Hashemite Kingdom of Jordan

Arab Potash Company Limited

Arab Potash Project
Solar Evaporation System

Refinery Water Supply Study

December 1990

SIR ALEXANDER
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Refinery Water Supply Study

BACKGROUND

1.1 Introduction

Estimates of the future water requirements for the different needs of the APC refinery are shown in Table 1. The present water requirements of the refinery are 7 Mm^3/y, but by the end of the decade, when potash production is expected to reach 2.2 Mt/y, the water demand will increase to about 11 Mm^3/y.

Existing demands are at present met from freshwater sources using a combination of groundwater abstraction from the shallow alluvial aquifer at Ghor Safi supplemented by baseflow supplies from the Wadi Hassa and Wadi Hudeira. However, there are competing demands for the freshwater sources in the Southern Ghors, most of which have now been integrated into local irrigation schemes.

As the future availability of freshwater sources for the refinery is somewhat uncertain, potential sources of poorer quality water are now being considered as a means of supplying up to about 65% to 80% of the total water demand. In the scenario of competing demands for fresh water, this would have to be allocated to irrigation and domestic use when brackish water is suitable for the majority of industrial use.

A review of possible alternative water sources has indicated that the sandstone aquifers bordering the Dead Sea could provide suitable supplies. Attention has now focused on the Dhira area some 20 km north of the refinery.

This study examines the feasibility of developing the following quantities of brackish water from Dhira.

a supply of 250 m^3/h (2 Mm^3/y) to meet the brackish water demand at the 1.8 Mt/y potash production level in combination with the existing sources;

a supply of 700 m^3/h (5.6 Mm^3/y) to meet the brackish water demand in conjunction with reduced abstraction from the existing Safi wellfield;

a supply of 1100 m^3/h (8.8 Mm^3/y) to meet the whole brackish water requirement at the 2.2 Mt/y potash production level with only the freshwater demand being met from existing sources.

1.2 Review of APC Water Supply Development

Ghor Safi was identified as the nearest source of water supply for the refinery from the Feasibility Study in 1977. (Ref.1). This was confirmed subsequently by a programme of drilling and testing together with aquifer model studies in 1978/9. (Ref.2).

TABLE 1 REFINERY WATER REQUIREMENTS

Year	Potash Mt/y	B Process water in refinery: Carnallite Area	B Process water in refinery: Sylvanite and Crystallizer	Total B		F/B Pans and other uses		F Power Plant and potable		Total F+B	
				Mm3/y	m3/h	Mm3/y	m3/h	Mm3/y	m3/h	Mm3/y	m3/h
1990	1.40	4.2	1.4	5.6	700	1.05	130	0.35	45	7.00	875
1991	1.40	4.2	1.4	5.6	700	1.05	130	0.35	45	7.00	875
1992	1.40	4.2	1.4	5.6	700	1.05	130	0.35	45	7.00	875
1993	1.40	4.2	1.4	5.6	700	1.05	130	0.35	45	7.00	875
1994	1.60	4.8	1.6	6.4	800	1.20	150	0.40	50	8.00	1000
1995	1.80	5.4	1.8	7.2	900	1.35	170	0.45	55	9.00	1125
1996	1.80	5.4	1.8	7.2	900	1.35	170	0.45	55	9.00	1125
1997	1.80	5.4	1.8	7.2	900	1.35	170	0.45	55	9.00	1125
1998	2.00	6.0	2.0	8.0	1000	1.50	190	0.50	60	10.00	1250
1999	2.20	6.6	2.2	8.8	1100	1.65	205	0.55	70	11.00	1375
2000	2.20	6.6	2.2	8.8	1100	1.65	205	0.55	70	11.00	1375

Abstraction from the shallow aquifer at Ghor Safi was chosen in preference to the direct diversion of the Wadi Hassa to avoid affecting the existing irrigation, interruption to supplies by floods, and to allow the use of a single collection system. A wellfield of seven high yielding boreholes designed to reduce the risk of upconing of deeper saline water began production in 1982. In the longer term, it was considered that, if necessary, the water requirements of APC would be met directly from the Wadi Hassa or the proposed Mujib conveyor with the wellfield acting as a standby source. (Refs. 3 & 4).

APC have routinely monitored and assessed the water supply situation. (Refs. 6,11 & 13). This has enabled appropriate measures to be taken to improve the efficiency of water use and to provide adequate water supplies up to the present level of potash production despite competing demands from other users following the rapid development of the region during the 1980's.

The potential impact of the Stage I Mujib and Southern Ghors Irrigation Scheme on recharge of the shallow aquifer at Safi and the direct availability of Wadi Hassa baseflow was examined in 1980 (Ref.5). The first stage of this scheme was commissioned in 1985 and should achieve the planned increase in the area of irrigation by 1992.

By 1985 the wellfield was operating close to its design yield. A review of the situation at this time led to improvements in water use, integration of baseflow supplies from the Wadi Hudeira and Wadi Hassa, an assessment of monitoring data from Ghor Safi, and measures to improve wellfield abstraction. Other possible sources of water supply, including deep brackish groundwaters, were also reviewed. (Ref.6).

The pumping capacity of the APC wellfield was affected by a decline in water levels of about 6m by 1988 due to a combination of fan edge drainage by the irrigation scheme, limited recharge from floods and by APC abstraction. A programme of further drilling was undertaken during 1989/90 to ensure adequate water supplies for the 1.4 Mt/y potash production level.

A further detailed review of the use of brackish water and more distant sources was undertaken in 1989 to develop a strategy to meet the substantial increase in water requirements for an expansion in potash production to 2.2 Mt/y. (Ref.13). Deep groundwater from Ed Dhira was considered to be the most likely source for future water supplies, which could be used in conjunction with existing sources or to replace existing sources.

2. EXISTING WATER SUPPLIES

Water use at the Refinery from 1982 to 1990 and the contributions from the Safi wellfield, Wadi Hassa, and Wadi Hudeira are given in Table 2 of this Report. The Safi wellfield now contributes about two thirds of the total water supply to the refinery. The Wadi Hassa is a lower cost source of supply than the existing wellfield but its use is limited by irrigation demands. Various measures have been implemented to maintain production from the wellfield and to integrate baseflow supplies. (Ref. 11). These measures are considered capable of meeting the water requirements of the 1.4 Mt/y potash production level at the present water demand. Recent measures include:

(a) A sand filter and a permanent pipeline with a capacity of 750 m^3/h, which were installed by APC during 1987/8 in cooperation with JVA to gravity feed surplus baseflow from the Wadi Hassa to the Safi pumping station. This supply became available in December 1988.

(b) Five new boreholes which were drilled and equipped at Safi during 1989/90 to provide a wellfield having 11 boreholes with a pumping capacity of about 845 m^3/h (See Table A1 in Appendix A):

two boreholes (SPB6 and SPB7) were drilled adjacent to the APC Hassa pipeline to make full use of the pipeline capacity when surplus flow was less than the pipeline capacity and during interruptions to the diverted supply during floods.

three boreholes (SPB8 , SPB 1B and S 2B) were drilled to replace two of the original wellfield boreholes and to provide a new borehole near SPB 3.

The present status of the wellfield boreholes and yield drawdown curves for the new wells are shown in Appendix A.

(c) In 1989 the 3 No. old pumps were replaced by new higher capacity pumps to provide a total pumping capacity of about 900 m^3/h.

The existing freshwater sources of supply at Safi and Hudeira will be needed to provide about 20% to 35% of the water requirements of the refinery complex, which amounts to about 2.2 Mm^3/y (275 m^3/h) to 3.85 Mm^3/y (480 m^3/h) in 1999. The Wadi Hudeira can supply about 100 m^3/h and is allocated to APC for potable water supplies. The remaining requirement of 175 to 380 m^3/h can be supplied from the Wadi Hassa or the Safi wellfield. The whole freshwater requirement could be met from the wellfield if the baseflow supplies are interrupted or to meet peak daily demands. The quality of the baseflow should be monitored as there is some risk of contamination.

Floods can interrupt the baseflow supplies during the winter months. High turbidities may prevent diversion for up to 10 days, although each flood usually only lasts about 1 to 3 days. The frequency and timing of flood events is irregular and unpredictable. The Safi wellfield can continue to be used as the source of supply during these floods.

TABLE 2 ANNUAL WATER USE AT REFINERY Mm3

Year	Total	Safi Wells	Hassa	Hudeira
1982	1.22	1.22		–
1983	4.01	4.01		
1984	4.65	4.65		
1985	6.02	6.02		
1986	6.77	6.39		0.38
1987	6.64	5.36	0.66	0.62
1988	6.63	4.22	1.72	0.69
1989	6.52	4.34	1.48	0.70
1990	[5.19]	[3.25]	[1.19]	[0.68]

[ ] Jan to Sept only

3. COMBINED USE OF FRESH AND BRACKISH SOURCES

3.1 General

The existing sources could be used in conjunction with brackish water from Dhira. This would allow brackish water to be introduced in stages and enable a blended supply of a more acceptable quality to be delivered to the refinery. If the resources of the Dhira area prove sufficient then the existing sources would eventually be used to meet the freshwater requirements and to provide a standby supply for occasional use if the supply from Dhira is interrupted.

By using poor quality water APC would be able to reduce demand on the existing freshwater sources at Safi. This would give APC more control over their water supply and allow the fresh groundwater to be conserved for municipal uses (estimated as 0.38 Mm^3/y in 2000). Agriculture would not necessarily benefit if APC reduce the diversion of surplus baseflow from the Wadi Hassa.

3.2 Existing Sources Only

Table 3(a) shows that the water requirements up to a potash production level of 1.6 Mt/y, which should be achieved in 1994, could be met from the existing sources of supply. Thereafter additional supplies will be required to meet the further increase in potash production. These predictions are based on information supplied by APC on the existing diversion of surplus baseflow from the Wadi Hassa, the present wellfield capacity (Appendix A, Table A1), and the capacity of the main pipeline from Safi.

If the amount of water diverted by APC from the Wadi Hassa in future remains the same then the wellfield will need to be operated at rates of 600 m^3/h up to its maximum capacity of 840 m^3/h, averaging about 800 m^3/h. Shortfalls in supply could occur between September and December and during floods.

The demand on the Safi wellfield will be between 6 and 6.5 Mm^3/y. This level of abstraction in 1985/6 contributed to a decline in water levels (see Appendix A, Figure A3). Sustained abstraction for several years at this rate could therefore cause a further decline in water levels eventually leading to a reduction in wellfield abstraction and possible effects on other groundwater users.

The decline in water levels has decreased in the past two years as the agricultural scheme nears completion and with reduced abstraction by APC (see Appendix A). The future rate of water level decline is uncertain as the diversion of the Hassa baseflow by APC, which began in December 1988, reduces the water that would otherwise continue down the wadi channel to recharge the aquifer and few floods have occured in recent years.

The future availability of surplus Wadi Hassa baseflow for APC diversion is uncertain. A farm survey being undertaken by JVA will provide more representative estimates of the irrigation demands. However, future changes in crop patterns, crop types, or water use efficiency could alter the availability of surplus flow.

TABLE 3a PREDICTED SHORTFALL IN SUPPLY USING EXISTING SOURCES ONLY (m3/h)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Hudeira	100	100	100	100	100	100	100	100	100	100	100	100
Hassa Diversion *	200	250	130	200	250	250	300	150	40	40	50	60
Wellfield Capacity	840	840	840	840	840	840	840	840	840	840	840	840
Total	1140	1190	1070	1140	1190	1190	1240	1090	980	980	990	1000
Actual total **	1000	1000	1000	1000	1000	1000	1000	1000	980	980	990	1000
Shortfall in supply:												
1.4 Mt/y (875 m3/h)	0	0	0	0	0	0	0	0	0	0	0	0
1.6 Mt/y (1000 m3/h)	0	0	0	0	0	0	0	0	-20	-20	-10	0
1.8 Mt/y (1125 m3/h)	-125	-125	-125	-125	-125	-125	-125	-125	-145	-145	-135	-125
2.0 Mt/y (1250 m3/h)	-250	-250	-250	-250	-250	-250	-250	-250	-270	-270	-260	-250
2.2 Mt/y (1375 m3/h)	-375	-375	-375	-375	-375	-375	-375	-375	-395	-395	-385	-375

* Present APC diversion
** Main pipeline capacity 900 m3/h

3.3 Supplies from Dhira

Abstraction from the Safi wellfield could be reduced if an alternative source of water, such as brackish water from Dhira, can be developed by 1994. Table 3(b) indicates how a supply of brackish water from Dhira could be phased in to reduce abstraction from the Safi wellfield to meet future water requirements up to a potash production level of 2.2 Mt/y. The contributions from the Hudeira and Hassa baseflow are assumed to continue at their present levels.

A supply of 250 m^3/h of brackish water from Dhira would reduce abstraction from the Safi wellfield by 125 m^3/h and would meet the water requirements at a potash production of 1.8 Mt/y. Peak abstraction from the Safi wellfield would be about 735 m3/h.

An initial supply of 700 m^3/h can be substantiated from engineering considerations. This would reduce abstraction from the Safi wellfield by a further 325 m^3/h to between 150 and about 400 m^3/h at a potash production of 2.0-2.2 Mt/y.

If the resources of the Dhira areas can meet all of the brackish water requirements of 1100 m^3/h at the 2.2 Mt/y potash production level, then the existing sources would only be needed to meet the freshwater requirements. The maximum standby capacity would still be about 1000 m^3/h. There would be no blending of the brackish and freshwater supplies at this level.

TABLE 3b CONJUNCTIVE USE OF FRESH AND BRACKISH WATER SOURCES (m3/h)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
A. Potash Production 1.6 Mt/y. Water Requirement 1000 m3/h. Existing Sources												
Hudeira	100	100	100	100	100	100	100	100	100	100	100	100
Hassa Diversion *	200	250	130	200	250	250	300	150	40	40	50	60
Safi Wellfield Requirement	700	650	770	700	650	650	600	750	860	860	850	840
B. Potash Production 1.8 Mt/y. Water Requirement 1125 m3/h. Existing Sources plus 250 m3/h from Dhira												
Hudeira	100	100	100	100	100	100	100	100	100	100	100	100
Hassa Diversion *	200	250	130	200	250	250	300	150	40	40	50	60
Safi Wellfield Requirement	575	525	645	575	525	525	475	625	735	735	725	715
C. Potash Production 2.0 Mt/y. Water Requirement 1250 m3/h. Existing Sources plus 700 m3/h from Dhira												
Hudeira	100	100	100	100	100	100	100	100	100	100	100	100
Hassa Diversion *	200	250	130	200	250	250	300	150	40	40	50	60
Safi Wellfield Requirement	250	200	320	250	200	200	150	300	410	410	400	390
D. Potash Production 2.2 Mt/y. Water Requirement 1375 m3/h.												
(i) Existing Sources plus 700 m3/h from Dhira												
Freshwater Requirement	275	275	275	275	275	275	275	275	275	275	275	275
Hudeira	100	100	100	100	100	100	100	100	100	100	100	100
Hassa Diversion *	175	175	130	175	175	175	175	150	40	40	50	60
Safi Wellfield Requirement	0	0	45	0	0	0	0	25	135	135	125	115
Brackish Water Requirement	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
Hassa Diversion *	25	75	0	25	75	75	125	0	0	0	0	0
Safi wells	375	325	400	375	325	325	275	400	400	400	400	400
TS1D plus new Dhira well(s)	700	700	700	700	700	700	700	700	700	700	700	700
(ii) Existing Sources plus full brackish water requirement of 1100 m3/h from Dhira												
Freshwater Requirement	275	275	275	275	275	275	275	275	275	275	275	275
Hudeira	100	100	100	100	100	100	100	100	100	100	100	100
Hassa Diversion *	175	175	130	175	175	175	175	150	40	40	50	60
Safi Wellfield Requirement	0	0	45	0	0	0	0	25	135	135	125	115
Brackish Water Requirement	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
TS1D plus new Dhira well(s)	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100

* Present APC Diversion

4. BRACKISH WATER SUPPLIES

4.1 General

Earlier reviews have identified the deep sandstone aquifers (Kurnub and Disi Groups) as possible sources of brackish water supply for the APC refinery. Only limited information is available for these aquifers due to their depth over most of Jordan.

It has been concluded from a recent programme of drilling by APC and WAJ along the escarpment area between Wadi Issal and the APC refinery at Wadi Qunaiya that no significant groundwater resources are present in the sandstones close to the refinery. Most of the sandstone sequence has been eroded in this area, which is also rather inaccessible.

As shown on Figure 1, the Dhira plateau has been identified as the closest area to the refinery having a potential for groundwater development. This area lies some 20km north of the refinery and covers an area of some 30 km^2 between Wadi Ibn Hammad and Wadi Issal. Geological maps of the area at 1:50000 have been published recently. (Refs. 8 & 14).

The southern part of the Dhira area is bordered to the southeast by an extension of the Dead Sea fault. The thickness of the Kurnub and Disi sandstones has been reduced by erosion to the east of this fault. Faulted overturned strata are likely to restrict groundwater movement into this part of Dhira and as yet no deep boreholes have been drilled in this particular area. A thick sequence of Tertiary formations exist in the southern part of Dhira such that the sandstone aquifers are likely to occur at depths of more than 1000m. The Tertiary formations have a relatively limited potential.

The Belqa and Ajlun limestone aquifers in the southern part of Dhira may occur in the area of the APC township at depths of 250 to 750m and could be a possible target for exploration.

The eastern boundary fault passes northwards beyond Wadi Karak into a steep monoclinal fold that could allow hydraulic connection between the northern part of Dhira with the upland recharge area to the east lying between the Siwaqa Fault and the Karak graben. The deep sandstones form inliers along the Wadis Karak and Ibn Hammad just east of the scarp. A combined spring discharge of about 400 l/s is reported from these inliers which subsequently recharge the limestones underlying the northern part of Dhira.

The general dip of the strata in the Dhira area is southeast and faults mainly downthrow to the south. Consequently, progressively older strata are closer to the surface in the northwestern area around Ain Maghara. The sandstones reappear to the north of Ain Maghara to form the escarpment along the northern shores of the Dead Sea.

Dhira Area

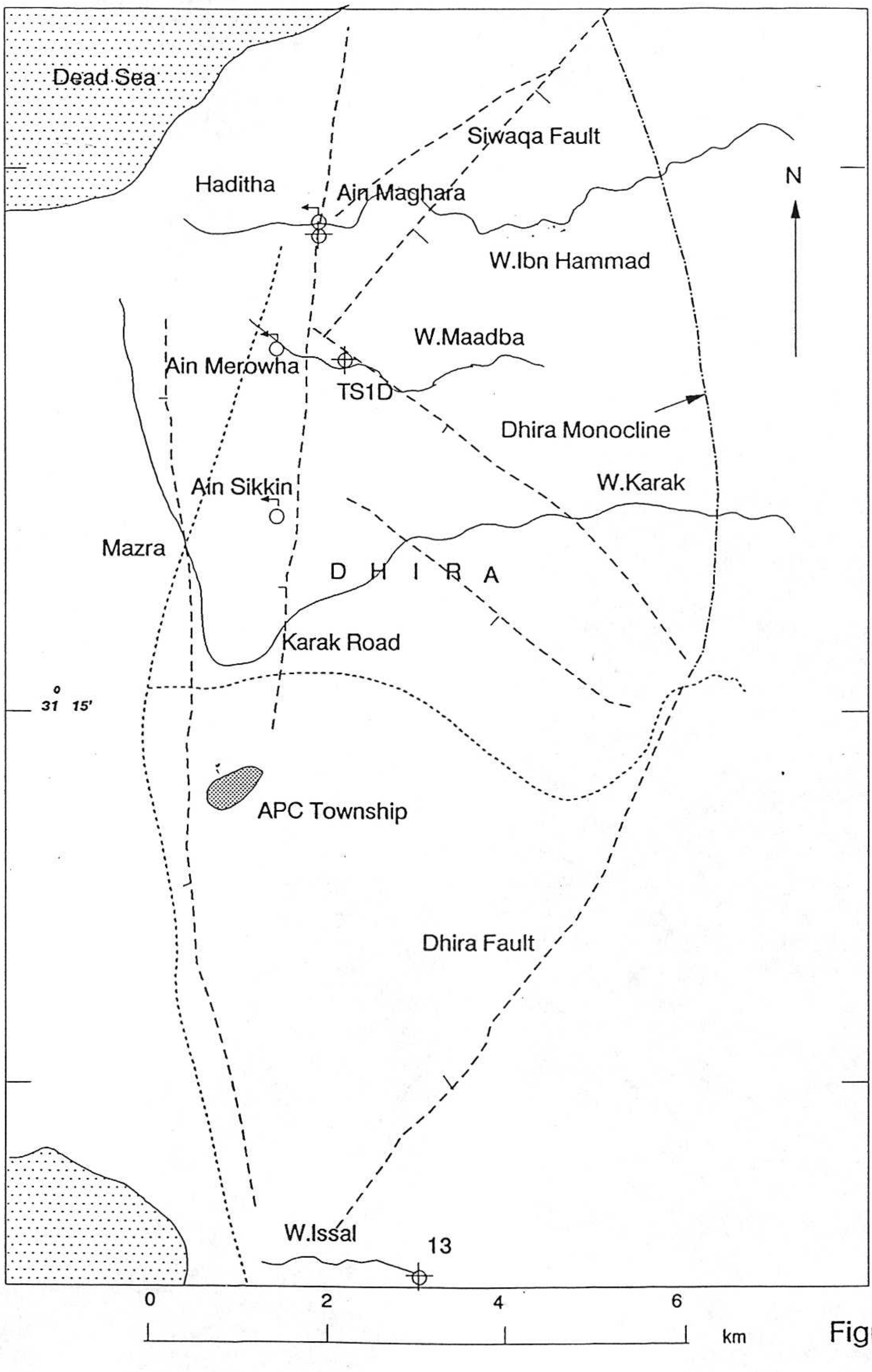


Figure 1

4.2 Abstraction from Dhira

Development on the scale required for the APC refinery (up to about 9 Mm^3/y) would normally be preceded by detailed groundwater resource studies. As the cost of an appropriate exploration programme would be high, a monitored phased approach is considered a more practical alternative to confirm well yields and the availability of resources in the Dhira area.

As part of the NRA Tar Sand Project a deep borehole (TS1D) was drilled to 777 m. depth in the Wadi Merowe just south of Ain Maghara. (See Figure 1 for locations in the Dhira area). This encountered hot brackish water containing hydrogen sulphide at 598m in the upper part of the Kurnub Sandstone which produced an artesian flow of 60 m^3/h. Hot (50°C) brackish water, apparently without hydrogen sulphide, was encountered in the lower part of the Kurnub at depths of 637 and 664m which produced an artesian head of about 110m above ground level and an estimated flow of 400 m^3/h. Casing was cemented in to a depth of 633m. The borehole has not been tested.

Water analysis results are given in Table 4, although a complete chemical analysis is still required. An isotope analysis would also be desirable. The water has been undergoing trials by APC and would appear to be satisfactory for use in the refinery.

As the artesian head declines, the water quality may deteriorate as water is drawn from greater depth particularly close to the main Dead Sea fault. Ain Merowhe, a highly mineralised spring, emerges in the wadi a short distance downstream of Borehole TS1D.

A supply from Borehole TS1D, which has an estimated elevation of minus 300m below sea level, would be gravity fed to the refinery. The yield is likely to decline with time but whilst the supply remains artesian this will not incur pump or operating costs. However, the borehole diameter is only 177mm (7 inch) and consequently this borehole could not be pumped at rates of more than about 30 m^3/h if the head declines below ground level. This is an estimate of the capacity of a pump that could be inserted in a borehole fitted with 7 inch casing. The borehole could not be reamed to a larger diameter and pumped abstraction from this site would require a replacement borehole of up to 20 inch diameter to provide about 250 m^3/h. The casing sealing off the overlying limestones is likely to corrode fairly rapidly.

Borehole TS1D is possibly located in a particularly favourable position at the intersection of major fractures. Other boreholes drilled into the sandstone aquifer in the southern Ghors area have low specific capacities. It is therefore uncertain as to whether TS1D will be able to sustain the high initial yield and whether new boreholes in the same area would provide similar yields.

A borehole was drilled by WAJ adjacent to Ain Maghara which penetrated a few metres into Kurnub sandstone at 35m. It had an artesian head of 1.5m above ground level. The borehole was tested in 1980 at 67 m^3/h with a drawdown of 10.6m after one day, although the Kurnub may have been sealed off prior to the test.

It will be necessary to make appropriate arrangements with NRA before testing and using Borehole TS1D as a source of supply. Prior to such tests, it is assumed that the additional supply of 250 m^3/h required for a potash production of 1.8 Mt/y can be obtained from this borehole, which would be used in conjunction with the existing sources.

For planning purposes it is assumed that any boreholes in this area could supply an average of 250 m^3/h ($2Mm^3/y$). This will need to be confirmed. A supply of 700 m^3/h would require a wellfield of four boreholes, one of which would be TS1D. The full brackish water requirement of 1100 m^3/h would need about five boreholes.

Possible targets for further boreholes occur within one kilometre of TS1D. These would be drilled at fault intersections in separate major fault blocks to command groundwater flow over a wide area from the north, northeast and east. Detailed mapping of the area is required to select appropriate and accessible sites. The Kurnub will occur at shallower depths to the north of Borehole TS1D which would allow more of the aquifer thickness to be utilised, but it is assumed for planning purposes that each borehole would be about 600m in depth.

Whilst acceptable yields should be possible from the area around Borehole TS1D the groundwater resource is considered to be a fossil water, with perhaps some recent recharge occurring from the overlying limestones through major faults east of the escarpment. The artesian head elevation at Borehole TS1D would indicate a potential for upward groundwater flow from the sandstones into the limestones in the Dhira area.

The sandstones and limestone sequences are separated by a thick aquiclude of shales and mudstones (Ajlun Series). These should prevent the depletion of the freshwater resources in the younger limestones used for irrigation in the Dhira-Mazra area.

Resource estimates will require a survey of springs and their bedrock source to assist estimates of groundwater inflow to the area. An assessment will be needed as to whether proposed schemes in the Mujib Catchment, such as the Lajjun Oil Shale Project, could affect the long term availability at Dhira.

5. PROPOSED STRATEGY

It is necessary to consider a number of factors in arriving at a practicable method of introducing the use of brackish water from the Dhira wellfield. These are as follows:-

Borehole TS1D exists but as a source of water its reliability has to be confirmed. Time is required to prove that this source is reliable.

The use of poorer quality water at the plant needs to be introduced gradually to ensure that no problems occur from its use.

A move away from the use of all freshwater at the plant would be beneficial to other users but it is not yet mandatory to use brackish water to the maximum extent.

Although a single pipeline from the Dhira wellfield would be cheaper than a duplicated pipeline, a single line of limited capacity would supply adequate brackish water to the plant for a number of years.

Following on from the above it is considered that the new water source should be developed in stages as outline below. On the basis of present knowledge the reliable yield of each borehole in the Dhira area is taken as a nominal 250m^3/h, and pumping at this rate is considered to be feasible from a 20 inch borehole.

(a) In Stage I the existing Borehole TS1D should be extensively tested to determine its long term yield and to see if any drawdown occurs after it has been delivering water for a period of time. The outcome of this testing could be the development of a reliable source yielding about 250 m^3/h, which is an provide the initial contribution towards the longer term target of 1100m^3/h.

(b) Once the supply from Borehole TS1D has been confirmed an additional borehole should be constructed with a 20 inch diameter casing to provide a standby in case of damage to Borehole TS1D and to enable the Dhira source to be more extensively monitored. These works would also be part of Stage I.

(c) To make a more significant step towards the target, two further boreholes should be constructed, each with 20 inch diameter casing as part of Stage II. It is expected that these two boreholes, together with Stage I boreholes would achieve a total flow of about 700 m^3/h, which should be considered as a reasonable second stage development.

(d) Stage III would involve the construction of a further borehole, each with a 20 inch diameter casing. The total flow from the wellfield would then have achieved the target of 1100m^3/h. Should the artesian pressure in borehole TS1D fail then this borehole would have to be replaced with a further borehole, with a 20 inch casing.

Thus at the end of Stage III there would be adequate amounts of brackish water to supply the full 8.8 Mm^3/y requirements of the refinery when production of potash has risen to 2.2 Mt/y.

6. ENGINEERING WORKS FOR BRACKISH SUPPLY

(i) Source of Water

As discussed above in Section 5, this will be developed as follows:-

Stage I	Existing borehole TS1D plus one further borehole to give 250 m^3/h.
Stage II	Two further boreholes, making four in total, to give 700 m^3/h.
Stage III	One further borehole with a replacement for Borehole TS1D, to give 1100 m^3/h.

(ii) Quality of Water

Table 4 gives details of Borehole TS1D and also gives results of the physical and chemical tests done on the water produced by this borehole. The temperature of the water is about 50°C and, although it would be feasible to cool this water by an evaporation process, it is not considered necessary as the elevated temperature would not be detrimental to the process used at the refinery.

The water from borehole TS1D is brackish and would not be suitable for domestic use without treatment. However, it is understood that its quality is acceptable for use at the refinery and since its use will conserve supplies of fresh water it is considered reasonable to arrange to convey it to the potash plant, but to keep it separate from the fresh water system.

Although the quality of the water is such that it could deposit scale on the pipeline conveying it to the refinery, it is not considered that this would be serious and it could be controlled to a certain extent. Monitoring of the pipeline condition would be advisable.

(iii) Headworks

If artesian pressures can be relied on to persist in the boreholes this has the advantages in yield per borehole but it also has implications regarding the design of the headworks at the boreholes. Although it would be feasible to connect the delivery pipeline to the refinery, this would raise the pressure in the gravity pipeline considerably. For example, an artesian pressure at the top of a borehole of 100 metres would increase pressure at the lower and of the gravity pipeline to 128 metres, which is unnecessary. It is therefore recommended that a collector tank should be constructed at a suitable location adjacent to the boreholes, and all boreholes would deliver water into this tank, either under natural pressure or by pumping. The capacity of this collector tank would be about 1100 m^3, representing about 1 hour of pumping from the wellfied. This collector tank would be equipped with electrodes which would control the flow into the tank, either by stopping and starting the borehole pump or by controlling inlet valves automatically.

(iv) Gravity Pipeline

The headworks' collector tank would have a top water level of about - 340 metres and the top water level of the main reservoir at the refinery's 368.2 metres, giving a static head differential of 28.2 metres. With a pipeline length of about 20 kilometres this gives a hydraulic gradient of 1 in 710. At this gradient a 700 mm diameter pipeline would convey about 1600m^3 of water per hour. (A 600mm diameter pipeline would not convey the flow of 1100m^3/h required in the year 2000.) A 700mm pipeline would therefore easily deliver the total estimated quantity of brackish water required at the refinery. As an alternative and preferable method of development, a pipeline of 500 mm diameter could be installed to convey about 700m^3/h. This would defer capital expenditure and would give more opportunity for the new wellfield to be developed and tested. It would also allow time for the brackish water supply system to be integrated into the fresh water supply system at the refinery. A second pipeline of the same diameter or possibly 400mm diameter could be installed later to suit increasing demand.

(iv) Details of Pipeline

The pipeline or pipelines should be buried in a trench for security reasons and for general stability. The following possible pipe materials have been considered.

Asbestos Cement	AC
Ductile Iron	DI
Glass Fibre Reinforced Concrete	GRP
Medium Density Polyethylene	MDPE
Steel	St
Unplasticised Polyvinyl Chloride	UPVC

All the above pipes are manufactured in 400mm to 700mm diameters and are available in the required pressure classes. However, due to the temperature of the raw water (50°C) UPVC is not considered to be suitable. Although polythylene pipes are in general resistant to corrosion by soils and waters, these pipes can be degraded by exposure to ultraviolet radiation in sunlight and are not considered suitable for this application.

Prestressed concrete pipes are heavy to handle during transport and laying and the sizes required are not entirely suitable for this application. Steel pipes are strong but they will need to be adequately protected from corrosion internally with cement lining and externally with bituminous or polymer material, and will therefore be expensive.

Table 4

Chemical Analyses Borehole TS1D (Wadi Merowhe)

mg/1

	1 598m	2 773m	3		
Temperature C	42	50			
pH	7.2	7.5	6.0	7.0	
Total Dissolved Solids	9103	9034	9000		
EC mS			17500	15200	
Ca	723	1100	2310	816	
Mg	448	515	520	565	
Na	1385	894	1190	1030	
K	181	119		153	
C1	4970	4473	5012	4650	153
Total Hardness		4455	4372		
Alkalinity			145	175	
S (as sulphide)			3.84	0.8	
H2S			4.1		
Si02				11.4	
Fe			0.2		

1,2 from NRA records

3,4 from APC (Dec 1987 and Dec 1989)

Asbestos cement pipes are resistant to corrosion by most soils and waters though sulphate bearing soils and soft waters can attack the cement. The pipes are strong and rigid but are susceptible to impact damage before and after laying. Normal laying lengths are 4 or 5 metres. Joints are made by either push fit asbestos cement sleeves or mechanical bolted couplings, both with sealing gaskets.

Ductile iron pipes are normally lined internally with cement mortar and coated externally with a zinc rich coating, bitumen paint and a polyethylene sleeve. This system provides corrosion resistance against the conveyed water and most combinations of soil and groundwater. More comprehensive corrosion resistant systems can be used if considered necessary. DI pipes are strong and rigid and do not rely on the trench backfill for support. Normal laying lengths are 5 to 6 metres. Joints are made by push-fit sockets with sealing gaskets, a system that ensures a flexible pipeline.

Glass fibre reinforced plastic pipes are resistant to corrosion by soils and waters, provided that the strain in the pipe walls is kept within safe limits. GRP pipes are light and strong but rely on the trench backfill for support when subjected to ground surface loads. The pipe must be manufactured to have a stiffness appropriate to the trench and backfill conditions existing on site. Normal laying length is 6 metres. Joints are made by spigot and socket, push-fit collars or mechanical bolted couplings with sealing gaskets.

Taking all factors into consideration it is recommended that ductile iron would be the most appropriate material for the gravity pipeline, and also for the collecting pipelines at the boreholes. The main gravity pipelines would extend from the collecting tank at the wellfield site to a new storage reservoir at the refinery.

(vi) Storage Reservoir at Refinery

The gravity pipeline or pipelines will terminate at a reinforced concrete storage reservoir at the refinery. In the year 2000, when 8.8 Mm^3/y of brackish water is estimated to be used at the refinery, it would be prudent to have storage capacity of about 24 $000m^3$, which represents 24 hours of storage at the average consumption. Top water level would be - 368.20 metres to match the existing main storage reservoir. This reservoir would be unroofed and would be developed in two stages to defer expenditure.

Although it would be possible to defer construction of the first stage ($12000m^3$) of this reservoir until Stage II it is probably not advisable since there would be complications in arranging the existing two tanks such that one would store brackish water and the other fresh water. However, if it were considered essential to reduce the cost of Stage 1 then this deferment should be considered.

Provision should be made for control valves at the main inlet to this reservoir to regulate the flows of brackish water into it. It would be prudent to arrange for pipework to bring fresh water to it from the Hudeira system and also from Safi pumping station, so that mixing of waters could take place. Care must of course be taken to ensure that brackish water cannot contaminate either of the two fresh water reservoirs at the site or the storage reservoir on the Hudeira system.

(vii) Integration with Present System

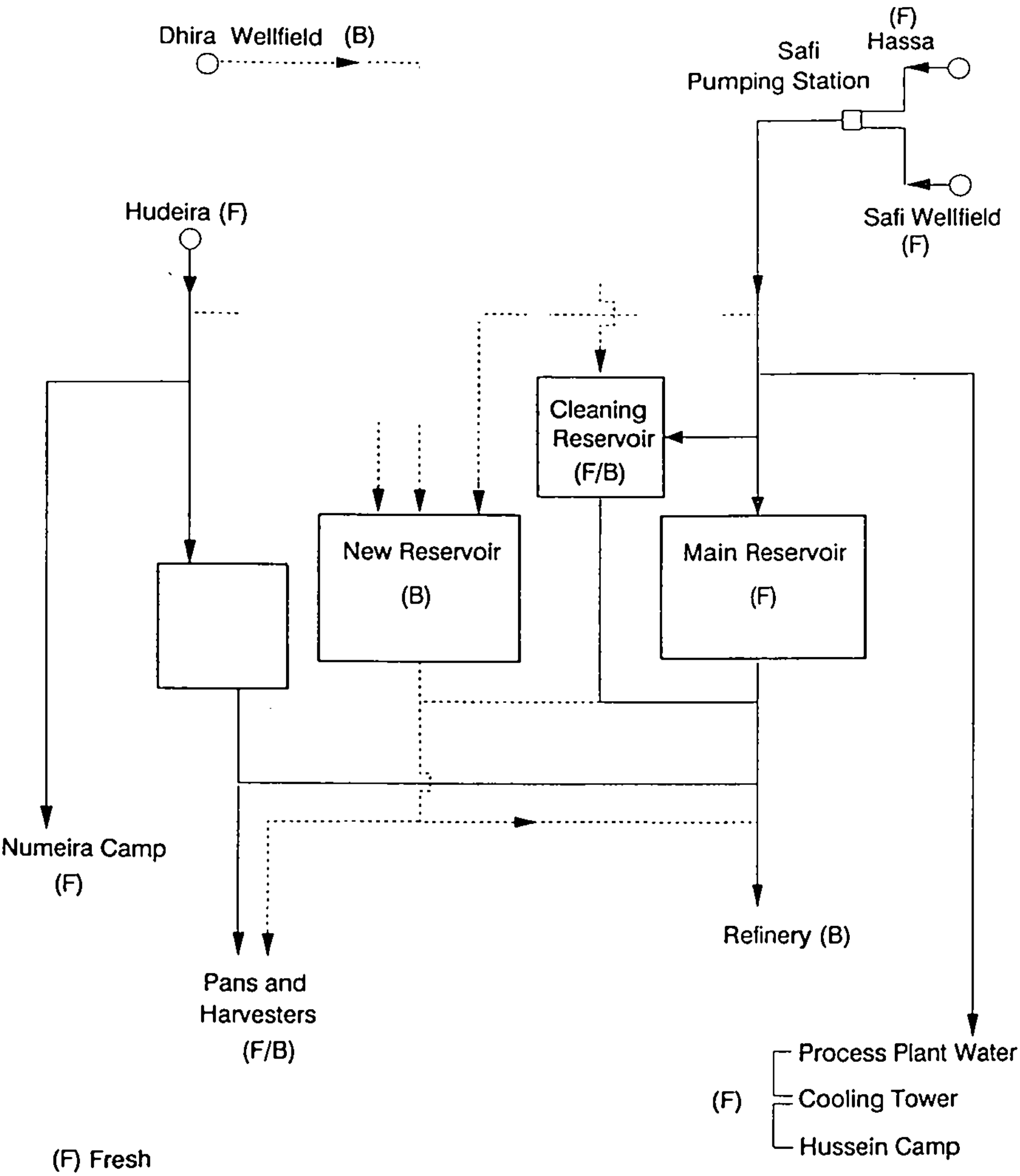
Figure 2 shows in outline the location of the headworks, the route of the pipeline and the location of the refinery.

Figure 3 shows the present water distribution system and the proposed method of integrating into it the new brackish water supply system. Water from the gravity mains from the new wellfield would discharge directly into the brackish water storage reservoir. This would then supply water as required into the existing supply pipelines to the Pans and Harvesters area and to the Refinery. Pipelines would be constructed to enable fresh water from the Hudeira syustem and from the Safi Pumping Station to be supplied into the new brackish water reservoir.


HASHEMITE KINGDOM OF JORDAN
Proposed Wellfield
BH TS1D
Existing Jetty at Hadiatha
To Karak
Wadi Karak
EMPLOYER'S TOWNSHIP
POWER STATION
TOWNSHIP TRANSMISSION LINE 33 KV
Wadi Isal
Mazra – Aqaba Highway
EXISTING EMPLOYER'S CAMP
Wadi Hudeira
WADI HUDEIRA FLOOD CHANNEL
DIKE TRANSMISSION LINES 33 KV (Not shown)
PROCESS PLANT SITE
WADI QUNAIYA FLOOD CHANNEL
Wadi Qunaiya
Wadi Hashesin
SAFI TRANSMISSION LINE 11 KV
FRESH WATER SUPPLY TO PROCESS PLANT SITE
SAFI PUMP STATION
SAFI WELLFIELD
Wadi Hasa
SAFI
LISAN GULF
Contours in this area are extrapolated from 1977 site survey
35° 30 Longitude
35° 30' Longitude
200 000 E
195 000 E
85 000 N
80 000 N
75 000 N
70 000 N
65 000 N
60 000 N
55 000 N
50 000 N
45 000 N
MAZRA
Wadi Karak
Extent of Salt Pan in April 1985
Proposed Pipeline
NUMEIRA FAN
LISAN TRANSMISSION LINES 33 KV
Lisan intake Road
FRESH WATER SUPPLY TO CANAL OUTFALL
SALT PAN
Trial dike 2
Trial pond
Trial dikes 1, 3A, 3B & 3C
DIKE 1
DIKE 2
DIKE 3
DIKE 4
DIKE 5
DIKE 6
DIKE 7
DIKE 8
DIKE 9
DIKE 10
DIKE 11
PC1
PC2
C1
C2
C3
C4
C5
C6
WADI CROSSING
LISAN PENINSULA
BRINE INTAKE
BRINE CANAL
Cape Molineux Road
PAN UPPER LIMIT
CANAL OUTFALL
DEAD SEA
Predicted Dead Sea level in May 1989 (see note 6)
TRUCE LINE FLOOD CHANNEL
℄ Dead Sea Works dike
DEAD SEA WORKS
ALTERNATIVE EXTENSIONS
SCALE
1000 0 1000 2000 3000 4000 METRES

Figure 2

WATER DISTRIBUTION SYSTEM



(F) Fresh

(B) Brackish

——— Existing Supply System

Proposed Integration of Brackish Water System

FIGURE 3

PRELIMINARY COST ESTIMATE

This cost estimate is based on October 1990 prices.
The exchange rate has been taken as £1 sterling = 1.255JD.

Item	'000JD	Year of Construction
Stage 1 (250 m^3/h)		
Testing of TS1D and survey of Dhira area	25	1991
Borehole Construction:		
exploratory drilling in Dhira to 500m	100	1991
one borehole in Dhira to 600m	120	1992
Pumping Plant - one pump at 50m head, 250m^3/h	15	1993
Headworks		
collector tank 1100m^3 capacity	120	1993
collecting pipework	90	1993
Pipeline		
500 mm dia, 20km long	2200	1993
Storage Tank		
12000m^3 capacity	1100	1993
Total for Stage I	3770	
Stage II (700 m^3/h)		
Borehole Construction:		
two boreholes in Dhira to 600m	240	1994
Pumping Plant two pumps each at 50m head, 250m^3/	30	1994
Headworks		
collecting pipework	90	1994
Total for Stage II	360	

Stage III (1100m^3/h)

Item	'000JD	Year of Construction
Borehole Construction:		
one borehole in Dhira to 600m	120	1997
borehole to replace TSID to 650m	130	1997
Pumping plant - two pumps each at 50m head, 250m^3/h	30	1998
Headworks		
Collecting pipework	45	1998
Pipeline		
500mm dia, 20km long	2200	1998
Storage Tank		
12000 m^3 capacity	1100	1998
Total for Stage III	3625	

SUMMARY OF COSTS

		'000JD	'000 JD
Stage I	(1991)	125	
"	(1992)	120	
"	(1993)	3525	
	Total for Stage I		3770
Stage II	(1994)	360	
	Total for Stage II		360
Stage III	(1997)	250	
"	(1998)	3375	
	Total for Stage III		3625
	Total for Stage I to III		7755
	Engineering and Management Costs (Assumed at 10% of Construction Cost each year)		775
			8530

8. IMPLEMENTATION PROGRAMME

Stage I (1991 to 1993)

1991

test Borehole TSID (including full chemical analyses), local geological mapping and regional groundwater resource survey of Dhira.

selection of new well locations, well design and prepare drilling tenders, including exploratory site in southern Dhira.

preliminary design of pipeline route and modifications to the water distribution system.

1992

drill and test new boreholes to supply 250 m^3/h

detailed engineering designs and tender documents

1993

construct 500 mm pipeline suitable for 700 m^3/h and modify distribution system to provide brackish water supply by start of 1994.

construct collector tank and collecting pipework

construct storage tank at 12000m^3 capacity.

Stage II (1994)

drill, test and equip two further boreholes to increase supply to 700m^3/h

construct collecting pipework for new boreholes.

Stage III (1995 to 1998)

1995-1997

monitor abstraction of 700m^3/h from Dhira (used in conjunction with Wadi Hassa and Safi Wellfield).

by 1997 decide whether or not to increase abstraction to 1100m^3/h from Dhira.

1997

provided water available from Dhira, drill test and equip two further boreholes to increase supply to $1100m^3/h$.

1998

construct collecting pipework for new boreholes

construct second 500mm pipeline

construct second half of storage tank

9. CONCLUSIONS AND RECOMMENDATIONS

(i) Conclusions

Existing sources together with the implementation of Stage I of the brackish water supply system from Dhira could supply the total water requirement of 1.8 Mt/year of potash production in 1995 provided that the Safi wellfield can sustain prolonged abstraction without causing a decline in water quantity and quality. However, use of fresh water would compete with local irrigation and domestic demands.

The Dhira area would be a suitable source of brackish water although this needs to be confirmed by further testing.

(ii) Recommendations

It is recommended that a combined fresh and brackish water system be developed with the use of Dhira water introduced in three stages as follows:

Stage I

Investigate wellfield characteristics at Dhira, drill and develop boreholes to a capacity of 250 m^3/h and install conveyance system for brackish water from wellfield to refinery. Freshwater would continue to be required from Wadi Hudeira, Wadi Hassa and the Safi wellfield to satisfy the total estimated water demand at the refinery of $1000m^3/h$ in 1994.

Stage II

Drill and develop further boreholes to increase the Dhira wellfield capacity to $700m^3/h$. This will be a much larger contribution to the water demand at the refinery of $1125m^3/h$, which is the estimate for the years 1995 to 1997.

Stage III

Drill and develop further boreholes to increase the Dhira wellfield capacity to $1100m^3/h$ and duplicate conveyance system from wellfield to refinery. When this stage has been implemented, the whole of the estimated brackish water requirements will be satisfied by the Dhira wellfield and only 275 m^3/h will be required from the freshwater sources.

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Appendix A

Safi Wellfield Production

1982-1990

1. Borehole Data

2. Yield Drawdown Curves, New Boreholes

3. Monitoring Information

TABLE A1 SAFI WELLFIELD [OCTOBER 1990] m

Safi Wellfield	SPB1	SPB2	SPB3	SPB4	SP85	SPB6	SPB7	SPB8	BN309 B	S1	S2 B
Depth	44	39.15	33.35	31.35	30.55	52	73	52	42	45	58.6
Top of screen(s)		27	19.5 25	23.5 27.2	23.4	40	65	21 36 44	34	30	27
Screen Length(s)	4 3		3 7.2	1.8 3				3 6 4			19.5
Rest Water Level	24.5	20.2	11.4	11.2	17.15	16.35	26.75	10.4	20.4	19.3	27.51
Pump Intake	35	28.8	23.8	19	23.68	37.5	61.5	31.2	32	29.5	40.3
Cut out level	[32]	25.8	19	21.6	21.7	34.5	59.5	[28]	29.5	24	[37]
Pumping Rate m3h	75	80	90	72	80	65	75	97	80	32	100
Pumping Water Level	28.5	22.4	12.78	16.8	19.7	33.75	46.75	12.3	21.7	23.6	31.9
Available Drawdown	10.5	8.6	12.4	7.8	6.53	21.15	34.75	20.8	11.6	10.2	12.79
Remaining Drawdown *	6.5	6.4	11.02	2.2	3.98	3.75	14.75	18.9	10.3	5.9	8.4
Yield Drawdown m3/h/m	18.8	36.4	94.2	12.9	31.4	3.7	5.1	51.1	61.5	9.3	20.5

[ ] Value uncertain
* To Pump Intake
Total Pumping Capacity 845 m3/h

ARAB POTASH COMPANY
SAFI WELLFIELD
Yield Drawdown Curves New Boreholes

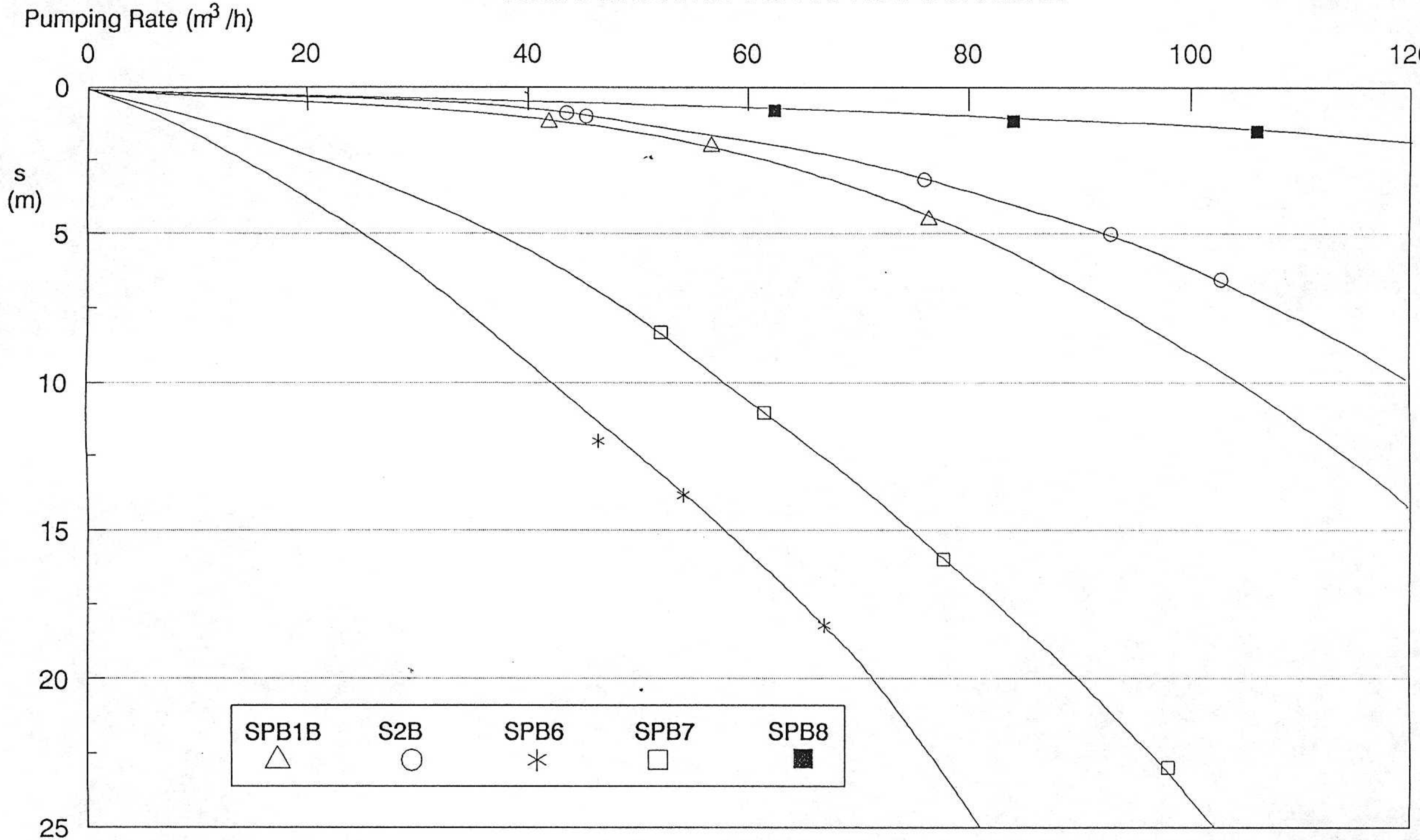

FIGURE A2

Well Hydrographs and Wellfield Abstraction

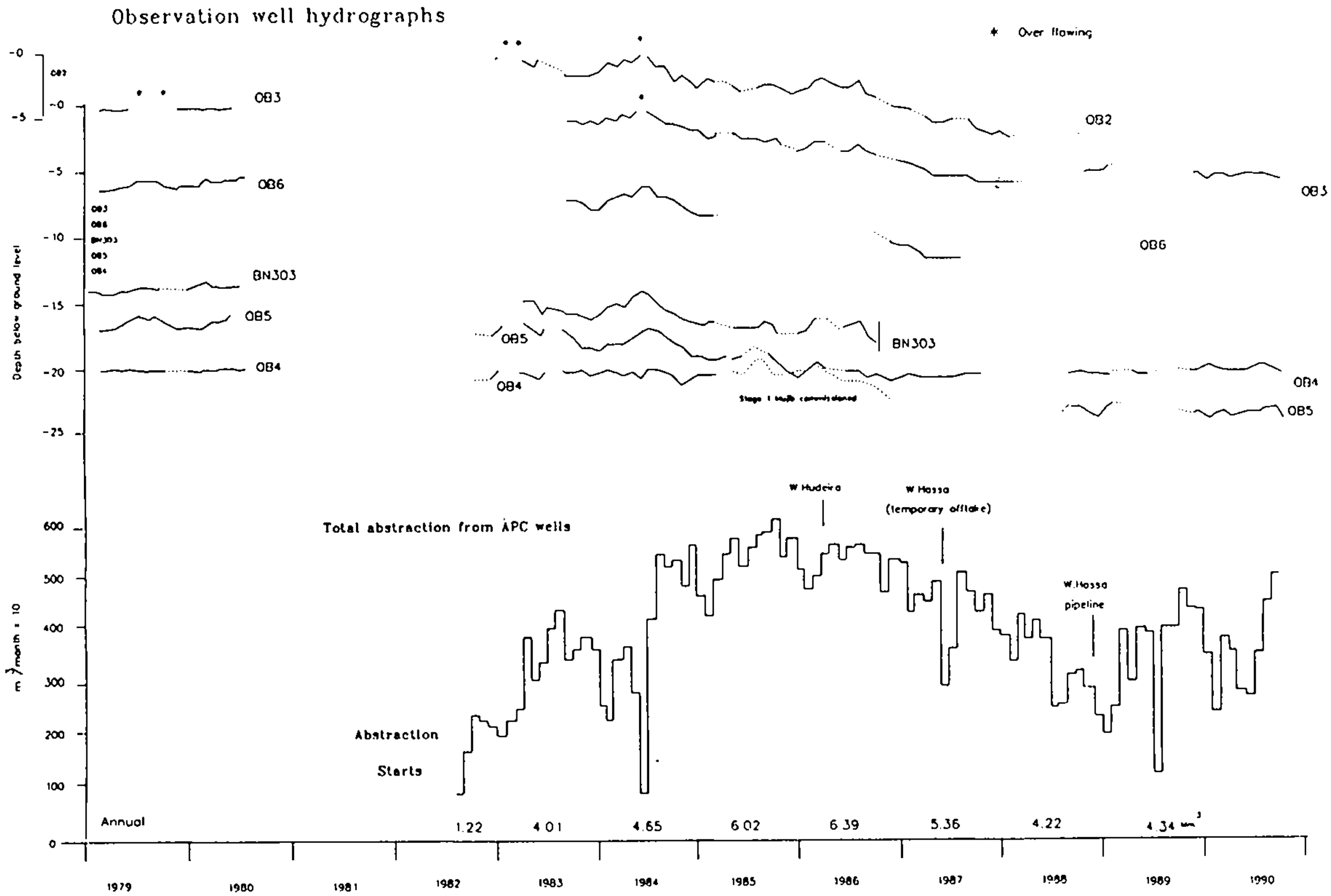

FIGURE A3