FUTURE WATER SUPPLIES FOR THE NORTHERN TRUCIAL STATES

(A report to the Ministry of Overseas Development
by M.J. Burley, Water Research Association)

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1. TERMS OF REFERENCE

The recently completed water resources survey in the Northern Trucial States has shown that reserves of potable water are limited and should be exploited for agricultural production rather than transported over considerable distances for domestic purposes.

In the light of future trends of demand for domestic water and electric power, and in view of special conditions in the Trucial States, advice is required to determine the following, *inter alia*.

(1) The point in time when desalination plants should be in commission.

(2) The recommended type of plant.

(3) Capital costs and the costs of production.

(4) The extent to which desalination and power generation should be combined.

(5) Centralization of plants.

(6) Management problems.

The Northern Trucial States refers to the semi-independent sheikdoms of Ajman, Dubai, Fujaira, Ras Al Khaima, Sharja and Um Al Guwain, but excludes Abu Dhabi. Population figures are based upon the 1968 census and a growth rate of 10% p.a. is assumed for Dubai and Sharja whilst 3% p.a. is assumed elsewhere.

Since large errors are introduced when estimating long-term water demands, this analysis of desalination requirements only covers the period up to 1975.

The ground rules for this period are sound unless new oil reserves are found. In that event the demand estimates used here will probably prove unrealistically low.

As stated above the transport of fresh water resources over long distances will not be considered. The demands of Ras Al Khaima, Um Al Guwain, and the urban population centres of the east coast are taken to be supplied from natural fresh water reserves. This is reasonable since long distance transport of water is not involved. Thus desalination will be considered for Dubai, Sharja and Ajman.

The general policy adopted is that it is desirable to reduce the salinity of water supplied to 500 mg/l TDS, although values up to 1200 mg/l TDS will be tolerated.

2. POPULATION AND WATER DEMAND

Table 1 shows the estimated population of each state to the year 1975, based upon the 1968 census, and the growth rates defined in the terms of reference.

TABLE 1

ESTIMATED POPULATION IN 1000's
(10% growth rate for Dubai and Sharja, 3% elsewhere)

	1968	1969	1970	1971	1972	1973	1974	1975
Dubai	59	64.9	71.4	78.5	86.4	95.0	104.5	115.0
Sharja	31.6	34.8	38.3	42.1	46.3	50.9	56.0	61.6
Ras Al Khaima	24.4	25.2	25.9	26.6	27.4	28.3	29.1	30.0
Fujaira	9.7	10.0	10.3	10.6	10.9	11.3	11.6	12.0
Ajman	4.2	4.33	4.45	4.59	4.73	4.87	5.03	5.2
Um Al Guwain	3.8	3.92	4.04	4.16	4.28	4.41	4.57	4.7
TOTAL	133	143	154	167	180	195	211	228

The estimated water demands in the States to be considered are presented in Table 2. These are based upon the <u>per capita</u> demand as experienced in Dubai since 1961, well field abstraction rates as quoted by Sir William Halcrow and Partners and discussion with officials in the Trucial States.

TABLE 2

ESTIMATED WATER DEMANDS

(in '000 g.p.d., 30% p.a. increase for Dubai and Sharja, 22% elsewhere)

	1969	1970	1971	1972	1973	1974	1975	1976
Dubai	1800	2340	3040	3960	5150	6680	8700	11300
Sharja + R.A.F.	700	798	925	1090	1310	1590	1960	2520
Sharja (no R.A.F. demand after 1971)	700	798	925	715	930	1210	1580	2060
Ajman	50	61	75	91	111	136	165	200
Um Al Guwain	33	40	49	60	73	90	109	132

The record of supplies to Dubai shows that the water demand is increasing at the rate of 30% p.a. which corresponds to a <u>per capita</u> demand increase rate of 18% p.a. when a 10% p.a. population growth rate is assumed. The increasing demand rate appears high for estimating purposes but compares with the development rate in Kuwait (25% p.a.) where water prices are high.

An increase in <u>per capita</u> demand of 18% p.a. is assumed for all States. When coupled to the 3% p.a. population growth a water demand rate of 22% p.a. results. This rate is used for Ajman and Um Al Guwain.

At the present time (1969) about 50% of the Sharja supply goes to the R.A.F. base. The future of this base is not yet clear, therefore two water demand estimates have been calculated for Sharja. One assumes that a demand equal to that of the R.A.F. will be maintained whilst in the second case the R.A.F. demand is assumed to cease in 1971. In both instances the R.A.F. demand is considered as constant.

At present Ajman is supplied from Sharja. However, in the estimates given in Table 2, the demands are separated.

3. WATER SUPPLY FOR THE NORTHERN TRUCIAL STATES

The water resources survey conducted by Sir William Halcrow and Partners for the Trucial States Council*, includes a water balance. It is estimated that 85.10^6 m^3/year leaves the central gravel plain and passes into the central desert foreland. This represents only 50 m.g.d. It is from the central gravel foreland that all water supplies for the west coastal towns are taken. In principle, it is sensible to use much of this water for irrigation in the central gravel plain which is the most extensive of the fertile areas. As soon as significant quantities of water are used for irrigation, the quantities of water available for abstraction in the central desert foreland will diminish and in all probability become more saline. Thus even the present supplies from Awir and Bida'at may become too saline for use without employing electrodialysis to remove dissolved solids. In the view of Mr. E. Tulloch, the State Engineer, the well fields at Awir could be developed to give about 6 m.g.d. Bida'at can also be developed, perhaps to give 4 m.g.d. Thus at this stage 10 m.g.d. of the 50 m.g.d. leaving the central gravel plain could be utilized. It is highly unlikely that greater quantities than this could be developed. At the estimated rate of demand this 10 m.g.d. will be fully utilized by mid 1974.

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* Water Resource Survey, Trucial States Council, Draft Report 1967, by Sir William Halcrow and Partners.

The basic question therefore becomes; what should be the source of water after 1974? Costs aside it is unrealistic to rely heavily upon the electrodialysis of brackish ground water. Without doubt ground water salinity will rise with greater abstraction and if electrodialysis is installed one is very likely to find that the feed to the plant becomes more saline and cannot be treated to an adequate standard by the plant installed.

This leads to the conclusion that whatever the cost, distillation of sea water should be used after 1974 and that it is safer to use distillation in the short-term.

The most economic means of using desalination is to build plant at a single site together with all power generating facilities for the west coast of the Northern Trucial States. The most suitable site is on the coast south of Dubai, although other factors might favour a site between Dubai and Sharja.

During the period covered by this report (up to 1975) the type and size of installation considered for the State of Dubai alone (Appendix 2) would be adequate. Thus, to cater for the demand up to 1975, 2 m.g.d. of distillation plant should be installed at a cost of £1.01 million (QDR 11.6 million), to be operated in conjunction with a 60 mW power plant. The cost of the distilled water produced would be 100 d/1000 gal (QDR 4.8/1000 gal) distributed to Dubai, and a little more distributed to other towns. While there is mildly brackish water available in the vicinity of Awir, advantage can be taken of blending. Blending of an equal portion of 2000 mg/l brackish water with distillate would give water costs of about 57 d/1000 gal (QDR 2.8/1000 gal). After 1975 the potential for blending is likely to be negligible since greater abstractions will cause salinity rises.

Comparative costs for electrodialysis have been calculated in Appendix 2. These are lower than those of distillation but since no potential for blending exists, overall water costs will be higher after the first year of desalination (after October 1974) if the scheme involving electrodialysis is used. Thus 2 m.g.d. of distillation should be installed for operation in October 1973 followed by blending of 2 m.g.d. of brackish water in October 1974. From 1975 all new supplies should be provided by distillation of sea water. A single site should be selected for all power generation and sea water desalination to supply the towns on the west coast of the Northern Trucial States.

Since there may be special reasons why each State should have an independent supply, the requirements of the individual States are considered separately in the following section.

4. WATER SUPPLY FOR THE INDIVIDUAL STATES

Dubai

Dubai is supplied from the well field at Awir. At present 1.8 m.g.d. is fed through a 22 in. main to the township. However, by installing a booster station the capacity of this existing main could be raised to 8 m.g.d.

Little knowledge exists at present as to the ultimate yield of the fresh water resources at Awir. The State Engineer of Dubai, Mr. E. Tulloch, thinks it likely that the present well field at Awir can be extended to provide 4 m.g.d. and that a further 2 m.g.d. will be available from Wahoosh, some 8 km from Awir. If this proves to be the case the estimated demand can be met until about October 1973. From this date onwards desalination must be used.

Of the various desalination processes only two are commercially proven at the present time; multi-stage flash distillation has been used extensively in the Arabian Gulf and elsewhere for sea water conversion, whilst electrodialysis is used for the treatment of mildly brackish waters (1000 - 4000 mg/l TDS). Reverse osmosis and freezing techniques are under development but it is premature as yet to consider the use of these processes.

Electrodialysis

Electrodialysis could be used in Dubai for the treatment of brackish underground water. It would be excessively costly to treat the very saline waters close to Dubai town by this means, but the brackish waters close to Awir could be dialysed.

In Appendix 1 the costs of treating two different waters have been estimated. A plant size of 2 m.g.d. has been considered and alternative costs provided for treatment to TDS levels of 500 and 1000 mg/l. Including pumping requirements from a site 5 km from Awir and using the excess capacity of the 22 in. pipeline, costs range from QDR 2.17 to 4.11. The lower cost corresponds to the conversion of a 2024 mg/l TDS water to give a product of 1000 mg/l TDS, whilst the upper value relates to the treatment of a feed with 3150 mg/l TDS to give a product with 1000 mg/l TDS.

Variations in feed water quality cause problems with electrodialysis and it has been shown * how the salinity of groundwater at the Awir well field has changed. Such changes in quality can result in increased salinity in the product and a reduced plant output. These may in turn dictate the installation of additional plant.

* Figures 38 and 39 in the Water Resource Survey carried out for the Trucial States Council by Sir William Halcrow and Partners.

Distillation

An alternative to the use of electrodialysis is to distil sea water at the coast. In most cases the cheapest way to operate the distillation plant is to use low pressure steam from a power station. In Appendix 2, the costs of a dual-purpose power plant are estimated. The plant considered was Hagevap-dosed and optimization showed that a performance ratio of 8 should be used.

It is proposed that 2 units each of 1 m.g.d. capacity should be installed with a 60 mW power station in late 1972. Although this is some 12 months earlier than necessary according to demand forecasts, the leeway would be an excellent thing. Experience in plant operation can be achieved and the early installation would provide a safeguard against potable groundwater supplies not coming up to expectation.

The estimates in Appendix 2 show the capital cost of distillation plant to be £1,050,000 (QDR 13,200,000) and water costs to be 95 to 100 d/1000 gal (QDR 4.6 - 4.8/1000 gal) including pumping to Dubai. A further capital cost is involved in the construction of a pipeline from the desalting site to Dubai. It is estimated that a 16 km, 24 in. pipe would cost £250,000 (QDR 2,880,000). Such a large main is not essential in the early stages of the scheme, it is recommended, however, since after only 5 years (in 1978) it would be at full capacity (12 m.g.d.).

The cost of distilled water pumped to Dubai (95 d/1000 gal, QDR 4.6/1000 gal) is much greater than that of electrodialysis. However the 2 m.g.d. capacity of the distiller would be fully utilized by mid 1974, and at this stage, brackish water could be added to the fresh water in the Awir pipeline. The salinity would rise, of course, to an unacceptable level, but by blending with the distillate adequate quality could be maintained. Table 7 shows the costs of blending brackish water with distillate compared with the alternative of electrodialysis and distillation which would apply in all years after 1974.

TABLE 7

COMPARATIVE WATER COSTS DUBAI

Development sequence	Oct 1973 - 2 m.g.d. electrodialysis Oct 1974 - 2 m.g.d. distillation After Oct 1975 - all distillation	Oct 1973 - 2 m.g.d. distillation Oct 1974 - 2 m.g.d. brackish water to be blended. After Oct 1975 - all distillation
1. Cost of water from plant installed for Oct 1973 (2 m.g.d.)	45 d/1000 gal (QDR 2.1/1000 gal)	100 d/1000 gal (QDR 4.8/1000 gal)
2. Cost of water from works commissioned in Oct 1974. (2 m.g.d.)	100 d/1000 gal (QDR 4.8/1000 gal)	14 d/1000 gal (QDR 0.6/1000 gal)
Average cost of this 4 m.g.d. supply	72.5 d/1000 gal (QDR 3.6/1000 gal)	57 d/1000 gal (QDR 2.8/1000 gal)

It can be seen from this table that in the first year of desalination (1973 - 74) the scheme involving electrodialysis would be cheaper but in the next year (and indeed in all subsequent years) the alternative of distillation and blending is cheaper (57 d/1000 gal, c.f. 72.5 d/1000 gal, QDR 2.7/1000 gal, QDR 3.5/1000 gal).

From this analysis it follows that the most economic sequence of desalination development for Dubai is as follows.

Oct. 1972	Install 2 units each of 1 m.g.d. multi-stage flash distillation in conjunction with 60 mW steam power station. This plant comes into operation Oct. 1973 if groundwater development proceeds as planned. Capital investment by Oct. 1972 £1,300,000 (QDR 15,000,000).
Oct. 1974	Put 2 m.g.d. of 2000 mg/l brackish water into existing Awir pipeline together with the 6 m.g.d. of fresh water. Capital investment by Oct. 1974 if well field is 5 km from Awir £200,000 (QDR 2,300,000)
Oct. 1975 onwards	Distillation plant in conjunction with new power plant. Capital investment by Oct. 1975 for two units each 2 m.g.d. £1,760,000 (QDR 20,200,000).

General policy

The installation of distillation must be closely allied to the installation of power plant. Siting is of prime importance. Distillation plant will not operate satisfactorily on estuary water - good clean sea water is essential. Therefore both power plant and distillation plant should be sited on the coast. The most advantageous site is probably between Dubai and Jabal Ali.

The use of back-pressure turbines and distillation plant often causes problems. The scheme proposed in Fig. 1, with a low pressure turbine on a separate shaft, provides maximum flexibility. It is recommended that the following station as well as the Oct. 1972 station should have one set with this arrangement. Thus low pressure steam can always be available for distillation, independent of the maintenance of power units. A further advantage of such a scheme is that water production can be stopped for short periods to assist the power plant in meeting extreme daily peaks.

When purchasing distillation plant an experienced consultant should be used and since delivery will take at least 1 year, planning should be set in progress at least 2 years prior to the scheduled commissioning date.

It is recommended that distillation plant management, operation and maintenance should be made the responsibility of the power authorities.

With the introduction of extensive distillation after 1975 a general improvement in overall water quality can be achieved by blending with the entire Awir supply.

SHARJA

The question of water supply for Sharja is over-shadowed by the future of the Royal Air Force establishment. Table 2 shows the estimated demands both with and without a continuing demand equal to that of the R.A.F. It can be seen that by 1975 the demand will have risen to 1.58 m.g.d. if the R.A.F. demand diminishes to zero in 1971. The present capacity of existing works (1.6 m.g.d.) would be adequate to deal with this demand.

If a demand equal to that of the R.A.F. continues after 1971 the 1.6 m.g.d. supply will be fully utilized by 1974, and by March 1975 will have risen to approximately 2.5 m.g.d. In such a case works of about 2 m.g.d. capacity should be put in hand. The present pipeline from Bida'at to Sharja would be capable of carrying this extra capacity.

It is likely that the well field at Bida'at can be developed to provide the extra 2 m.g.d. required for 1975. Ultimately this well field must become fully exploited and at this stage detailed consideration must be given to the use of desalination. It is probably premature to predict requirements beyond 1975 although distillation of sea water and blending with brackish water are also likely to be favoured for Sharja. In recommending distillation of sea water rather than electrodialysis of brackish water, great attention is given to the limited ground water resources. Sir William Halcrow and Partners estimate that only 85.10^6 m^3/year (50 m.g.d.) leave the entire central gravel plain on a front of 60 km. If electrodialysis were installed at or near Bida'at the salinity may well increase after a relatively short period due to increased abstractions at Awir or even greater irrigation abstractions in the central gravel plain. Increases in salinity would dictate the installation of extra treatment plant in order to maintain product quality and quantity.

When the time comes to install desalination for Sharja (and this time cannot yet be predicted) a similar system as that proposed for Dubai in Appendix 2 is recommended. Costs will again be of the same order.

As stated elsewhere the most economic and practical method of using desalination in the Trucial States would however, be to install one single complex, close to Dubai, and supply all the water short coastal areas from this one plant.

AJMAN

The present water demand of Ajman is 50,000 g.p.d. for a population of 4,200. Sharja supplies this water to Ajman from the Bida'at water main. The most economic solution is for Ajman to continue taking this water from Sharja. However to ensure 100% reliability and for administrative reasons there is a demand for an independent water supply.

Adequate supplies are available at Al Helewa but as these have a salinity of 3500 mg/l electrodialysis would be required. Estimates for the supply of treated brackish water from Al Helewa have been calculated and compared with the alternative of sea water distillation in Appendix 3. Electrodialysis is significantly cheaper, (117 d/1000 gal, QDR 5.6/1000 gal) compared with (189 d/1000 gal, QDR 9.1/1000 gal), and since only small groundwater abstractions are involved an electrodialysis scheme can be undertaken with confidence.

Therefore, if an independent supply is essential a scheme involving the electrodialysis of brackish water at Al Helewa is recommended. In general, electrodialysis is not recommended for the Trucial States. However, as the demand of Ajman is too small, and Al Helewa is less likely to experience rises in salinity (pumping rate will be low) electrodialysis appears acceptable in this case.

UM AL GUWAIN, RAS AL KHAMA, FUJAIRA AND EAST COAST CENTRES

In all of these areas sufficient fresh water resources are available to fulfil demands during the period under consideration (up to 1975). If irrigation for agriculture is expanded very rapidly there is a slight possibility that present sources will become brackish before 1975. However, this is not likely and in view of the uncertainty it is inappropriate to provide estimates at this early date.

5. <u>CONCLUSIONS AND RECOMMENDATIONS</u>

1. Water supplies in the Trucial States are limited particularly in the case of the west coast towns.

2. The continued use of groundwater should provide adequate supplies for Ras Al Khaima and the east coast demands for many years. It will also be well beyond 1975 before the new supply for Um Al Guwain is exhausted.

3. It is unlikely that more than 10 m.g.d. of potable water can be pumped from underground sources for the supply of Dubai, Sharja and Ajman. Furthermore, since salinity will rise with greater abstraction and the development of irrigation, even these present supplies may eventually become saline.

4. In general, the use of electrodialysis is not favoured since long-term salinity rises may render the plant ineffective.

5. Distillation of sea water at a single site commencing in Oct. 1973 (if 10 m.g.d. of groundwater can be developed) is recommended. The estimated cost of initial works providing 2 m.g.d. is £1.01 m (QDR 11.6 million). During the first year (1973 - 74) the distilled water would be put into supply at a cost of 100 d/1000 gal (QDR 4.8/1000 gal) but in the second year (1974 - 75) 4 m.g.d. could be supplied at a cost of 57 d/1000 gal (QDR 2.8/1000 gal) by blending with 2 m.g.d. of brackish water fed down the Awir pipeline.

6. The most technically sensible and the most economic means of providing both distilled water and electricity for the Northern Trucial States is to construct a single installation, on the coast, in the vicinity of Dubai or Sharja.

7. Since this proposal may not be acceptable the water supplies of the individual states have been assessed independently.

8. Dubai

If potable groundwater development reaches expectations, 2 multi-stage flash distillation plants should be constructed in Oct. 1972 to be operated in conjunction with a 60 mW power station on the coast. The distillation plant would come into operation 1 year later and in Oct. 1974 2 m.g.d. of 2000 mg/l brackish water should be fed, with the 6 m.g.d. potable supply from Awir to Dubai. Blending with distillate in Dubai will maintain an adequate water quality. All developments after 1975 must involve the use of distillation. Costs up to 1975 are the same as those quoted in paragraph 5.

9. Sharja

The present supply for Sharja will be sufficient until 1975 if the demand of the R.A.F. establishment diminishes to zero in 1971. If in fact a demand equal to that of the R.A.F. is maintained in Sharja new supplies must be developed. The ultimate yield of Bida'at is not known but will probably be sufficient to maintain supplies to 1975. After this period distillation of sea water should be introduced in a similar manner to that suggested for Dubai. Costs are likely to be of the same order.

10. Ajman

Ajman should continue to take supplies from Sharja. If an independent supply is essential then a 100,000 g.p.d. electrodialysis plant should be constructed at Al Helewa. The capital cost of works is estimated at £11,000 (QDR 1,280,000) and water costs would be 117 d/1000 gal (QDR 5.6/1000 gal) when the scheme is fully utilized.

11. Um Al Guwain, Ras Al Khaima and the East Coast

Um Al Guwain should fully exploit the recently completed pipeline. The present resources will thus be adequate well beyond 1975. In Ras Al Khaima and the towns on the east coast, potable groundwater reserves appear adequate to supply the modest increases in demand forecast for well beyond 1975.

12. Proposals in this entire report depend heavily on population and demand forecasts. The Trucial States are developing so rapidly that any such forecasts are liable to sizeable errors. It is certainly unreasonable in such circumstances to predict water requirements beyond 1975.

APPENDIX 1

ELECTRODIALYSIS COSTS FOR DUBAI

The best location for electrodialysis cannot be stated at the present time but a suitable feed water is almost certainly available within 10 km of Awir. The costs of electrodialysis are dependent upon the quality of the feed water and this, of course, is not yet known. It is, however, likely that a feed with 2000 to 3000 mg/l TDS could be located. Therefore costs of electrodialysis for feeds of 2000 and 3000 mg/l TDS are calculated. The present fresh water supply contains about 1000 mg/l TDS. Electrodialysis costs are presented both for this, as the acceptable product quality, as well as 500 mg/l TDS, the recommended World Health Standard.

Case 1

In calculating costs the feed water quality is assumed to be the same as that at Tawi al Hibab as given in Halcrow's report for Sample No. 48. This quotes a total dissolved solids content of 2024 mg/l and an alkalinity of 280 mg/l. For such a water, pretreatment by ion exchange to remove hardness is desirable. Regeneration of much of the softening unit is by contact with the waste brine.

TABLE 3

ELECTRODIALYSIS COSTS (2 m.g.d. - FEED WATER 2025 mg/l TDS)

	PRODUCT QUALITY mg/l TDS	
	500	1000
CAPITAL COSTS £		
Capital cost of electrodialysis plant including pretreatment, rectifiers and installation	394,000	239,000
Building	7,000	5,000
Contingency 15%	59,000	36,000
TOTAL CAPITAL COST	£460,000 (QDR 5,300,000)	£280,000 (QDR 3,220,000)

	PRODUCT QUALITY mg/1 TDS	
	500	1000
OPERATING COSTS d/1000 gal		
Interest and amortization (6.5% over 10 years + 2% p.a. for maintenance and insurance)	24.2	14.7
Power (at 2 d/kWh)	16.0	12.0
Membrane replacement (25% of membrane complement p.a.)	6.6	3.6
Labour/4 men at £15/week	1.0	1.0
TOTAL COST	47.8 d/1000 gal (QDR 2.3/1000 gal)	31.3 d/1000 gal (QDR 1.5/1000 gal)

Case 2

The quality of the feed is taken to be the same as that at T. Murrah, Sample No. 129* namely 3150 mg/l TDS with an alkalinity of 172 mg/l. Again it is economic to pretreat by ion exchange to remove calcium and magnesium hardness. The concentrated brine waste can be used for regeneration.

TABLE 4

ELECTRODIALYSIS COSTS (2 m.g.d. - FEED WATER 3140 mg/l TDS)

	PRODUCT QUALITY mg/l TDS	
	500	1000
CAPITAL COSTS £		
Capital cost of electrodialysis plant including pretreatment, rectifiers and installation	517,000	386,000
Building	10,000	7,000
Contingency 15%	78,000	58,000
TOTAL CAPITAL COST	£605,000 (QDR 7,000,000)	£451,000 (QDR 5,200,000)
OPERATING COSTS d/1000 gal		
Interest and amortization (6.5% over 10 years + 2% p.a. for maintenance and insurance	31.9	23.8
Power (at 2d/kWh)	29.6	22.4
Membrane replacement (25% of membrane complement p.a.)	9.0	6.5
Labour (4 men at £15/week)	1.0	1.0
TOTAL COST	71.5 d/1000 gal (QDR 3.5/1000 gal)	53.7 d/1000 gal (QDR 2.6/1000 gal)

* Footnote as page 4.

In both these cases the waste stream would be about 10% of the product stream, i.e. 200,000 g.p.d. By pumping this waste some distance from the well field it could be spread onto an area where the salinity is already very high. Part of the water would be evaporated and the remainder would pass into the aquifer. Careful observation of salinity in the area would be necessary to ensure that this very saline source does not flow into a relatively fresh groundwater area.

The expense of pumping the waste away and of pumping the product to the 22 in. pipeline at Awir are not included in the above costs since the best site is not yet known. However, if 5 km of 15 in. pipeline is necessary to transport the water to Awir, and 5 km of 6 in. pipeline is required to dispose of the waste, then the additional cost of pipelines is likely to be about £50,000 (QDR 580,000). The cost of the well field would be approximately £150,000 (QDR 1,730,000).

These works when amortized over 25 years would amount to 10.6d/1000 gal (QDR 0.51/1000 gal) and pumping costs for the distances assumed above would amount to approximately 0.5 d/1000 gal (QDR 0.02/1000 gal).

Thus total water costs for the two salinities considered would amount to the figures shown in Table 5.

TABLE 5

TOTAL COST OF WATER FROM ELECTRODIALYSIS

	FEED WATER QUALITY mg/l TDS			
	2024		3150	
	Product water Quality mg/l TDS			
	500	1000	500	1000
Total cost of treatment by electrodialysis	47.8	31.3	71.5	53.7
Cost of well field	8.0	8.0	8.0	8.0
Cost of new mains	2.6	2.6	2.6	2.6
Cost of pumping to Awir	0.5	0.5	0.5	0.5
Cost of pumping Awir to Dubai	2.6	2.6	2.6	2.6
TOTAL WATER COST d/1000 gal	61.5	45.0	85.2	67.4
QDR/1000 gal	2.95	2.17	4.11	3.25

APPENDIX 2

DISTILLATION FOR DUBAI

It is necessary to refer to the growth of the power supply when considering the costs of dual-purpose water power plant. At present the power demand in Dubai is increasing at the rate of 60% p.a. On this basis the power demand will be as given in Table 6.

TABLE 6

ESTIMATED POWER DEMAND

Year	1971	1972	1973	1974	1975
mW	28	45	72	115	185

A 30 mW power plant is scheduled for installation in April 1971. By Oct. 1972 further capacity will be required. At this stage approximately 60 mW should be installed and this should be a steam plant.

The desalination scheme considered here involves the installation of an oil-fired high pressure (2150 p.s.i. 1050^{o}F) boiler with a reheat cycle. Steam is exhausted from the intermediate turbine at 18 p.s.i.a. Part of this steam passes to the distillation plant, whilst the remainder feeds the low pressure turbine which is mounted on a separate shaft with its own alternator. A simplified flowsheet of such a scheme is given in Fig. 1.

Such a scheme has much in its favour; by using the L.P. turbine to drive a separate alternator much greater flexibility can be achieved. For example more desalination plants can be installed at a later date without causing undue difficulties. A further advantage is that the steam supply to the distillation plant can be diverted to the turbine for short periods to assist in daily peak load supply.

If the anticipated fresh water supply of 6 m.g.d. can be achieved, desalination is not necessary until mid 1973. It would however, be sound policy to construct 2 m.g.d. of distillation plant to be installed together with the power plant in Oct. 1972. This allows useful leeway to provide experience in plant operation and as a safeguard against unfavourable development of the well field.

The costs of such a scheme are presented below.

Two units each of 1 m.g.d. capacity are recommended since this eases problems created during maintenance.

With fuel oil costing £7/ton (QDR 80.5) high pressure steam can be generated at 65 d/1000 lbs (QDR 3.12). Approximately one third of the available energy is lost to power generation when steam is fed to the distiller, therefore $\frac{1}{3}$ x 65 d/1000 lb must be attributed to the steam fed to the distiller. A slightly more complex power system must be used and it is reasonable that the water plant should bear this cost. Therefore 27 d/1000 lbs (QDR 1.29) is used as the cost of steam to the distillation plant. The selection of this figure is somewhat arbitrary but without investigating the detailed design of the power plant a more precise value cannot be selected.

The following bases are used in estimating.

Interest rate 6.5%

Amortization period 20 years

Fixed charges (including maintenance and insurance) 12%

Average desalination load factor 90%

COST ESTIMATE 2 UNITS EACH 1 m.g.d. DISTILLATION

CAPITAL COSTS £	
Distillation plant including erection	960,000
Contribution to jetty and sea water intake	50,000
TOTAL	1,010,000
	(QDR 11,600,000)
OPERATING COSTS d/1000 gal	
Amortization, interest, maintenance and insurance	44
Steam cost	33.8
Chemical additives	3.0
Electricity at (1d/kWh)	9.8
Labour	2.0
TOTAL WATER COST	92.6 d/1000 gal (QDR 4.45/1000 gal)

To this cost must be added the cost of transporting to Dubai. The site for such a plant has not yet been designated.

It is essential however to operate the distillation plant on sea water (estuarial or river water tend to be polluted and this type of feed will cause fouling within the plant).

The most suitable site for the power station and water plant is on the coast since both the power plant and the water plant require large quantities of cooling water. A suitable site could probably be selected between Dubai and Jabal Ali.

After 1975 all new water supplies must be from distillation plant. It is logical therefore to install a large pipeline, about 24 in. from the water plant site to Dubai. In the early stages this would prove very expensive but over the entire life of the pipeline it would be heavily utilized.

If the distillation plant were 16 km from Dubai a 24 in. pipe would carry approximately 12 m.g.d. This may appear excessive but such a main is likely to be running full in 1978, only five years after installation.

In costing such a main it is assumed that it is running full although costs in the initial years are much greater.

The installed cost of the main would be approximately £250,000 (QDR 2,880,000).

Amortized cost	=	1.1 d/1000 gal (at 12 m.g.d.) (QDR 0.052)
Pumping cost	=	1.2 d/1000 gal (at 1d/kWh) (QDR 0.056)
Total	=	2.3 d/1000 gal (QDR 0.11)

While pumping only 2 m.g.d. the total cost would be 7.8 d/1000 gal (QDR 0.38). Thus the cost of distilled water pumped to Dubai would be 100 d/1000 gal (QDR 4.8/1000 gal) in 1973 reducing to 95 d/1000 gal (QDR 4.6/1000 gal) after 1978.

APPENDIX 3

DESALINATION FOR AJMAN

Electrodialysis - 100,000 g.p.d.

Feed water quality at Al Helewa - 3500 mg/l TDS (alkalinity 230 mg/l, hardness 616 mg/l). Product water quality - 1000 mg/l TDS.

CAPITAL COSTS £	
Electrodialysis plant including ion exchange softening pretreatment, erection and building	45,000
Pipeline Al Helewa to Ajman (6 in.)	51,000
Well field development	15,000
TOTAL	£111,000 (QDR 1,280,000)
OPERATING COSTS d/1000 gal	
1. Interest amortization maintenance and insurance of electrodialysis plant (6.5% interest over 10 years)	47.5
2. Pipeline and well field (6.5% interest over 25 years)	31.2
3. Electric power at (2 d/kWh)	26.0
4. Membrane replacement (25% p.a.)	7.5
5. Labour (1 man at £15/week)	5.0
TOTAL	117 d/1000 gal (QDR 5.6/1000 gal)

It may appear anomalous to cost the well field and pipeline over 25 years when the electrodialysis plant is costed over only 10 years. However, only a small supply is planned and it is likely that such a supply could be maintained for many years. When the electrodialysis plant is written off it would be replaced.

Writing pipeline and well field off over 10 years would raise the water cost to 145.5 d/1000 gal (QDR 7/1000 gal).

Distillation - 100,000 g.p.d.

A distillation plant would require a separate oil-fired boiler plant and would require siting on the coast. The recommended distillation plant would be Hagevap-dosed for scale control and have a performance ratio of 8.

CAPITAL COSTS £	
Distillation plant and boilers	109,000
Sea water intake	20,000
Pipeline (3 km, 4 in.)	5,000
TOTAL	134,000 (QDR 1,540,000)
OPERATING COSTS d/1000 gal	
Interest and amortization (6.5% over 20 years including maintenance and insurance)	117
Fuel for boiler at £7/ton	58
Chemical dosing	3
Electricity at 2 d/kWh	6
Labour	5
TOTAL	189 d/1000 gal (QDR 9.1/1000 gal)

When the demand has risen to 100,000 g.p.d. (the size of the plant) it is possible to extend the supply by blending with brackish water. 1 part Al Helewa water could be blended with 2.5 parts of distilled water and the overall product quality would still be maintained at 1000 mg/l.

The blended water would cost approximately 145 d/1000 gal (QDR 6.9/1000 gal). It must be appreciated that this lower cost will not apply until the 100,000 g.p.d. is fully utilized and blending would only provide a further 40,000 g.p.d.

FIGURE 3.

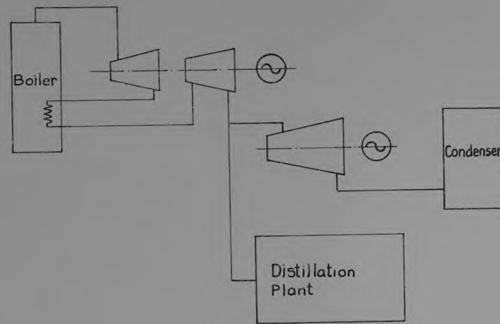

Fig. 1 Simplified Flowsheet of Power/Water Plant.