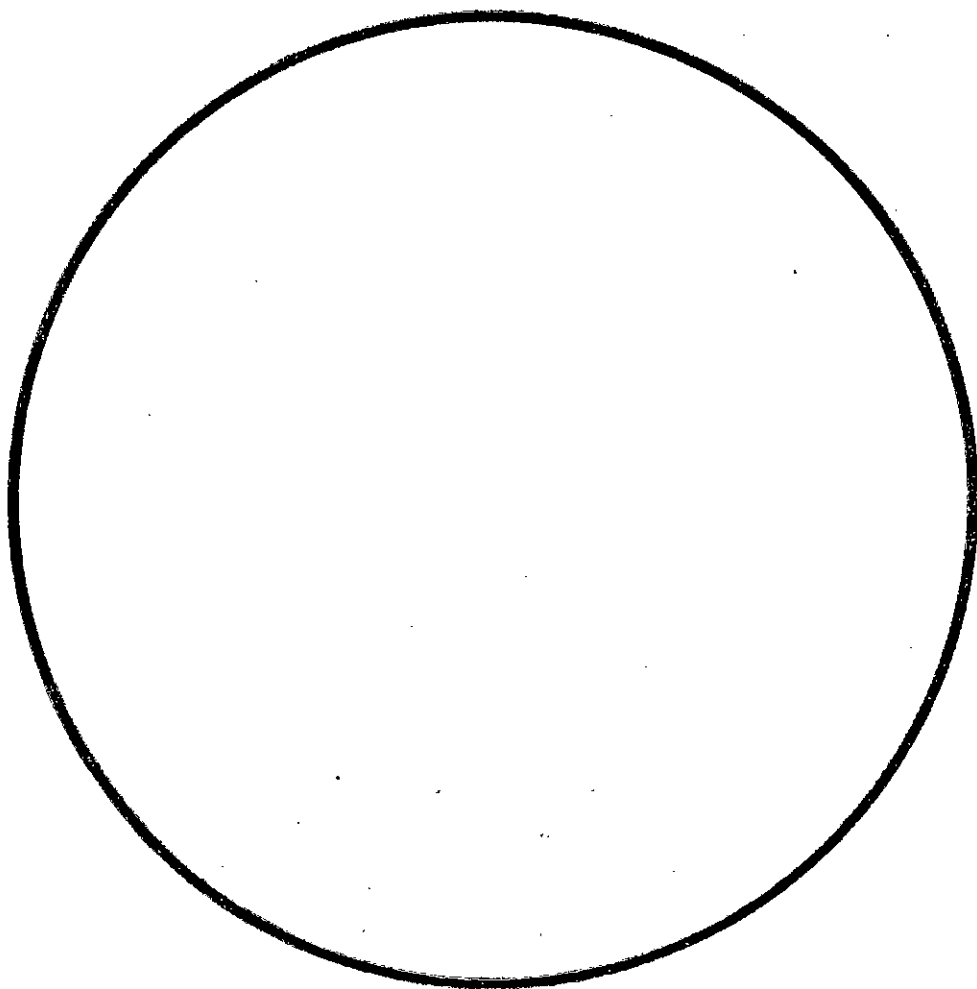


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ARAB POTASH PROJECT
CONTRACT III
FRESH WATER SUPPLIES

FURTHER INVESTIGATIONS OF GHOR SAFI

SUPPLEMENTARY REPORT
ON WATER CHEMISTRY

(This report is to accompany the main report dated April, 1979)

May 1979



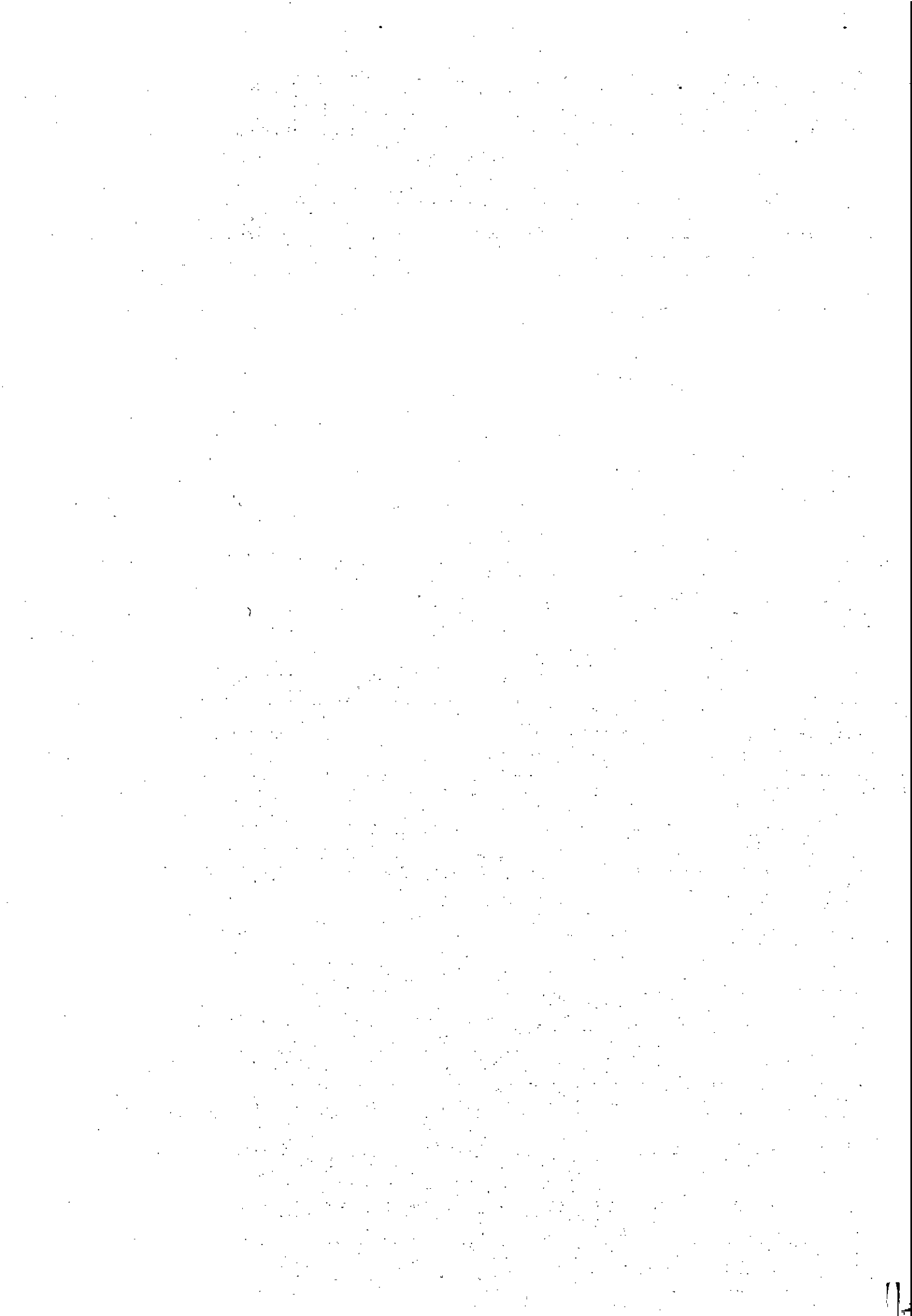
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WATER CHEMISTRY

1. General

The water requirements of the Potash Process Plant during Stage 1 are expected to be 5.0 million m³/year, which may be of brackish water quality (up to 5000 mg/l dissolved salts), and 0.6 million m³/year, which must be of potable water quality (say, < 1000 mg/l dissolved salts). However, it is desirable that the total supply should be of a potable water standard to avoid the necessity of a separate supply for each of these requirements.

The chemical quality of the Wadi Hasa and of groundwater in the alluvial deposits of Ghor Safi was studied in 1977¹ from which the following conclusions were drawn:

- the main aquifer sequence contains groundwater of potable quality and of a similar composition to the Wadi Hasa.
- the clays underlying the main aquifer contain poor quality non-potable groundwater. The ingress of such water can lead to a deterioration in the quality of borehole supplies from the main aquifer unless precautions are taken.
- there is no firm evidence for the intrusion of saline water from the Dead Sea.

Water samples were collected for chemical analysis from the new observation boreholes. The results have been used to review our earlier conclusions, particularly concerning the groundwater composition in the proposed wellfield development area. In order to do so it is necessary to examine the composition of the Wadi Hasa baseflow, which might also be used for supply purposes.

1. *Final Feasibility Report, Arab Potash Project, Vol IX, Appendix N, Hydrology (Dec. 1977).*

2. Baseflow Composition

The aquifer is recharged largely by the baseflow of the Wadi Hasa; as infiltration along the wadi channel and from the seepage of diverted baseflow applied to the irrigated fields. The recharge from flood flows is considered to be small and direct recharge from rainfall unlikely.

Seven analyses of the Wadi Hasa baseflow are given in Table 1. Apart from the analysis in 1966, these analyses suggest that the baseflow has a relatively constant composition. The average composition, based on the analyses given in Table 1 (excluding that for 1966), is as follows:

Conductivity	700 micromhos
T.D.S.	450 mg/l
pH	8.1
Major cations (meq/l)	Ca 2.6, Mg 1.9, Na 2.2, K 0.17
Major anions (meq/l)	Cl 2.5, HCO ₃ 2.3, SO ₄ 1.6, CO ₃ 0.2

Springs in the Ajlun limestones of the eastern highlands provide the baseflow of the Wadi Hasa and consequently the baseflow has a relatively high total dissolved solids (T.D.S.) and a composition largely originating from the passage of meteoric water through these limestones.

Using the data from the available analyses the baseflow is of a suitable potable quality, based on World Health Organisation drinking water standards. However, as thermal springs contribute a large proportion of the baseflow there may be minor constituents that could affect potability but which have not yet been measured.

At best the groundwater quality in the main aquifer will be of the same quality as the Wadi Hasa baseflow and such groundwater would occur

WADI HASA AT GHOR SAFI

Chemical Analyses

Sample	29.7.65	1966	28.6.66	1969	4.8.76	7.6.77	20.6.77
	(1)	(2)	(2)	(2)	(3)	(4)	(4)
Conductivity (micromhos)	720	1140	670	740	700	670	670
T.D.S. at 110°C (mg/l)	461	730	429	474	448	429	429
pH	8.08	8.10	8.10	8.00	7.90	8.45	8.15
Ca (meq/l)	3.10	2.60	2.30	3.00	3.00	2.20	2.20
Mg (meq/l)	1.70	3.40	1.70	2.70	2.50	1.12	1.64
Na (meq/l)	1.60	5.20	2.50	2.05	2.20	2.40	2.45
K	-	-	0.17	-	-	0.12	0.17
Total cations	(6.40)	(11.20)	6.67	(7.75)	(7.70)	5.84	6.45
Cl (meq/l)	2.40	5.80	2.55	1.60	3.60	2.65	2.55
HCO ₃ (meq/l)	2.50	1.90	2.32	2.10	2.80	0.86	2.11
CO ₃ (meq/l)	0.20	0.20	0.17	0.20	-	0.85	0.17
SO ₄	(1.3)	3.30	1.64	3.85	1.60	1.61	1.61
Total anions	(6.4)	11.20	6.68	7.75	8.00	5.97	6.44

- Sources of data: (1) MMP (1966) Appendix Table III
 (2) NRA files
 (3) APC Feasibility Study 1977 Table 2.2
 (4) BP (1978) Table B38

SO₄ content for sample 29.7.65 estimated by difference

in the proximity of the wadi channel.

3. Groundwater Compositions

Water samples were collected for chemical analysis during the development of each new observation borehole in February 1979. The analyses were carried out by the Building Materials Research Centre of the Royal Jordanian Scientific Society. The results are given in Table 2. This table also includes other selected groundwater analyses available from our previous investigations in 1977 and from NRA files. The recent water samples were collected after a short period of abstraction and therefore may not be wholly representative of water quality after prolonged periods of pumping.

The reliability of the analyses was checked by comparing the sum of the cations and the anions in milli-equivalents per litre (meq/l); preferably the difference between these should not exceed 1 per cent of the total of cations and anions. The difference shown by the analyses averages less than 2 per cent which we consider to be acceptable.

The available analyses represent two types of groundwater; groundwater associated with the main aquifer and groundwater from the underlying laminated clays. We have distinguished those analyses belonging to each type in Table 2. In certain cases the analysis suggest a mixture between both types of groundwater.

Groundwater composition of the main aquifer

The likely groundwater composition in the main aquifer based on the analyses of samples from OBI, 2, 3 and 5 and S1, 2, 6 and 10 given in Table 2 is as follows:

TABLE 2 (Contd)

Sample No. Date Remarks	OB6 Feb 1979 2.1m	OB6 Feb 79 4.2m	OB7 5.2.79 1.1m	BN 302 6.6.77	SI 27.6.54 Start of pumping	SI 28.6.54 after 24 hours	S2 3.4.77	SI0 5.4.77	S6 29.9.62
Conductivity (micromhos)	1250	1210	1060	1650			860	1000	
T.D.S. at 110°C (mg/l)	1005	1065	795	1280	678	1779	550	640	659
pH	8.30	8.25		7.5			7.75	7.48	8.0
Ca (meq/l)	5.00	5.02	5.40	9.21	3.68	7.50	3.44	4.10	4.2
Mg (")	4.11	3.90	3.80	4.59	2.72	11.13	2.16	2.42	2.6
Na (")	5.35	5.48	3.78	6.74	3.64	8.97	2.80	3.25	4.2
K (")	0.24	0.24	0.93	0.41			0.17	0.17	
Total cations	14.70	14.62	13.91	20.95	10.04	27.60	8.57	9.94	11.0
Cl (meq/l)	6.39	6.87	3.63	8.45	3.7	9.0	2.85	3.34	3.9
HCO (")	4.80	4.91	7.45	2.80	4.0	5.0	2.96	3.73	3.55
SO (")	3.22	3.29	2.76	9.65	2.34	13.77	2.64	2.70	3.35
NO (")			0.048	0.064			0.12	0.10	
Total anions	14.41	15.07	13.89	20.96	10.04	27.77	8.57	9.87	10.8
Type	A/B	A/B	A/B	B	A	B	A	A	A

Notes: Dates not recorded for samples from OB1, OB2 and OB6. No analysis available from OB4.
 Depths shown refer to depth of air-line during development
 Samples from BN302, SI, S2 and S6 (originally SI5) reproduced from Table A7 of
 Final Feasibility Report IX App N Dec 1977.

Classification A ~ main aquifer groundwaters
 A/B ~ transitional
 B ~ deeper groundwaters

Major cations (meq/l) Ca 3.7, Mg 2.9, Na 3.3

Major anions (meq/l) Cl 3.6, HCO₃ 3.6, SO₄ 2.5

Although there is an almost equal increase in each of the major cations or anions of about 50 per cent, the relative composition and the potassium concentration (0.17 meq/l) are essentially the same as that of the Wadi Hasa.

Conductivities range from 800 to 1000 micromhos and the TDS from 550 to 700 mg/l; the higher values occurring towards the fan-edge.

Groundwater in the main aquifer is of a good, potable quality. Bacterial analyses have not been carried out but nitrate concentrations, where reported, are low (maximum about 0.12 meq/l or 7.5 mg/l at OB5, S2 and S10) and probably localized. Significant pollution is not indicated by these results but we advise the chlorination of drinking water supplies.

It is unlikely that groundwater in the main aquifer will result in significant incrustation or corrosion of well screens.

Groundwater composition of the laminated clays

The groundwater chemistry of the laminated clays underlying the aquifer appears to be a modified composition of that in the main aquifer and is more variable. The sample analyses from BN 302 and S1 (later sample) are thought to be typical of these groundwaters. Those from OB7 and OB6 are perhaps transitional between groundwater in the main aquifer and deeper groundwaters (Table 2).

Conductivities of more than 1000 micromhos have been reported for the deeper groundwaters; the maximum recorded conductivity is 9000 micromhos at S14 after 26 hours of pumping (no analysis available). The laminated clays underlying the main aquifer are reported to have a TDS of 1000 to 2000 mg/l but there are indications of even higher concentrations of dissolved salts, particularly with increasing depth. Very low resistivities were identified at elevations of more than -400m OD in the north-east and south of the wellfield area by the geophysical survey and these are probably due to high TDS concentrations.

Higher potassium concentrations appear to characterize groundwaters associated with the laminated clays, the maximum reported being 0.93 meq/l (36 mg/l) at OB7. An increase in potassium with depth was recorded at OB1 from 0.14 meq/l at 24 m to 0.23 meq/l at 45 m. The presence of 0.24 meq/l potassium at OB6, together with a higher TDS and chloride content, suggests that the sample from this borehole is affected by the deeper groundwaters.

The sample from BN 302, collected during drilling after penetrating 30 m into the laminated clays underlying the main aquifer, and the late sample from S1 have similar compositions and the high chloride and sulphate concentrations make these waters non-potable.

The analysis of the sample from OB7 differs from BN 302 and S1 in having a high bicarbonate content (7.45 meq/l, $\text{HCO}_3 > \text{Cl} \approx \text{SO}_4$). This sample was collected from the silty deposits which overlie the laminated clays penetrated in this borehole. The high bicarbonate concentration suggests a high dissolved carbon dioxide content and sulphate reduction.

Waters subject to sulphate reduction usually contain hydrogen sulphide (H_2S) and the presence of this gas has been reported in boreholes which have penetrated the laminated clays, such as BN 302, OB6 and OB7. The concentrations of hydrogen sulphide have not been measured but only 1 mg/l will impart a strong odour. Hydrogen sulphide gas, whilst unpleasant, can be removed by aeration and need not affect the potability. However, corrosion of well screens might occur when this gas is present and it would seem best to avoid such waters.

4. Deterioration in Groundwater Quality

Although water of brackish quality (up to 5000 mg/l) is acceptable for the industrial water requirements of the potash plant, a separate potable supply and measures to combat corrosion would be required.

The laminated clays underlying the main aquifer contain non-potable groundwater with a moderate to high TDS whereas the main aquifer itself

has potable groundwater with a low TDS. At several private boreholes, such as S1 or S14, the water quality has deteriorated after a short period of pumping from a composition associated with the main aquifer to one associated with the laminated clays (see analyses for S1 in Table 2) returning to the initial composition after the cessation of pumping.

The deterioration in water quality appears to be due to excessive drawdowns causing an upward movement of water from the laminated clays. Where the screen is placed within the clay sequence, such as at S14, poor quality water will be obtained directly. Boreholes S2 and S10 have consistently supplied good quality groundwater showing that it is possible to obtain potable groundwater for prolonged periods by avoiding the withdrawal of water from the underlying clays.

Excessive drawdowns should be avoided by obtaining the required supply from a number of boreholes spaced over the exploitable area of the main aquifer. Each production borehole should also be completed at a depth of 4 m above the top of the laminated clays. This design is illustrated by BN 309, only 15 m from BN 302. The sample from BN 302, collected after penetrating the laminated clays, is of a non-potable quality (Table 2) whereas BN 309, which was completed 5 m above the clays, did not show a deterioration in water quality during a 27-hour pumping test.

With such safeguards we believe that it will be possible to maintain a supply of potable water for the total requirements of Stage 1 and to avoid any potential risk of corrosion or incrustation. However, if water levels decline significantly due to abstraction exceeding recharge then an upward movement of deeper groundwaters could result in a deterioration of water quality. It is not possible as yet to predict the composition of the groundwater delivered to the potash plant should groundwater mining occur.

Recommendations

1. The main aquifer in the wellfield area contains groundwater of potable quality. We believe that it should be possible to prevent a deterioration in quality by suitable well design and by spreading the abstraction. Nonetheless, we recommend that the quality of water at each production borehole and of the supply delivered to the potash plant is monitored. Regular conductivity measurements should be suitable to monitor any changes and should a deterioration be observed then samples should be taken for full analysis. As a general guide sampling will be necessary when the conductivity exceeds 1000 micromhos for above this level there may be particular ions which have unacceptable concentrations.
2. More detailed analyses are necessary to examine minor constituents which might affect potability and to examine incrustation or corrosion potential.
3. Analyses are required of the fan-edge springs, the saline springs east of Mujahid and from the new borehole S18 in order to develop our understanding of the variations in water chemistry.

