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Arab Potash Company Limited

Arab Potash Project

WATER SUPPLY

CONJUNCTIVE USE STUDY

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CJI

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TITLE: WATER SUPPLY CONJUNCTIVE USE STUDY

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EXECUTIVE SUMMARY

APC are planning to supplement existing fresh water supplies to the refinery from Wadi Hassa, Safi wellfield and Wadi Hudeira with groundwater from the Ghor Dhira area. Current refinery output of 1.4Mt/y of potash requires approximately 850m³/h of water. Plans are in hand to increase refinery capacity in stages to a maximum of 2.2Mt/y in 1999, requiring a maximum water supply of the order of 1300m³/h. This is substantially greater than that available from existing supplies.

Construction of a pipeline from the Dhira area designed to convey flows of up to 1100m³/h to the APC refinery is to start in early 1994. The pipeline is intended to carry groundwater from the Dhira wellfield.

Well drilling is currently under way at Dhira, but from the results of well testing carried out to date, it appears unlikely that a long term sustainable yield 1100m³/h could be obtained from the Dhira wellfield. In order to supply this quantity of water, the conjunctive use of surplus irrigation flows from surface water sources together with groundwater, has been examined in this study. A number of water supply scenarios have been examined under conjunctive use, including the use of the existing sources at Safi.

Conjunctive use in principle involves the maximum use of surplus irrigation flows when these are available. This allows groundwater sources to be rested and decreases total annual groundwater abstraction. At times of year when surplus flows are insufficient, groundwater sources are operated to make up the supply to the required amount. At some periods of the year, no surplus irrigation flows are available and all the supply is made up of groundwater.

Figures from the JVA have been obtained for surplus irrigation flows from Ain Maghara, Wadi Karak, Wadi Dhira and Wadi Issal. These figures indicated that flows at Ain Maghara and Wadi Karak are sufficiently large to justify development. It has been assumed that all flows surplus to JVA requirements can be readily captured for use by APC. This assumption needs to be verified by further investigation of the flows available.

In examining conjunctive use scenarios, the use of the Safi wellfield has been considered up to an annual abstraction rate of 4.5Mm³/y. This, together with an annual use of surplus flows from the Wadi Hassa scheme of 1.4Mm³/y, is the present estimate of the long term reliable yield of the Safi system, and corresponds to a constant flow of about 670m³/hr from the two sources used conjunctively.

The scenarios have chiefly been examined with respect to annual abstraction from the Dhira Wellfield. This figure is likely to be critical in determining reliable long term water availability. Data is not currently available to estimate the reliable yield of the Dhira Wellfield but scenarios with lower annual abstraction rates are more likely to provide reliable long term supplies.

Some of the main scenarios examined are summarised as follows:

(i) The wells presently under construction at Dhira will have an installed capacity of 700m³/h. To provide a constant supply of 700m³/h from these wells alone would result in annual abstraction of 6.1Mm³/y. However, under conjunctive use of the wells along with the Ain Maghara and Wadi Karak sources, annual abstraction from the wellfield could be reduced to 2.4 Mm³/y while still providing a constant supply of 700m³/h.

(ii) To provide a constant supply of 1100 m^3/h from the Dhira wellfield would result in annual abstraction of 9.6Mm^3/y. This figure is unlikely to be sustainable and would result in excessive drawdowns and high pumping costs as the water levels in the aquifer decline. Under conjunctive use of the wells along with the Ain Maghara and Wadi Karak sources, annual abstraction from the wellfield could be reduced to 5.3Mm^3/y while still providing a constant supply of 1100 m^3/h. In both cases, the installation of two additional wells at Dhira would be needed.

(iii) The conjunctive use of the Dhira wellfield, Ain Maghara and Wadi Karak supplies has been considered, together with the use of the Safi wellfield operating conjunctively with the Wadi Hassa scheme. This can give a total constant supply of 1300m^3/h with annual abstraction of 2.0Mm^3/y from the Dhira wellfield. No additional wells would need to be installed at Dhira.

In order to convey the surplus irrigation flows from Ain Maghara and Wadi Karak into the APC water supply system, civil works involving pipelines, filtration units, tanks and a pumping station would be required. The supplies would be fed into the closest points on the Dhira pipeline shortly to be constructed. The estimated cost of these works are as follows:

supply from Ain Maghara (max 800m^3/h)	- JD 785 000
supply from Wadi Karak (max 300m^3/h)	- JD 600 000

The study has concluded that conjunctive use of groundwater and surplus irrigation flows could have a considerable benefit in maximising the amount of water supply available to APC and assist in limiting the annual abstraction of groundwater to sustainable levels.

Before proposals are taken any further, it is recommended that the availability of the surplus flows be investigated in cooperation with the JVA to confirm the figures used in this report. Permission of the JVA will, of course, be required in order to develop the supplies.

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- A.2 (a-d) Estimates of surplus flow from each northern source.
- A.3 Summary of surplus flows for various combinations of northern wadis.
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1. INTRODUCTION

1.1 Scope and Objectives

This report presents the results of a study into the feasibility of extending the conjunctive use of surface water from surplus irrigation flows together with water from groundwater sources to meet future demands of the Arab Potash Company (APC).

The objectives of the study are as follows:

(a) to estimate the availability of surplus irrigation flows

(b) to prepare a strategy for combining the use of surplus irrigation flows and groundwater abstraction to meet APC water demands

(c) to identify in outline the engineering measures required to utilize surplus irrigation supplies, along with preliminary cost estimates.

The study has been carried out as a desk study in the UK, using data already available to GIBB and IH.

The use of surplus irrigation flows by APC may involve wider water resources issues, including the potential impact on resources downstream, such as changes in the amount of recharge to the alluvial aquifers. Whilst such issues are discussed where possible, they are considered beyond the scope of this study.

1.2 Background

The process water requirements of the APC refinery are presently met from Ghor Safi to the south of the refinery by the conjunctive use of surplus flows from the Wadi Hassa and abstraction from the Safi wellfield. The water requirements are expected to increase to 1100 m^3/h from mid-1994 following the expansion of the refinery. To meet this increased demand, a new wellfield with an initial total capacity of about 700 m^3/h is being constructed at Dhira some 25 km north of the refinery to abstract groundwater from the deep Kurnub sandstone aquifer. A pipeline designed to carry 1100 m^3/h will connect the wellfield to the refinery. Initial development of the Dhira wellfield to 700m^3/h was proposed in the GIBB/IH Design Report of July 1991. Subsequent to that report, APC decided that the pipeline to the wellfield was to be designed to carry 1100m^3/h; this flow quantity together with the flow from Safi/Wadi Hassa would supply the refinery at potash production rates of well over 2.2Mt/y.

From the results of well testing carried out at Dhira to date, it appears unlikely that a long term sustainable yield of 1100m^3/hr could be obtained from the Dhira wellfield alone. In order to supply this quantity of water, it has been proposed that conjunctive use of surplus irrigation flows from surface water and groundwater supplies be considered.

The surface water sources under consideration are operated by the Jordan Valley Authority (JVA) and their agreement will be necessary for the implementation of any scheme to use flows surplus to their requirements.

The construction of the new northern pipeline presents the opportunity to use surplus flows from several wadis in the Dhira area in conjunction with the Dhira wellfield together with supplies from Safi to meet future APC water demands. Preliminary estimates of the surplus flows available indicated that these could be sufficient to meet APC water demands during the non-irrigation season and reduce the demand on the Dhira aquifer during the irrigation season. By integrating both the northern and southern sources it should also be possible to meet the process water requirements in the longer term with greater security and lower operating costs without competing with irrigation supplies. Nonetheless, there must still be sufficient pumping capacity at the Dhira and/or Safi wellfield to meet the full water demands of the refinery solely by groundwater abstraction during the period of peak irrigation demands when no surplus flows are available.

The different sources that could become available to APC could be used in many different combinations. As the present scheme already in operation at Safi represents a significant investment that could still continue to contribute to future APC supplies, the various options that have been examined to meet the process water demands all involve the use of Safi as well as Dhira.

To distinguish the various option, conjunctive use in this report refers to a scheme that combines surplus surface water flows with groundwater abstraction in either the north (Dhira) or south (Safi) whilst the term integrated use refers to a scheme that provides supplies from both the northern and southern sources together.

The locations of the various sources discussed in this report are shown in Figure 1.1.

1.3 Concept of Surplus Irrigation Flows

The wadi baseflows in the south-eastern ghors are derived predominantly from springs that occur in the upper part of each catchment in the highlands to the east. Historically, these supplies have been used for irrigation with traditional irrigation techniques. Undiverted flows, flood flows and irrigation returns from fields and unlined canals provided recharge to the alluvial fan aquifers that was lost subsequently at the fan edges by springs, seepages and groundwater evaporation. The Mujib and Southern Ghors Irrigation Scheme, which was implemented during the 1980's, has improved the efficiency of baseflow diversion and introduced modern irrigation methods to expand the area under cultivation along the southern ghors.

The area that can be cultivated from each source of baseflow is determined by the rate of flow available at the peak crop water demand. As the baseflows (and major springs, such as Ain Maghara) are essentially constant throughout the year and from year to year,the baseflow of each wadi exceeds the irrigation requirements during the rest of the year. This water is surplus to the irrigation requirements and could be used for other purposes. For example, during the 1980's surplus flows were used to reclaim land in the fan-edge areas.

The surplus flows after meeting irrigation demands can be made available by direct diversion or indirectly by pumped abstraction and/or drainage from the aquifers recharged from the surplus flows. Either method reduces the amount of water lost at the fan-edge enabling a more effective management of the total water resources without affecting irrigation supplies.

Potable supplies are obtained from the alluvial fan aquifers. Direct diversion of the surplus flows reduces recharge to these aquifers and would cause groundwater levels to decline. This may result in a deterioration of groundwater quality and increase pumping costs. The potable supplies need to be protected and this should be taken into account in assessing the impact of improved use of the wadi baseflows. Hence surplus flows should not be considered as an additional resource since the groundwater supplies from the alluvial aquifers depend largely on the recharge from baseflow. There is also the need to treat each wadi catchment as a single water resources unit for water management purposes whereby the increased use of water at any point in the system will have an impact on the availability of water to users downstream.

The diversion of baseflows for irrigation takes place usually where the wadi emerges from the main escarpment. The diversion can vary in a particular month from year to year depending on cropping patterns, winter temperatures etc and can also be interrupted when silt-laden flood flows occur. The measures required to capture the surplus flows are outlined in Chapter 4.

1.4 Availability of Information

Baseflow and flood flow data up to 1977 for the wadis draining the eastern escarpment between Wadi Mujib to the north of Dhira and Wadi Khanzeira to the south of Safi were assembled and analysed in some detail as part of the Mujib and Southern Ghors Irrigation Project [Binnies, 1979]. Whilst some records date from the 1930's, they do not form a continuous sequence and comprise mainly irregular point measurements. Fortunately, the baseflows show only small natural variations throughout the year and from year to year, although monthly values based on spot measurements must invariably contain some uncertainty. Estimates of the 50% and 80% reliable baseflows prepared by the MSGIP for Ain Maghara and wadis Karak, Dhira, Issal, Hudeira and Hassa are given in Table 1.1. The design of the irrigation scheme is based on the 80% reliable baseflow estimates.

The Jordan Valley Authority (JVA) records the flow diverted each month to each major irrigation unit served by each source of supply. Records are available for 1990 to 1992 for each area of Ghor Safi served by the Wadi Hassa (irrigation areas 40, 41 and 42) but for 1992 only for Ain Maghara, Wadi Karak and Wadi Dhira. However, the 1991 record for Ghor Safi was not supplied by JVA. The records for the northern sources are combined for the irrigation units served by each of these sources as follows:

- area served by Maghara and Karak (areas 45 and 46)
- area served by Maghara only (area 47)
- area served by Karak and Dhira (area 48).

The flow diverted for irrigation from Wadi Issal is not recorded. This flow is supplemented by local borehole abstraction.

1.5 APC Water Requirements

Table 1.2 gives the annual water use by APC since potash production began in 1982. Monthly water use is shown in Figure 1.2. The Safi wellfield, which was commissioned in January 1982, presently contributes about 80% of the total supply. A conjunctive use scheme has been operated by APC since June 1987 when surplus irrigation water was obtained from the Wadi Hassa to supplement the supply from the Safi wellfield. Additional wells were drilled at Safi during 1993 to ensure sufficient water production until the Dhira wellfield is commissioned.

The history of water use and potash production has been used by APC to estimate their future process water demands, which are given in Table 1.4 for 1993-2000. The process water demand is expected to increase from 700 m^3/h to 1300 m^3/h over this period to meet the planned production of potash.

The process water requirements are almost constant throughout the year, although with slightly higher requirements during the summer months and somewhat lower requirements during the winter. The process plant is operated usually for about 8000 h/yr. The water quality should be preferably of a freshwater composition, although tests indicate that water containing up to 20000 mg/l TDS could be utilised.

Since April 1986, the freshwater requirements of the refinery have been met from the Wadi Hudeira (100m^3/h) supplemented by the sources at Safi. It is anticipated that these arrangements will continue in future. The APC Township demands are met separately by a wellfield at Ghor Mazra supplemented by surplus flows from the JVA irrigation system at Haditha-Mazra.

Table 1.1

Estimated Monthly Baseflows (m3/h)

	Maghara	Karak	Dhira	Issal	Hudeira	Hassa
50% reliable (median)						
Jan	1314	673	187	126	158	3240
Feb	1260	641	176	108	126	3240
Mar	1188	641	176	108	126	3096
Apr	1152	612	169	108	126	2970
May	1152	612	169	108	126	2916
Jun	1152	576	162	108	108	2700
Jul	1152	540	151	108	108	2700
Aug	1080	540	151	108	108	2700
Sep	1152	540	151	108	108	2628
Oct	1206	612	169	119	108	2844
Nov	1134	641	176	119	115	3060
Dec	1188	641	176	126	137	3096
Year	1188	612	169	112	122	2916
80% reliable						
Jan	1080	540	176	112	115	2970
Feb	1080	504	169	104	108	2844
Mar	1080	504	169	104	108	2844
Apr	1080	486	162	101	104	2700
May	1080	486	162	101	104	2700
Jun	1080	450	155	97	101	2556
Jul	1080	432	144	90	94	2430
Aug	1080	432	144	90	94	2430
Sep	1080	432	144	90	94	2430
Oct	1080	486	162	101	104	2700
Nov	1008	504	169	104	108	2844
Dec	1008	504	169	104	108	2844

Source: Binnie, Jan 1979

Notes: Based on available flow measurements up to 1977.
Diurnal variations of +/-15% can occur.
Maghara includes residual flow of Ibn Hammad.
Hudeira used solely by APC.

Table 1.2

APC Annual Water Production in Mm3 1982-1992 (incl.)

	Safi Wellfield	Hassa	Total Safi	Wellfield % of Total Safi	Hassa % of Total Safi	Hudeira	Total
1982	1.22		1.22	100.0			1.22
1983	4.01		4.01	100.0			4.01
1984	4.65		4.65	100.0			4.65
1985	6.49		6.49	100.0			6.49
1986	6.39		6.39	100.0		0.38	6.77
1987	5.36	0.65	6.02	89.2	10.8	0.62	6.64
1988	4.22	1.71	5.93	71.2	28.8	0.58	6.51
1989	4.34	1.48	5.82	74.6	25.4	0.70	6.52
1990	4.64	1.45	6.09	76.2	23.8	0.91	7.00
1991	5.11	1.60	6.71	76.1	23.9	0.83	7.55
1992	5.77	1.08	6.86	84.2	15.8	0.71	7.57
Total	52.20	7.97	60.17			4.74	64.92
Average				78.6	21.4		

Table 1.3

APC Process Water Requirements, 1993-2000

	Planned Potash Production Mt/y	Annual Mm3/y	Rate m3/h
1993	1.4	7.5	855
1994	1.6	8.5	970
1995	1.8	9.5	1100
1996	1.8	9.5	1100
1997	2.0	10.5	1200
1998	2.0	10.5	1200
1999	2.2	11.5	1300
2000	2.2	11.5	1300

Source: APC

Note: Rate based on continuous supply.

Arab Potash Project
Water Supply Source Locations

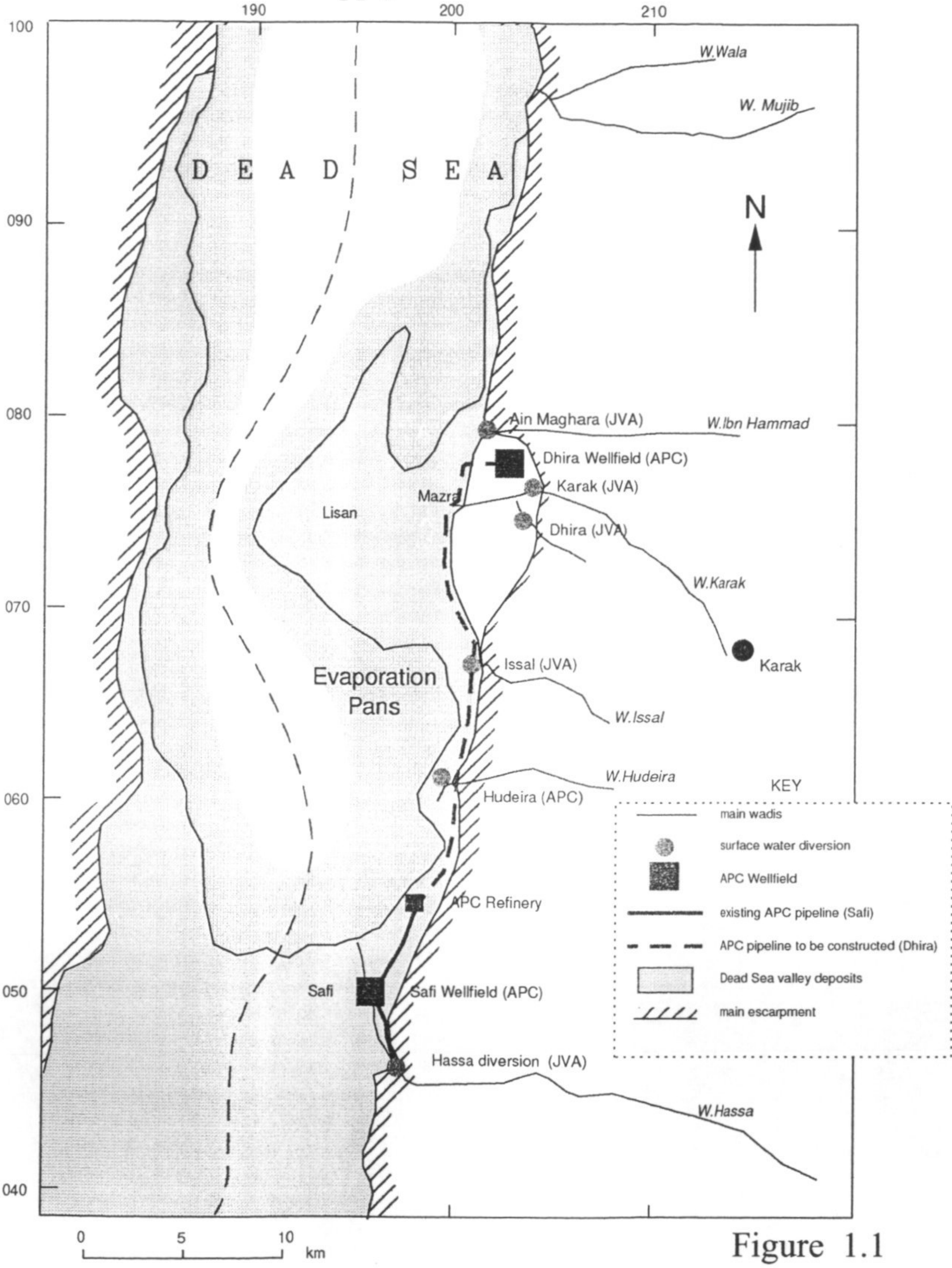


Figure 1.1

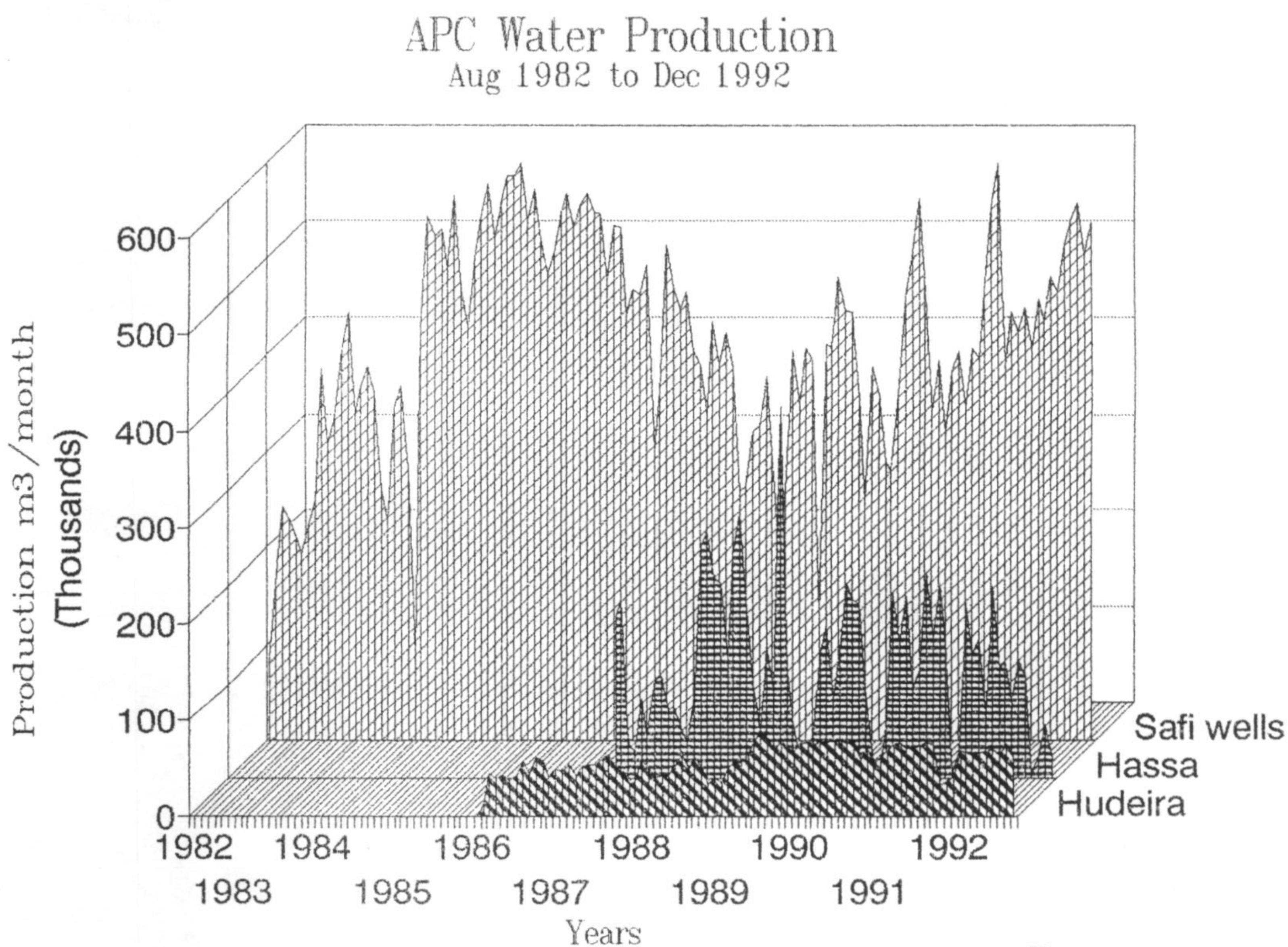

APC Water Production
Aug 1982 to Dec 1992
Production m3/month
(Thousands)
0
100
200
300
400
500
600
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
Years
Safi wells
Hassa
Hudeira

Figure 1.2

2. AVAILABILITY OF SURPLUS IRRIGATION FLOWS

2.1 General

Estimates of surplus flow on a monthly and annual basis have been made for the following wadis:

(a) Northern sources - Ain Maghara, Wadi Karak, Wadi Dhira and Wadi Issal.
(b) Southern sources - Wadi Hassa.

Flow from Wadi Hudeira (Numeira), none of which is used for irrigation, will be diverted into a separate system to meet the freshwater requirements in the process plant area. These freshwater requirements (for potable use and boiler feed) will need to be supplemented by supplies from Safi in the future, but as the quantities required are relatively small, this demand on the Safi wellfield has not been considered further in this study. Other small wadis (wadis Feifa, Umruq and Khanzeira) south of Ghor Safi are also used for local irrigation supplies but are not considered in this study, nor is the Wadi Mujib to the north of Dhira. Plans have been under consideration for many years to bring a supply from Wadi Mujib to the Safi area and beyond, primarily for irrigation use. It is possible that APC could receive a supply from this project in the future, but until then APC must rely on local supplies.

The estimates of surplus flow have been derived from estimates of the 80% reliable total flow and available JVA records of irrigation diversion.

JVA is the authority in charge of irrigation water sources and hence their agreement and cooperation will be required for the development and use of any of these sources by APC.

2.2 Northern Sources

The flow record of Ain Maghara includes the flow of the spring as well as any residual flow of the Wadi Ibn Hammad that reaches Ain Maghara. A similar flow to that of Ain Maghara is recorded on the Wadi Ibn Hammad upstream of the main escarpment which disappears into the wadi bed downstream. However, it is thought that this flow re-emerges at Ain Maghara and therefore, on the basis of available information, the baseflow of the Wadi Ibn Hammad above the escarpment does not represent a separate untapped source of baseflow but forms part of the flow at Ain Maghara. The relatively minor pumped abstraction for irrigation on Dhira that began recently from the Wadi Ibn Hammad upstream of Ain Maghara may influence the total availability of flow at Ain Maghara.

Flows records are available of the Wadi Karak, measured at the main escarpment. These flows show diurnal and seasonal variations of perhaps +/- 15% due to upstream diversions and evaporation losses. The flow measurements of each wadi may also include occasional residual flood flows during the winter months.

Table 2.1 gives the monthly and annual irrigation diversion in 1992 for each irrigated area served by the northern sources, together with the monthly percentage of the total amount diverted during the year. In the absence of data for other years, it is assumed that the flow diverted during 1992 is reasonably representative, which in percentage terms is broadly similar to the Hassa irrigation diversion in 1992 (see Table A.5).

As the data on diverted flows are given by irrigated area rather than separately for each source, it has been necessary to derive a general monthly pattern of irrigation diversion that could be used to estimate the surplus flow available from each individual source and also for the Wadi Issal for which no diversion records are available. The combined monthly total flow of Ain Maghara, Wadi Karak and Wadi Dhira (at both the 50% and 80% reliability) was compared to the combined monthly flow diverted for irrigation in 1992 to derive the percentage (to the nearest 5%) of flow diverted for irrigation (see Table A.1). The values derived for the 80% reliable flow were adopted to provide a more conservative estimate of the surplus flow and applied to the 80% reliable flow estimates of each northern wadi to estimate the surplus flow of each wadi, as detailed in Annex A, Tables A.2 a-d..

The total annual surplus flow from the four northern sources is estimated to be about 5.5 Mm^3/y (see Table 2.3), or about one-third of the total flow of these sources. This is based on a comparison of actual year data (1992) with the average flow data. Ain Maghara accounts for about 60% of the total surplus flow from the northern sources. The total monthly surplus from the four northern sources varies from less than 100 m^3/h in September/October (maximum irrigation demand) to over 1500 m^3/h in July/August (minimum irrigation demand). It is anticipated that the annual surplus may vary from 25-40% depending on the particular conditions governing the irrigation demand in any one year.

Estimates of the monthly surplus flow for various combinations of the four sources available in the north are included in Annex A, Table A.3.

2.3 Wadi Hassa

APC have utilised surplus flows from the Wadi Hassa since June 1987 to supplement abstraction from the Safi wellfield. The overflow at the JVA settling tank is passed through a sand filter and conveyed in a pipeline of 700m^3/h capacity to the Safi pumping station.

Table 2.2 gives the monthly flow of the Wadi Hassa diverted for irrigation by JVA in 1990 and 1992. It is assumed that the APC diversion is included in these records. The JVA flow diversion figures were compared to the total flow of the Hassa at the 50% and 80% reliable flows (see Table A.4) to estimate the likely surplus flow. In some months the diverted flows exceed the total flow, which is probably due to comparing actual year data with average total flow or perhaps underestimates of the total flow (e.g. residual flood flow). The percent monthly diversion of total flow in 1992 is broadly similar to that for the northern sources. (Table A.5). Slight differences can be expected because of different cropping patterns, crop planting dates and estimates of total flow in each area.

The total surplus flow of the Wadi Hassa based on the 80% reliable flow estimates was 4 Mm^3/y in 1990 (including 1.45 Mm^3/y supplied to APC) and 8.8 M^3/y in 1992 (including 1.08 Mm^3/y supplied to APC), which represent 17% and 38%, respectively, of the average total flow. The monthly surplus varies from about 200 m^3/h in September/October to as much as 2000 m^3/h in July/August.

The historical use of surplus flow from the Wadi Hassa by APC is given in Table A.6. The average annual surplus flow used by APC was about 1.4 Mm^3/y, or about 6% of the annual flow of the Hassa. The monthly rate ranges from about 30 m^3/h in September and October to 300 m^3/h in July (based on continuous diversion).

The estimates of the available surplus flow from the Hassa considerably exceed the surplus flow diverted by APC since 1987 and also the capacity of the APC pipeline from the Hassa in several months. The ability to command this surplus may be constrained by using overflows at the collecting tank (which would be by-passed by any undiverted flow allowed to continue down the wadi channel), the present capacity of the APC Hassa pipeline and Safi pumping station (950 m^3/h) and during days when floods occur.

Whilst there is scope for increasing the use of Hassa surplus flows by APC, it may now be impractical to alter the offtake position, sand filter etc to make full use of the surplus flows potentially available. Increased use of the surplus flows would also decrease the amount of recharge to the Safi aquifer and pose a risk to abstraction. Consequently, for the purposes of this study, we have adopted the more conservative average historical use by APC of Hassa surplus flows (see Annex A Table A.6 or Table 2.3).

2.4 Total Surplus Flow

Table 2.3 summarises the monthly availability of surplus flows for the northern sources together with the average historical use of the Wadi Hassa surplus by APC. The total annual availability is 12.4 Mm^3/y. The monthly total surplus varies from effectively nil in September to 3400 m^3/h in July, but generally ranges from about 700 m^3/h to 1400 m^3/h. Together, Wadi Dhira and Wadi Issal have surplus flows of generally less than 100 m^3/h in most months, totalling 0.78 Mm^3/y.

2.5 Potential Constraints on the Use of Surplus Flows

There are surplus flows that could potentially be used by APC to meet future water requirements in conjunction with groundwater abstraction. The amount of surplus flow available or that can be commanded by appropriate engineering works would determine the amount of groundwater that would need to be abstracted. During certain months in the irrigation season, all of the supply would have to be met by groundwater abstraction.

Various considerations that might influence the actual contribution from surplus flows are discussed briefly below.

The total flows may be less than those estimated by the Mujib and Southern Ghors Irrigation Scheme. The 80% reliable total flow estimates have been used to provide more conservative values of surplus flow. The design of the irrigation scheme is also based on the 80% reliable flow estimates. These estimates, however, are based on rather infrequent point flow measurements and may contain measurement errors. The annual flows are considered to be reasonably accurate but there may be diurnal and monthly variations that are not represented fully by the available flow measurements.

The efficiency of the JVA diversion structures and points of offtake may not command all of the available baseflow. As it is necessary for APC to use overflows from the JVA collecting tanks to avoid competing with the irrigation supplies, the amount of surplus flow that can be commanded by APC depends upon the amount of flow diverted by JVA.

In the case of the Wadi Hassa, any flow not captured by JVA and APC recharges the Safi aquifer and could be abstracted by the Safi wellfield.

The availability of surplus flows in any one month can vary from year to year due to different planting times, cropping patterns and crop types. However, increased demand in some months (e.g. higher than usual demand from the northern sources in August 1992) may be offset by reduced demands in other months. Wetter than average years or cooler winter months also reduce demands (e.g. January 1992 on the Wadi Hassa). It is likely that the irrigated area will not be fully cultivated each year thereby reducing the total demand for irrigation supplies.

Only limited data is available on the flows diverted for irrigation as the irrigation scheme has only been fully operational for a few years. The 'typical' pattern of irrigation use is still uncertain, although JVA consider that the data for 1992 is reasonably representative. The actual amount of water diverted for irrigation has been compared to the average year estimates of total flow to derive the amount of surplus flow potentially available. Consequently, the actual amount of surplus flow may differ from the estimated surplus flow from month to month.

Any increase in water use in the headwater region could affect both the irrigation scheme and the surplus flows available to APC. At present, there does not appear to be controls on upstream use, whether directly on the use of wadi flows or indirectly on abstraction from the aquifers supplying the baseflow. The proposed Tannour dam is situated upstream of the major springs that provide the baseflow of the Wadi Hassa and consequently would not have a direct effect on the quantity of baseflow. Any long term trends or variation in the amount of baseflow have not been identified, for example due to prolonged droughts.

The use of surplus flows could also have an impact on users downstream. This would apply mainly to the Wadi Karak which recharges Ghor Mazra from which local drinking water supplies and the supply to the APC Township are obtained. However, the diversion of flows for irrigation would have a much greater impact than APC use of the surplus flows. In the longer term flood flows will become the main source of recharge below the escarpment if baseflows are diverted for other purposes. Use of the surplus flows from Ain Maghara would have little impact on Ghor Haditha as little or no abstraction is thought to take place from this small alluvial fan, although there are date groves at the fan edge which may make use of these surplus flows. APC currently use surplus flows from the irrigation system at Ghor Mazra to supplement their wellfield supplies to the APC Township.

APC wellfield abstraction would be used to supplement the surplus flows to maintain a constant supply to the refinery. Hence, if the amount of surplus flow available or that can be commanded proves to be less than that estimated, then the difference would be met by additional groundwater abstraction up to the limit of the sustainable yield of the aquifers. As yet, the sustainable yield of the deep aquifer system at Dhira still has to be determined since there is only limited information on this complex aquifer and how it will respond to abstraction. The sustainable yield of the Safi aquifer can be affected by changes in the recharge from baseflows and is also partly dependent on irregular recharge from variable flood flows.

Table 2.1

JVA Diversion of Ain Maghara, Wadi Karak and Wadi Dhira in 1992

	Karak & Dhira m3	Maghara m3	Karak & Maghara m3	Karak & Maghara m3	Total m3	% annual diversion
Irrig. area no.	48	47	46	45		
Jan	125020	133120	256520	246740	761400	7.6
Feb	153840	156780	294420	284100	889140	8.9
Mar	129910	177816	280590	277682	865998	8.7
Apr	189755	190860	313080	380900	1074595	10.7
May	179460	177072	265126	398168	1019826	10.2
Jun	145890	148464	216139	307635	818128	8.2
Jul	54453	10920	32626	44458	142457	1.4
Aug	40641	12953	56587	34729	144910	1.4
Sep	328261	141583	401841	491964	1363649	13.6
Oct	225662	152454	350817	445906	1174839	11.7
Nov	189834	135401	279185	361896	966316	9.7
Dec	133808	108461	211185	330303	783757	7.8
Total m3	1896534	1545884	2958116	3604481	10005015	

Source: JVA

Table 2.2

JVA Irrigation Diversion of Wadi Hassa in 1990 and 1992.

	Total Flow m3	Diverted Flow in m3 1990	1991	1992
Jan	2209680	2902081		1527673
Feb	1911168	1921136		1440351
Mar	2115936	1539508		1553823
Apr	1944000	1637459		1241034
May	2008800	1302171		764176
Jun	1840320	1003971		572125
Jul	1807920	591658		173284
Aug	1807920	747820		354861
Sep	1749600	1897741		1494843
Oct	2008800	2187862		2120445
Nov	2047680	1932220		1878781
Dec	2115936	1844455		1599560
Total	23567760	19508082		14720956
% diverted		82.8		62.5

Notes: Source JVA

Data not supplied for 1991.

Total flow based on 80% reliable flow [Binnies, 1979]

Table 2.3

Summary of Monthly Surplus Baseflows (m3/h).

Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
Maghara	486	270	378	162	216	378	972	972	0	50	202	353	3.27
Karak	243	126	176	73	97	158	389	389	0	24	101	176	1.44
Dhira	79	42	59	24	32	54	130	130	0	8	34	59	0.48
Issal	50	26	36	15	20	34	81	81	0	5	21	36	0.30
Total North	858	464	649	274	365	624	1572	1572	0	87	358	624	5.48
Hassa	225	210	155	140	210	180	300	160	50	55	110	150	1.42
All surplus flows	1941	1138	1453	688	940	1428	3444	3304	50	229	826	1398	12.37

Notes: Based on 80% reliable total flow and JVA diversion records.
Details given in Annex A.

3. AVAILABILITY OF GROUNDWATER SUPPLIES

3.1 General

Groundwater is presently abstracted by APC from the alluvial fan aquifer at Ghor Safi which provides the bulk of the fresh water requirements of the refinery. Further new wells were constructed at Ghor Safi during 1993 to provide sufficient pumping capacity to meet demands until the new wellfield presently under construction at Dhira is commissioned.

Groundwater flow models have been constructed for the Safi aquifer and the northern Dhira area. These have been used to provide initial predictions of the aquifer response to selected water demand scenarios. In the case of the Dhira aquifer model, these predictions are of a very preliminary nature as no operational data are yet available. Full reports on the model studies are to be submitted separately.

3.2 Dhira Wellfield

The Dhira wellfield comprises an existing flowing brackish well (TS1D) and three new wells (TA1, TA2 and TA6). Flow tests on TS1D and TA1 suggest that artesian flows will decline significantly during the first few years of production. Brackish water is present at TS1D but water of good quality is found at TA1 and TA2. Well TA6 is still under construction.

The new wells will have a total fitted pumping capacity of about 700 m^3/h. However, the aquifer system in the Dhira area is extremely complicated and possible hydraulic constraints (such as saline intrusion and boundary effects), as well as, uncertainties in the amount of groundwater inflow from above the main escarpment that can be commanded in the long-term, suggest that a conservative approach to abstraction in this area should be adopted until monitoring data become available from the first few years of production.

For current purposes it would be prudent to assume that the Dhira wellfield would be operated up to a maximum rate of 700 m^3/h to supplement surplus flows from the northern surface water sources. The operating regimes for different combinations of sources to meet demands of 700 and 1100 m^3/h and the model predicted response of the deep aquifer to selected rates of annual abstraction are described in Chapter 5.

3.3 Safi Wellfield

The average annual abstraction from the Safi wellfield over the period 1983-1993 was about 5 Mm^3/y. The present maximum output from the Safi wellfield (or the combined surplus flow and wellfield abstraction) is limited by the existing capacity of the Safi Pumping Station to about 950 m^3/h.

With the introduction of surplus flows from the Wadi Hassa in 1987, abstraction from the wellfield was reduced by 20-25%. However, the 'net abstraction' from the aquifer is the combined total of the wellfield abstraction and surplus flow, since the use of the surplus flow represents a loss of recharge to the aquifer rather than an additional resource.

Water levels showed a regional decline of about 7m between 1982 and 1992. However, water levels have declined by only about 1m in the period from 1987-1992 compared to 6m in the period 1982-1987. The model studies suggest that the decline in water level up to 1987 was mainly associated with changes taking place during the implementation of the Mujib and Southern Ghors Irrigation Scheme as the aquifer adjusted to a new equilibrium.

The Ghor Safi aquifer also provides municipal supplies for Ramleh (new Safi) and water supplies for the new tomato processing factory. The annual requirements were estimated to be 0.28 and 0.12 Mm^3/y, respectively in 1990. This is expected to increase to a total of about 0.5 Mm^3/y by 2000 [SAGP/IH, 1989].

The average annual 'net abstraction' from the Safi aquifer over the period 1988-1992 was as follows (in Mm^3/y):

APC wellfield	4.82
APC use of surplus Hassa flows	1.46
Other abstraction	0.4
	6.68

This rate of abstraction is still causing a slow decline in water levels, partly because of the gradual increase in APC abstraction (see Figure 2). The preliminary results of the model studies suggest that the present safe yield of the Safi aquifer is about 4.5 Mm^3/y with about 1.5Mm^3/y diversion of the Hassa by APC. However, the present recharge situation is uncertain because of the changes that have taken place in recharge and in discharge from the fan-edge due to the irrigation scheme. Recharge also occurs occasionally from flood flows, which occur on average for a total of about 12 days per year at Safi between October and April [Binnies, 1979]. These are irregular in amount and occurrence. Low rainfall during the 1980's also produced limited flood flow recharge and floodflows may be further affected by the proposed construction of the Tannour Dam. However, the safe yield estimate does not take flood flow recharge into account due to its unpredictability.

Groundwater from the Safi aquifer is of good quality and has not shown any significant deterioration as a result of the APC abstraction. However, saline water occurs in the fan-edge area and has been proven at depths of about 100m in the upper part of the fan. Water quality changes cannot be examined with the groundwater model but it would be necessary to ensure that the 'net total abstraction' does not adversely affect the quality of the potable water supplies.

Hence, the annual APC abstraction should not exceed about 4.5 Mm^3/y with the continued use of surplus flows the present rate of about 1.5 Mm^3/y. Abstraction should be reduced in direct proportion to any increase in the diversion of surplus flows so that the 'net abstraction' does not exceed about 6 Mm^3/y.

4. ENGINEERING MEASURES

4.1 General

In this section of the report, the feasibility of developing the various potential sources of surplus irrigation flows are discussed. Outline designs of the pipelines and other works required to convey these flows into the APC water supply system are developed, and preliminary cost estimates given.

4.2 Existing Scheme at Wadi Hassa

APC already operate a scheme that utilises irrigation flows surplus to JVA requirements from the Wadi Hassa. The JVA system at Wadi Hassa comprises a weir including an intake in the wadi bed from where water gravitates to a settling basin, where sand and silt is settled out. Water then passes on into the JVA irrigation system. Following agreement with the JVA, APC constructed an overflow chamber at the settling basin. From this chamber, a pipeline leads to a set of pressure sand filters where fine material is filtered out. After the sand filters, the pipeline continues to the APC pumping station at Safi where it discharges into a tank, mixing with water abstracted from the Safi wellfield. The water is then pumped on to the APC refinery.

With the above system, the JVA demand for irrigation supplies is satisfied first. If there is a surplus, the water level in the settling basin backs up and overflows into the APC system. If APC do not require some or all of the surplus, then the surplus flow overflows back to the Wadi Hassa. One advantage of this system is that it is readily apparent to the users of the irrigation system that only surplus water is taken by APC.

4.3 Potential Sources in the Northern Areas

The potential sources of surplus irrigation water in the Northern areas are at the JVA intake works at Ain Maghara, Wadi Karak and Wadi Dhira. Wadi Issal is also a potential source but it is not known whether the JVA have any intake works there. The quantities available from these sources are discussed in Section 2 of this report.

For Ain Maghara, Wadi Karak and Wadi Dhira, figures have been obtained from the JVA for flow diverted into the irrigation system but these figures do not give flows diverted at each source individually, only for the three sources combined. It appears from these figures that the JVA intake works have sufficient capacity to divert the flows given in Section 2. Therefore, it is assumed that no additional works would be needed in the wadi beds to capture and divert further wadi flow, and that surplus flows can be taken from the JVA systems downstream of the existing JVA intake works.

The JVA figures for flow diverted did not include Wadi Issal, however, and it has not been possible to establish if there are any existing diversion works in this wadi. There are, however, only relatively small flows available in Wadi Issal.

Surplus flows are summarised in Table 4.1 along with the proposed maximum utilisation of these surpluses.

Table 4.1

SURPLUS FLOWS AVAILABLE AND PROPOSED MAXIMUM UTILISATION (DHIRA AREA)

SOURCE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Availability of surplus baseflows:												
Maghara	486	270	378	162	216	378	972	972	0	50	202	353
Karak	243	126	176	73	97	158	389	389	0	24	101	176
Dhira	79	42	59	24	32	54	130	130	0	8	34	59
Issal	50	26	36	15	20	34	81	81	0	5	21	36
Total	858	464	649	274	365	624	1572	1572	0	87	358	624
Proposed maximum utilisation of surplus baseflows:												
Maghara	486	270	378	162	216	378	800	800	0	50	202	353
Karak	243	126	176	73	97	158	300	300	0	24	101	176
Dhira	0	0	0	0	0	0	0	0	0	0	0	0
Issal	0	0	0	0	0	0	0	0	0	0	0	0
Total	729	396	554	235	313	536	1100	1100	0	74	303	529

As can be seen from the table, Ain Maghara and Wadi Karak are the major sources and it is proposed that these be developed to provide a combined peak capacity of $1100m^3/h$. The figure of $1100m^3/h$ is the design flow for the pipeline being constructed from the Dhira wellfield to the Refinery under the Refinery Water Supply scheme and is regarded as the target supply required from the Dhira area for present consideration.

The JVA intake works at Ain Maghara and Wadi Karak have both been briefly visited and it appears that surplus flows could be taken by APC by constructing similar works to those at Wadi Hassa. The proposed works are discussed further in the following subsection.

The existing JVA intake works at Wadi Dhira have not been visited and so details are not known. The works are, however, a considerable distance (about 7km) from the proposed APC pipeline supplying the refinery. Therefore, a relatively long pipeline from Wadi Dhira would be required to convey surplus flows into the APC system. Considering the quantities of water available, the works required at Wadi Dhira are likely to be uneconomic and so development at Wadi Dhira is not recommended.

As regards Wadi Issal, it has not been possible to establish whether there is an existing

JVA intake for surface water in this wadi. The quantities of water available are relatively small, however, and in terms of water supplied it is unlikely to be economic to develop this source.

Other considerations may apply to Wadi Issal, however. Surface water presently flowing down the wadi finds it way into the APC salt pans, and this reduces their efficiency by diluting the brine. APC have stated that it would be desirable to divert any surplus flows in the wadi to reduce flow to the salt pans. The main effect on the salt pans is likely to be from flood flows, however, and diversion works would be of insufficient capacity to affect these significantly. Also, in the absence of an existing JVA intake at Wadi Issal, any APC scheme would require the construction of diversion works in the wadi. This could interfere with supplies from JVA boreholes in the area. Further study of the Issal system would be required in collaboration with the JVA before any scheme for Wadi Issal could be considered further but it appears at this stage that such a scheme is unlikely to be feasible.

4.4 Outline Schemes

Outline schemes for the supply of surplus irrigation flows are described below and shown in Figure 4.1. Schemes are proposed for Ain Maghara and Wadi Karak. No schemes for Wadi Dhira or Wadi Issal are proposed as development of these sources is not considered to be economic. The Ain Maghara and Wadi Karak schemes together would provide a peak supply of surplus irrigation flows of 1100m^3/h. However, at certain times of year there are no surplus irrigation flows available and so output would be limited to the capacity of the groundwater system. This is currently planned as 700m^3/h inferring that the difference to make up the refinery requirements has to be made up by pumping from Safi wellfield or by the installation of additional wells at Ghor Dhira.

(a) Ain Maghara

The existing JVA works at Ain Maghara consist of intake works in the bed of Wadi Ibn Hammad to collect spring flows and residual wadi base flows. A canal conveys these flows to a settling basin, and from there to a storage tank and on into the irrigation system.

It is proposed that surplus irrigation supplies up to a maximum of about 800 m^3/h be taken from the settling basin at Ain Maghara, by constructing an overflow chamber at the settling basin, with pipeline leading to the APC system. The overflow system would operate in the same way as the Wadi Hassa system described in Section 4.2.

A 450mm diameter pipeline would lead from the JVA settling basin south west towards the Mazra-Aqaba highway, then south alongside the highway to Wadi Madbaa as shown in Figure 4.1. As for the Wadi Hassa scheme, sand filtration of the water is likely to be necessary and so a set of pressure filters are proposed. These would be situated between Ain Maghara and Wadi Madbaa, depending on the availability of a site. A total of 20 sand filter units similar to those used for the Wadi Hassa system would be required, which allows for 20% standby capacity which would be required during filter backwashing. Flow would be by gravity from Ain Maghara through the sand filters and on to discharge into a storage tank provided at a site near to Wadi Madbaa.

A pumping station would then be required to pump water from the storage tank into the 700mm diameter pipeline which is to be constructed shortly from the Dhira wellfield to the refinery.

The size of storage tank proposed is 100m³, and this tank is necessary to provide a reservoir for the pumps. Pumping is necessary as the pressure in the 700mm diameter pipeline will be higher than that in the supply from Ain Maghara. The pumping station would have 4 pumps, 3 duty and 1 standby each of capacity 270m³/hr at about 57m pumping head. A typical arrangement of the pumping station and storage reservoir is shown in Figure 4.2.

The pumps would operate automatically and be controlled by level sensors in the storage tank and in the balancing tank at the Dhira wellfield. This system could be set up such that any surplus irrigation flows available from Ain Maghara are pumped into supply before operation of any of the Dhira wells.

(b) **Wadi Karak**

The existing JVA headworks at Wadi Karak consists of an intake works in the wadi bed linked to a settling basin a short distance downstream. From the settling basin, a pipeline leads to a storage pond about 500m downstream and from there a pipeline leads westward for several kilometres to the irrigated areas.

It is proposed that surplus irrigation supplies up to a maximum of about 300m³/hr be taken from the settling basin at the Wadi Karak headworks, by constructing an overflow chamber at the settling basin. The overflow system would operate in the same way as the Wadi Hassa system described in Section 4.2.

From the JVA settling basin, it is proposed that an APC pipeline run westwards to discharge at the balancing tank near well TS1-D, which is being provided under Contract No. APC/42/91, the Refinery Water Supply Contract. A plan of the proposals is shown in Figure 4.1. The pipeline route would be a total length of 5.5km and the pipeline of 250mm diameter. For the first 4.3km, the route would be alongside the existing JVA pipeline. The intake works at Wadi Karak are about 150m higher in elevation than the balancing tank near TS1-D, and to avoid excessive pressures in the lower sections of the pipeline, a break pressure tank will be necessary at about elevation -225m.

As for Ain Maghara, a set of pressure filters is proposed for the supplies from Wadi Karak. A total of 8 sand filter units similar to those used for the Wadi Hassa system would be required, which allows for about 20% standby capacity which would be required during filter backwashing. It is proposed that the filters be located near the balancing tank, close to well TS1-D.

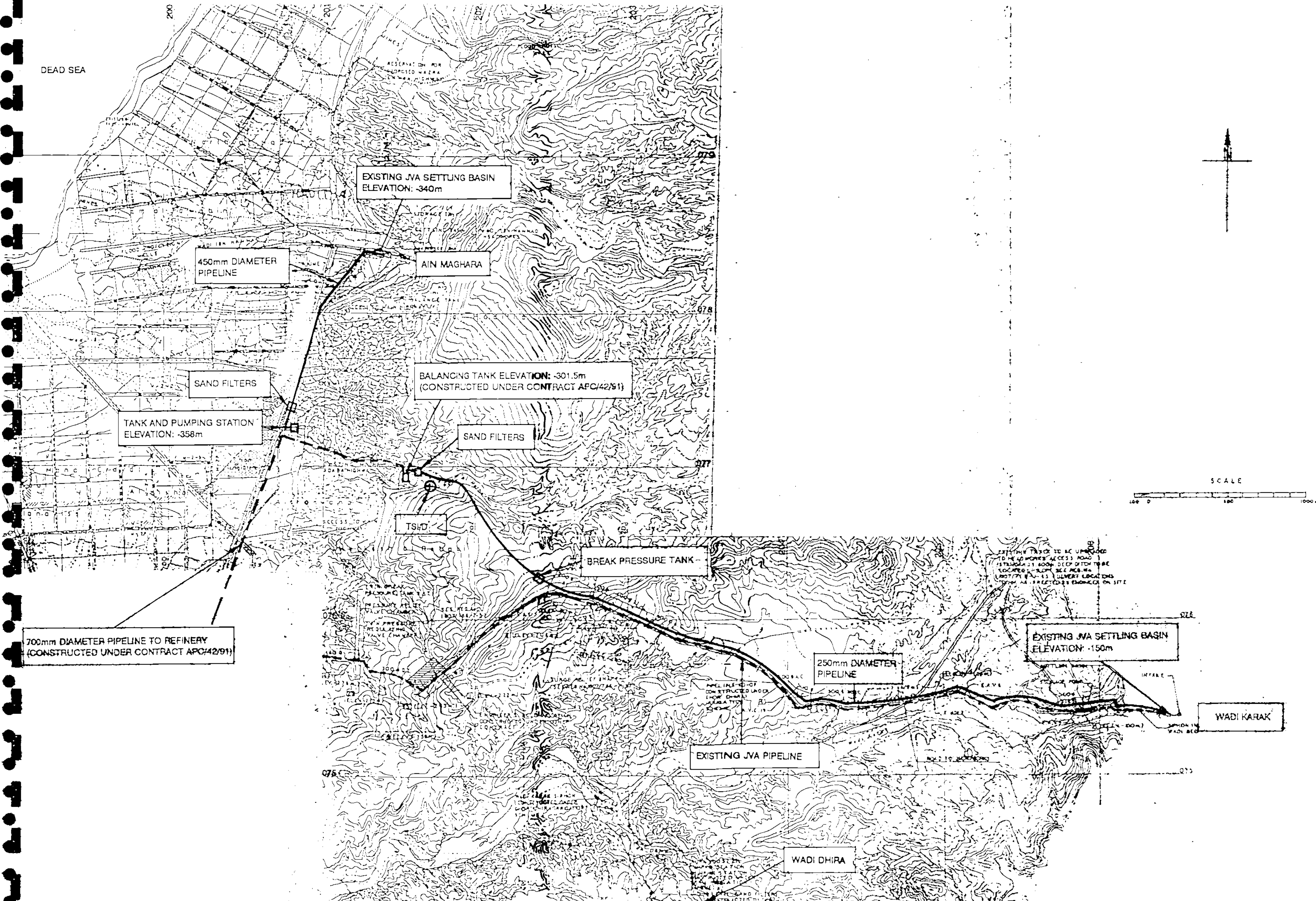
Flow would be by gravity from Wadi Karak to the balancing tank. As no pumping is required, this supply would be the cheapest to operate and so would be used first in preference to supplies from Ain Maghara. The supply would be automatically regulated by a float-controlled valve located in the balancing tank near TS1-D.

An alternative means of taking surplus irrigation flows would be possible, involving the use of the existing JVA pipeline. This would require a connection into the JVA pipeline at the point shown on Figure 4.1 where the JVA and the APC pipeline routes diverge. The length of APC pipeline required from this point to the balancing tank near TS1-D would be about 1.2km, compared with 5.5km for the scheme described above, and so would lead to a considerably cheaper scheme. However, it is considered that the modifications required to the JVA system together with potential problems involved in joint JVA/APC operation of the pipeline and of the works upstream of the connection point mean that this alternative scheme would not be feasible. It also does not have the advantage that the system can clearly be seen to be taking only surplus flows.

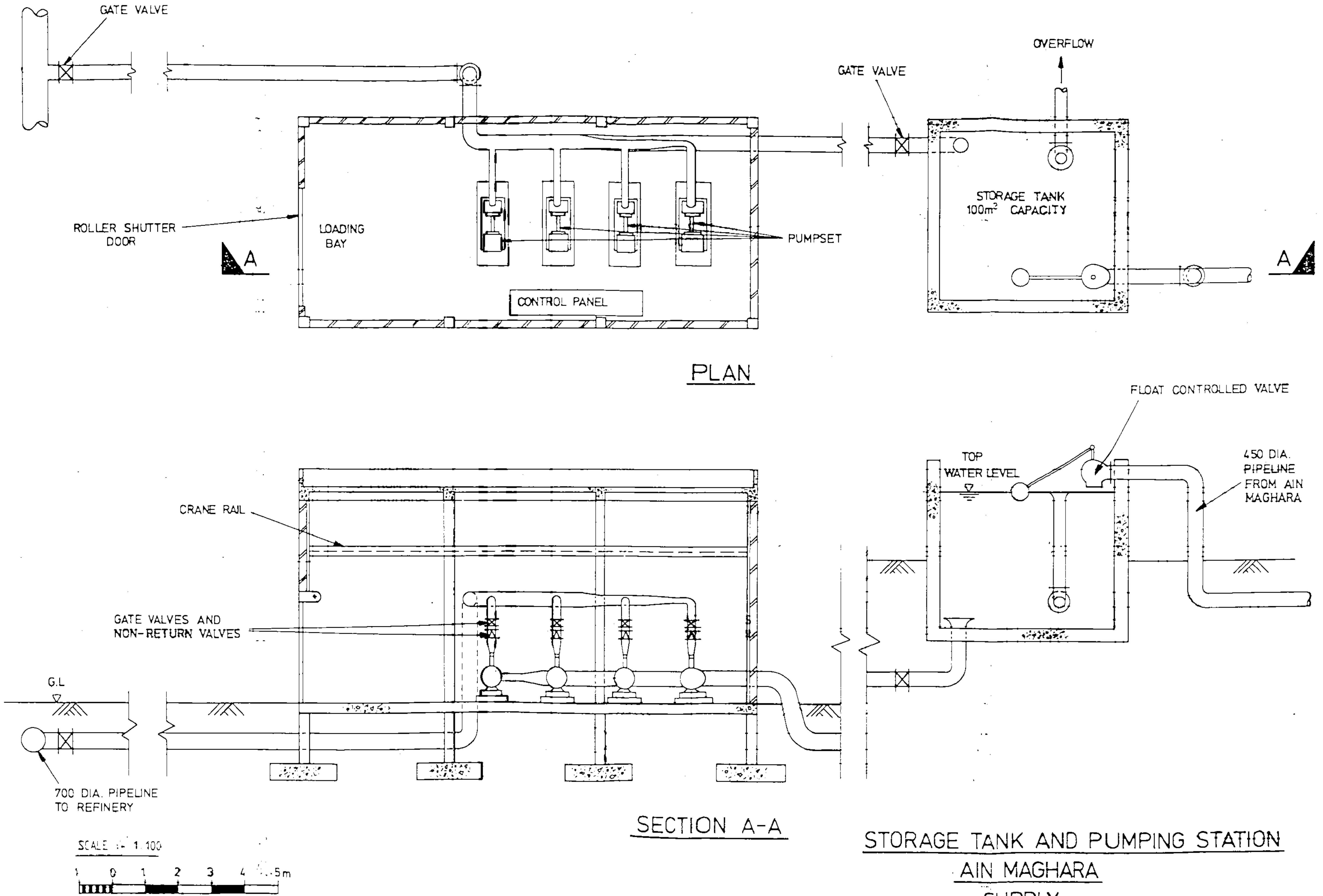
4.5 Cost Estimates

Preliminary cost estimates for the schemes described in Section 4.3 are as follows:

		JD
(a)	**Ain Maghara**	
	Overflow chamber at settling basin Pipeline - 450mm dia	5 000
	Pipeline - 450mm dia 1.4 km long	294 000
	Sand filter units - 20 no.	246 000
	Storage tank - $100m^3$	32 000
	Pumping station - 4 pumps each $270m^3/h$ at 57m head	208 000
	Sub-total	785 000
(b)	**Wadi Karak**	
	Overflow chamber at settling basin	5 000
	Pipeline - 250mm dia x 5.5km long	468 000
	Break pressure tank	22 000
	Sand filter units - 8 no.	105 000
	Sub-total	600 000
	Total for both schemes	1 385 000



MAGHARA AND KARAK PIPELINES
FIGURE 4.1



STORAGE TANK AND PUMPING STATION

AIN MAGHARA

SUPPLY

FIGURE 4·2

5. OPTIONS FOR CONJUNCTIVE-USE AND INTEGRATED-USE SCHEMES

5.1 General

The following sources of supply are proposed for conjunctive-use (north or south) and integrated-use (north and south):

- Wadi Karak and Ain Maghara together with the Dhira wellfield in the north
- Wadi Hassa and Safi wellfield in the south.

As discussed in Section 4, it is considered that development of the Wadi Issal and Wadi Dhira sources in the north would not be economic and our review, therefore, does not include these sources.

All the sources (with the exception of well TS1D) are of freshwater quality, although the water from the Dhira wells has a high temperature and iron content.

The various sources could be incorporated and used in many different combinations. As a general principle the surplus surface water sources would be used first, since these can be supplied at a lower operating cost. The wellfields would be used to supplement the surface water supplies to meet the monthly water demand and to provide the entire supply during those months when surplus surface water flows are not available.

In general, when surplus flows are available, supplies would be drawn from each source in the following descending order:

* Wadi Karak	-	moderate availability and low operating cost (gravity supply).
* Ain Maghara	-	moderate availability but higher operating costs than Wadi Karak (pumped supply).
* Wadi Hassa	-	moderate (to high) availability but significant operating costs (pumped supply) and possible limits on the amount that can be diverted with the existing arrangements.
* Safi wellfield	-	high operating costs, use only up to safe yield.
* Dhira wellfield	-	uncertain resources availability in longer term, poorer quality and higher operating costs; safe yield yet to be determined.

The following assumptions were made to develop several possible supply scenarios:

* APC would continue to use the southern sources as part of an integrated use scheme.
* that the engineering measures will command all of the estimated average surplus irrigation flows, with the exception of the Wadi Hassa which would continue to provide the same (average) quantities that have been obtained in the past by APC.
* both Ain Maghara and Wadi Karak would be utilised.
* surplus flows from Ain Maghara would have to be pumped into the APC pipeline up to a maximum rate of 800 m^3/h.
* surplus flows from Wadi Karak would be gravity fed to the collecting tank at TS1D to a maximum rate of 300 m^3/h.

- use of Wadi Karak flows would take priority over those from Ain Maghara, since the gravity supply from the Wadi Karak would cost less than pumping from Ain Maghara.
- it would be desirable to minimise abstraction from the Dhira wellfield until the aquifer response can be evaluated from monitoring data.
- the total fitted pumping capacity of the Dhira wellfield is limited to 700 m^3/h for the present.
- abstraction from the Safi wellfield would be limited to the estimated safe yield of the Safi aquifer (presently 4.5 Mm^3/y).
- the maximum supply carried by the northern pipeline is 1100 m^3/h, the pipeline/pumping capacity from Safi is 950 m^3/h and the Hassa pipeline capacity is 700 m^3/h.

In addition, it has been assumed that Wadi Hudeira would continue to be used solely for the freshwater requirements (supplemented when necessary by abstraction from the Safi wellfield) and not for process water requirements.

The monthly and annual potential contribution from the five main sources of supply (Hassa, Maghara, Karak and the Dhira and Safi wellfields) is described in the subsequent sub-sections for the following selected supply and demand scenarios:

(1) - supply from southern sources with either variable or constant abstraction from the Safi wellfield
(2) - supplying 700 m^3/h from the northern sources
(3) - supplying 1100 m^3/h from the northern sources
(4) - supplying 1100 m^3/h by the integrated use of northern and southern sources
(5) - meeting a demand of 1300 m^3/h by the integrated use of northern and southern sources with a constant supply from the south.

The different operational scenarios have been converted to an annual volume (assuming continuous diversion/abstraction), for simulation runs with the Dhira and Safi groundwater models.

5.2 Supply from Southern Sources

The southern sources (Wadi Hassa and Safi wellfield) have a combined annual availability of 5.93 Mm^3/y, which comprises an average of 1.42 Mm^3/y from surplus flow from the Hassa together with the estimated present safe yield of the Safi aquifer of 4.51 Mm^3/y These sources could be operated as follows:

- use the Safi wellfield at a variable rate each month to supplement the lower cost Hassa surplus to provide a constant combined total of about 677 m^3/h (5.93 Mm^3/y)
- use the Hassa only or the Safi wellfield only.
- operate the Safi wellfield at a continuous rate of 515 m^3/h (4.51 Mm^3/y) to supplement the use of surplus Hassa flows totalling 1.42 Mm^3/y.

Table 5.1 gives the monthly abstraction requirements from the Safi wellfield to provide a total combined continuous supply of 677 m^3/h and the total monthly availability if the wellfield is operated at a constant rate of 515 m^3/h. In both cases the total annual abstraction is 4.51 Mm^3/y. With a constant output from the wellfield, a combined supply ranging from about 570 m^3/h to a peak of about 815 m^3/h would be available.

5.3 Supply of 700 m³/h from the Northern Sources

Table 5.2 shows the demand on the Dhira wellfield to provide a supply of 700 m^3/h, for different combinations of sources in the north. The annual demand on the Dhira wellfield decreases from 6.13 Mm^3/y without the use of surplus baseflows to 2.44 Mm^3/y with the use of surplus flows from Ain Maghara and Wadi Karak. The drawdowns predicted by the Dhira model at these rates of abstraction are described in Section 5.9.

5.4 Supply of 1100 m³/h from the Northern Sources only

Table 5.3 shows the demand on the Dhira wellfield to provide a supply of 1100 m^3/h for different combinations of the northern sources. If the pumping capacity of the Dhira wellfield is limited to 700 m^3/h, then:

- the combined surplus flows from Maghara and Karak can meet the full 1100 m^3/h requirement in July/August, but with a shortfall in supply for five months of the year (April, May and September to November with a peak of 400 m^3/h in November) even with the conjunctive use of Ain Maghara, Wadi Karak and the Dhira wellfield; this is due to the wellfield pumping capacity constraint.
- if surplus flows were obtained from Ain Maghara only then the pumping constraint would result in a shortfall for about 7 months/year.
- if surplus flows were only obtained from Wadi Karak then there would be shortfall throughout the whole year due to the pumping constraint.

5.5 Integrated Use of all Sources to supply 1100 m³/h

The presently proposed capacity of the Dhira wellfield (700 m^3/h) will not be sufficient to meet a demand of 1100 m^3/h even with the full use of surplus flow sources in the north. Increasing the pumping capacity by drilling additional wells in the Dhira wellfield is limited by the high cost of new wells, constraints on well spacing, the limited scope for further sites and the as yet unproven sustainability of the deep aquifer. The sources in the north must, therefore, be integrated with the present southern sources to meet demands. This would be required when the demand for process water exceeds about 950 m^3/h (the pumping capacity of the southern sources), which is expected to be reached in 1994.

Table 5.4 shows the demand on the Dhira wellfield with a constant supply from the south of 677 m^3/h (see Section 5.1), gravity supply of surplus flows from the Wadi Karak and pumped surplus flows from Ain Maghara (the preferred use arrangement). The annual demand on the Dhira wellfield is reduced to about 0.9 Mm^3/y with a peak of 423 m^3/h in September and abstraction required for only five to six months each year.

Other combinations of integrating the northern and southern sources are possible. A scheme that would make maximum use of surplus flows is examined in Table 5.5. The preferred use would be Wadi Karak, Wadi Hassa and then Ain Maghara. These can supply about 5.4 Mm^3/y. The total demand could be met by a combination of the Safi and Dhira wellfields. The contribution from each wellfield could depend on whether it is required to minimise abstraction from Safi (option (a) in Table 5.5) or minimise the use of the Dhira wellfield (option (b) in Table 5.5). The maximum demand on the Safi wellfield should not exceed the safe yield of the Safi aquifer (4.5 Mm^3/y). Both options require a total groundwater supply of about 4.25 Mm^3/y. Option (b) requires an abstraction of 1.05 Mm^3/y from Dhira with a peak rate of nearly 550 m^3/h and an abstraction from the Safi wellfield of 3.19 Mm^3/y. This would be the preferred groundwater resources option since it makes greater use of the renewable resources of the Safi aquifer.

As regards the preference for using the Safi or the Dhira wellfields, APC do not have full control of the Safi aquifer as the JVA are also involved and APC compete with irrigation demands for use of the aquifer. At present, no-one is competing with APC for use of the Dhira aquifer, unless some link to Ain Maghara is proved. However, the Dhira aquifer has not yet been evaluated and a cautious approach to abstraction is recommended. The use of the Safi wellfield would, therefore, have preference over the Dhira wellfield, at least until more is known of the Dhira aquifer.

5.6 Integrated Use of all Sources to supply 1300 m^3/h

Table 5.6 illustrates the demand on the Dhira wellfield by the integrated use of a constant supply of 677 m^3/h from the sources at Safi and surplus flows from Ain Maghara and Wadi Karak to provide a supply of 1300 m^3/h (1999 demand level). The annual demand on the Dhira wellfield increases to nearly 2 Mm^3/y with a peak requirement of 623 m^3/h.

Also illustrated in Table 5.6 is the demand on the Dhira wellfield by the integrated use of a variable supply from the southern sources along with supplies from the northern sources. This mode of operation also results in an annual demand on the Dhira wellfield of about 2 Mm^3/y.

The constant supply of 1300m^3/h approximately corresponds to the maximum reliable supply available from the sources under consideration, with their presently proposed pumping capacities. It is the supply required for potash production of about 2.2Mt/y.

5.7 Required Peak Pumping Capacities with Integrated Use

The planned peak pumping capacity of the Dhira wellfield is 700 m^3/h and the maximum pumping capacity of the Safi wellfield is limited to about 950 m^3/h by the present pumping capacity of the pumping station and pipeline at Safi.

Without the continued use of groundwater supplies from Safi, the capacity of the Dhira wellfield would have to be expanded to 1100 m^3/h by constructing at least two new wells in order to provide a supply of 1100m^3/h to the refinery. The potential for expanding the Dhira wellfield is limited and costly. However, by continuing to make use of the Safi wells at a peak rate of 677 m^3/h consistent with the safe yield of the Safi aquifer and by integrating the northern and southern sources of surplus surface supply water then the Dhira peak rate would only be about 423 m^3/h at the 1100 m^3/h demand level (and 623 m^3/h at the 1300 m^3/h level). This would avoid the need to expand the present planned pumping capacity of the Dhira wellfield. The Safi wellfield would still have spare pumping capacity of about 325 m^3/h.

5.8 Dhira Model Predictions (Preliminary)

The groundwater model of the Dhira wellfield has been expanded to represent the region from Wadi Issal (065N) to Wadi Ajawid (85N) and from the Lisan (198E) to Karak

(215E). A regional transmissivity (T) value of 150 m^2/d, based on the well tests to date, was applied with hydraulic connection across the main escarpment between Wadi Karak and Wadi Ibn Hammad. A vertical permeability of $1x10^{-3}$ m/d to allow leakage through the Fuheis Formation aquiclude, overlying the Kurnub Sandstone aquifer in the wellfield area, was required to achieve a calibration if the Dead Sea Fault acts as a barrier to groundwater flow. This value would suggest that the aquiclude is fractured in this area allowing upward leakage. This interpretation has still to be confirmed. A full report on the final model is being prepared separately.

T values of about 35-50 m^2/d were derived from the longer term pumping test data. These values may be due to partial penetration of the total Kurnub Sandstone-Um Ishrin aquifer system and hence the total drawdown at each production well cannot be represented directly by the model. However, a close match was achieved between the model predictions and the drawdown at TA1 and TS1D during the pumping test at TA2 using a T of 150 m^2/d. The ratio of the model predicted drawdown at TA2 to the actual drawdown is the same as that of the ratio between the regional T compared to the lower T with partial penetration effects.

Under steady-state conditions, without abstraction and with the regional T value, the flow across the escarpment was about 10.5 Mm^3/y without allowing for springflow losses along the main wadis (Ibn Hammad, Karak, Dhira and Issal).. A model run that assumed all of the baseflow recorded at the main escarpment was derived from the Kurnub aquifer did not produce an acceptable head distribution. This would suggest that most of the baseflow is derived from the overlying Belqa Group in the area of the main watershed further east.

Further calibration and sensitivity runs are to be undertaken with the Dhira regional groundwater model when the full results from the current drilling programme become available. However, with the existing revised model representation, two steady-state simulation runs were undertaken with the following abstraction rates:

a) at 6.1 Mm^3/y representing a constant total abstraction rate of 700 m^3/h from TA1, TA2 and TA6 without a conjunctive use scheme.

b) at 2.6 Mm^3/y representing an average total abstraction rate of 300 m^3/h from the Dhira wellfield (TA1, TA2 and TA6) if used in conjunction with surplus flows from Ain Maghara and Wadi Karak (see Table 5.2).

The results of the trial model runs were as follows, which are adjusted for partial penetration but do not include the additional drawdown from well losses:

Rate (Mm^3/y)	Drawdown (m)			Escarpment flow (Mm^3/y)
	TA1	TA2	TA6	
2.6	131	139	121	11.34 (+0.87)
6.1	182.5	184	161	12.5 (+2.01)

These preliminary results suggest that abstraction is partly supported (about one-third) by an increase in flow across the main escarpment and that increasing the pumping rate from 2.5 to 6 Mm^3/y causes an additional drawdown of about 50 m. These drawdowns, together with an allowance for well losses, need to be taken into account when determining the borehole pump duties and setting levels required.

The above results should be treated as indicative only at this stage as the Dhira model is not yet complete and is based on the present conceptual interpretation of the aquifer conditions which may alter as additional information is obtained. Further runs are to be undertaken to establish the potential safe yield of the aquifer, but these preliminary drawdown predictions would provide support for the development of a conjunctive use/integrated use scheme to minimise demands on the Dhira wellfield.

Table 5.1

Potential Supply from Southern Sources.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
a) Variable abstraction													
													Mm3/y
Hassa	225	210	155	140	210	180	300	160	50	55	110	150	1.42
Safi Wellfield	452	467	522	537	467	497	377	517	627	622	567	527	4.51
Total	677	677	677	677	677	677	677	677	677	677	677	677	5.93
b) Constant abstraction													
Hassa	225	210	155	140	210	180	300	160	50	55	110	150	1.42
Safi Wellfield	515	515	515	515	515	515	515	515	515	515	515	515	4.51
Total	740	725	670	655	725	695	815	675	565	570	625	665	5.93

Notes: Hassa contribution based on average APC use 1989-1992.
Abstraction supplements Hassa surplus up to safe yield of Safi aquifer.

Table 5.2

Supplying 700 m3/h from Northern Sources Only.

Option	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
Maghara	486	270	378	162	216	378	400	400	0	50	202	353	2.41
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Dhira Wellfield	0	304	146	465	387	164	0	0	700	626	397	171	2.44
Maghara	486	270	378	162	216	378	700	700	0	50	202	353	2.86
Dhira Wellfield	214	430	322	538	484	322	0	0	700	650	498	347	3.27
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Dhira Wellfield	457	574	524	627	603	542	400	400	700	676	599	524	4.83
Dhira Wellfield only	700	700	700	700	700	700	700	700	700	700	700	700	6.13

Table 5.3

Supplying 1100 m3/h from Northern Sources Only.

Option	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
Maghara	486	270	378	162	216	378	800	800	0	50	202	353	3.01
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Dhira Wellfield	371	704	546	865	787	564	0	0	1100	1026	797	571	5.32
Deficit [1]	0	4	0	165	87	0	0	0	400	326	97	0	0.79
Maghara	486	270	378	162	216	378	800	800	0	50	202	353	3.01
Dhira Wellfield	614	830	722	938	884	722	300	300	1100	1050	898	747	6.63
Deficit [1]	0	130	22	238	184	22	0	0	400	350	198	47	1.15
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Dhira Wellfield	857	974	924	1027	1003	942	800	800	1100	1076	999	924	8.33
Deficit [1]	157	274	224	327	303	242	100	100	400	376	299	224	2.20

Notes: [1] Shortfall in supply with pumping constraint of 700 m3/h.

Table 5.4

Integrated Use of Northern and Southern Sources to meet 1100 m3/h demand using constant supply from South.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
Hassa+Safi Wellfield	677	677	677	677	677	677	677	677	677	677	677	677	5.93
Maghara	180	270	247	162	216	265	123	123	0	50	202	247	1.52
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Dhira Wellfield	0	27	0	188	110	0	0	0	423	349	120	0	0.89

Table 5.5

Integrated Use of Northern and Southern Sources to supply 1100 m3/h, with alternative wellfield options.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
Surplus Flows:													
Hassa	225	210	155	140	210	180	0	0	50	55	110	150	1.08
Maghara	486	270	378	162	216	378	800	800	0	50	202	353	3.01
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Total	954	606	709	375	523	716	1100	1100	50	129	413	679	5.39

Option (a) Minimizing abstraction from Safi wellfield.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
Dhira Wellfield	146	494	391	700	577	384	0	0	700	700	687	421	3.77
Safi Wellfield	0	0	0	25	0	0	0	0	350	271	0	0	0.47

Option (b) Using safe yield of Safi aquifer to minimize use of Dhira wellfield.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
Safi wellfield	146	494	391	513	513	384	0	0	513	513	513	421	3.19
Dhira wellfield	0	0	0	212	64	0	0	0	537	458	174	0	1.05

Table 5.6

Integrated Use of Northern and Southern Sources to meet 1300 m3/h demand.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y
a) Constant supply from South.													
Hassa+Safi Wellfield	677	677	677	677	677	677	677	677	677	677	677	677	5.93
Maghara	380	270	378	162	216	378	323	323	0	50	202	353	2.22
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Dhira Wellfield	0	227	69	388	310	87	0	0	623	549	320	94	1.93
b) Variable supply from South													
Hassa+Safi Wellfield	740	725	670	655	725	695	815	675	565	570	625	665	5.93
Maghara	317	270	378	162	216	378	185	325	0	50	202	353	2.07
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30
Dhira Wellfield	0	179	76	410	262	69	0	0	700	656	372	106	2.06
Supplementary from Safi wellfield.									35				

Table 5.7

Demand on Dhira Wellfield with Maximum Use of All Other Sources.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mm3/y	
Hassa	225	210	155	140	210	180	300	160	50	55	110	150	1.42	
Maghara	486	270	378	162	216	378	800	800	0	50	202	353	3.01	
Karak	243	126	176	73	97	158	300	300	0	24	101	176	1.30	
Safi Wellfield	515	515	515	515	515	515	515	515	515	515	515	515	4.51	
Total	1469	1121	1224	890	1038	1231	1915	1775	565	644	928	1194	10.24	
Dhira Wellfield [1]	371	704	546	700	700	564	0	0	700	700	700	571	4.54	[2]
Total all sources	1840	1825	1770	1590	1738	1795	1915	1775	1265	1344	1628	1765	14.78	

Notes: [1] Abstraction to fill 1100 m3/h north pipeline with pumping constraint of 700 m3/h.
[2] Aquifer ability to sustain this abstraction not yet known.

6. CONCLUSIONS AND RECOMMENDATIONS

This study was initiated following indications that the sustainable yield of the Dhira wellfield may not be as high as had previously been hoped. Derivation of an annual limit for the long term sustainable yield of the Dhira aquifer will be dependent on future experience of abstraction from the aquifer and cannot be defined at present. However, it is evident that the Dhira wellfield alone will not be able to supply the new Dhira pipeline with the design flow of $1100m^3/h$.

In considering the total water supply available to APC from the existing Safi sources along with the Dhira wellfield, the indications are that for potash production of over 2.2Mt/y (requiring a total process water supply of about $1300m^3/h$ from all sources), additional sources of water will be required to be developed. It is not yet known whether supplies below $1300m^3/h$ will require additional sources, as this is dependent on the sustainable yield of the Dhira wellfield. This study has identified Ain Maghara and Wadi Karak as potential additional water sources, by making use of flows that are surplus to irrigation requirements. The study has shown that by conjunctive use of these sources in combination with the Dhira wellfield, for any given flow annual abstraction from the Dhira wellfield can be considerably reduced compared with the operation of the Dhira wellfield alone. The effect of this will be to increase the reliable long term supply available to APC. It should be noted that for conjunctive use, the full installed capacity of the Dhira wells is required at those times of year when no surplus irrigation flows are available.

The study has considered the conjunctive use of surplus irrigation flows from Ain Maghara and Wadi Karak in combination with the Dhira wellfield, together with the conjunctive use of surplus irrigation flows from Wadi Hassa in combination with the Safi wellfield. It has been found that operation in this way to give a constant supply of $1300m^3/h$ to APC would require annual abstraction of about $2Mm^3/y$ from the Dhira wellfield (see Table 5.6). Operation without Ain Maghara and Wadi Karak would require annual abstraction from the Dhira wellfield of about $5.5Mm^3/y$. The scale of the effect on annual abstraction can clearly be seen from this. In deriving the above figures, annual abstraction from Safi wellfield has been taken as $4.5Mm^3/y$, which is currently estimated as the safe yield of the aquifer.

Outline engineering schemes to convey surplus irrigation flows from Ain Maghara and Wadi Karak have been derived to convey a maximum of 1100 m^3/h from these sources into the APC process water supply system. The preliminary cost estimates for these schemes are JD 785 000 for Ain Maghara and JD 600 000 for Wadi Karak.

A number of matters need to be finalised before detailed design of the engineering works can be put in hand. It is recommended that a visit to site is made by GIBB staff to carry out the following:

(1) to confirm by discussions with JVA the estimates of surplus irrigation flows and the ability to fully utilise these flows.

(2) to determine the detailed engineering arrangements for the works and how the offtakes would fit in with existing JVA facilities.

(3) to assist APC if necessary in discussions to secure the agreement and co-operation of JVA in the use of surplus irrigation flows.

Subject to the successful outcome of the above, it is recommended that detailed design of the necessary engineering measures should then proceed, with a view to incorporating the construction work in the Refinery Water Supply Contract during 1994.

In addition to the above, it is desirable that long term measures to monitor the flows in Wadi Karak and at Ain Maghara be implemented. This is seen primarily as the responsibility of JVA and it is recommended that it be raised in discussions with them.

References

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Table A.1

Monthly estimates of total surplus flow in Dhira area.

a) 50% reliable flow

1992

	Total flow		JVA diversion		Surplus flow	
	m3/h	m3	m3	%	m3	m3/h
Jan	2174	1617754	761400	47	856354	1151
Feb	2077	1395878	889140	64	506738	754
Mar	2005	1491869	865998	58	625871	841
Apr	1933	1391904	1074595	77	317309	441
May	1933	1438301	1019826	71	418475	562562
Jun	1890	1360800	818128	60	542672	754
Jul	1843	1371341	142457	10	1228884	1652
Aug	1771	1317773	144910	11	1172863	1576
Sep	1843	1327104	1363649	103	0	0
Oct	1987	1478477	1174839	79	303638	408
Nov	1951	1404864	966316	69	438548	609
Dec	2005	1491869	783757	53	708112	952
		17087934	10005015	59	7119464	

b) 80% reliable flow

1992

	Total flow		JVA diversion		Surplus flow		Adopted diversion *	Estimated surplus
	m3/h	m3	m3	%	m3	m3/h	%	m3/h
Jan	1796	1336522	761400	57	575122	773	55	808
Feb	1753	1178150	889140	75	289010	430	75	438
Mar	1753	1304381	865998	66	438383	589	65	614
Apr	1728	1244160	1074595	86	169565	236	85	259
May	1728	1285632	1019826	79	265806	357	80	346
Jun	1685	1213056	818128	67	394928	549	65	590
Jul	1656	1232064	142457	12	1089607	1465	10	1490
Aug	1656	1232064	144910	12	1087154	1461	10	1490
Sep	1656	1192320	1363649	114	0	0	100	0
Oct	1656	1232064	1174839	95	57225	77	95	83
Nov	1681	1210464	966316	80	244148	339	80	336
Dec	1681	1250813	783757	63	467056	628	65	588
		14911690	10005015	67	5078004		65	

Notes: * 'typical' year to nearest 5%.

These percent values applied to individual northern sources of surface flow.

Total flow refers to combined flow of Ain Maghara, Wadi Karak and Wadi Dhira.

Table A.2 Estimates of Surplus Flows in North.

a) Ain Maghara

	80% reliable total flow		Diverted flow		Surplus flow		
	m3/h	m3/mth	%	m3/mth	%	m3/h	m3/mth
Jan	1080	803520	55	441936	45	486	361584
Feb	1080	725760	75	544320	25	270	181440
Mar	1080	803520	65	522288	35	378	281232
Apr	1080	777600	85	660960	15	162	116640
May	1080	803520	80	642816	20	216	160704
Jun	1080	777600	65	505440	35	378	272160
Jul	1080	803520	10	80352	90	972	723168
Aug	1080	803520	10	80352	90	972	723168
Sep	1080	777600	100	777600	0	0	0
Oct	1008	749952	95	712454	5	50	37498
Nov	1008	725760	80	580608	20	202	145152
Dec	1008	749952	65	487469	35	353	262483
Annual		9301824	65	6036595	35		3265229

b) Wadi Karak

	80% reliable total flow		Diverted flow		Surplus flow		
	m3/h	m3/mth	%	m3/mth	%	m3/h	m3/mth
Jan	540	401760	55	220968	45	243	180792
Feb	504	338688	75	254016	25	126	84672
Mar	504	374976	65	243734	35	176	131242
Apr	486	349920	85	297432	15	73	52488
May	486	361584	80	289267	20	97	72317
Jun	450	324000	65	210600	35	158	113400
Jul	432	321408	10	32141	90	389	289267
Aug	432	321408	10	32141	90	389	289267
Sep	432	311040	100	311040	0	0	0
Oct	486	361584	95	343505	5	24	18079
Nov	504	362880	80	290304	20	101	72576
Dec	504	374976	65	243734	35	176	131242
Annual		4204224	66	2768882	34		1435342

Table A.2 (cont.)

c) Wadi Dhira

	80% reliable total flow		Diverted flow		Surplus flow		
	m3/h	m3/mth	%	m3/mth	%	m3/h	m3/mth
Jan	176	130944	55	72019	45	79	58925
Feb	169	113568	75	85176	25	42	28392
Mar	169	125736	65	81728	35	59	44008
Apr	162	116640	85	99144	15	24	17496
May	162	120528	80	96422	20	32	24106
Jun	155	111600	65	72540	35	54	39060
Jul	144	107136	10	10714	90	130	96422
Aug	144	107136	10	10714	90	130	96422
Sep	144	103680	100	103680	0	0	0
Oct	162	120528	95	114502	5	8	6026
Nov	169	121680	80	97344	20	34	24336
Dec	169	125736	65	81728	35	59	44008
Annual		1404912	66	925711	34		479201

d) Wadi Issal

	80% reliable total flow		Diverted flow		Surplus flow		
	m3/h	m3/mth	%	m3/mth	%	m3/h	m3/mth
Jan	112	83328	55	45830	45	50	37498
Feb	104	69888	75	52416	25	26	17472
Mar	104	77376	65	50294	35	36	27082
Apr	101	72720	85	61812	15	15	10908
May	101	75144	80	60115	20	20	15029
Jun	97	69840	65	45396	35	34	24444
Jul	90	66960	10	6696	90	81	60264
Aug	90	66960	10	6696	90	81	60264
Sep	90	64800	100	64800	0	0	0
Oct	101	75144	95	71387	5	5	3757
Nov	104	74880	80	59904	20	21	14976
Dec	104	77376	65	50294	35	36	27082
Annual		874416	66	575641	34		298775

Table A.3

Summary of Surplus Flows for Various Combinations of Northern Wadis (m3/h).

	M	K	D	I	M+K+D	M+K	M+D	M+I	K+D	K+I	D+I	M+K+	M+K+I	M+D	K+D+
Jan	486	243	79	50	858	729	565	536	322	293	129	808	779	615	372
Feb	270	126	42	26	464	396	312	296	168	152	68	438	422	338	194
Mar	378	176	59	36	649	554	437	414	235	212	95	613	590	473	271
Apr	162	73	24	15	274	235	186	177	97	88	39	259	250	201	112
May	216	97	32	20	365	313	248	236	129	117	52	345	333	268	149
Jun	378	158	54	34	624	536	432	412	212	192	88	590	570	466	246
Jul	972	389	130	81	1572	1361	1102	1053	519	470	211	1491	1442	1183	600
Aug	972	389	130	81	1572	1361	1102	1053	519	470	211	1491	1442	1183	600
Sep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	50	24	8	5	87	74	58	55	32	29	13	82	79	63	37
Nov	202	101	34	21	358	303	236	223	135	122	55	337	324	257	156
Dec	353	176	59	36	624	529	412	389	235	212	95	588	565	448	271

Notes:

Based on 80% reliable flows.

M Ain Maghara
K Wadi Karak
D Wadi Dhira
I Wadi Issal

Table A.4

Wadi Hassa Surplus Baseflow

A. 50% reliable flow

	Total flow		1990				1992			
	m3/h	m3	JVA diversion m3	%	Surplus m3	m3/h	JVA diversion m3	%	Surplus m3	m3/h
Jan	3240	2410560	2902081	120	0	0	1527673	63	882887	1187
Feb	3240	2177280	1921136	88	256144	381	1440351	66	736929	1097
Mar	3096	2303424	1539508	67	763916	1027	1553823	67	749601	1008
Apr	2970	2138400	1637459	77	500941	696	1241034	58	897366	1246
May	2918	2169504	1302171	60	867333	1166	764176	35	1405328	1889
Jun	2700	1944000	1003071	52	940029	1306	572125	29	1371875	1905
Jul	2700	2008800	591658	29	1417142	1905	173284	9	1835516	2467
Aug	2700	2008800	747820	37	1260980	1695	354861	18	1653939	2223
Sep	2628	1892160	1897741	100	0	0	1494843	79	397317	552
Oct	2844	2115936	2187862	103	0	0	2120445	100	0	0
Nov	3060	2203200	1932220	88	270980	376	1878781	85	324419	451
Dec	3096	2303424	1844455	80	458969	617	1599560	69	703864	946
Total		25675488	19508082	76	6736434		14720956	57	10959041	

B. 80% reliable flow

Jan	2970	2209080	2902081	131	0	0	1527673	69	682007	917
Feb	2844	1911168	1921136	101	0	0	1440351	75	470817	701
Mar	2844	2115936	1539508	73	576428	775	1553823	73	562113	756
Apr	2700	1944000	1637459	84	306541	426	1241034	64	702966	976
May	2700	2008800	1302171	65	706629	950	764176	38	1244624	1673
Jun	2556	1840320	1003971	55	836349	1162	572125	31	1268195	1761
Jul	2430	1807920	591658	33	1216262	1635	173284	10	1634636	2197
Aug	2430	1807920	747820	41	1060100	1425	354861	20	1453059	1953
Sep	2430	1749600	1897741	108	0	0	1494843	85	254757	354
Oct	2700	2008800	2187862	109	0	0	2120445	106	0	0
Nov	2844	2047680	1932220	94	115460	160	1878781	92	168899	235
Dec	2844	2115936	1844455	87	271481	365	1599560	76	516376	694
Total		23567760	19508082	83	5089250		14720956	62	8958449	

Notes: No data supplied for 1991.

Table A.5

Comparison of diversion by JVA for northern wadis and Wadi Hassa in 1992.

	K+M+D % of annual diversion	Hassa % of annual diversion	K+M+D % of total flow	Hassa % of total flow
Jan	7.6	10.4	57	69
Feb	8.9	9.8	75	75
Mar	8.7	10.6	66	73
Apr	10.7	8.4	86	64
May	10.2	5.2	79	38
Jun	8.2	3.9	67	31
Jul	1.4	1.2	12	10
Aug	1.4	2.4	12	20
Sep	13.6	10.1	114	85
Oct	11.7	14.4	95	106
Nov	9.7	12.8	80	92
Dec	7.8	10.9	63	76
Annual			67	62

Notes: K+M+D Karak+Maghara+Dhira
Based on 80% reliable flow and JVA flow diversion records.

Table A.6

Historical Use of Wadi Hassa by APC m3/month

	1987	1988	1989	1990	1991	1992	Average m3	Av. m3/h	Av. 89-92 m3/h	Adopted Average m3/h
Jan		110089	274536	131689	143445	146447	161241	217	234	225
Feb		71955	174584	158615	189801	67706	132532	197	220	210
Mar		75000	94312	87293	95857	199880	110468	148	160	155
Apr		54657	50554	136677	117144	118706	95548	133	147	140
May		37760	137577	204519	215336	124959	144030	194	229	210
Jun	167440	83608	97612	188058	150533	84861	128685	179	181	180
Jul	187912	241470	387215	181161	204240	126842	221473	298	302	300
Aug	37149	257380	114388	85950	142662	110030	124593	167	152	160
Sep	27071	209650	60929	15621	5485	2350	53518	74	29	50
Oct	83897	204810	18397	13470	27200	23362	61856	83	28	55
Nov	43516	129760	23071	52362	181830	55849	81065	113	109	110
Dec	105600	233270	44173	192453	130445	20942	121147	163	130	150
Year	652585	1709409	1477348	1447868	1603978	1081934	1436157			

Note: Av in m3/h assumes constant diversion of surplus flows at JVA tank.