearing and gland failures; other causes include suction problems, thermal-shock failure of cast iron and graphitization of cast iron.

Pumps and their drives constitute the major mechanical working parts in plants, and it is to be expected that they should be particularly susceptible to failure. Since pumps and drives constitute an important part of the capital investment and absorb a significant amount of the operating cost for fuel, low-cost construction and high operating efficiency are required.

The design and engineering of pumps for desalination presents special problems, particularly for large distillation plants. Suction difficulties are a severe problem in design; furthermore, pumps have to operate under adverse circumstances. Even where feed-water filtration is provided, it is not always economical to exclude completely fine abrasive material which can quickly damage bearings, glands and impellers.

Plants are frequently located in arid dusty areas where very penetrating sand is an ever-present threat to working machinery, such as motors and high-speed, highly stressed turbines and reduction gearing. It is entirely practical to engineer equipment for reliable operation under such conditions, but at increased cost.

In view of the incidence of pump failures, it would be appropriate when specifying a new plant to give very careful consideration to pump and drive designs and costs in order to obtain an acceptable compromise between the initial cost and the consequential costs of possible failures, taking particular account of the time and difficulty entailed in replacing parts. Such items as bearings and glands are normally regarded as replaceable;their cost is relatively small and they are normally stocked as spares. However, the time, facilities and skilled labour team required to dismantle and reassemble the machinery - particularly, a large pump and drive - depends upon the design and the accessibility, thereby determining the cost of repair and the loss of water production.

In other fields, e.g., power generation and oil refining, provision of installed duplicate spare machinery such as pumps was once common practice, but intensive development of more reliable equipment has rendered this much less necessary and has made it possible often to avoid the additional costs of spare machinery together with the associated piping, control and installation costs.

Feed-water filtration

For ten of the plants, shut-downs were caused by incoming solid material - sand, silt, sea shell and seaweed - leading to blockages. An additional factor, the adverse effects of abrasive material on pumps, has been discussed above. In one of the plants, the blockages were due not to natural solid material entering with the sea water, but to detachment of the protective rubber lining from the sea-water intakes. The indications are that more careful attention is required to the provision of feed-water filtration and chemical treatment.

Corrosion and leakages

More than half of the plants, thirty-seven, made sixty-two specific reports of corrosion and/or leakage as causes of shut-down during 1965.

Corrosion and leakage have been grouped together for discussion because they are frequently, though not necessarily, related, and from the nature of the reports it is not possible to be specific. Therefore, it is not apparent whether other reported problems, such as baffle failures, ejector troubles and pump failures, are due also to corrosion or to other factors.

Scale problems

Forty-three of the sixty-one plants, including two electrodialysis plants, report scale problems as causes of shut-down. It is not apparent whether these were indeed forced shut-downs in all cases or whether they refer to routine periodic acid cleaning. It should be noted that techniques have been developed for acid injection removal of scale while the plant continues production. In many cases, therefore, it should be possible to avoid shut-down for acid cleaning.

Chapter 4

PRODUCTION AND STORAGE CAPACITIES

The availability of water storage is of great importance in the water-supply systems. Storage generally forms an integral part of conventional water-supply systems, either naturally in the form of lakes or underground aquifers or artificially in the form of reservoirs. Such storage systems generally contain the equivalent of months or even years of water demand since they must relate seasonal variations in demand to seasonal variations in the natural sources of water, possibly extending to periods of several years of below-average rainfall.

In sea-water desalination systems, the uncertainties of supply are largely removed because the availability of source water is guaranteed. In brackish-water desalination systems, the availability of source water is subject to considerations similar to those for conventional water-supplies, but in these cases the desalination plant is subject to reliability and performance criteria similar to those required for conventional water-treatment plants. In desalination water-supply systems, therefore, the criteria for product-water storage are dictated by plant availability and, possibly, by the relation of peak demand and production capacity.

The subject of storage capacity in desalination water-supply systems is very complex and has been the subject of a special study by the United Nations. [4] In general, storage capacity can economically provide for peak demands in excess of supply for only limited periods, and in many cases storage capacity must be limited to what is necessary to ensure availability of water during periods of unavoidable shut-down or scheduled repair. The appropriate solution varies according to circumstances, such as the extent to which desalination is integrated with other water-supplies and the number of desalination plants included in the system, since this influences the effect of individual plant breakdown.

In table 31 are listed the characteristics of storage capacity associated with the plants in this survey. These plants have been categorized according to the number of days of production capacity provided by storage:

(a) Category A (three plants): storage capacity negligible;

(b) Category B (eleven plants): storage capacity one-half to two days;

(c) Category C (forty-eight plants): storage capacity one-half to two weeks;

(d) Category D (thirteen plants): storage capacity one-half to two months.

Category A (storage capacity negligible) includes only three plants and is of little significance as one plant supplements supplies from existing ground-water storage, and another is an experimental demonstration plant where storage is not an important factor in the project.

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[4] United Nations, op. cit.

Table 31

Production and storage capacities

Days' storage	Plant No.	Type of process	Total capacity (thousands of U.S. gallons per day)
	Category A (3 plants)		
0	15	MSFD	1,463
1/5	6	VCD	1,000
1/7	13	VCD	20
	Category B (11 plants)		
1/2	27	MSFD	30
1/2	7	E	650
1/2	29	E	13
1/2	36	E	100
1	32	MSFD	94
1	10	E	70
2	16	VCD	22
2	11	E	55
2	20-22	MSFD	60
	Category C (48 plants)		
3	87	VCD	104
3	58-67	STD	1,200
3	68-77	STD	1,200
3	9	E	44
3	33-34	MSFD	100
3	4-5	VCD	29
3-1/2	38-40	MSFD	90
4	12	MSFD	60
4	35	MSFD	200
4	8	E	28
4	79-84	VCD	86
6	18	MSFD	156
7	1	MSFD	140
7	41	MSFD	50
12	3	VCD	40
13	44-47	MSFD	2,520
14	48-49	MSFD	2,400

Table 31 (continued)

Production and storage capacities (continued)

Days' storage	Plant No.	Type of process	Total capacity (thousands of U.S. gallons per day)
	Category D (13 plants)		
15	78	VCD	895
21	50-57	STD	960
28	43	MSFD	720
35	17	VCD	36
40	19	VCD	200
55	42	MSFD	360

Note: Multi-stage flash distillation = MSFD.
Vapour-compression distillation = VCD.
Submerged-tube distillation = STD.
Electrodialysis = E.

Category B (storage capacity one-half to two days) contains only eleven plants: five of the seven electrodialysis plants surveyed; one small vapour-compression distillation plant; and five relatively small multi-flash distillation plants. With the exception of one multi-flash distillation plant, the annual load factors are very low, averaging on an over-all basis, only 33 per cent.

Category C (storage capacity one-half to two weeks) and Category D (storage capacity one-half to two months) together total sixty-one plants.

Over-all, taking into account multiple-plant complexes, the majority of desalination installations have storage capacities of between one week and one month of production capacity.

ANNEX I

PLANT IDENTIFICATION AND GENERAL DATA

Table 32

Plant identification and general data

Plant identification							
No.	Location	Process	Manufacturer	Year of erection	Purpose	Unit capacity (thousands of U.S. gallons per day)	Storage capacity (thousands of U.S. gallons)
	North America						
1	Southern California Edison Co. Catalina Island, California, United States of America	Multi-flash distillation	Aqua-Chem	1965	Dual	140.0	1,000
2	OSW Demonstration Plant Freeport, Texas, United States of America	Long-tube vertical distillation	Chicago Bridge and Iron	1961	Single	1,000.0	Nil
3	Hill Air Force Base Utah, United States of America	Vapour compression	Aqua-Chem	1964	Single	40.0	500
4-5	Point Barrow Naval Station Alaska, United States of America	Vapour compression	Aqua-Chem	1964	Single	14.4	90
6	OSW Demonstration Plant Roswell, New Mexico, United States of America	Vapour compression	Chicago Bridge and Iron	1963	Single	1,000.0	200
7	Buckeye Municipality Buckeye, Arizona, United States of America	Electrodialysis	Ionics	1962	Single	650.0	300
8	Coalinga, California, United States of America	Electrodialysis	Ionics	1959	Single	28.0	100
9	Fortuna Air Force Base Fortuna, North Dakota, United States of America	Electrodialysis	Ionics	1960	Single	44.0	125
10	Hanna Air Force Base Hanna, Illinois, United States of America	Electrodialysis	Ionics	1958	Single	70.0	60
11	Havre Air Force Base Havre, Montana, United States of America	Electrodialysis	Ionics	1961	Single	55.0	100

Table 32 (continued)

Plant identification							
No.	Location	Process	Manufacturer	Year of erection	Purpose	Unit capacity (thousands of U.S. gallons per day)	Storage capacity (thousands of U.S. gallons)
	<u>South America</u>						
12	La Libertad, Ecuador	Multi-flash distillation	Richardsons Westgarth	1960	Dual	60.0	226
13	San Juan, Peru	Vapour compression	Cleaver Brooks	1955	Single	20.0	3
14	Compania Shell Punta Cardon, Venezuela	Multi-flash distillation	-	1961	-	1,080.0	-
	<u>Caribbean</u>						
15	Clifton Pier, Nassau, Bahamas	Multi-flash distillation	Weir	1962	Dual	1,463.0	Nil
16	Little Carter Cay, Bahamas	Vapour compression	Mechanical Equipment	1956	Single	21.6	48
17	Grand Turk Airfield, Bahamas	Vapour compression	Mechanical Equipment	1955	Single	36.0	1,260
18	King Edward VII Hospital, Bermuda	Multi-flash distillation	Aqua-Chem	1964	Single	156.0	1,000
19	Kindley Air Force Base, Bermuda	Vapour compression	Aqua-Chem	1955	Single	200.0	8,000
20-22	United States Naval Base, Guantanamo, Cuba	Multi-flash distillation	Westinghouse	1964	Dual	750.0	4,000
23	Navfac, Antigua Leeward Islands	Vapour compression	Mechanical Equipment	1965	Single	14.4	-
24	Shell Curacao N.V. Emmastad, Curacao, Netherlands Antilles	Multi-flash distillation	Weir Westgarth	1963	Single	1,600.0	-
25-26	Island Government Willemstad, Curacao Netherlands Antilles	Multi-flash distillation		1963		1,710.0	-

Table 32 (continued)

Plant identification							
No.	Location	Process	Manufacturer	Year of erection	Purpose	Unit capacity (thousands of U.S. gallons per day)	Storage capacity (thousands of U.S. gallons)
	Caribbean (continued)						
27	Maxim, St. John, Virgin Islands	Multi-flash distillation	AMF	1958?	Single	30.0	18
28	Virgin Islands Corp., St. Thomas, Virgin Islands	Multi-flash distillation	Aqua-Chem	1961	Dual	275.0	-
	Europe						
29	Islands, Gulf of Finland	Electrodialysis	Boby-Bronswerk	1964	Single	13.0	5
30	City Council, Gibraltar	Multi-flash distillation	Weir Westgarth	1964	Dual	85.0	19,000
31	North Atlantic Treaty Organization Base, Gibraltar	Multi-flash distillation	Aqua-Chem	1960	Single	73.0	-
32	Sulcis Power Station, Porto Vesme, Cagliari, Italy	Multi-flash distillation	Aqua-Chem	1964	Single	94.0	100
	Africa						
33-34	Es Sider, Tripolitania, Libya	Multi-flash distillation	Westinghouse	1962	Dual	50.0	300
35	Esso. Marsa El Brega, Libya	Multi-flash distillation	Aqua-Chem	1965	Dual	200.0	800
36	Zliten, Libya	Electrodialysis	Boby	1964	Single	100.0	50
	Asia						
37	Abu Dhabi, Arabian Gulf	Multi-flash distillation	Aqua-Chem	1963	Dual	30.0	-
38-40	Adma, Das Islands, Arabian Gulf	Multi-flash distillation	Aiton	1962	Single	30.0	300

Table 32 (continued)

Plant identification							
No.	Location	Process	Manufacturer	Year of erection	Purpose	Unit capacity (thousands of U.S. gallons per day)	Storage capacity (thousands of U.S. gallons)
	Asia (continued)						
41	American Independent Oil Co., Kuwait	Multi-flash distillation	Westinghouse	1962	Single	50.0	350
42	KOC No. 9 Mina Al Ahmadi, Kuwait	Multi-flash distillation	Richardson Westgarth	1959	Dual	360.0	20,000
43	KOC No. 10 Mina Al Ahmadi, Kuwait	Multi-flash distillation	Weir	1962	Dual	720.0	20,000
44-47	MEW "C&D" Shuwaik, Kuwait	Multi-flash distillation	Westinghouse	1957	Dual	630.0	34,000
48-49	MEW "E" Shuwaik, Kuwait	Multi-flash distillation	Weir	1960	Dual	1,200.0	34,000
50-57	KOC No. 1-8 Mina Al Ahmadi, Kuwait	Submerged-tube distillation	Westinghouse	1950	Dual	120.0	20,000
58-67	MEW "A" Shuwaik, Kuwait	Submerged-tube distillation	Westinghouse	1953	Dual	120.0	34,000
68-77	MEW "B" Shuwaik, Kuwait	Submerged-tube distillation	Weir	1955	Dual	120.0	34,000
78	Sakito Salt Co. Kyushu, Japan	Vapour compression	Mitsubishi	1955	Water and salt	895.0	13,200
79-84	Eniwetok, Marshall Islands	Vapour compression	Cleaver Brooks	1951	Single	14.4	326
85-86	French Polynesia	Submerged-tube distillation	Electro-mecanique	1963	Single	16.0	-
87	Auxiliary Airfield, Ascension Islands	Vapour compression	Mechanical Equipment	1957	Single	103.6	353

ANNEX II

MULTI-FLASH DISTILLATION

Table 33

Multi-flash distillation plant design

Plant No.	Stages			Brine recirculation	Incondensible removal	Recycle brine-pump drive
	Recovery	Rejection	Total			
1	22	4	26	Yes	Ejector	Electric
12	11	2	13	Yes	Ejector	Turbine and Electric
14	-	-	8	No	Ejector	-
15	20	-	20	Part	Pump	Electric
18	40	-	40	No	Ejector	-
20	26	2	28	Yes	Ejector	Electric
21-22	12	3	15	Yes	Ejector	Electric
24	15	3	18	Yes	Ejector	Turbine
25-26	-	-	30	Yes	Ejector	-
27	2	6	8	Part	Ejector	Electric
28	24	4	28	Part	Ejector	-
30	11	2	13	Yes	Pump	Electric
31	5	-	5	No	Ejector	-
32	2	2	4	Yes	Pump	Electric
33-34	3	2	5	Yes	-	-
35	-	-	24	-	Ejector	Electric
37	2	-	2	No	Ejector	Electric
38-40	3	3	6	Yes	Ejector	Electric
41	3	2	5	Yes	Ejector	Electric
42	20	2	22	No	Ejector	Electric
43	18	3	21	Yes	Ejector	Turbine
44-47	3	1	4	Yes	Ejector	Electric
48-49	16	3	19	Yes	Ejector	Turbine

Table 34

Multi-flash distillation heat exchangers

Plant No.	Recovery	Rejection	Heater	Outside diameter	Wall thickness
	Material and unit outside surface area (square feet)			(inches)	
1	Al-Brass 6,000	Al-Brass 1,130	Al-Brass 920	.625	.049
12	Al-Brass 4,150	Al-Brass 690	Al-Brass 563	.875	.046
14	Al-Brass -	Al-Brass -	- -	.750	-
15	Al-Brass -	Nil Nil	Al-Brass 5,234	1.0	.048
18	Al-Brass -	Nil Nil	Al-Brass 427	.625	.048
20	Al-Brass and Cu-Nickel 90-10 82,361	Cu-Nickel 90-10 7,029	Cu-Nickel 90-10 3,170	.750	.049
21-22	Cu-Nickel 90-10 63,565	Cu-Nickel 90-10 10,568	Cu-Nickel 90-10 2,800	.625	.035
24	Al-Brass 55,500	Cu-Nickel 70-30 20,650	Al-Brass 8,500	1.0	.064
25-26	Al-Brass 183,450	Al-Brass 18,700	Cu-Nickel 90-10 8,975	1.0	-
27	Monel 774	Cu-Nickel 50-10 1,572	Cu-Nickel 50-10 -	.375	-
28	Al-Brass -	Al-Brass -	Al-Brass -	.625	.049
30	Cu-Nickel 70-30 4,757	Cu-Nickel 70-30 1,175	Cu-Nickel 70-30 730	.750	.048
31	Al-Brass -	Nil Nil	Al-Brass -	-	-
32	Cu-Nickel 90-10 -	Al-Brass -	Cu-Nickel 90-10 -	.625	.049
33-34	Al-Brass 1,170	Cu-Nickel 90-10 740	Cu-Nickel 70-30 -	.750	.049
35	Al-Brass -	Al-Brass -	Al-Brass 1,048	1.0	.049
37	Al-Brass 3,000	Nil Nil	Al-Brass 475	.625	.049
38-40	Al-Brass 975	Al-Brass 975	Al-Brass 340	1.0	.080
41	Al-Brass -	Cu-Nickel 90-10 -	Al-Brass -	.750	.049
42	Al-Brass 20,837	Al-Brass 6,453	Al-Brass 3,212	1.0	.048
43	Al-Brass 54,000	Al-Brass 7,700	Al-Brass 3,630	1.0	.048
44-47	Cu-Nickel 70-30 88,000	Cu-Nickel 70-30 26,400	Cu-Nickel 70-30 7,000	.875	.049
48-49	Cu-Nickel 70-30 70,900	Cu-Nickel 70-30 22,600	Cu-Nickel 70-30 8,350	1.0	.065

Table 35

Multi-flash distillation; scale, foam and corrosion control

Plant No.	Scale control	Scale removal	Foam control	Corrosion control
1.	Sulphuric acid	-	Dow "C"	Nil
12	Hagevap	Hydrochloric acid	Hagevap	Nil
14	Nil	Acid	-	Neoprene
15	Hagevap or Calgon	Taprogge	Hagan C1	Cathodic protection
18	Hagevap	-	Hagevap	Nil
20-22	Hagevap	Sulphuric acid	Hagevap	Epoxy
24	Sulphuric acid	-	Yes	Monel and rubber
25-26	Hagevap or Calgon	Acid	Hagevap	Rubber
27	Hagevap	H 400	Hagevap	Nil
30	Calgon	Hydrochloric acid	Al-14	Rubber
32	Aqua-Chem AC-1	-	-	Nil
33-34	Hagevap	-	Hagevap	Cathodic protection
35	Sulphuric acid	-	Nil	Nil
37	Hagevap	-	Hagevap	Non-ferrous
38-40	Hagevap	Hydrochloric acid	Hagevap	Cathodic protection and epoxy
41	Hagevap	Hydrochloric acid	Hagevap	Cathodic protection and chlorinated rubber paint
42	Hagevap	-	Hagevap	Chlorinated rubber paint
43	Hagevap	-	Hagevap	Chlorinated rubber paint
44-47	Hagevap	Acid	Hagevap	Chlorinated rubber paint
48-49	Hagevap	Acid	Hagevap	Chlorinated rubber paint

Table 36

Multi-flash distillation, feed water and product water

Plant No.	Feed water			Product water			
	Source	Salinity (ppm)	Temperature (°F)	Salinity (ppm)		Temperature (°F)	
				Design	Actual	Design	Actual
1	Sea	35,000	57-66	500	10-30	85	80
12	Sea	33,000	73-80	66 cu	66 cu	110	-
14	Sea	-	85	10	10	-	109
15	Sea	35,000	75-85	60	5	105	105
18	Sea	36,000	61-80	6	2	100	85
20-22	Sea	35,000	81-83	50	30	-	115
24	Sea	20,000	84-87	1	-	167	174
25-26	Sea	-	80-85	5	5	100	100
27	-	-	-	4.3	4.3	115	115
28	-	-	-	5	-	-	-
30	Harbour	20,000	58-67	10	4	98	96
31	-	-	-	10	-	100	-
32	Sea	37,000	50-79	.25	.35	108	104
33-34	Sea	21,000	65-85	-	10	-	110
35	Sea	38,000	62-82	6	10	100	94
37	-	-	-	10	-	-	-
38-40	Sea	42,000	75-92	150	10-50	120	110
41	Sea	38,760	50-90	20	20	110	110
42	Sea	42,000	59-87	25	100	180	110
43	Sea	42,000	59-87	25	10	110	110
44-47	Sea	45,000	58-90	80	150	120	117
48-49	Sea	45,000	58-90	100	80	110	100

Table 37

Multi-flash distillation, thermodynamics

Plant No.	Maximum brine temperature (°F)		Performance ratio (pounds per 1,000 BTU steam)		Feed product ratio b/
	Design	Actual	Design	Actual	
1	220	210	5.26	-	2.00
12	-	182	5.30	4.68	2.00
14	221	221	3.67	3.21	11.00
15	190	-	6.25	-	8.76
18	195	-	6.55	6.68	10.00
20-22	195	195	7.09	7.51	3.00
24	248	243	6.95	5.95	3.00
25-26	190	-	7.50	-	2.40
27	198	-	3.45 a/	-	-
28	195	-	3.60	-	-
30	190	190	4.68	4.68	2.20
31	175	-	3.30	-	-
32	153	133	.92	.92	2.00
33-34	200	200	-	-	16.00
35	225	225	-	-	2.50
37	170	-	1.60	-	-
38-40	180	160	1.87	-	2.00
41	200	190	-	-	2.00
42	180	180	4.73	3.99	-
43	194	192	6.30	4.83	1.45
44-47	200	194	3.36	3.15	2.10
48-49	192	192	5.77	5.67	1.80

a/ Pounds per 1,000 BTU fuel equivalent.

b/ Per unit of product.

Table 38

Multi-flash distillation, annual water production, by month

(Thousands of U.S. gallons)

	Plant No.								
Month	1	12	15	18	20-22	24	27	30	32
January	-	-	2,470	1,560	65,290	26,130	-	1,030	260
February	-	-	190	-	56,260	19,330	-	1,680	130
March	-	-	-	2,750	68,360	22,350	-	1,150	260
April	227	-	6,670	2,900	67,680	31,870	-	1,530	130
May	2,921	-	8,900	4,150	62,080	26,410	-	1,220	260
June	3,135	-	36,300	4,650	55,860	24,620	-	1,720	-
July	3,284	-	39,260	1,530	61,930	29,810	-	1,370	-
August	3,444	-	42,000	2,990	66,810	19,090	-	1,770	1,060
September	3,911	-	25,520	2,590	62,260	21,260	-	1,240	1,060
October	3,100	-	26,100	770	61,870	24,150	-	1,960	1,060
November	2,053	-	19,880	1,530	54,300	21,270	-	1,490	1,060
December	-	-	15,660	2,230	67,370	8,670	-	1,590	1,060
Total	22,075	21,485	222,950	27,640	750,070	274,960	7,800	17,750	6,340

Table 38 (continued)

Multi-flash distillation, annual water production, by month (continued)

(Thousands of U.S. gallons)

Month	33-34	35	38-40	41	42	43	44-47	48-49
	Production							
January	770	3,180	610	1,110	7,700	22,160	37,950	57,310
February	700	3,580	440	1,200	5,720	18,000	60,830	36,500
March	810	3,450	510	1,500	8,000	12,740	67,300	49,400
April	730	3,820	450	1,310	7,840	21,670	35,200	72,000
May	1,340	4,310	410	1,350	9,770	14,160	61,610	73,450
June	1,270	4,670	500	1,340	8,060	21,430	60,350	71,550
July	1,090	5,050	590	1,340	8,960	22,640	52,020	73,780
August	1,150	4,470	520	1,300	9,120	22,250	59,340	60,200
September	1,320	5,170	490	1,250	9,430	21,300	66,050	67,000
October	1,330	4,820	540	1,310	9,790	22,730	50,660	75,000
November	1,210	4,440	440	1,260	7,640	22,380	45,520	69,420
December	1,300	4,640	470	1,170	940	22,780	35,310	40,650
Total	13,020	51,600	5,970	15,440	92,970	244,240	632,140	746,260

Table 39

Multi-flash distillation, energy and chemical consumption

Plant No.	Energy		Electricity (kWh)	Chemicals	
	Fuel				
	Type	Quantity		Type	Quantity
1	Fuel oil	-	548,000	Sulphuric acid Anti-foam	1,800 gal 1,900 lb
12	Bunker oil	462,000 gal	429,000	Hagevap Hydrochloric acid	2,000 lb 250 gal
14	-	-	(558 kW)	-	-
15	Bunker oil	-	958,710	Hagevap Calgon Anti-foam	14,559 lb 6,500 lb 1,770 lb
18	Bunker oil	236,277 gal	173,094	Hagevap Hydrated lime	2,315 lb 227 lb
20-22	Oil	11,417,364 gal	14,610,000	Chlorine, Hagevap, Sulphuric Acid Limestone	- -
24	Steam	-	1,050,000	Sulphuric acid Anti-foam	1,050,000 lb 60 gal
25-26	-	-	(1,050 kW)	-	-
27	Diesel oil	173,250 gal	-	Hagevap H400 Solvent	1,125 lb 630 gal
30	Diesel exhaust	-	467,789	Calgon S Lubrol Al 14 Hydrochloric acid	1,410 lb 22 lb 494 gal
32	Coal or oil	-	90,000	Morpholine Aqua-Chem AC 1	2,200 lb 772 lb
33-34	Crude Oil	966,000 gal	527,000	Hagevap	400 lb
35	Crude Oil	896,700 gal	-	Disodium phosphate Caustic soda Sulphite	400 lb 400 lb 300 lb
38-40	Gas	51,900,000 cu ft	400,000	Hagevap Hydrochloric acid	700 lb 120 gal
41	Gas	105,900,000 cu ft	750,000	Hagevap Hydrochloric acid	1,500 lb 1,000 gal
42	Steam	203,800,000 lb	786,000	Hagevap	23,000 lb
43	Steam	441,800,000 lb	530,800	Hagevap	34,000 lb
44-47	Steam	1,756,000,000 lb	8,000,000	Hagevap Acid	90,000 lb 3,000 gal
48-49	Steam	1,150,000,000 lb	1,100,000	Hagevap Acid	90,000 lb 4,000 gal

Table 40

Multi-flash distillation, staff and operating status

Plant No.	Number of staff				Operating status		
	Supervisory	Operating	Maintenance	Total	Shut-down	Partial hours	Full
1	-	-	-	2	-	-	-
12	.1	2.6	1.3	4	180	2,750	5,830
15	-	4	-	4	-	-	-
18	1	4	2	7	3,915	1,871	2,806
20-22	3	19	8	30	-	-	-
24	.25[a]	.5[a]	-	-	960	6,600	-
27	1	3	.5	4.5	-	-	-
30	-	-	-	-	1,992	2,820	3,948
32	-	.5[b]	.5	1	160	3,000	Nil
33-34	2[b]	10[b]	3[b]	15[b]	695	2,920	5,145
35	-	1	-	1	1,950	4,086	1,724
38-40	1(partial)	8	1	10	500	-	5,410
41	1	1	-	2	1,000	2,750	5,000
42	1[a][c]	1[a][c]	6[c]	8	674	700	7,386
43	1[a][c]	1[a][c]	6[c]	8	504	219	8,037
44-47	2	3	8	13	1,160	Nil	6,680
48-49	2	2	7	11	855	Nil	7,284

[a] Per shift.

[b] In conjunction with power plant.

[c] Total for plants Nos. 42, 43 and submerged-tube plants Nos. 50-57.

Table 41

Multi-flash distillation, investment costs

Plant No.	Total investment		Expected life	Interest rate	Total fixed charge rate
	Thousands of dollars	Dollars per gallon per day	(years)	(percentage)	
12	240	4.00	15.0	-	6.7
15	2,270	1.55	25.0	5.5	9.6
18	520	3.36	15.0	-	1.6
20-22	7,450	3.31	25.0	2.5	6.4
24	1,210	.76	16.7	7.0	9.8
27	220	7.37	10.0	3.0	13.0
30	200	2.35	15.0	6.0	11.0
32	230	2.37	15.0	6.0	10.0
33-34	460	4.57	-	-	-
38-40	140	1.55	10.0	10.0	20.0
41	120	2.40	8.0	-	12.5
42	380	1.06	-	-	9.9
43	610	.85	-	-	9.9
44-47	3,910	1.55	20.0	-	5.0
48-49	1,970	.82	20.0	-	5.0

Table 42

Multi-flash distillation, cost analysis

Plant No.	Fixed charges	Labour[a]	Maintenance[b]	Chemicals	Fuel	Electricity	Total	Water cost (dollars per 1,000 gallons)
				(thousands of dollars)				
12	16.3	13.5	17.7	14.0[c] 1.6	34.4[d]	10.7	108.2	5.04
15	218.0	45.2	5.3	10.6	86.0	26.1	391.2	1.75
18	8.3	31.6	15.5	4.8	36.1	7.2	103.5	3.73
20-22	473.1	193.3	28.4	[e]	532.7[d]	33.3	1,260.8	1.68
24	119.0	61.1	20.6	.7	92.3[f]	4.1	297.8	1.07
27	28.8	21.6	1.2	.7	28.7	5.0	86.0	11.03
30	22.0	2.8	Nil	.9	Nil	8.2	33.9	1.91
32	23.0	5.0	.5	7.0	.8	.8	37.1	5.85
33-34	-	51.0	29.0	9.0	-	-	-	-
38-40	28.0	19.6	9.2	[e]	Nil	5.6	62.4	10.46
41	15.0	35.0	10.0	2.0	5.0	11.2	78.2	5.07
42	37.6	-	-	-	-	-	-	2.15
43	60.4	-	-	-	-	-	-	1.99
44-47	196.0	190.4	12.6	91.4	131.6[d]	42.0	665.0	1.06
48-49	98.0	126.0	84.0	86.8	86.8[d]	5.6	487.2	.65

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[a] Including overhead.
[b] Including materials.
[c] Feed water.
[d] Steam.
[e] Included in maintenance.
[f] Steam and cooling water.

ANNEX III

LONG-TUBE VERTICAL AND SUBMERGED-TUBE DISTILLATION

Table 43

Long-tube vertical and submerged-tube distillation plant design

Plant No.	Effects	Material	Heat exchanger: Unit outside surface area (square feet)	Heat exchanger: Outside diameter (inches)	Heat exchanger: Wall thickness (inches)	Incondensible removal	Brine pump drive
			Long-tube vertical distillation				
2	12	Al-Brass Cu-Nickel	71,150	2.0	.065	Ejector	Electric
			Submerged-tube distillation				
50-57	3	Cu-Nickel 70-30	6,220	1.0	.049	Ejector	Electric
58-67	3	Cu-Nickel 70-30	8,120	1.0	.049	Ejector	-
68-77	3	Cu-Nickel 70-30	8,300	.75	.065	Ejector	-
85-86	5	Al-Brass	1,076	.55	.039	Pump	Electric

Table 44

Long-tube vertical and submerged-tube distillation, scale, foam and corrosion control

Plant No.	Scale control	Scale removal	Foam control	Corrosion control
		Long-tube vertical distillation		
2	Hagevap	-	Nil	Nil
		Submerged-tube distillation		
50-57	Hagevap	-	Hagevap	Nil
58-67	Hagevap	Hydrochloric acid	Hagevap	Aluminium and chlorinated rubber paint
68-77	Hagevap	Hydrochloric acid	-	Nil
85-86	Hagevap	-	Hagevap	-

Table 45

Long-tube vertical and submerged-tube distillation, feed water and product water

Plant No.	Feed water			Product water			
	Source	Salinity (ppm)	Temperature (°F)	Salinity (ppm)		Temperature (°F)	
				Design	Actual	Design	Actual
			Long-tube vertical distillation				
2	Sea	33,000	61-82	50	10	87	100
			Submerged-tube distillation				
50-57	Sea	42,000	59-87	85	4	-	110
58-67	Sea	45,000	58-90	100	5	110	110
68-77	Sea	45,000	58-90	15	5	110	110
85-86	-	-	-	50	-	104	-

Table 46

Long-tube vertical and submerged-tube distillation, thermodynamics

Plant No.	Maximum brine temperature (°F)		Performance ratio (pounds per 1,000 BTU steam)		Feed product ratio[a/]
	Design	Actual	Design	Actual	
	Long-tube vertical distillation				
2	250	-	12.6	10.9	9.60
	Submerged-tube distillation				
50-57	175	184	2.52	2.10	-
58-67	185	180	2.41	2.21	2.00
68-77	196	180	2.41	2.21	2.00
85-86	165	-	-	-	-

a/ Per unit of product.

Table 47

Long-tube vertical and submerged-tube distillation, annual water production, by month

(Thousands of U.S. gallons)

Month	Plant No.			
	2	50-57	58-67	68-77
January	27,930	24,100	14,150	16,450
February	8,850	20,650	14,050	20,650
March	20,930	20,050	15,400	23,300
April	Nil	19,250	17,350	17,900
May	13,060	20,300	20,800	19,350
June	1,210	19,100	23,300	25,150
July	28,950	19,450	26,300	21,400
August	32,810	18,050	17,300	17,200
September	24,580	18,050	12,450	23,900
October	32,160	17,600	15,800	21,650
November	4,170	18,650	15,650	17,750
December	31,110	13,450	14,950	16,700
Total	225,760	228,700	207,500	241,400

Table 48

Long-tube vertical and submerged-tube distillation, energy and chemical consumption

Plant No.	Energy			Chemicals	
	Fuel	Quantity	Electricity (kWh)	Type	Quantity
			Long-tube vertical distillation		
2	-	-	2,540,000	Sulphuric acid Caustic soda Polyphosphate	347,715 lb 62,342 lb 13,323 lb
			Submerged-tube distillation		
50-57	Steam	953,232,000 lb	235,000	Hagevap	4,900 lb
58-67	Steam	823,000,000 lb	1,470,000	Hagevap Hydrochloric acid	22,000 lb 6,000 gal
68-77	Steam	958,000,000 lb	2,107,000	Hagevap Acid Ferric chloride	22,000 lb 2,000 gal 1,653,500 lb

Table 49

Long-tube vertical and submerged-tube distillation, staff and operating status

Plant No.	Staff				Operating status (hours)		
	Supervisory	Operating	Maintenance	Total	Shut-down	Partial	Full
	Long-tube vertical distillation						
2	5	4	5	14	2,062	-	3,365
	Submerged-tube distillation						
50-57	1[a/b/]	1[a/b/]	6[a/]	8[a/]	202	155	8,403
58-67	2	6	8	16	1,260	-	4,198
68-77	2	5	8	15	1,240	-	5,018

---

a/ Including multi-flash distillation plants Nos. 42 and 43.

b/ Per shift.

Table 50

Long-tube vertical and submerged-tube distillation, investment costs

Plant No.	Total investment: Thousands of dollars	Total investment: Dollars per gallons per day	Expected life (years)	Interest rate (percentage)	Total fixed-charge rate (percentage)
		Long-tube vertical distillation			
2	1,570	1.57	20	4	9.0
		Submerged tube distillation			
50-57	1,560	1.30	-	-	3.7
58-67	4,950	4.13	15	Nil	6.7
68-77	3,640	3.03	15	Nil	8.3

Table 51

Long-tube vertical and submerged-tube distillation, cost analysis

Plant No.	Fixed charges	Labour[a]	Maintenance[b]	Chemicals	Fuel	Electricity	Total	Water cost (dollars per 1,000 gallons)
	(thousands of dollars)							
				Long-tube vertical distillation				
2	141.6	104.7	7.9	10.5	165.5	24.7	454.9	2.02
				Submerged-tube distillation				
50-57	56.0	-	-	-	-	-	-	1.99
58-67	330.0	249.0	39.2	84.0	61.5[c]	8.4	772.1	3.72
68-77	302.0	215.5	25.2	159.6	72.8[c]	11.2	786.3	3.26

[a] Including overhead.

[b] Including materials.

[c] Steam.

ANNEX IV

VAPOUR-COMPRESSION DISTILLATION

Table 52

Vapour-compression distillation plant design

			Heat exchangers					
Plant No.	Evaporators	Brine circulation	Material	Unit outside surface area (square feet)	Outside diameter (inches)	Wall thickness (inches)	Incondensible removal	Compressor drive
3	1	Forced	Cu-Nickel	2,566	1.0	.049	Pump	Electric
4-5	1	Forced	Cu-Nickel	-	.75	.049	-	Gas engine
6	2	Forced	Al-Brass	105,400	1.0	.065	Ejector	Electric
13	2	Natural	Cu-Nickel	900	.875	.049	-	Diesel and Electric
16	3	Natural	Al-Brass	660	.625	.065	Pump	Diesel
17	5	Natural	Al-Brass	660	.625	.065	Pump	Diesel
19	4	Forced	Cu-Nickel 90-10	-	.625	.065	Pump	Diesel
23	-	Natural	Al-Brass	1,480	.750	.065	-	Diesel
78	6	Forced	Al-Brass	52,100	0.95-1.9	.091	Pump	Electric
79-84	8	Forced	Everdur	454	1.0	.049	-	Electric
87	14	Natural	Al-Brass	660	.625	.065	Pump	Diesel

Table 53

Vapour-compression distillation, scale, foam and corrosion control

Plant No.	Scale control	Scale removal	Foam control	Corrosion control
3	Sulphuric acid	-		
4-5	Sulphuric and Hydrochloric acid	-	Nil	Nil
6	Sulphuric acid	-	Nil	Nil
13	Hydrochloric acid	-	Nil	Nil
16	Nil	Sulphamic acid	Nil	Nil
17	Nil	Sulphamic acid	Nil	Nil
19	Hydrochloric acid	-	Nil	Nil
23	Nil	Acid	-	Nil
78	Anhydrite seeding	-	Yes	Nil
79-84	Nil	Acid	Nil	Nil
87	Nil	Sulphamic acid	Nil	Nil

Table 54

Vapour-compression distillation, feed water and product water

Plant No.	Feed water			Product water			
	Source	Salinity (ppm)	Temperature (°F)	Salinity (ppm)		Temperature (°F)	
				Design	Actual	Design	Actual
3	Well	13,800	40-60	0	-	90	90
4-5	Lake	4,200	44-50	2	2	66	66
6	Well	15,400	69	50	50	100	78
13	Sea	35,000	58-61	30	5	150	110
16	Sea	35,000	77	40	10	85	83
17	Sea	35,000	77	40	10	85	83
19	Sea	33,000	66-82	50	6	100	90
23	Sea	35,000	85	5	3	-	100
78	Sea	36,000	75-86	-	110	-	94
79-84	Sea	-	89-94	21	21	104	104
87	Sea	35,000	77	40	30	85	83

Table 55

Vapour-compression distillation, thermodynamics

Plant No.	Brine temperature (^{o}F)		Performance ratio (pounds per 1,000 BTU fuel)		Feed product ratio a/
	Design	Actual	Design	Actual	
3	110	110	39	10	1.70
4-5	220	220	-	-	2.00
6	232	225	44 b/	-	3.40
13	215	220	-	-	3.00
16	225	210	11	8	2.00
17	225	210	11	8	2.00
19	219	214	11	-	2.00
23	216	216	11	14	2.20
78	268	268	-	-	1.14
79-84	104	104	39 b/	25 b/	2.00
87	225	210	11	8	2.00

a/ Per unit of product.

b/ Pounds per 1,000 BTU electrical equivalent.

Table 56

Vapour-compression distillation, annual water production, by month

(thousands of US gallons)

	Plant No.					
Month	3	4-5	6	13	16	17
January	180	317	9,153	519	120	428
February	134	329	Nil	201	123	347
March	138	359	6,061	405	111	463
April	110	396	20,657	Nil	113	434
May	074	364	Nil	53	145	115
June	074	381	Nil	72	143	241
July	198	351	Nil	91	121	306
August	213	371	19,224	Nil	118	270
September	303	327	11,488	344	117	108
October	268	326	Nil	44	119	48
November	373	289	13,189	Nil	119	Nil
December	142	308	12,210	Nil	130	Nil
Total	2,207	4,118	91,982	1,729	1,479	2,760

Table 56 (continued)

Vapour-compression distillation, annual water production, by month (continued)

Month	Plant No. 19	23	78	79-84	87
January	-	-	27,700	1,241	1,122
February	-	-	25,100	1,184	1,219
March	-	-	27,700	1,340	1,267
April	-	-	26,950	1,156	1,145
May	-	-	24,150	1,267	1,247
June	-	-	26,950	1,220	1,258
July	-	-	26,000	1,267	1,204
August	-	-	27,700	1,311	1,150
September	-	-	26,950	1,420	1,181
October	-	-	27,700	1,235	1,174
November	-	-	23,400	1,164	1,141
December	-	-	27,700	1,421	1,204
Total	33,270	1,621	318,000	15,226	14,312

Table 57

Vapour-compression distillation, energy and chemical consumption

Plant No.	Energy			Chemicals	
	Fuel		Electricity (kWh)		
	Type	Quantity		Type	Quantity
3	Oil	12,909 gal	286,500	Sodium hexameta phosphate Sodium hydroxide Sulphuric acid	46 lb 65 lb 487 gal
4-5	Gas	-	-	Sulphuric acid Hydrochloric acid	- 116 gal
6	Oil	45,066 gal	15,658,320	Sulphuric acid Caustic	147,170 lb 8,278 lb
13	Diesel oil	17,000 gal	9,300	Hydrochloric acid	865 gal
16	Diesel oil	10,584 gal	Nil	Sulphamic acid	2,959 lb
17	Diesel oil	19,740 gal	Nil	Sulphamic acid	5,520 lb
19	Diesel oil	183,312 gal	218,241	Hydrochloric acid	148,750 lb
23	Diesel oil	-	8,460	Sodium bisulphate	5,000 lb
78	Steam	221,456 ton	7,358,514	-	-
79-84	Diesel oil	27,620 gal	149,760	Calcium hypochlorite Soda ash	3,600 lb 4,800 lb
87	Diesel oil	102,228 gal	Nil	Sulphamic acid	28,625 lb

Table 58

Vapour-compression distillation, staff and operating status

Plant No.	Staff				Operating status (hours)		
	Supervisory	Operating	Maintenance	Total	Shut-down	Partial	Full
3	1[a]	3[a]	3[a]	7[a]	-	-	-
4-5	-	3	-	3	-	-	-
6	3	8	3	14	5,931	Nil	2,829
13	-	1	1	2	6,518	2,242	Nil
16	-	1	1	2	1,170	2,920	Nil
17	1	1	1	3	-	-	-
19	1	11	2	14	-	-	-
23	-	-	-	[a]	3,636	-	2,700
78	11[a][b]	37[b]	11[a][b]	48[b]	380	-	8,380
79-84	1	1	1	3	-	-	5,300
87	1	4	2	7	-	-	-

[a] Part-time.

[b] Including salt production.

Table 59

Vapour-compression distillation, investment costs

Plant No.	Total investment: Thousands of dollars	Total investment: Dollars per gallon per day	Expected life (years)	Interest rate (percentage)	Total fixed charge rate (percentage)
3	192	4.80	20	4.5	2.7
4-5	82	2.85	-	-	-
6	1,790	1.79	20	2.0	6.5
13	120	6.00	20	6.0	-
16	159	7.36	20	4.0	7.4
17	200	5.55	20	4.0	7.4
19	551	2.76	5	-	-
23	45	3.16	15	2.5	6.8
78	1,280	1.44	10	8.0	-
87	990	9.56	20	4.0	7.3

Table 60

Vapour-compression distillation, cost analysis

Plant No.	Fixed charges	Labour[a]	Maintenance[b]	Chemicals	Fuel	Electricity	Total	Water cost (dollars per 1,000 US gallons)
	(Thousands of dollars)							
3	5.1	6.9	2.9	.2	1.3	3.4	19.8	8.98
4-5	-	33.1	2.1	.2	-	-	-	-
6	116.2	89.5	46.3	9.4	4.5	84.2	350.1	3.81
13	-	3.7	6.5	.2	1.2	1.5	-	-
16	11.7	20.0	17.5	.9	1.5	Nil	51.6	34.85
17	14.8	48.0	22.5	1.6	2.9	Nil	89.8	32.54
19	-	69.7	169.9	16.3	69.2	4.4	-	-
23	3.1	Nil	.3	[c]	.5	.3	4.2	2.59
79-84	-	50.6	15.6	[c]	2.4	4.9	-	-
87	72.8	102.0	104.0	8.6	14.8	Nil	302.2	21.13

[a] Including overhead.

[b] Including materials.

[c] Included in maintenance.

ANNEX V

ELECTRODIALYSIS

Table 61

Electrodialysis plant design

Plant No.	Operation	Cells per stack	Stacks per stage	Number of stages	Nominal cell dimensions (inches X inches)	Total nominal membrane area (square feet)	Disassembly period (days)	Annual membrane replacement (percentage)
7	Continuous	275	3	2	18 x 40	16,500	30-60	20
8	Continuous	150	1	4	18 x 20	3,000	14	20-33
9	Continuous	100	2	4	18 x 20	4,000	90	33
10	Continuous	102	2	2	18 x 20	2,040	21	33
11	Continuous	150	1	5	18 x 20	3,750	56	33
29	Batch	300	1	1	16 x 40	2,670	-	-
36	Batch[a]	200	4	1	20 x 60	12,120	30	50

[a] Double pass.

Table 62

Electrodialysis, water treatment

Plant No.	Feed-water filter	Feed-water chemical treatment	Product-water treatment
7	10 μ	Nil	Nil
8	5 μ	Nil	Chlorination
9	Yes	Acid	Hypochlorite
10	Yes	Acid	Hypochlorite
11	Yes	Aeration	Hypochlorite
29	Sand	Hydrochloric acid	Caustic soda and chlorination
36	Gravel	Hydrochloric acid	-

Table 63

Electrodialysis, feed-water and product water

		Feed water		Product water			
				Salinity (ppm)		Temperature (°F)	
Plant No.	Source	Salinity (ppm)	Temperature (°F)	Design	Actual	Design	Actual
7	Well	2,300	80-90	500	500	-	80
8	Well	2,650	75-86	350	300-500	90	-
9	Well	-	45	1,000	855	47	-
10	Well	-	68-72	-	796	-	-
11	Well	5,400	90[a]	500	500	-	-
29	Sea	7,000	32-54	500	500-800	-	61
36	Well	3,500	59-86	500	500	-	-

[a] Heated water.

Table 64

Electrodialysis, thermodynamics

Plant No.	Brine temperature (^{o}F)	Performance ratio (kWh per 1,000 gallons)		Feed product ratio a/
		Design	Actual	
7	80	12	-	1.28
8	-	16	-	1.50
9	-	-	-	1.70
10	-	-	15	1.40
11	80	-	-	1.40
29	68	70	62	1.50
36	-	29	-	-

a/ Per unit of product.

Table 65

Electrodialysis, annual.
Water production, by month

(Thousands of U.S. gallons)

Month	Plant No. 7	8	9	10	11	36
January	4,850	580	770	650	700	-
February	4,310	580	700	610	540	-
March	4,330	590	840	710	700	-
April	5,400	600	870	690	80	-
May	6,150	610	1,030	800	Nil	-
June	6,670	610	1,030	940	Nil	-
July	6,570	610	1,120	500	Nil	-
August	6,520	610	950	990	420	-
September	6,110	610	810	860	550	-
October	4,910	610	810	780	560	-
November	4,960	600	710	720	580	-
December	4,640	580	510	680	780	-
Total	65,420	7,190	10,150	9,930	4,910	12,500

Table 66

Electrodialysis, energy and chemical consumption

Plant No.	Electricity (kWh)	Chemicals	
		Type	Quantity
7	475,000	Sulphuric acid	47,500
8	116,800	H.T.H.	100 lb
		Sulphuric acid	25,000 lb
9	71,500	Sulphuric acid	105,000 lb
10	81,660	Sulphuric acid	3,300 lb
11	62,721	Sulphuric acid	-
29	-	Hydrochloric acid	2.2 lb[a]
		Caustic soda	.1 lb[a]
36	(32,400)[b]	Hydrochloric acid	66,000 lb

---

[a] Per cubic metre of product.

[b] Gallons of diesel oil.

Table 67

Electrodialysis, staff and operating status

Plant No.	Staff				Operating status (hours)		
	Supervisory	Operating	Maintenance	Total	Shut-down	Partial	Full
7	-	1	-	1	180	4,355	Nil
8	1	2	-	3	-	-	-
9	.1	1.5	.4	2	-	-	5,720
10	.1	.5	.4	1	624	-	1,300
11	.3	1.5	.5	2.3	1,040	-	3,120
29	-	.5	.2	.7	-	-	-
36	1	4	1	6	-	-	-

Table 68

Electrodialysis, investment costs

Plant No.	Total investment		Expected life	Interest rate	Total fixed charge rate
	Thousands of dollars	Dollars per gallon per day	(years)	(percentage)	
7	305	.47	25	4.4	6.7
8	100	3.57	10	6.0	12.0
10	60	.86	-	-	-
11	84	1.53	-	-	-
29	75	5.77	10	6.0	13.3
36	560[a]	5.60[a]	10	5.0	18.0

---

[a] Including power plant.

Table 69

Electrodialysis, cost analysis

Plant No.	Fixed charges	Labour[a]	Maintenance[b]	Chemicals	Electricity	Total	Water cost (dollars per 1,000 gallons)
	(thousands of dollars)						
7	20.5	6.1	11.5	.5	6.6	45.2	.69
8	12.0	6.0	7.0	1.3	1.1	27.4	3.81
9	-	12.6	1.2	3.5	1.4	-	-
10	-	4.7	1.0	c/	1.5	-	-
11	-	17.2	3.9	5.0	.9	-	-
29	10.0	3.0	.5	.3	4.2	18.0	6.84

a/ Including overhead.

b/ Including materials.

c/ Included in maintenance.

ANNEX VI

DUAL-PURPOSE PLANTS

Table 70

Dual-purpose plants, capacity, investment, costs and production

Plant No.	Total plant capacity: Water (thousands of U.S. gallons per day)	Total plant capacity: Electricity (kWh)	Total investment	Total annual costs: Investment	Total annual costs: Operation	Total annual costs: Fuel	Annual production: Water (millions of U.S. gallons)	Annual production: Electricity (millions of kWh)
			(thousands of dollars)					
1 a/	140	750	-	-	-	-	22.1	-
15 a/	1,463	-	6,610	637	322	347	222.9	-
20-22 a/	2,250	15,000	10,860	690	555	638	750.1	75.9
30 a/	85	5,300	-	-	-	-	17.8	26.8
33-34 a/	50	3,000	1,460	-	290	-	13.0	5.0
36 b/	100	525	-	-	-	-	12.5	-
42 a/	360)	37,500	11,000	692	2,030	708	93.0)	192.1
43 a/	720)						244.2)	
50-57 c/	960)						288.7)	
44-47 a/	2,520)	33,000	27,400	1,580	1,930	Nil	632.1)	164.8
48-49 a/	2,400)						746.3)	
58-67 c/	1,200)						207.5)	
68-77 c/	1,200)						241.3)	
78 d/	895	(Salt)	-	-	-	-	318.0	e/

a/ Multi-flash distillation.

b/ Electrodialysis.

c/ Submerged-tube distillation.

d/ Vapour-compression distillation.

e/ Salt: 34,636 tons.

Litho in U.N.
03387-May 1969-5,000
ST/ECA/112

Price: $U.S. 2.00
(or equivalent in other currencies)

United Nations publication
Sales No.: E.69.II.B.17