INSTITUTE OF HYDROLOGY

ARAB POTASH PROJECT

CONTRACT III

FRESH WATER SUPPLIES

FURTHER INVESTIGATIONS OF GHOR SAFI

This report was prepared for:

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ABSTRACT

The water resources of the south-easter ghors of the Dead Sea were investigated in 1977[1]. Ghor Safi was identified as the only area likely to be able to supply the water requirements of the Potash Process Plant. Additional investigations have since been carried out at Ghor Safi, including an observation borehole drilling programme, a geophysical survey and regular hydrological measurements.

The results of these additional investigations are presented and used to describe the occurrence of groundwater in the area selected for groundwater development in order to select locations for the proposed new production boreholes and to examine their basic design.

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

I. INTRODUCTION

I.1 GENERAL

The south-eastern ghors of the Dead Sea comprise a number of alluvial fans bordering the escarpment of the Jordan-Wadi Araba rift valley. The water resources of this region were investigated in 1977[1] to assess the availability of fresh water for the Potash Process Plant and associated township. These investigations identified Ghor Safi, the largest of the alluvial fans, as the only area likely to be able to meet the water requirements of the Potash Process Plant. The location of the study area is shown in Figure 1.1.

Ghor Safi is the alluvial fan of the Wadi Hasa. This wadi has a substantial, perennial baseflow derived from springs in the eastern highlands and most of this flow is diverted for the irrigation of Ghor Safi. However, as this irrigation recharges the alluvial fan deposits, it has been proposed to supply the Potash Process Plant by groundwater abstraction from a wellfield situated at Safi.

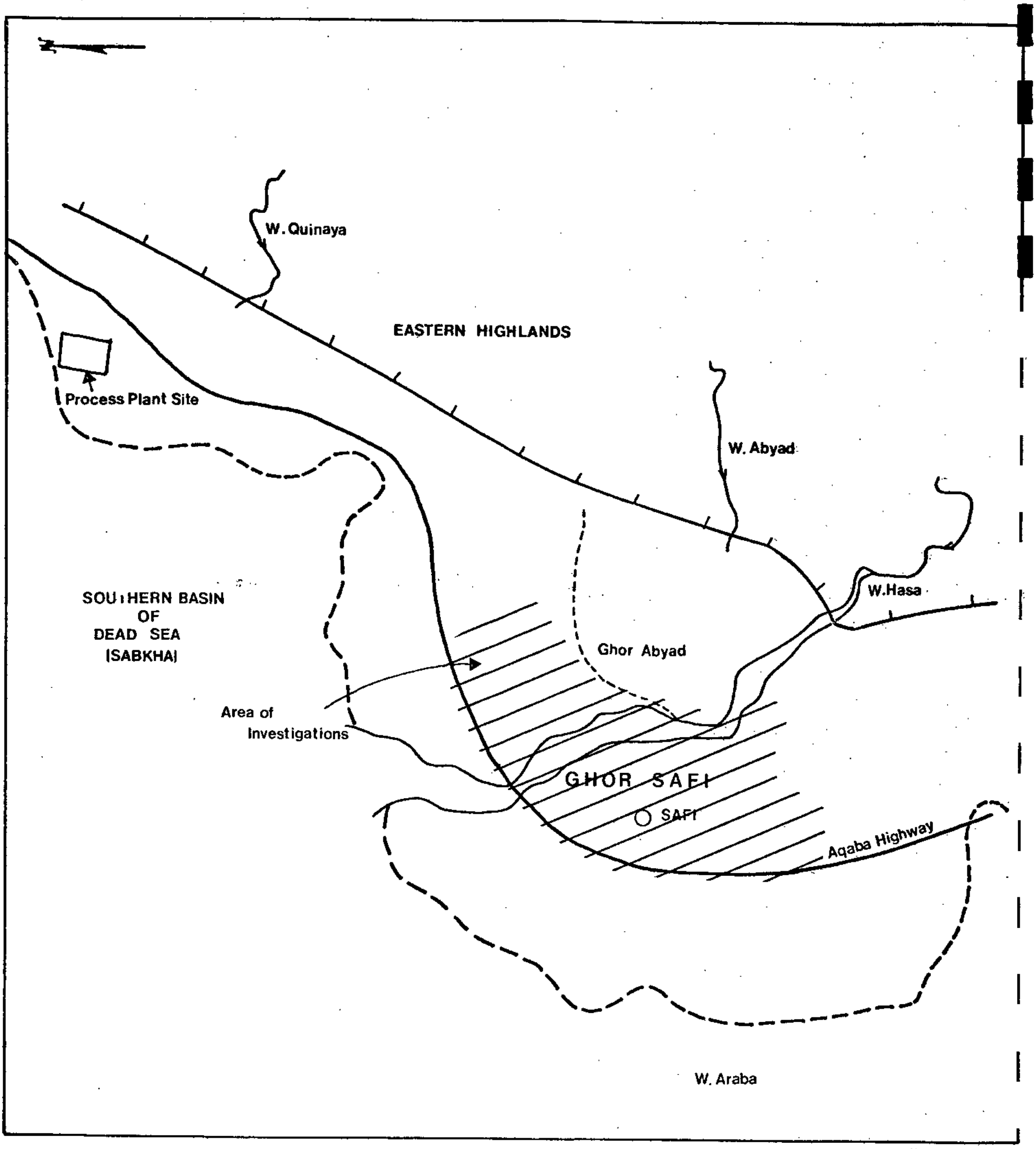
An area of about 6 km^2 around the village of Safi was selected for the wellfield location. The wellfield will consist of five new boreholes (SPB1 to 5) and incorporate existing boreholes S2 and BN309, with BN309 as a standby supply. The wellfield is designed for continuous abstraction to supply Stage I (1.2 MTYP of potash) water requirements of 5.6 million m^3/year.

Various management options were presented in the feasibility study report to supply the Stage II (1.7 MTYP of potash) water requirements; these options are not amplified in this report.

I.2 FURTHER INVESTIGATIONS

The Feasibility Report in 1977 recommended an observation borehole construction programme and geophysical survey of the

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



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LOCATION OF STUDY AREA

proposed groundwater development area at Ghor Safi. Together these would provide further information on the depth and configuration of the main aquifer and the lithological variation and relative permeability of the alluvial sequence. The observation boreholes are to form part of a network to measure water level changes to assess the distribution of recharge and to monitor the aquifer response to abstraction.

A programme of routine hydrological measurements began in mid-1977 and is still continuing. The total flow and diverted flow of the Wadi Hasa and water levels at two observation borehole locations are measured each month. In November 1978, preliminary surveys were made of the losses of undiverted flow of the Wadi Hasa as it crosses Ghor Safi and of the areal distribution of diverted flow.

The results of these further investigations are presented in Appendices A to C and are summarised in the following sections. Their importance in regard to the wellfield is discussed in Section 2.

I.3 OBSERVATION BOREHOLE CONSTRUCTION

The construction of seven observation boreholes was carried out by a local drilling contractor. Drilling began in early November 1978 and the programme was completed at the end of February 1979. These boreholes have been given the reference numbers OB1 to OB7 and their locations are shown in Figure 2.1.

The results obtained from the drilling programme are presented in Appendix A and include borehole logs, completion summaries and water and sieve analyses. A summary of the construction details of each observation borehole is given in Table 1.1

I.4 GEOPHYSICAL SURVEY

A geophysical survey of the wellfield area at Ghor Safi was carried out during November 1978. It was intended to employ two geophysical techniques for the survey: electrical resistivity soundings and shallow seismic refraction spreads. However, the seismic refraction

TABLE 1.1

OBSERVATION BOREHOLES, OB1-OB7

Summary of Construction Details

Number	Map location	Elevation of top of casing (M.O.D.)	Total depth drilled (m)	Constructed depth (m)	Depth of slotted casing (m)	Depth to rest water level (m)
OB1	195691E 50565N	-367.74	48	46	22-32	9.113
					34-45	
OB2	194423E 50750N	-377.92	56	51.5	13.5-43.5	0.119
					45.5-50.5	above ground level
OB3	196422E 51243N	-377.16	50	33.25	25.25-30.25	0.428
OB4	195241E 48540N	-348.06	47	27	22-26	20.353
OB5	194484E 48554N	-359.73	47	40.75	17.75-39.75	17.056
OB6	193867E 49445N	-371.78	50	44	16-32	6.238
					36-42	
OB7	194516E 47094N	-366.14	40	15	8-14	7.794

method did not yield useful results during preliminary trials due to absorption of the seismic energy by the unconsolidated sediments. The survey was therefore carried out using the resistivity method only.

The resistivity method involves passing an electrical current through the ground between two electrodes and measuring the current and resulting potential at two other electrodes. For depth soundings the electrodes are moved apart so that the current penetrates progressively deeper thereby measuring the resistivity of an increasing volume of material. The data obtained are plotted as an apparent resistivity curve for interpretation.

The resistivity values of the saturated alluvium will be a function of several factors, of which the three most important are pore water resistivity, porosity and clay content. For example, a low resistivity will generally be associated with clays and water containing a high dissolved solids content.

A total of 77 soundings were made over an area of 7 km^2 of the fan using the Wenner electrode array. The data were interpreted by computer techniques. A full description of the survey, a listing of the field data and the final interpretations are given in Appendix B.

The interpreted resistivity data were plotted as geoelectrical sections; these show the resistivities at each sounding as a series of layers that can then be identified in conjunction with a knowledge of the geology. These sections are included in Appendix B as Figures B2 to B5; the section lines are shown in Figure B1.

The interpretation was based on a maximum of six layers. We have designated these as layers A, B, C1, C2, D1 and D2, in order of decreasing depth. Layers D1 and D2 generally represent the unsaturated zone and are not of interest.

The general range in the resistivity values of layers A, B and C is as shown overleaf.

Layer C

C2	100-200 ohm-metres
C1	40-100 ohm-metres

Layer B	20- 40 ohm-metres

Layer A

A2	10- 20 ohm-metres
A1	less than 10 ohm-metres

Layer A

Very low resistivities of less than 20 ohm-m characterise this layer. It was not detected in the central area of the fan around Safi, although it may be present at greater depths. The low resistivity of Layer A is undoubtedly due to saline water within the deposits underlying the main aquifer.

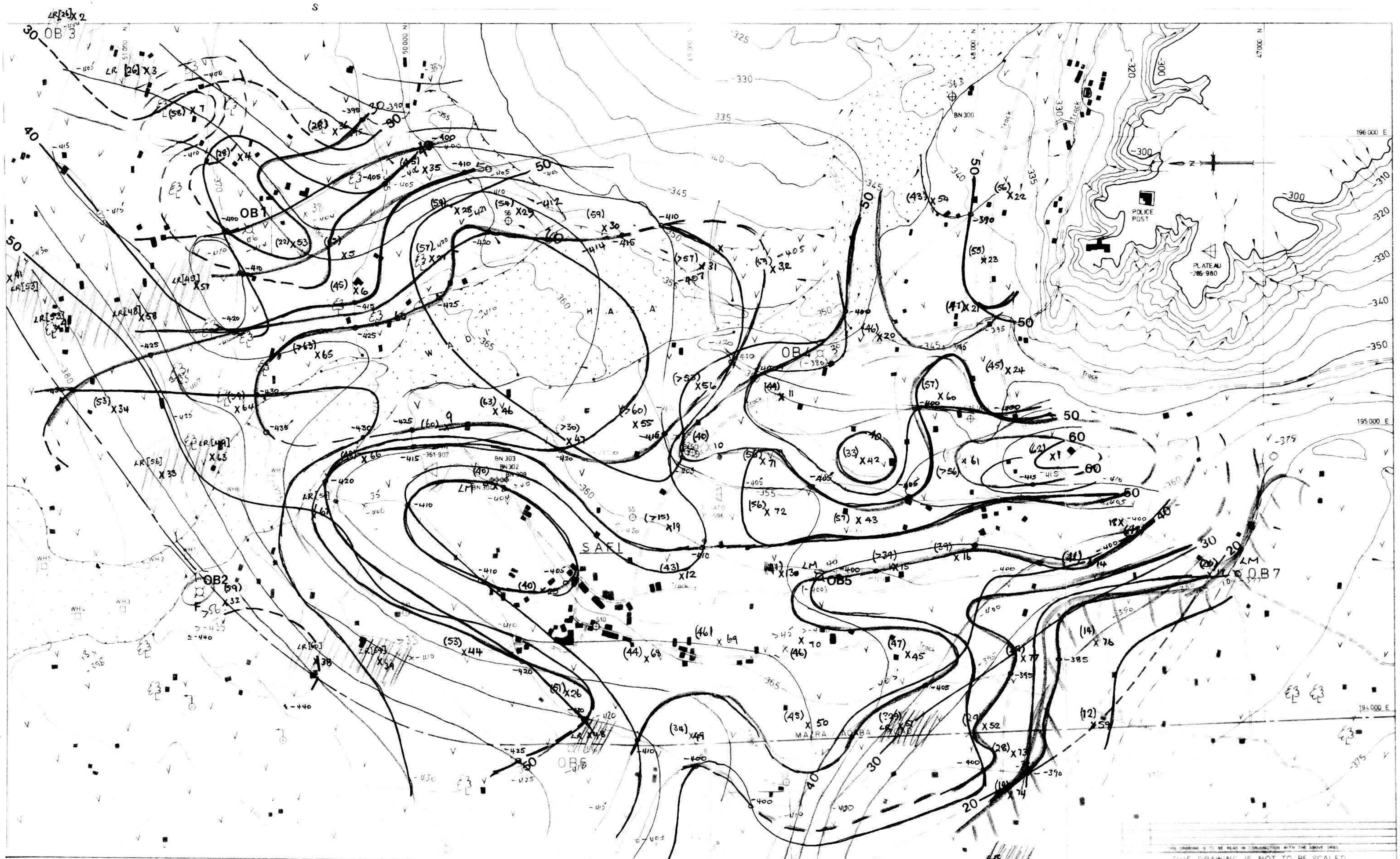
Layer B

This layer also has low resistivities, between 20 and 40 ohm-m, and underlies the whole of the survey area. It was the deepest layer detected in the central area of the survey.

Layer B correlates with a grey clay, which forms the base of the aquifer, encountered in most of the boreholes. The depth to this layer is contoured in Figure 1.2. The greatest depths, generally 45-55 m, occur around Safi. These depths are somewhat greater than suggested by borehole evidence but are within the experimental error of the resistivity method.

Layer C

This layer may be regarded as the main aquifer. Within this zone, we have differentiated two layers, C1 and C2. Layer C1 is continuous over the area and has a variable resistivity, whereas



X Location of resistivity sounding

—50 Lines of equal depth to low resistivity layer (m)

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DEPTH TO LOW RESISTIVITY LAYER

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MAR 1979

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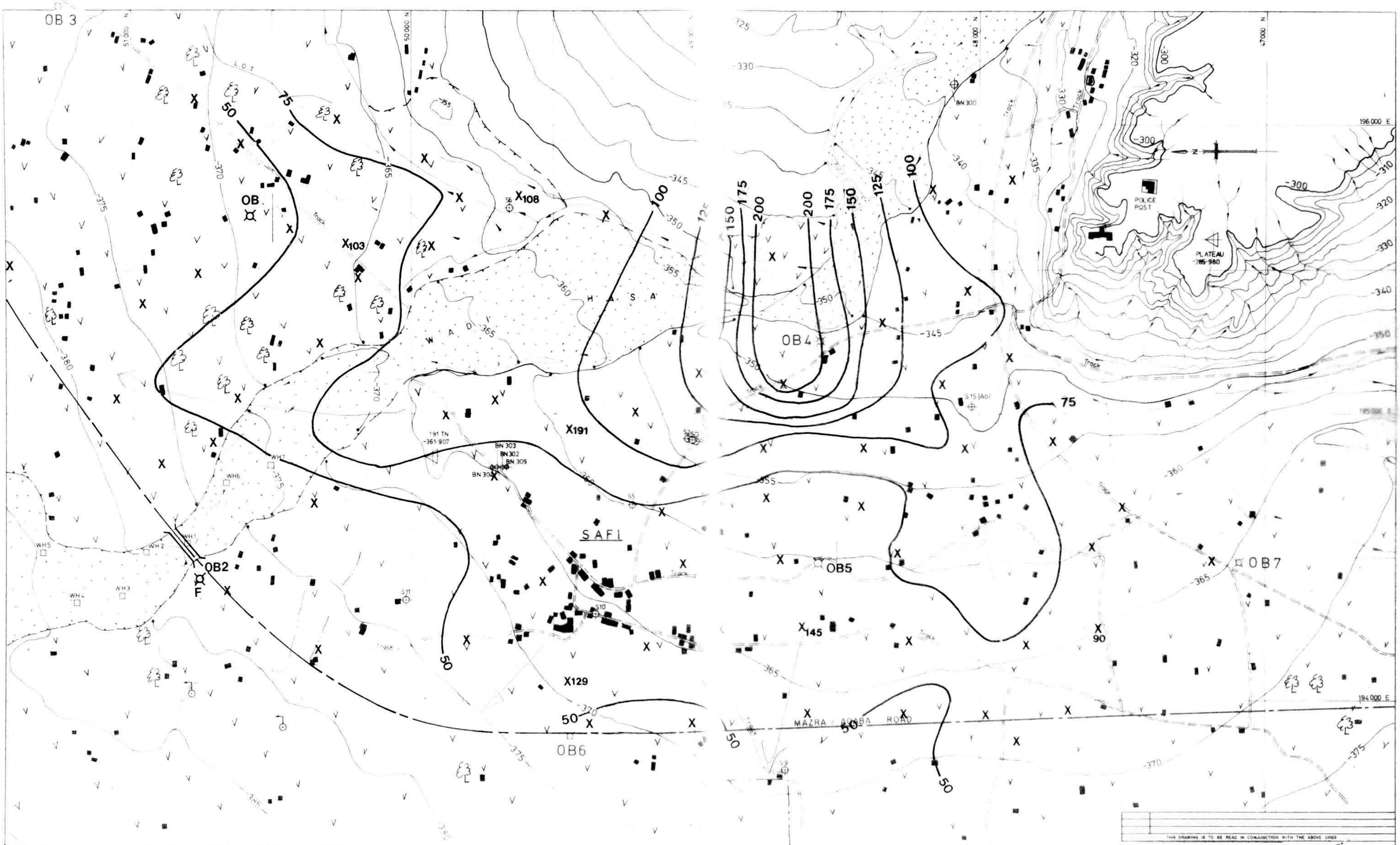

X Location of resistivity sounding

X 129 Local high resistivity values [not contoured] [ohm-m]

50 Isoresistivity contours [ohm-m]

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RESISTIVITY OF MAIN AQUIFER

(Layer C)

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CONSULTING ENGINEERS
READING & LONDON
ENGLAND

SCALE 1:12500	DRG No FIGURE 1.3	REV
DATE MAR 1979		

Layer C2 is of more local occurrence and has more consistent and generally higher resistivities.

The resistivity of Layer C has been contoured in Figure 1.3. The area of highest resistivity is situated south-east of Safi and is likely to be an area where very coarse deposits ~~which~~ receive recharge from undiverted flow ~~occur~~. Away from this area generally high resistivities (including Layer C2) spread out beneath the present wadi channel and into the area between OB5 and OB7. These areas may be channel-fill deposits and areas of better quality water. The resistivity of Layer C decreases westwards, reflecting perhaps both an increasing clay content as well as an increasing total dissolved solids content.

I.5 HYDROLOGICAL OBSERVATIONS

The hydrological measurements carried out during 1977/78 at Ghor Safi include flow measurements of the Wadi Hasa and water level measurements at boreholes S6 and BN 302/BN 303/BN 304. Although it was intended to measure regularly a selected fan-edge spring, interference with the weirs has prevented this. The hydrological measurements are presented and discussed in Appendix C.

Whilst the preliminary survey results of undiverted baseflow losses from evaporation and irrigation and the distribution of diverted flow should be examined by further surveys, the hydrological measurements collected during 1977/78 have indicated the following important aspects of the hydrology of Ghor Safi:

- significant volumes of undiverted baseflow, perhaps 35 per cent of total baseflow, continue down the wadi channel throughout the year, apparently because the diversion structures are not capable of diverting the whole baseflow;

- there is a seasonal variation in total baseflow. The volume of undiverted baseflow which continues down the wadi channel probably represents the excess of the seasonal variation in total baseflow over the diversion capability;

- the highest groundwater levels occur in August, which probably relates to irrigation practices, and during the winter months of December to January, which suggests recharge from winter flood flows.

II. SAFI WELLFIELD

The recent programme of further investigations has shown that the area around the village of Safi is suitable for groundwater development. The investigations have also allowed us to examine this area in more detail than was previously possible so that the locations and the basic designs of the new production boreholes can be selected.

II.1 GROUNDWATER OCCURRENCE

Lithology

The alluvial deposits comprise a complex sequence of unconsolidated gravels, sands and clays. These deposits represent the latest depositional stage of alternativing fluviatile and lacustrine deposits controlled by changes in climate and base level during the Pleistocene. Whilst the main aquifer varies in thickness from a few metres to more than 40 m, boreholes drilled for oil exploration at Ghor Safi show that the total thickness of Pleistocene deposits exceeds 2000 m.

The grey, laminated clays which are considered to form the base of the main aquifer, are of lacustrine origin and were deposited during a period of reduced erosion. Borehole evidence suggests that these clays extend beneath the fan as a continuous layer sloping in a north-west direction at 1:50 from -380 m at OB4 to -420 m at OB6 (Figure 2.2). They have been proved by drilling to be at least 30 m in thickness in the wellfield area and are thought to increase in thickness in a north-westerly direction.

Limits of exploitable aquifer

In section 2.3, we show that a minimum saturated aquifer thickness of at least 20 m is required in order to allow for the construction of boreholes capable of producing the water supply requirements with the chosen wellfield design. An exception to this requirement is the area between S2 and OB4 where the geophysical survey indicates coarse deposits of high permeability and hence it is likely that drawdowns will be smaller in this area than elsewhere.

With the additional information concerning water levels and the base of the aquifer provided by the drilling programme and geophysical survey, we have delineated an area where aquifer conditions are suitable for the construction of the production boreholes. These limits are shown in Figure 2.1 and are largely based on the thickness of the aquifer which is shown in Figure 2.2. The average aquifer thickness in this area is 25 m, increasing from 7 m at OB4 to about 40 m at OB7.

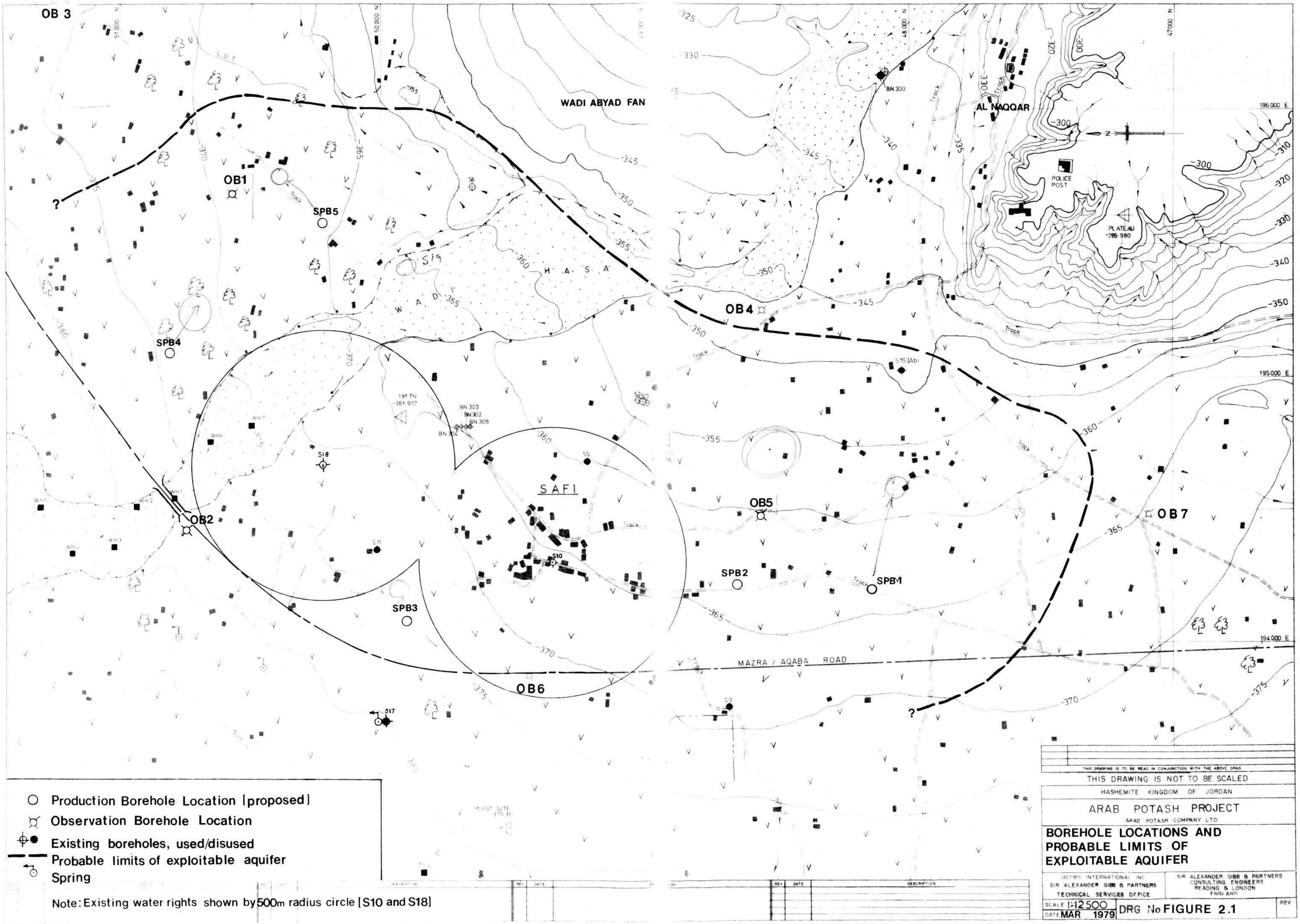
The southern limit of the exploitable area is marked by a rapid shallowing of the grey clays. These clays appear to have formed a barrier, extending in a north-west to south-east direction, which has prevented the deposition of coarse material. This is illustrated by the fine-grained sequence encountered at OB7 situated to the south of this barrier.

Northwards, the coarse deposits encountered around Safi pass laterally into a predominantly clay sequence where the deposition of coarse material was also restricted. The transition occurs between OB1 and OB3 but was not distinguished by the geophysical survey.

The eastern limit of the exploitable area has been taken as the 10 m contour of aquifer thickness (Figure 2.2) as drawdowns may be smaller in the area lying between the 10 and 20 m contours.

The area of exploitable aquifer east of the Aqaba road and within the above limits is about 4.5 km^2. The limits of the exploitable aquifer to the west of Aqaba road have not been defined by either the geophysical survey or the drilling programme. However, as an unexpectedly thick sequence of coarse deposits was encountered at OB2 and OB6, we believe that there is a development potential in the area to the west particularly in a north-west direction from OB2. However, this must be confirmed by further investigations.

The area which we have defined as being suitable for the siting of the production boreholes is in hydraulic connection with the rest



OB 3
OB1
SPB5
SPB4
OB2
SPB3
OB6
OB4
OB5
SPB2
SPB1
OB7
S10
S18
S11
S5
S6
S9
S17
S15 (Ab)
BN 300
BN 302
BN 303
BN 309
BN 304
WH1
WH2
WH3
WH6
WH7
WADI ABYAD FAN
AL NAQQAR
POLICE POST
PLATEAU -285·980
191 TN -361·907
W A D I H A S A
SAFI
MAZRA / AQABA ROAD
Track
PLANT SITE
50 000 N
51 000 N
48 000 N
47000 N
196 000 E
195 000 E
194 000 E
-300
-310
-320
-330
-340
-345
-350
-355
-360
-365
-370
-375
-380
?
○ Production Borehole Location (proposed)
Observation Borehole Location
Existing boreholes, used/disused
Probable limits of exploitable aquifer
Spring
Note: Existing water rights shown by 500m radius circle (S10 and S18)
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HASHEMITE KINGDOM OF JORDAN
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BOREHOLE LOCATIONS AND PROBABLE LIMITS OF EXPLOITABLE AQUIFER
JACOBS INTERNATIONAL INC
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TECHNICAL SERVICES OFFICE
SIR ALEXANDER GIBB & PARTNERS CONSULTING ENGINEERS READING & LONDON ENGLAND
SCALE 1:12500
DATE MAR 1979
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REV
DATE
DESCRIPTION

of the aquifer where, however, conditions are indicated as being less favourable for development. Hence, from the resources point of view, the exploitable area cannot be considered in isolation as the total groundwater resources of Ghor Safi, either those replenished each year or those in storage, are potentially available to contribute to abstraction by the wellfield. This would be particularly the case if the wellfield abstraction was to exceed the resources in the immediate area of the wellfield.

We estimate that the volume of groundwater in storage within the exploitable area of the aquifer, east of the Aqaba road, is 17 million m^3, assuming a storativity of 0.15. In the feasibility study of 1977, the total volume of groundwater in storage at Ghor Safi was estimated to be 67 million m^3. This was estimated assuming the same storativity and an aquifer thickness of 30 m. However, the recent investigations suggest that a lower storativity and a smaller thickness of aquifer are likely outside of the limited area of exploitable aquifer. Further studies are needed to quantify these aspects before the volume of storage that would be potentially available to the wellfield can be reliably quantified. We believe that the available storage is sufficient to maintain the water supply requirements if it should be necessary to develop other alternative supplies.

Transmissivity and storativity

During the water resources study of 1977 short duration pumping tests were carried out at boreholes BN 309, S2 and S10. The locations of these boreholes are shown in Figure 2.1. A transmissivity of 2400 m^2/d was estimated for BN 309 and subsequently adopted for estimates of flow through the aquifer. A much higher transmissivity of over 5000 m^2/d was estimated for S2, which we considered to be a localized value.

We have subsequently reviewed the available pumping test data. Whilst these data are open to more than one interpretation, we have computed more consistent transmissivities of 5600, 5150 and 5250 m^2/d at S2, BN 309 and S10 respectively.

These transmissivities may well be limited to the area east of Safi. However, as the hydraulic gradient does not alter west of Safi the likely decrease in permeability westwards, as clays become more common, may be offset by the greater thickness of saturated deposits to produce a similar transmissivity.

The average storativity, based primarily on the pumping test at S2, is about 0.15. This will decrease westwards as the aquifer becomes increasingly confined.

Groundwater flow

The depth to water table and the elevation of the water table are contoured in Figure 2.3. This map incorporates the additional information concerning rest water levels from the drilling programme. The groundwater flow is in a north-westerly direction and the hydraulic gradient in the wellfield west of OB4 is 1:750.

The flow through the estimated productive width of the aquifer of about 3 km, assuming a hydraulic gradient of 1:750 and a transmissivity of 5000 m^2/d, is estimated to be 6 million m^3/year.

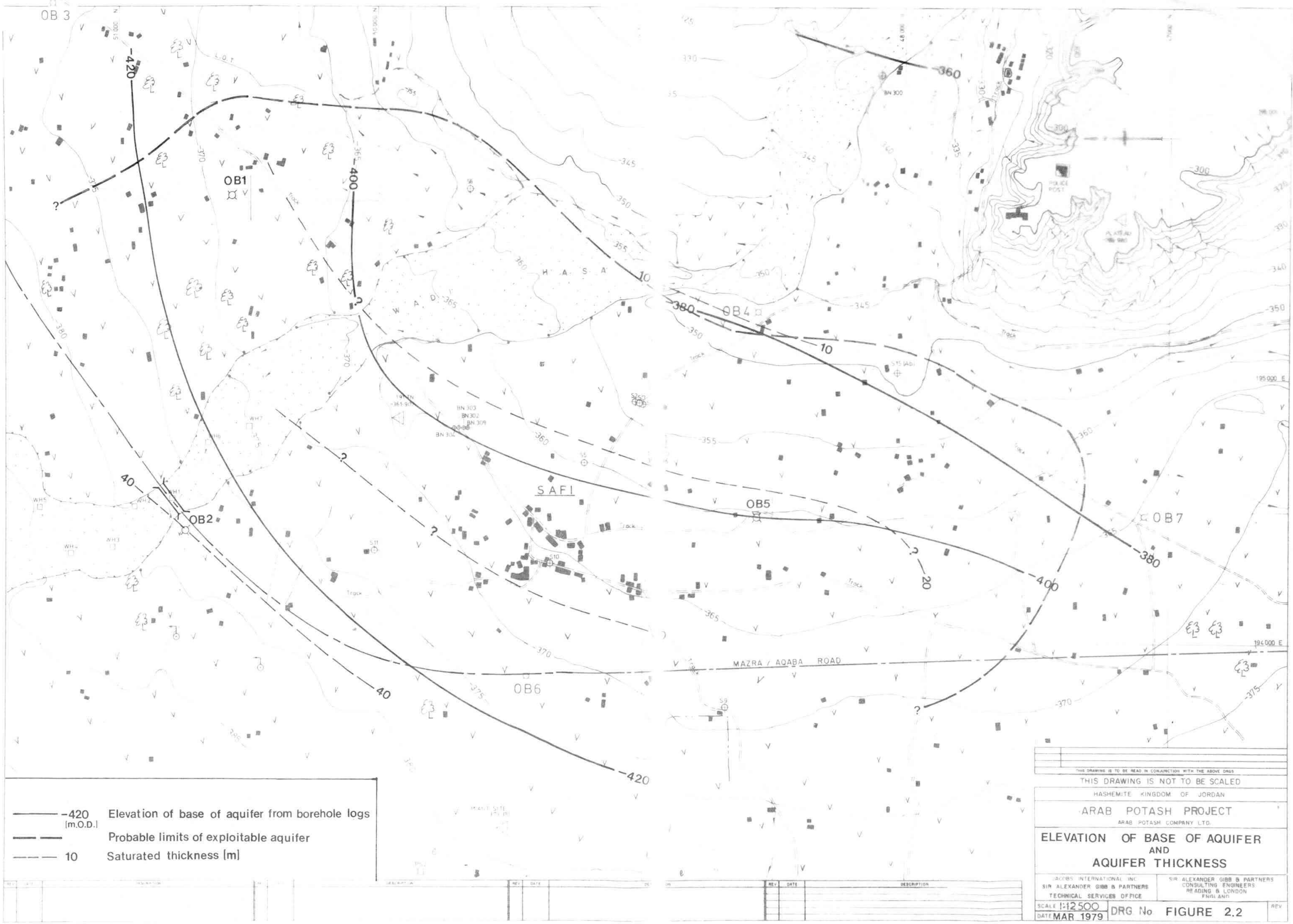
Recharge

The annual rainfall at Ghor Safi is only 50 mm whilst the annual evaporation is nearly 2 m. Consequently, direct recharge of the aquifer from rainfall is unlikely. Instead the principal source of recharge is provided by the Wadi Hasa as excess irrigation water, canal seepage and the infiltration of undiverted baseflow and flood flows along the wadi channel.

Whilst our understanding of the hydrology is by no means complete, we have used the additional measurements of undiverted baseflow, the areal distribution of diverted flow and of water level fluctuations to estimate recharge in the area of the exploitable aquifer.

We have chosen a conservative approach in our estimates of recharge using the following assumptions:

- the average annual diversion of baseflow for irrigation is estimated



OB 3
OB1
OB2
OB4
OB5
OB6
OB7
SAFI
W A D I H A S A
MAZRA / AQABA ROAD
POLICE POST
BN 300
BN 303
BN 302
BN 309
BN 304
194000 E
195000 E
-420
-400
380
360
10
20
40
400
420
?
-420 [m.O.D.] Elevation of base of aquifer from borehole logs
Probable limits of exploitable aquifer
10 Saturated thickness [m]
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THIS DRAWING IS NOT TO BE SCALED
HASHEMITE KINGDOM OF JORDAN
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ELEVATION OF BASE OF AQUIFER
AND
AQUIFER THICKNESS
JACOBS INTERNATIONAL INC
SIR ALEXANDER GIBB & PARTNERS
TECHNICAL SERVICES OFFICE
SIR ALEXANDER GIBB & PARTNERS
CONSULTING ENGINEERS
READING & LONDON
ENGLAND
SCALE 1:12500
DATE MAR 1979
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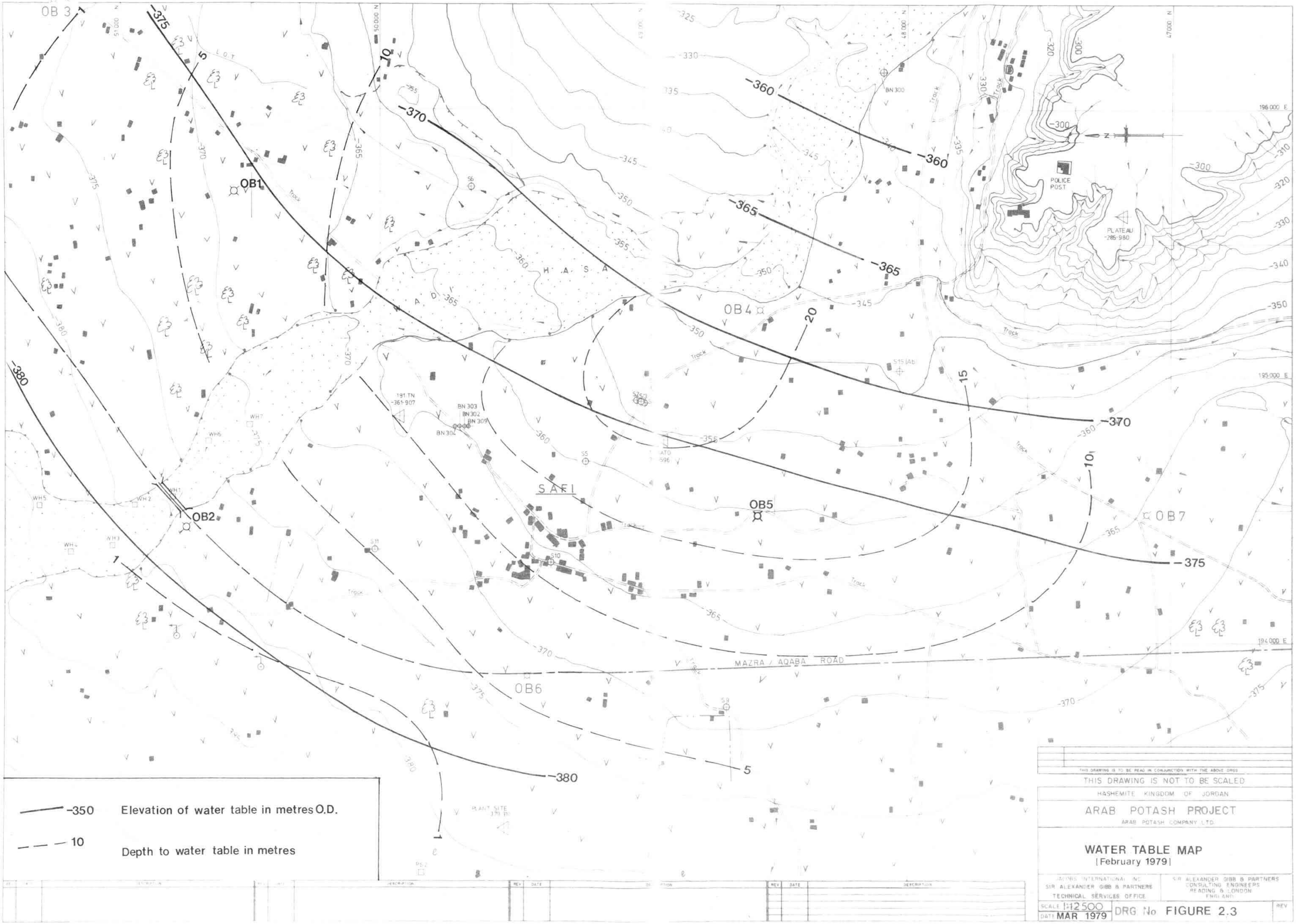

OB 3
OB1
OB2
OB4
OB5
OB6
OB7
H A S A
SAFI
POLICE POST
PLATEAU
MAZRA / AQABA ROAD
BN 300
BN 303
BN 302
BN 309
BN 304
191 TN -361·907
PLANT SITE
WH1
WH2
WH3
WH4
WH5
WH6
WH7
S5
S6
S10
S11
-350 Elevation of water table in metres O.D.
10 Depth to water table in metres
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HASHEMITE KINGDOM OF JORDAN
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WATER TABLE MAP
(February 1979)
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CONSULTING ENGINEERS
READING & LONDON
ENGLAND
SCALE 1:12500
DATE MAR 1979
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to be 25 million m^3, of which about 40 per cent, or 10 million m^3, enters the exploitable aquifer area. We have assumed that 10 per cent of this available diverted flow recharges the aquifer as canal seepage and that 25 per cent of the water actually applied to the cropped area also recharges the aquifer;

- the average annual availability of undiverted baseflow is estimated to be 5 million m^3. We have assumed that 50 per cent of this flow subsequently recharges the aquifer;

- we have used the average rise in water level measured at S6 and BN 302 during the winter months of 1977 and 1978 to estimate the likely contribution to recharge from flood flows. We have assumed that the same rise in water level occurs throughout the wellfield.

With these assumptions, we have estimated the annual recharge in the wellfield are to be as follows:

		Million m^3
Diverted baseflow recharge from canal seepage and excess irrigation water		3.3
Undiverted baseflow recharge along channel		2.5
Flood flow recharge along channel		0.3
	Total:	6.1

Although a number of assumptions have been made to estimate recharge, it is very similar to the annual flow through the exploitable area, estimated to be 6 million m^3. This would tend to confirm our higher estimates of transmissivity.

The estimated annual recharge is similar to the Stage 1 requirements of the Potash Process Plant of 5.7 million m^3/year. The present consumptive loss from private borehole abstraction (S10) is about

0.5 million m^3/year. Any increase in private abstraction is likely to be at the expense of the availability of groundwater for the wellfield.

Because of the similarity between recharge and the water supply requirements, we recommend the continued collection of hydrological data and detailed monitoring of the effects of abstraction in order to refine our estimate of recharge.

In our recharge estimates, we have examined only the exploitable aquifer area. This area is, of course, in hydraulic connection with the less favourable remaining area of the Ghor Safi alluvial aquifer. If recharge in the exploitable aquifer area were to be exceeded by total abstraction then the composite cone of depression would expand to intersect a greater volume of recharge. The controlling factor would then be whether the available drawdown at each production borehole was able to accommodate the deeper cones of depression that would consequently develop.

A digital model of the Safi wellfield would enable the hydrological information and the aquifer parameters to be brought together for comparison with the water table configuration to estimate recharge. Subsequently, the digital model could be used to test possible alternative management options for longer term planning purposes.

II.2 BOREHOLE LOCATIONS

Five new production boreholes are to be drilled to complete the Safi wellfield. These will have the reference numbers SPB1 to SPB5. Provisional locations for these boreholes were selected in 1978 based on findings of the water resources study of 1977. These locations have been altered to take advantage of more favourable locations indicated by the further investigations and to accommodate existing water rights. The new locations are shown in Figure 2.1.

Our selection of the borehole locations were largely governed by the following:

- suitable aquifer conditions to provide the required yields;

- sufficient spacing to intersect as much recharge as possible and to avoid the upconing of poor quality water from the underlying clays;

- Government regulations regarding interference with existing groundwater abstractions rights.

The aquifer conditions are more favourable and greater recharge occurs in the wellfield area south of the wadi channel. We have therefore concentrated the abstraction in this part of the wellfield from which about 66 per cent of the supply will be obtained.

We understand that since 1977 it has been necessary to obtain permission from Government to drill new boreholes in certain restricted areas of Jordan and also that no two wells may be closer than 500 m unless operated by the same owner. Within the wellfield area the only existing private borehole capable of abstraction is S10 at Safi but in November 1978 a drilling licence was granted to drill a private borehole (S18) at map reference 194608E 50153N (Figure 2.1). As this has now established water rights, this new borehole has been taken into account in selecting the production borehole locations to comply with Government regulations.

We understand that application has been made to abstract 12000 m^3/d from the new private borehole, S18. Although we believe it is unlikely that this abstraction rate can be maintained without excessive drawdown, the increase in the annual abstraction will certainly interfere with the availability of water for the Safi wellfield, particularly in regard to the longer term water supply requirements.

The original decision to abstract groundwater at Ghor Safi to supply the Potash Process Plant was partly based on the limited groundwater development of the aquifer and furthermore, the estimated annual recharge is similar to the water supply requirements of Stage 1. We therefore believe that private borehole abstraction must be limited and that permission should not be granted for further private borehole construction until the groundwater resources can be fully evaluated.

We have predicted the theoretical drawdowns at each of the selected borehole locations after four years' abstraction for well design purposes. For these predictions, we have used an abstraction of 2500 m^3/d per borehole (SPB1 to 5, S2) or a total abstraction of 5.5 million m^3/year, a transmissivity of 5000 m^2/d and a storativity of 0.15.

We have also predicted the additional drawdown resulting from interference at each new production borehole as given in Table 2.1. The same conditions as given above have been used for these predictions of interference, which are about 1 m at each borehole.

A number of assumptions have been made in predicting the likely drawdowns, such as an areally extensive and homogeneous aquifer, and private abstraction effects are not included. These predictions should be considered as a preliminary estimate of the ability of the aquifer to supply the requirements given uniform aquifer conditions. However, the other factor controlling the sustained yield of the aquifer, the amount of recharge, is best examined by means of a digital model.

II.3 BASIC WELL DESIGNS (SPB1 to SPB5)

The provisional design details for the boreholes forming the wellfield (SPB1 to 5, S2 and BN 309) are given in Contract 3, Vol. 11, Specification (June 1978). These details were based upon the aquifer conditions indicated by the groundwater investigations carried out in 1977. The proposed sites for SPB1 and SPB5 have now been relocated following the further investigations of the wellfield area and to accommodate existing groundwater abstraction rights. This in turn requires some redesign of each borehole, although the final design will depend on the aquifer conditions determined by drilling and testing.

TABLE 2.1

SAFI PRODUCTION BOREHOLES

PREDICTED INTERFERENCE EFFECTS
(metres)

	S2	SPB1	SPB2	SPB3	SPB4	SPB5
S2	-	0.205	0.225	0.19	0.16	0.18
SPB1	0.205	-	0.23	0.155	0.13	0.14
SPB2	0.225	0.23	-	0.19	0.14	0.145
SPB3	0.19	0.155	0.19	-	0.185	0.175
SPB4	0.16	0.13	0.14	0.185	-	0.22
SPB5	0.18	0.14	0.145	0.175	0.22	-
Total	0.96	0.86	0.93	0.895	0.835	0.86

Notes: Assumptions - T $\simeq$ 5000 m^2/d
S $\simeq$ 0.15
Q 2500 m^3/d borehole
Four years, continuous abstraction.

Private abstraction not included.
BN309 also not included as assumed to be standby supply

SAFI PRODUCTION BOREHOLES

BASIC WELL DESIGNS, SPB1 TO 5

	Borehole Number				
	SPB1	SPB2	SPB3	SPB4	SPB5
Proposed Location	19420E 4814N	19422E 4865N	19408E 4990N	19508E 5082N	19558E 5021N
Ground Level	-364	-364	-375	-374	-366
Depth to Rest Water Level (m)	12	13	5	4	10
Depth to Base of Aquifer (m)	41	41	40	46	39
Aquifer Thickness (m)	29	28	35	42	29
Drilled Depth (m)	37	37	36	42	35
Sump (m)	1	1	1	1	1
Base of Screen (m)	36	36	35	41	34
Screen Length (optimum minimum at 35% aquifer thickness) (m)	(10.1) 10	(10.1) 10	(12.25) 10	(14.7) 10	(10.1) 10
Top of Screen (or Casing Length) (m)	26	26	25	31	24
Maximum (Available Drawdown (m)	11	10	17	24	11
Maximum (Pumping Water Level (m)	22	23	22	28	21
Predicted Pumping Water Level (m)	15.5	16.5	8.5	7.5	13.5

Required Yield	2500 m^3/d/borehole
Fitted Pump Capacity	3000 m^3/d/borehole
Pump Bowl Nominal Diameter	200 mm
Optimum Casing and Screen Diameter	300 mm
Minimum Drilled Diameter	450 mm
Screen Slot Size	2.5 mm
Open Area	4170 mm^2/m/length
Transmitting Capacity of Screen (entrance velocity 3 cm/sec and full open area)	1100 m^3/d/m length

Drawdown estimates		
Drawdown estimates :	Theoretical Drawdown	1 m
(T 5000 m^2/d)	Well Loss 25%	0.25 m
S 0.15)	Interference	1 m
	Contingency	3 m
	Total (rounded)	5 m

The basic well designs are given in Table 2.2 and are based on the following minimum required aquifer thickness:

Allowance to avoid upconing		5 m
Screen length at 35 per cent of of aquifer thickness		10 m
Pump allowance and safety margin		3 m
Predicted possible drawdown	(say)	5 m
Minimum required aquifer thickness		23 m

Recently we suggested a location for SPB1 at reference 19454E/481N. Our appraisal of the basic well design requirements suggest that there may be insufficient available drawdown at this location, which was selected to take advantage of higher resistivities and to intercept some of the potential recharge from diverted flow that occurs in the southern area of the fan. We have now altered the location for SPB1 to 19420E/4815N where similar aquifer conditions to SPB2 should be encountered. Similarly the original location of SPB3 has been altered because of the construction of S18.

Upconing of poor quality water from the clays forming the base of the aquifer should be avoided to reduce the need for treatment. This risk would be minimized by setting the bottom of the screen 5 m above the clay. This will unfortunately increase the drawdown due to partial penetration.

We have recommended continuous-aperture type screen to minimize well losses and a minimum gravel pack thickness of 75 cm. The previously suggested slot size of 3 mm has been confirmed by the additional information collected concerning grain size distributions (see Appendix A).

The transmitting capacity of the recommended screen at optimum entrance velocities (3 cm/sec) is about 1100 m^3/d per metre length. At the effective open area about 6 m of screen would be required to meet the maximum capacity of the pump (3000 m^3/d). Greater aquifer thicknesses are indicated by the further investigations and therefore we have increased the original screen length from 6 m to 10 m to meet the normal practice of screening a minimum of 35 per cent of the aquifer thickness given unconfined conditions. This will produce a higher total transmitting capacity for the required yield, but will be beneficial in the longer term by increasing the well life, allowing higher pumping rates, and offsetting the loss of effective screen which can result where fine-grained horizons occur within the part of the sequence which is screened.

The predicted drawdowns have been estimated for comparison with the available drawdowns. These drawdowns must be proven by pumping tests on each new borehole. The available drawdown has allowed for the pump and a 1 m safety allowance. This assumes that the pump, at its lowest position, will be set at the bottom of the casing as the pump should not be set within the screen.

As it is likely that the production boreholes will be drilled by the percussion method, we suggest that pilot holes need not be constructed as originally planned.

III. CONCLUSIONS AND RECOMMENDATIONS

The area of Ghor Safi selected from the initial investigations during the feasibility study of 1977 has been confirmed as being suitable for the location of a wellfield to supply the Potash Process Plant. By incorporating two existing boreholes, five new boreholes will be required to complete the wellfield to provide the Stage 1 water supply requirements of 5.6 million m^3/year.

Suitable locations for the new boreholes have been selected with the additional information obtained from the geophysical survey and the observation borehole construction programme. Having established these locations, we have been able to review the preliminary borehole designs and to predict the likely drawdown at each borehole. The desired abstraction rates can be supported by the aquifer if the recharge is also sufficient.

Both the annual recharge and the groundwater flow in the exploitable area of the aquifer are estimated to be about 6 million m^3. We have examined this area in particular so that the well locations could be fixed, but in regard to the water resources this area cannot be considered in isolation from the rest of the Ghor Safi aquifer. Hence, the total groundwater resources of Ghor Safi might be potentially available to contribute to the wellfield. In this respect, we believe that the groundwater in storage in the aquifer is capable of maintaining supplies should this be necessary whilst other supply options are put into effect.

Nonetheless, the annual recharge is similar to the Stage 1 supply requirements; therefore any increase in private borehole abstraction or decrease in recharge will affect the supply to the Potash Process Plant. Consequently, we put forward the following recommendations:

1. Private borehole abstraction must be limited and permission should not be granted for any further private borehole construction

at Ghor Safi until the groundwater resources have been properly evaluated.

2. Similarly, any proposed changes in the use of the Wadi Hasa baseflow must be carefully considered if such changes are likely to reduce recharge to the aquifer.

3. All borehole abstractions and their effect on the aquifer must be carefully monitored as and when they come into production.

4. Observations should continue of natural groundwater level changes, losses of undiverted flow, the use of diverted flow and of fan-edge seepage. Such observations should be reviewed annually.

5. Digital model studies should be considered so as to examine the sustained yield of the aquifer and to test in advance the alternative management options for planning the provision of water supplies in the longer term.

APPENDIX A

OBSERVATION BOREHOLE DETAILS

The results obtained from the observation borehole construction are presented. A summary is given in diagrammatic form of the sample descriptions, the depths at which water was encountered, the final rest water level on completion and the design of each observation borehole OB1 to OB7.

The observation boreholes were drilled by the percussion method. Each was drilled to a depth of 50m or to prove the sequence of grey laminated clays which are believed to form the base of the main fresh water aquifer. Where these clays were encountered the drilled hole was backfilled to the overlying gravels. Slotted casing was installed from the rest water level to this depth. To avoid possible difficulties with borehole development lengths of blank casing were placed against any finer grained horizons. Development was carried out with an air-lift assembly.

During construction samples were collected at 1m intervals or at significant changes in the strata for lithological description. Brief descriptions of the strata encountered are given. Duplicate samples from selected horizons were collected for sieve analysis and water samples were also taken for routine chemical analysis.

LIST OF SYMBOLS

← Depth water was encountered, numbered consecutively.

Water level related to depth at which water was encountered.

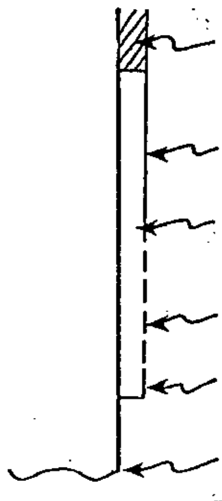
Rest water level at completion

c : coarse

m : medium

f : fine

NB: where grain size is undifferentiated, the deposits consists of fine, medium and coarse grain sizes.



Concrete seal

4" ID steel casing

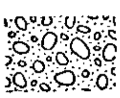
2" annulus gravel pack

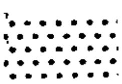
slotted casing

1m sump

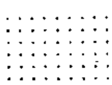
Drilled depth

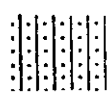
 gravel

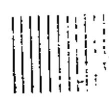
 sandy gravel

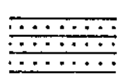
 coarse sand

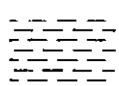
 medium sand

 fine sand

 sandy silt

 silt

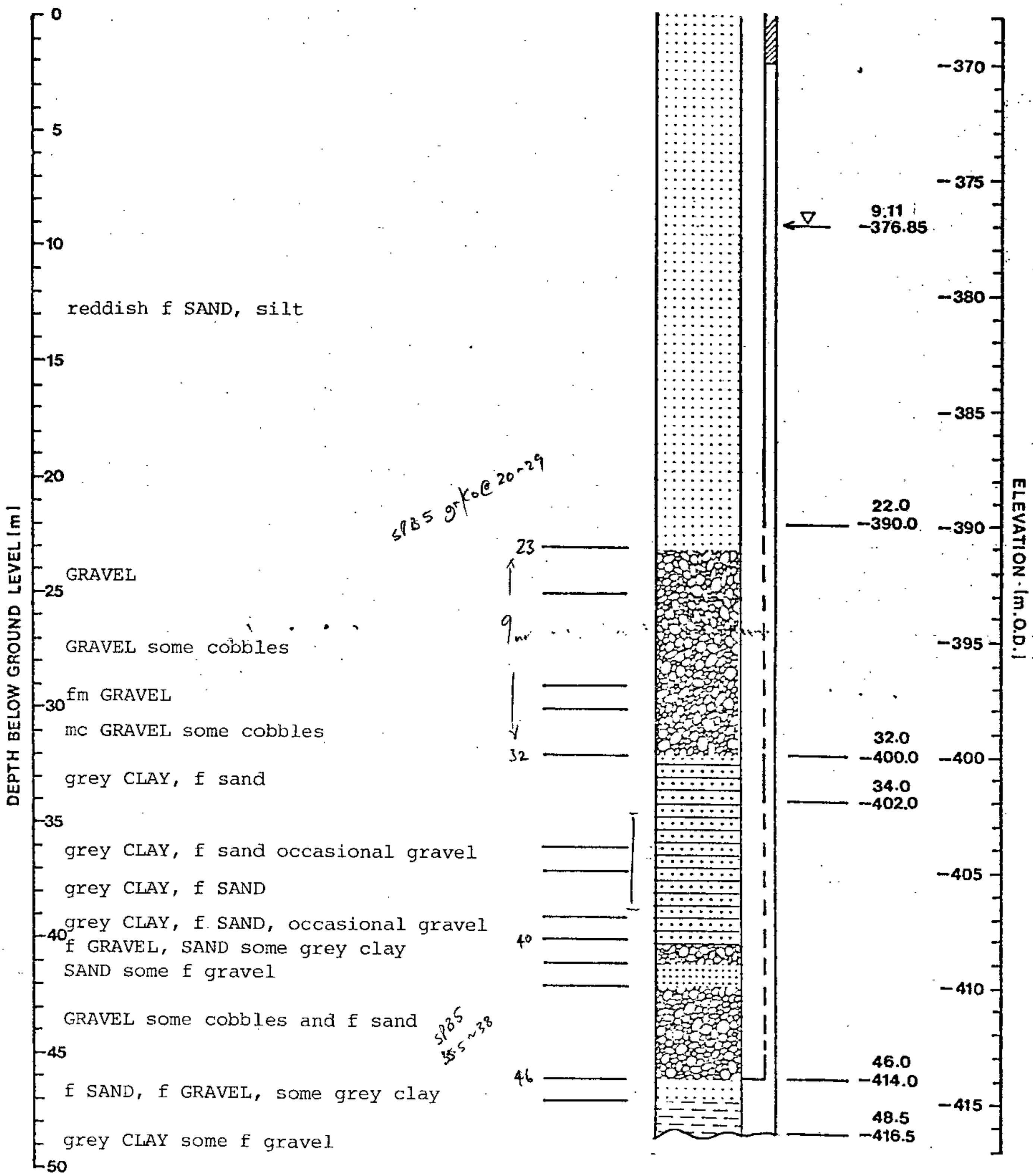
 sandy clay

 clay

OBSERVATION BOREHOLE, OB1

ELEVATION OF TOP OF CASING : − 367.74 m.O.D

MAP LOCATION: 195691 E 50565 N

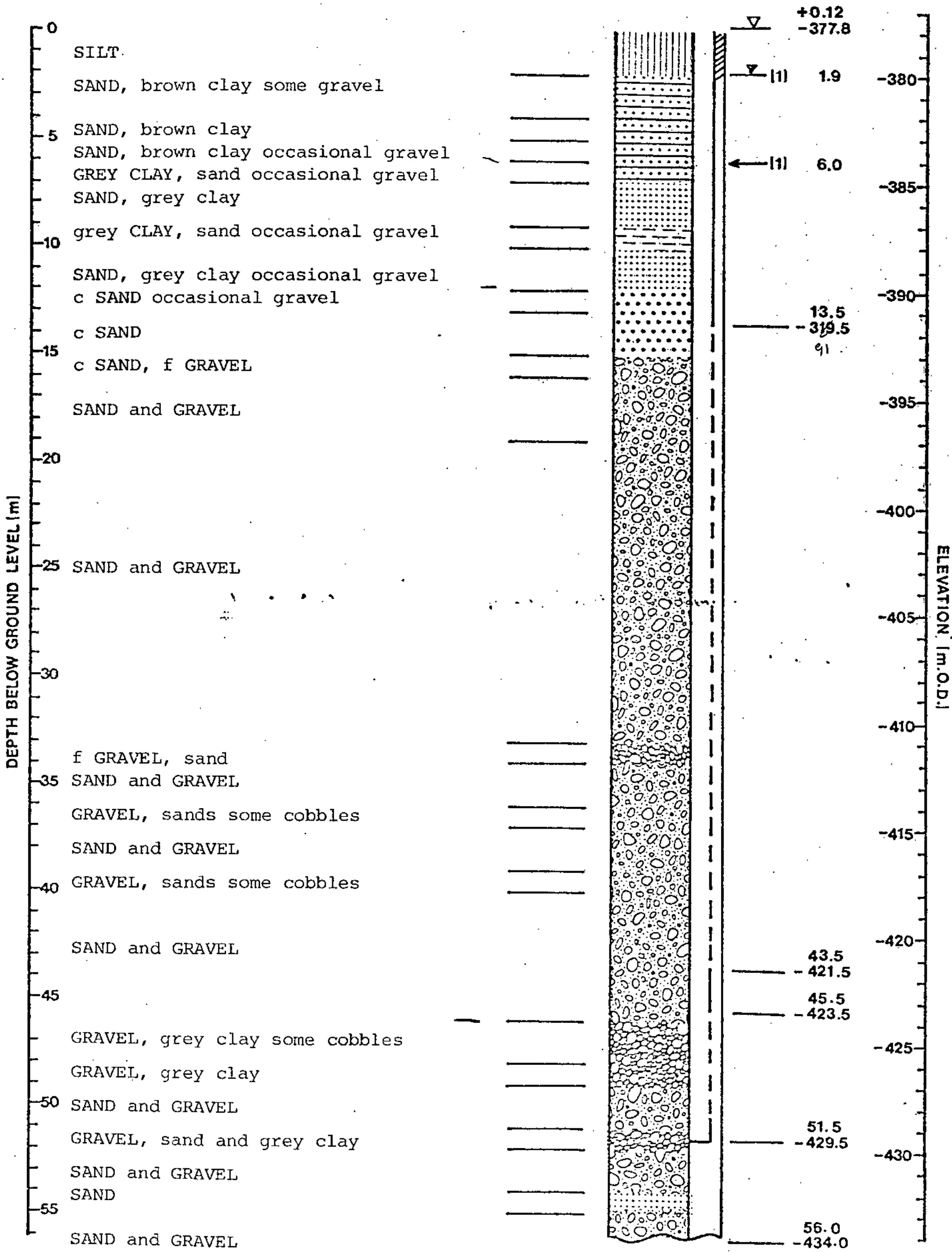


NOTE: Although indicated as clays, it is believed that the sequence from 35 to 39 m consists of gravels.

OBSERVATION BOREHOLE, OB2

ELEVATION OF TOP OF CASING: −377·92 m.O D

MAP LOCATION: 194423 E 50750 N



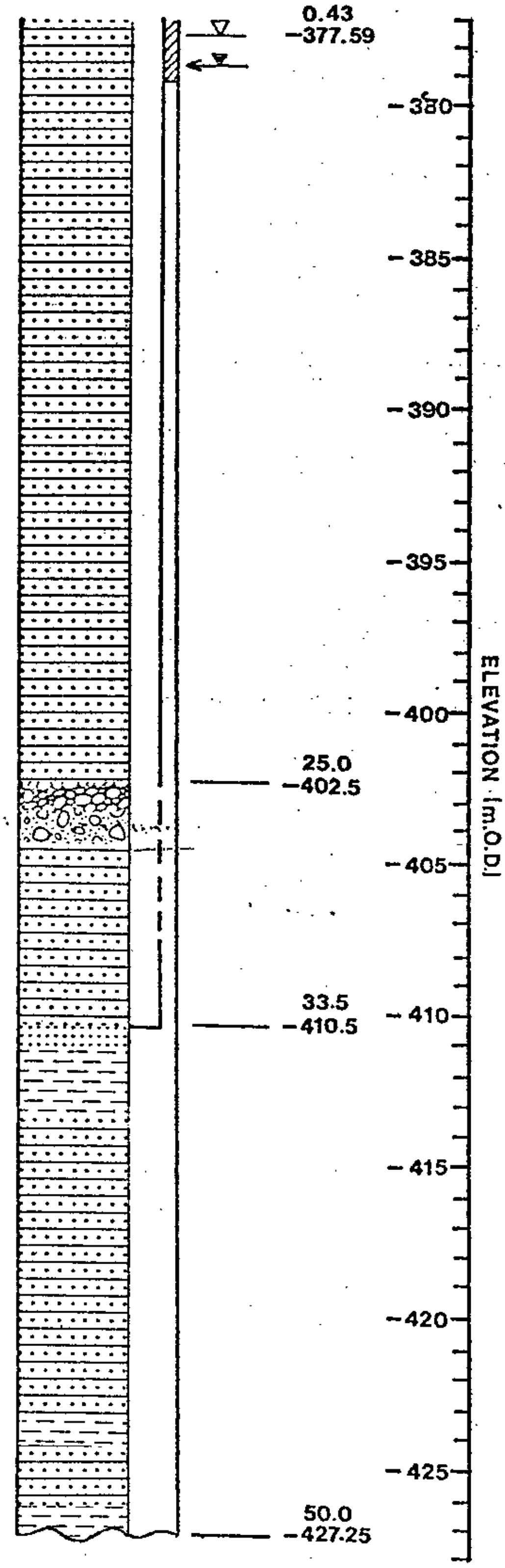
OBSERVATION BOREHOLE, OB3

ELEVATION OF TOP OF CASING : −377.16 m.O.D.

MAP LOCATION : 196422E 51243N

DEPTH BELOW GROUND LEVEL (m)

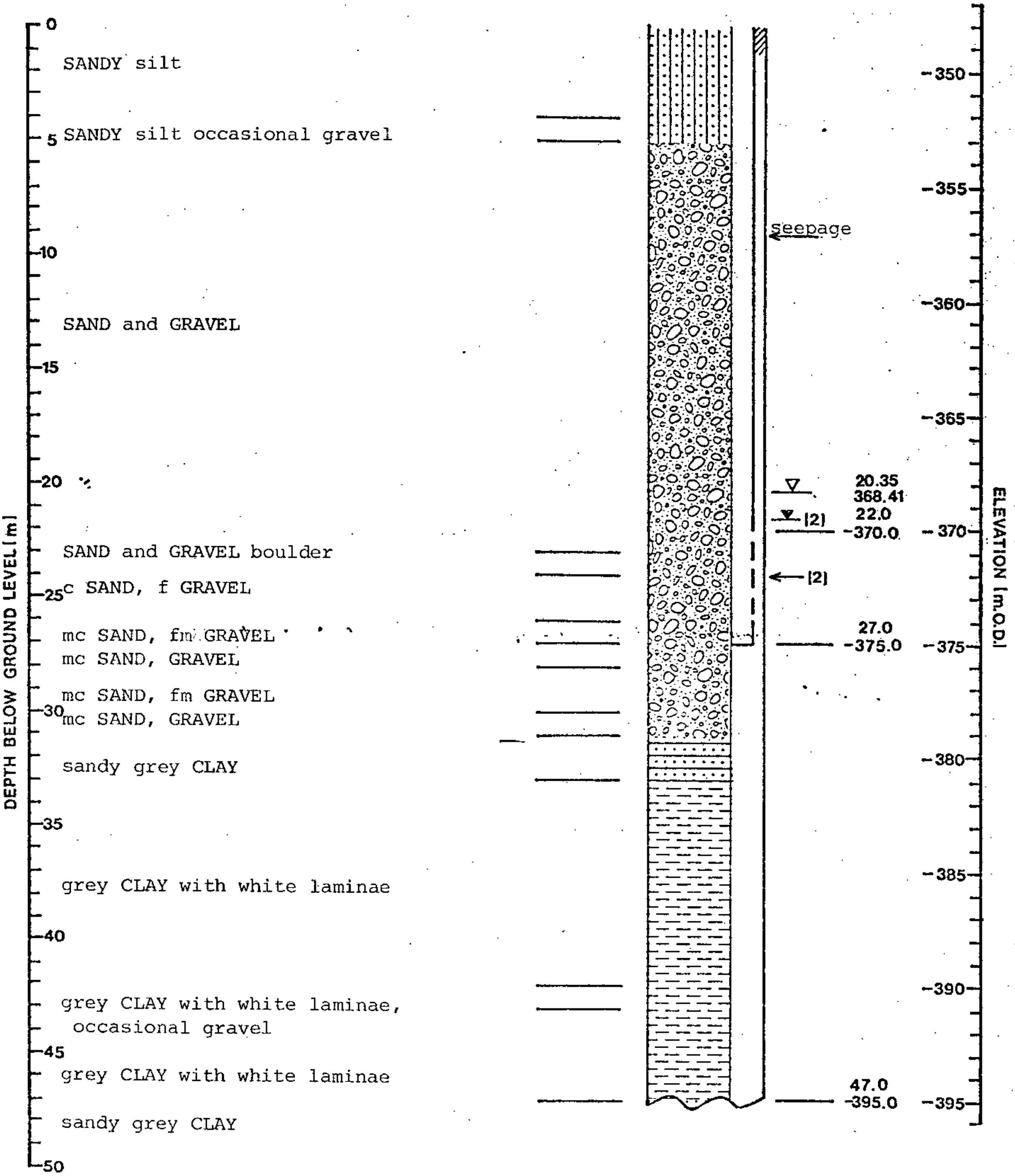
0
reddish m SAND, brown clay
brown CLAY, m sand
brown CLAY, f sand
5
brown CLAY, mc sand
brown CLAY, m sand
brown CLAY, f sand occasional f gravel
brown CLAY, f sand
10
brown CLAY, m sand
brown grey CLAY, f sand
brown grey CLAY, m sand occasional f/
15
brown CLAY, mc sand /gravel
brown CLAY, f sand and occasional/ /gravel
reddish brown CLAY, f sand occasional/ /f gravel
20
reddish grey CLAY, f sand
brown CLAY, m sand occasional f gravel
brown grey CLAY, f sand some f gravel
brown CLAY, f sand occasional f gravel
25
mc GRAVEL
f GRAVEL, mc SAND
grey CLAY, m sand, f gravel
grey CLAY, f sand, some f gravel
30
grey CLAY, f sand
mc SAND
35
grey brown CLAY some f gravel
grey brown CLAY, f gravel, f sand
brown CLAY, f sand
40
brown grey CLAY, f sand
brown grey CLAY, f sand occasional f/ /gravel
brown grey CLAY, fm sand
45
grey CLAY, f sand
grey CLAY some f gravel
grey CLAY, f sand
50
grey CLAY, f sand some f gravel
grey CLAY some f gravel



OBSERVATION BOREHOLE, OB4

ELEVATION OF TOP OF CASING: −348.06 m.O.D.

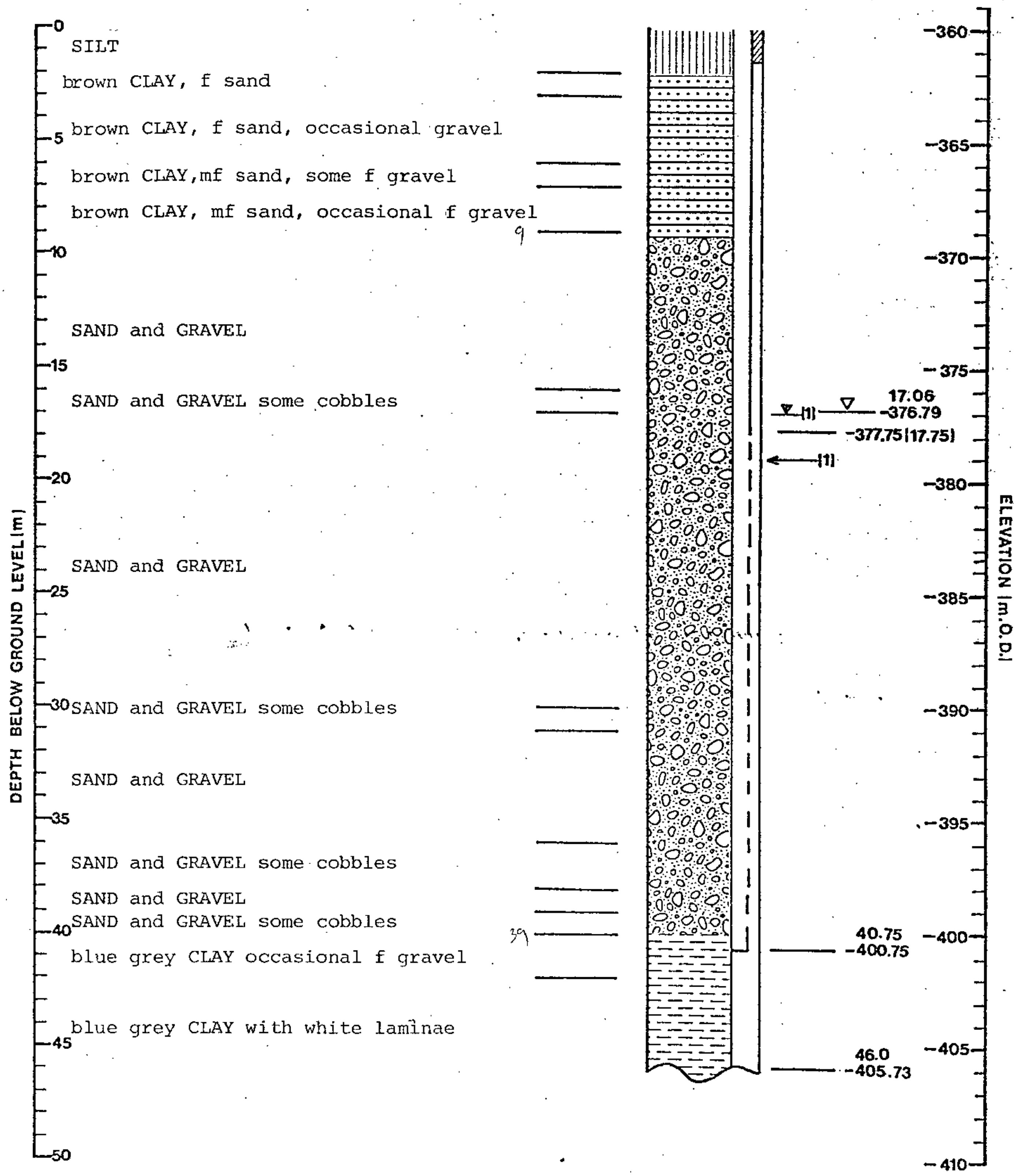
MAP LOCATION: 195241E 48540N



OBSERVATION BOREHOLE, OB5

ELEVATION OF TOP OF CASING: −359.73 m.O.D.

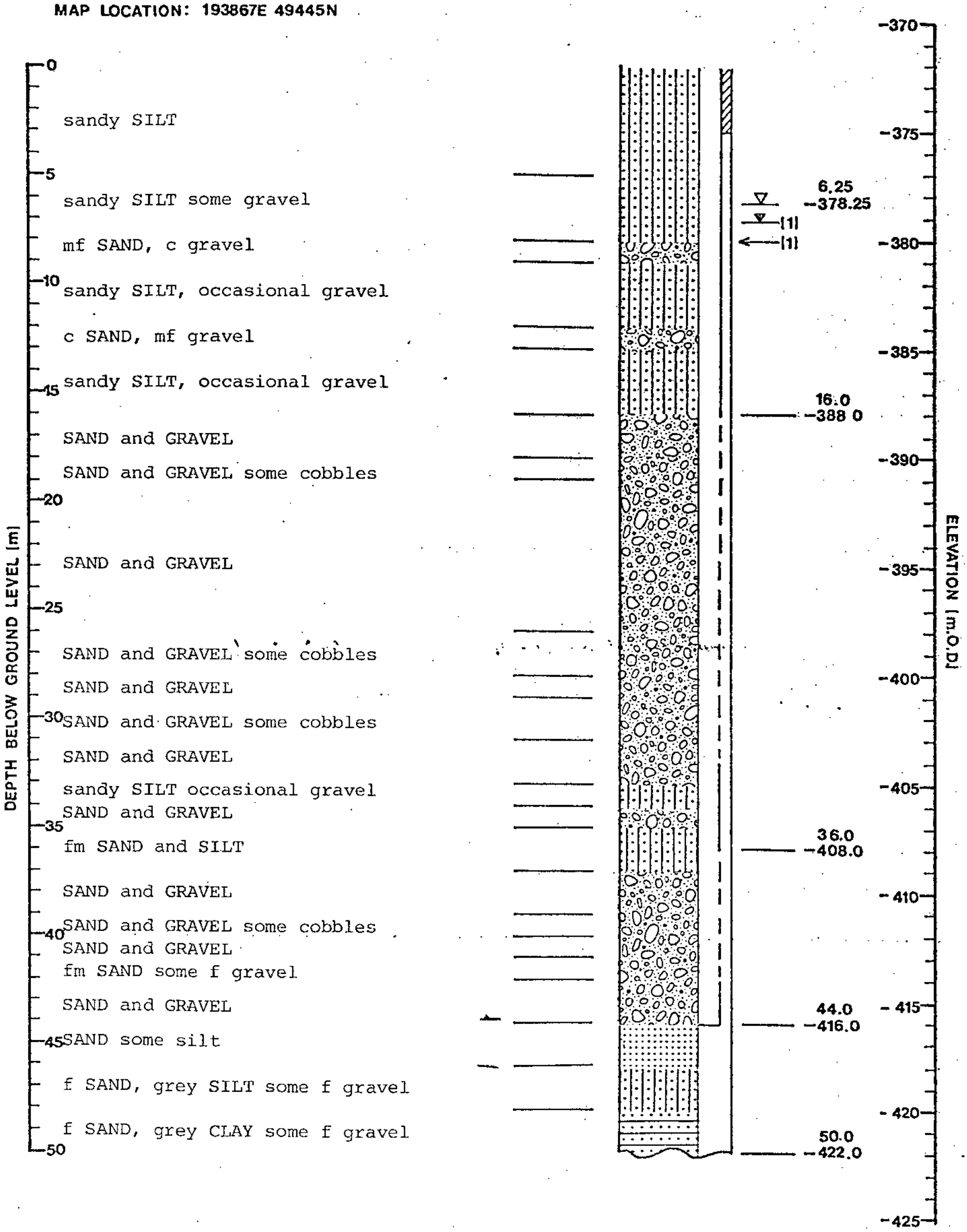
MAP LOCATION: 19448E 48554N



OBSERVATION BOREHOLE, OB6

ELEVATION OF TOP OF CASING: −371.78 m.O.D.

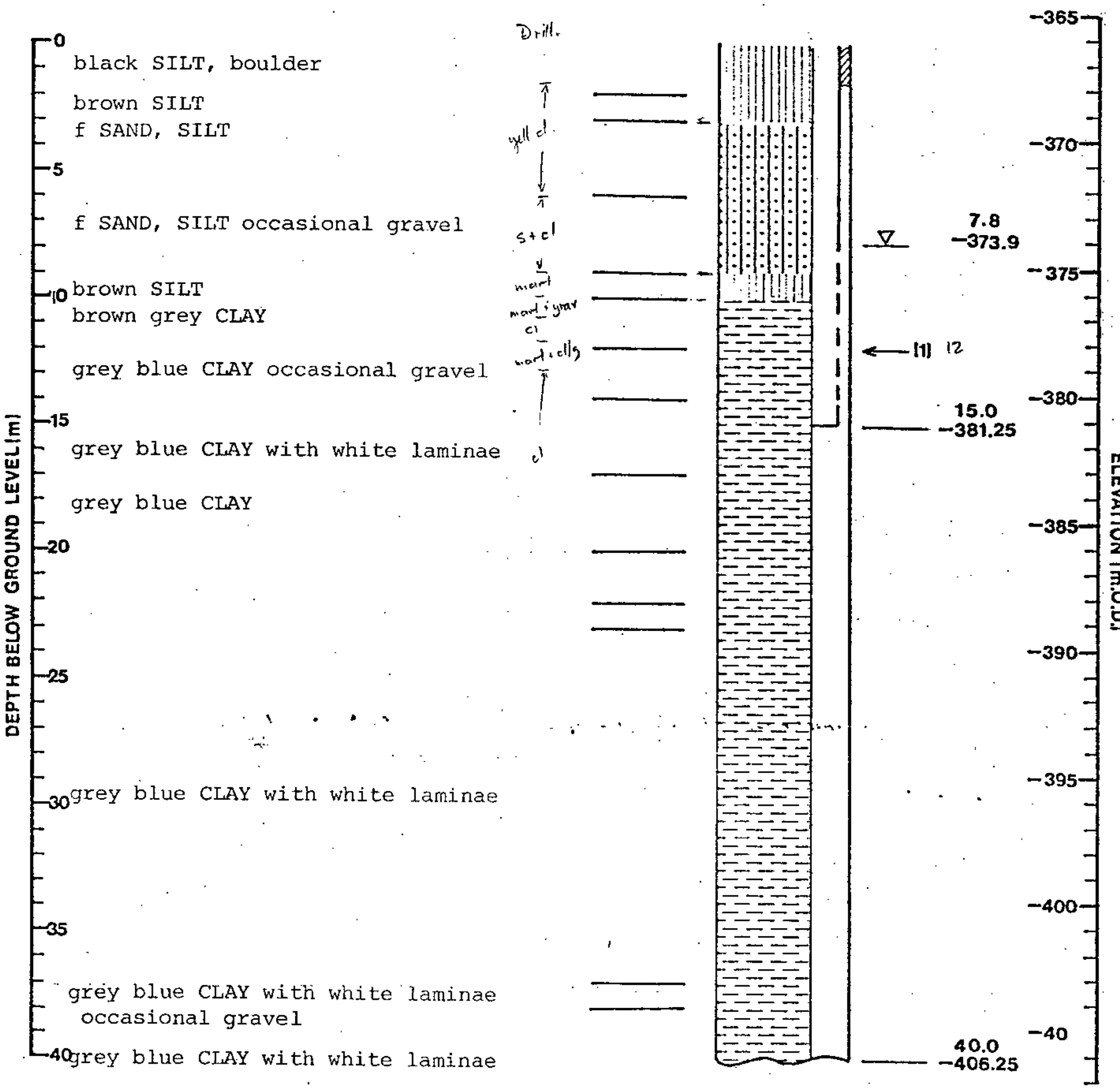
MAP LOCATION: 193867E 49445N



OBSERVATION BOREHOLE, OB7

ELEVATION OF TOP OF CASING: −366.14 m.O.D

MAP LOCATION: 194516E 47094N



ws 12

wl during drilling 7.7

final wl 7.8

The following completion reports were prepared by Nasr Brothers Well Drilling & Trading Co. on the completion of the observation boreholes at Ghor Safi (Contract 5).

COMPLETION REPORT O.B. NO.1

1. LOCATION - East 195 691   North 50 565
   Elevation -367.738 M.O.D.

2. DRILLING RIG TYPE - Cyclone 44, Percussion

3. TIME - Drilling - 8.12.1978 to 26.12.1978
   Developing - 12. 1.1979 to 18. 1.1979
   Capping - 24. 1.1979 to 12. 2.1979

4. CASING LOWERED DURING DRILLING -

12 inch N.D. casing with couplings	=	20.70 m.
10 inch N.D. casing with couplings	=	28.35 m.
8 inch N.D. casing with couplings	=	45.88 m.
Total depth of borehole	=	50.00 m.

5. FORMATION -

0	-	1	Alluvium
1	-	20	Sand
20	-	21	Sand and Gravel
21	-	31.5	Gravel
31.5	-	50	Sandy Clay

6. WATER - First seepage of water at 10 m.
   S.W.L. when water was encountered 9 m.
   S.W.L. after developing the well 9.11 m.

7. PIEZOMETER TUBE SETTING -

Blank	0	-	22 m.
Perforated	22	-	32 m.
Blank	32	-	34 m.
Perforated	34	-	45 m.
Blank with end cap	45	-	46 m.
Back filling	46	-	50 m.

The piezometer tube is 4 inch I.D. steel pipe, threaded 4 threads per inch, wall thickness 10 mm. approximately, with couplings.

8. GRAVEL - the well was gravel packed with gravel to the surface of the ground.

9. DEVELOPMENT - An air-lift was used for cleaning and developing. At the end of development gravel was added to male the top of the pack 3 metres from ground level.

The compressor was run from 12.1.1979 to 18.1.1979.

COMPLETION REPORT, O.B. No. 2

1. LOCATION - East 194 423 North 50 750
Elevation - -377.917 M.O.D.

2. DRILLING RIG - Bucyrus-Erie, 28L Percussion.

3. TIME -

Drilling	5.1.1979 to 24.1.1979	
Developing	27.1.1979 to 5.2.1979	
Cement Pad	5.2.1979 to 11.2. 1979	

4. CASING LOWERED DURING DRILLING

16" N.D. casing with couplings	=	5.97 m
12" N.D. casing with couplings	=	28.07 m
10" N.D. casing with couplings	=	37.31 m
8" N.D. casing with couplings	=	54.51 m
Total depth of borehole	=	56.00 m

5. FORMATION -

0 - 1	Alluvium
1 - 6	Sandy layer with some Gravel
6 - 10	Clayey layer
10 - 11	Clay with Sand and few Gravel
11 - 14	Clay with Sand
14 - 23	Silt with Gravel
23 - 26	Gravel
26 - 32	Gravel with Silt
32 - 40	Gravel with Sand
40 - 45	Gravel
45 - 46	Gravel with layer of Clay
46 - 47	Gravel with little Clay
47 - 52	Gravel
52 - 54	Gravel with some Clay
54 - 56	Gravel and Sand

6. WATER - First seepage of water was encountered at 7 m

S.W.L. when water was encountered	1.85 m
S.W.L. at the depth of 14 m	0.90 m
S.W.L. at the end of developing	Flowing

7. PIEZOMETER TUBE SETTING -

Blank	0	-	13.5 m
Perforated	13.5	-	43.5 m
Blank	43.5	-	45.5 m
Perforated	45.5	-	50.5 m
Blank with end cap	50.5	-	51.5 m
Back filled with Gravel	51.5	-	56.0 m

The piezometer tube is 4" I.D. steel pipe, 10 mm thick approximately, with coupling, threaded 4 threads per inch.

8. GRAVEL - The well was gravel packed to the surface.

9. DEVELOPMENT - Air-lifting was used to clean and develop the borehole. Gravel was added to the depth of 3 m from g.l. The Compressor was run from 27.1.1979 to 5.2.1979. The water was artesian and with a head of about 40 cms above the piezometer tube head.

COMPLETION REPORT O.B. No. 3

1. LOCATION - East 196 422 North 51 243
   Elevation -377.158 M.O.D.

2. DRILLING RIG TYPE - Cyclone 44, Percussion.

3. TIME -

Drilling	28.10.1978 to 8.12.1978
Developing	12. 2.1979 to 16. 2.1979
Well capping	17. 2.1979 to 18. 2.1979

4. CASING LOWERED DURING DRILLING -

16" N.D. casing with couplings	=	5.60 m
12" N.D. casing with couplings	=	12.29 m
10" N.D. casing with couplings	=	25.00 m
8" N.D. casing with couplings	=	48.00 m
Total depth of borehole	=	50.00 m

5. FORMATION -

0 - 4	Clayey topsoil
4 - 5	Silty Clay with Sand and Gravel
5 - 11	Sand
11 - 12	Sand with Gravel
12 - 15	Sand with Clay
15 - 16	Clay with some Gravel
16 - 24	Clay
24 - 26	Gravel
26 - 30	Clay
30 - 32	Clay with fine Sand
32 - 33	Sand
33 - 48	Clay with Sand
48 - 50	Clay with some Gravel

6. WATER -

First seepage of water at	3 m
S.W.L. was	1.08 m
S.W.L. after developing	0.43 m

7. PIEZOMETER TUBE - The Piezometer tube is 4" I.D. steel pipe with threads and couplings, threaded 4 threads per inch, wall thickness 10 mm approximately.

Blank	0 - 24 m
Perforated	24 - 29 m
Blank with end cap	29 - 32 m
Back-filled with Gravel	32 - 50 m

8. GRAVEL - The gravel was taken from Dead Sea shore, and the borehole was filled to the surface of the ground.

9. DEVELOPING - Air-lifting was used to clean and develop the borehole. Gravel was then added to 3 m depth from ground level.
The compressor was run from 12.2.1979 to 16.2.1979.
The water at the end of development improved to a great extent.

COMPLETION REPORT O.B. NO. 4

1. LOCATION - East 195 241 North 48 540
Elevation: -348.058 M.O.D.

2. DRILLING RIG TYPE - Bucyrus-Erie, 28 L, Percussion.

3. TIME -

Drilling	27.1.1979 to 19.2.1979
Developing	20.2.1979 to 22.2.1979
Well capping	24.2.1979 to 25.2.1979

4. CASING LOWERED DURING DRILLING -

16" N.D. casing with couplings	=	10.60 m
12" N.D. casing with couplings	=	24.73 m
10" N.D. casing with couplings	=	31.46 m
Total depth of borehole	=	47.00 m

5. FORMATION -

0 - 2	topsoil
2 - 4	Clay
4 - 9.5	Gravel with little Clay
9.5 - 16	fine Gravel with Sand
16 - 22	Gravel
22 - 23	Gravel with boulders
23 - 24	Gravel
24 - 26	Sand
26 - 31	Gravelly Sand
31 - 47	Clay

6. WATER -

Struck at the depth of	24 m
S.W.L. during drilling	21.5 m
S.W.L. after developing	20.35 m

7. PIEZOMETER TUBE SETTING -

Blank	0 - 22 m
Perforated	22 - 26 m
Blank with cap	26 - 27 m
Back-filled	27 - 47 m

The piezometer tube is 4" I.D. steel pipe with couplings, threaded 4 threads per inch, wall thickness 10 mm approximately.

8. GRAVEL - was poured to the surface of the ground

9. DEVELOPING - Air-lifting was used to clean and develop the borehole. The compressor was run from 20.2.1979 to 22.2.1979.

COMPLETION REPORT O.B. NO.5

1. LOCATION - East 194 484 North 48 554
   Elevation: -359.730 M.O.D.

2. DRILLING RIG TYPE - Cyclone 44, Percussion

3. TIME -

Drilling	14.1.1979 to 2.2.1979
Developing	7.2.1979 to 12.2.1979
Well capping	13.2.1979 to 19.2.1979

4. CASING LOWERED DURING DRILLING -

12" N.D. casing with couplings	=	26.60 m
10" N.D. casing with couplings	=	35.13 m
8" N.D. casing with couplings	=	41.95
Total depth of borehole	=	46.00 m

5. FORMATION -

0 - 4	Topsoil
4 - 10	Gravel with Clay
10 - 22	Gravel with big cobbles
22 - 39	Gravel
39 - 46	Lisan Marl with very bad smell

6. WATER - Water was encountered at the depth of 19.00 m
   S.W.L. during drilling 16.95 m
   S.W.L. after developing 17.06 m

7. PIEZOMETER TUBE SETTING -

Blank	0 - 18 m
Perforated	18 - 40 m
Blank with end cap	40 - 41 m
Back-filled with Gravel	41 - 46 m

   The piezometer tube is 4" I.D. Steel pipe, with couplings, threaded 4 threads per inch, and with wall thickness of 10 mm approximately.

8. GRAVEL - was poured to the surface of the ground.

9. DEVELOPING - Air-lifting was used to clean and develop the borehole. The Compressor was run from 7.2.1979 to 12.2.1979

COMPLETION REPORT O.B. NO. 6

1. LOCATION - East 193 867 North 49 445
   Elevation: -371.781 m O.D.

2. DRILLING RIG - Cyclone 44, Percussion

3. TIME - Drilling 26.12.1979 to 14.1.1979
   Developing 20. 1.1979 to 26.1.1979
   Well capping 27. 1.1979 to 10.2.1979

4. CASING LOWERED DURING DRILLING -

12" N.D. casing with couplings	=	17.65 m
10" N.D. casing with couplings	=	38.38 m
8" N.D. casing with couplings	=	45.76 m
Total depth of hole	=	51.00 m

5. FORMATION -

0 - 1	Alluvium
1 - 7	Gravelly Clay layer
7 - 8	Gravel
8 - 12	Sandy Clay and Gravel
12 - 13	Clay and Gravel
13 - 16	Clay
16 - 18	Gravel and Clay
18 - 25	Gravel with Sand and pebbles with heavy Clay mottled with red stain
25 - 32	Gravel, big and small
32 - 36	Silty Sand with Silt and Gravel
36 - 44	Sandy Gravel
44 - 51	Fine material with Clay pockets (Lisan Marl)

6. WATER -

Struck at	8.00 m
S.W.L. during drilling was	7.34 m
S.W.L. after developing was	6.24 m

7. PIEZOMETER TUBE -

The piezometer tube is 4 inch I.D. steel tube, with couplings, threaded 4 threads per inch, wall thickness 100 approximately.

Blank	0 - 16 m
Perforated	16 - 32 m
Blank	32 - 36 m

Perforated	36 - 42 m
Blank with end cap	42 - 44 m
Back filled	44 - 51 m

8. GRAVEL - was poured to the surface of the ground.

9. DEVELOPMENT - Air-ifting was used to clean and develop the borehole. The compressor was run from 20.1.79 to 26.1.79.

COMPLETION REPORT O.B. No. 7

1. LOCATION - East 194 516 North 47 094
   Elevation: -366.139 m O.D.

2. TYPE OF DRILLING RIG - Cyclone 44, Percussion

3. TIME -

Drilling	from 2.2.1979 to 15.2.1979
Developing	from 16.2.1979 to 20.2.1979
Well capping	from 22.2.1979 to 23.2.1979

4. CASING LOWERED DURING DRILLING -

12" N.D. casing with couplings	= nil
10" N.D. casing with couplings	= nil
8" N.D. casing with couplings	= nil
Total depth drilled	= 40. 00 m

5. FORMATION -

0	-	0.5	Topsoil
0.5	-	1.5	Hard Sandstone Boulder
1.5	-	6	Yellow Clay
6	-	9	Sand with Clay
9	-	10	Marl
10	-	11	Marl with Gravel
11	-	12	Clay
12	-	13	Marl with Clay and Gravel
13	-	40	Clay

6. WATER -

Struck at	12.00 m
S.W.L. during drilling	7.70 m
S.W.L. after extracting 3 bailers	9.40 m
S.W.L. after developing and cleaning	7.79 m

7. PIEZOMETER TUBE SETTING -

Blank	0 - 8 m
Perforated	8 - 14 m
Blank with end cap	14 - 15 m
Back-filled with gravel	15 - 40 m

The piezometer tube is 4 inch I.D. steel pipe, with threads and couplings, threaded 4 threads per inch, and with wall thickness of 10 mm approximately.

8. GRAVEL - was put in the borehole to the surface of the ground, before developing.

9. DEVELOPING - was done by air-lifting.
The compressor was run from 16.2.1979 to 20.2.1979.

Sieve Analysis Results

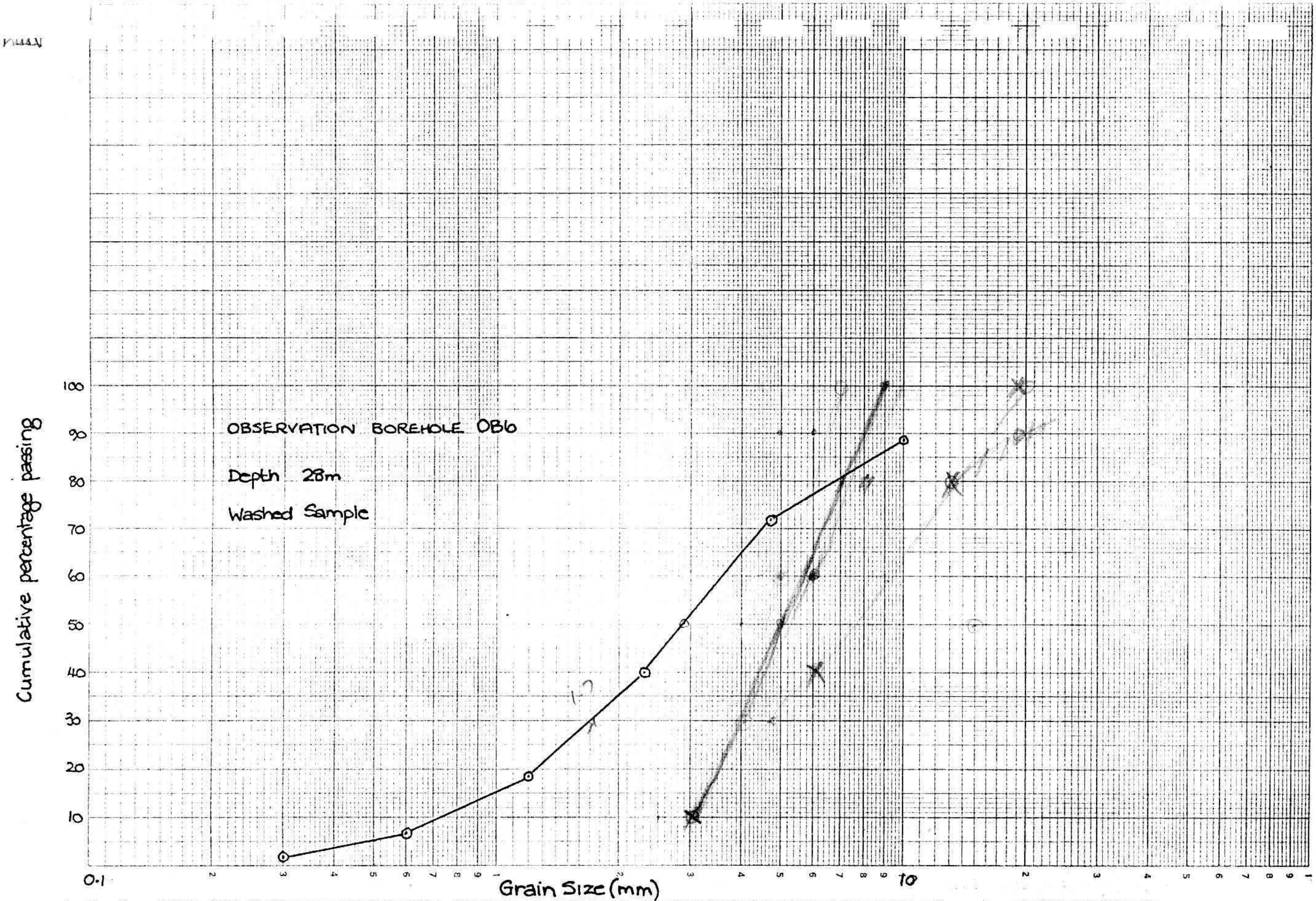
Eleven samples were collected for sieve analysis. These were selected from observation boreholes OB1, 2, 4, 5 and 6. The sieve analyses for the washed samples are given in the following figures.

The sieve analysis results were as follows:

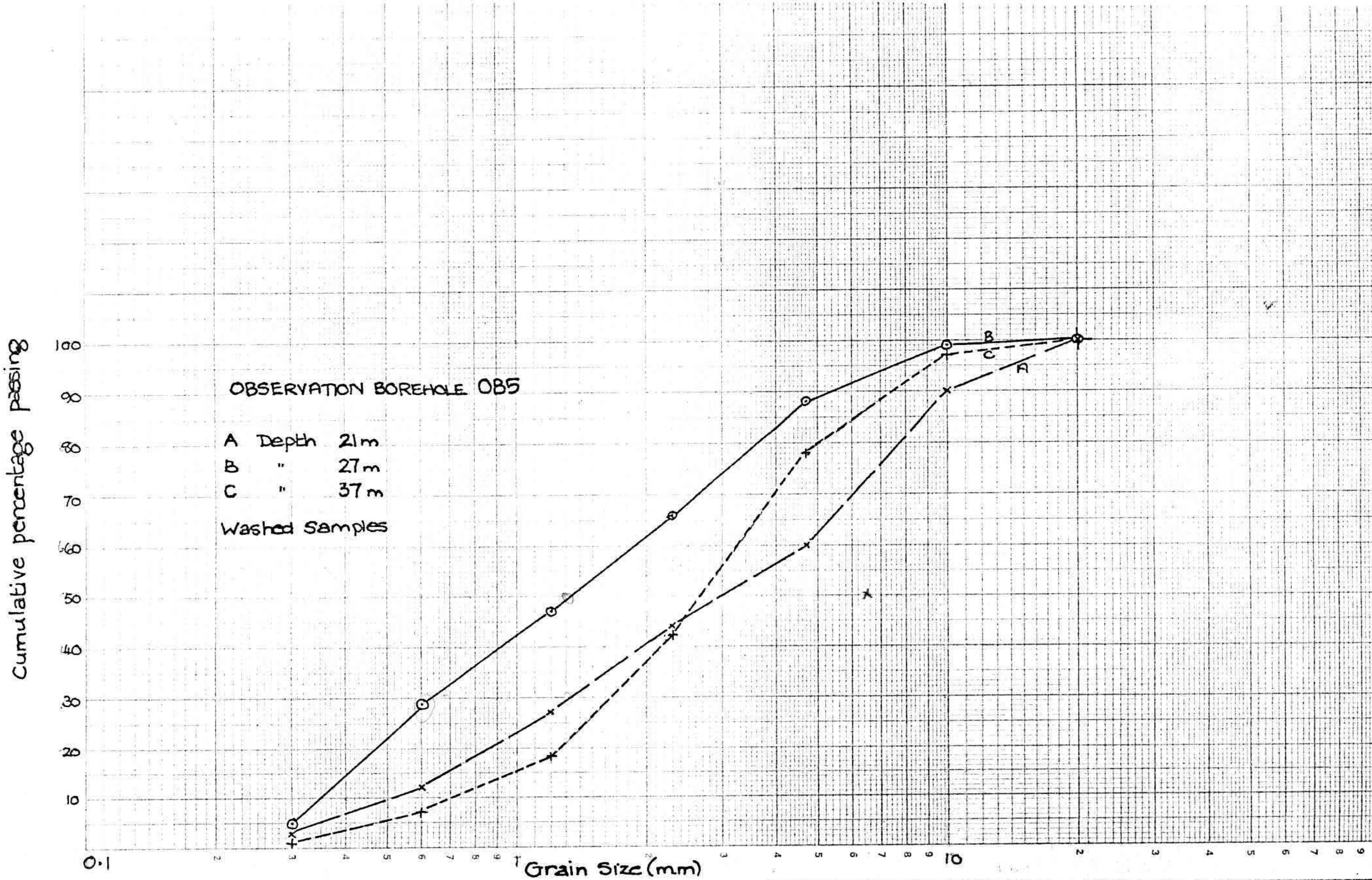
Borehole Number	Depth (m)	D_{10} (Effective size)	D_{50}	D_{60}	Uniformity coefficient ($Uc = D_{60}/D_{10}$)
			(mm)		
OB1	25	2.0	5.0	5.9	2.9
	29	0.80	4.3	5.9	7.4
OB2	18	0.42	3.1	3.9	9.3
	24	0.38	1.7	2.1	5.5
	36	0.36	1.6	2.1	5.8
OB4	17	1.90	10.0	13.0	6.8
	25	0.31	1.2	2.0	6.4
OB5	21	0.50	3.0	4.7	9.4
	27	0.34	1.3	1.9	5.6
	37	0.70	2.7	3.3	4.7
OB6	28	0.72	2.9	3.6	5.0

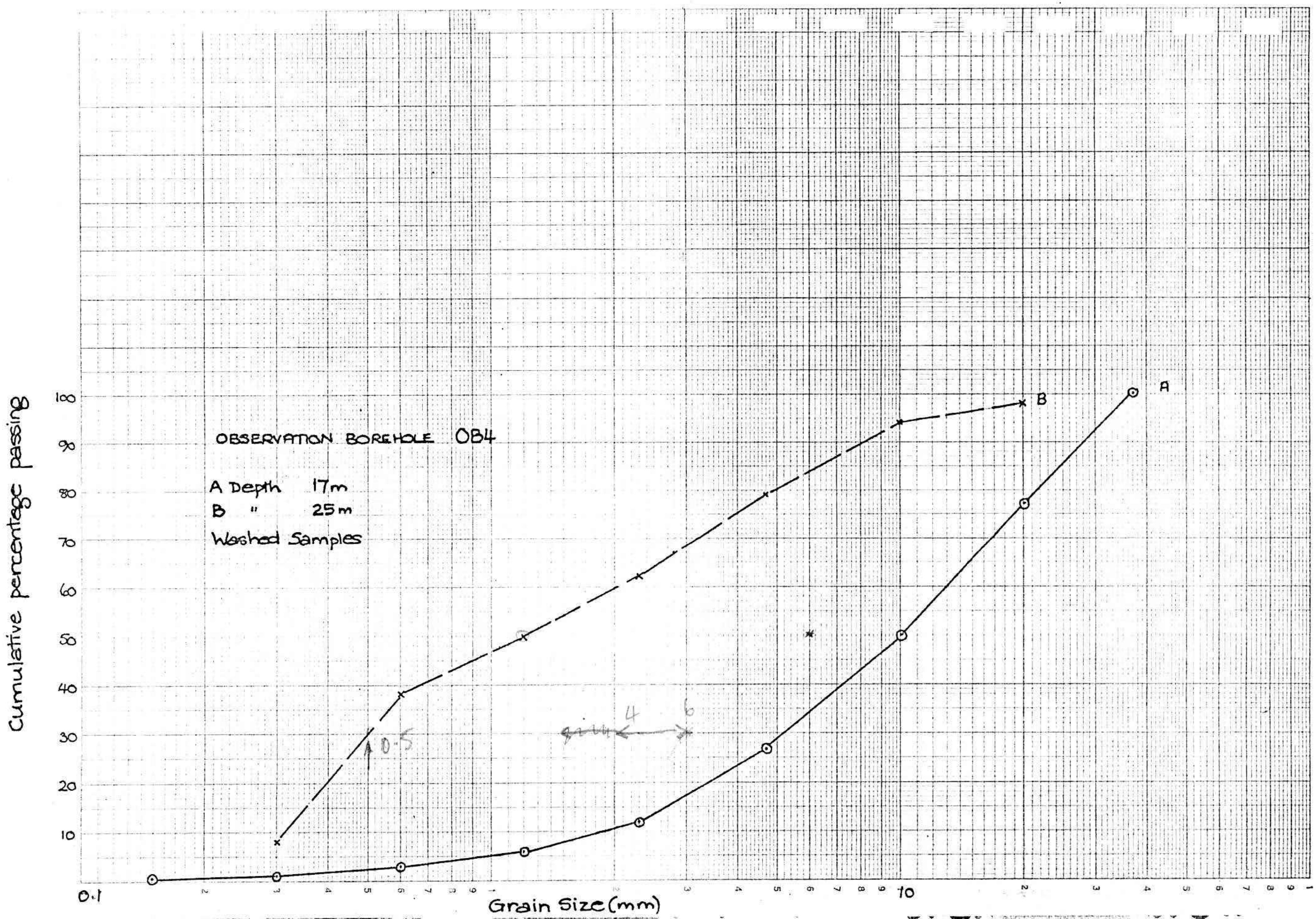
The uniformity coefficient generally is much greater than 3 and illustrates the poorly-sorted nature of the alluvial deposits.

We recommend the use of a gravel pack in view of the heterogeneous sequence rather than selecting different slot sizes to develop a natural pack. The D_{50} of the finest horizons is in the range 1.2 to 1.7 mm. Using D_{50} x 5 of the finest horizon to design the pack, we recommend a slot size of 3 mm and we suggest that the artificial pack size distribution should be as that given in the contract specifications.

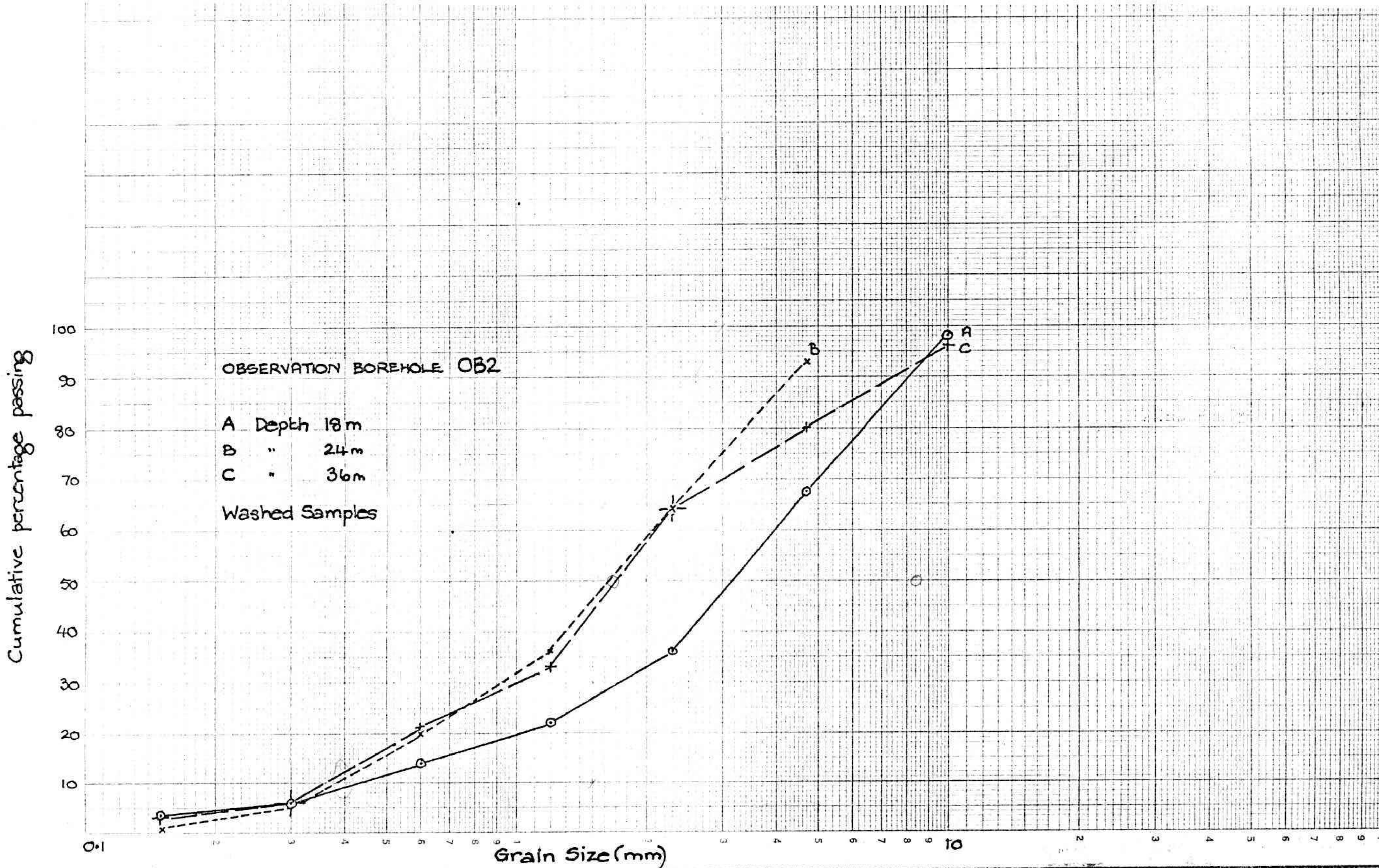


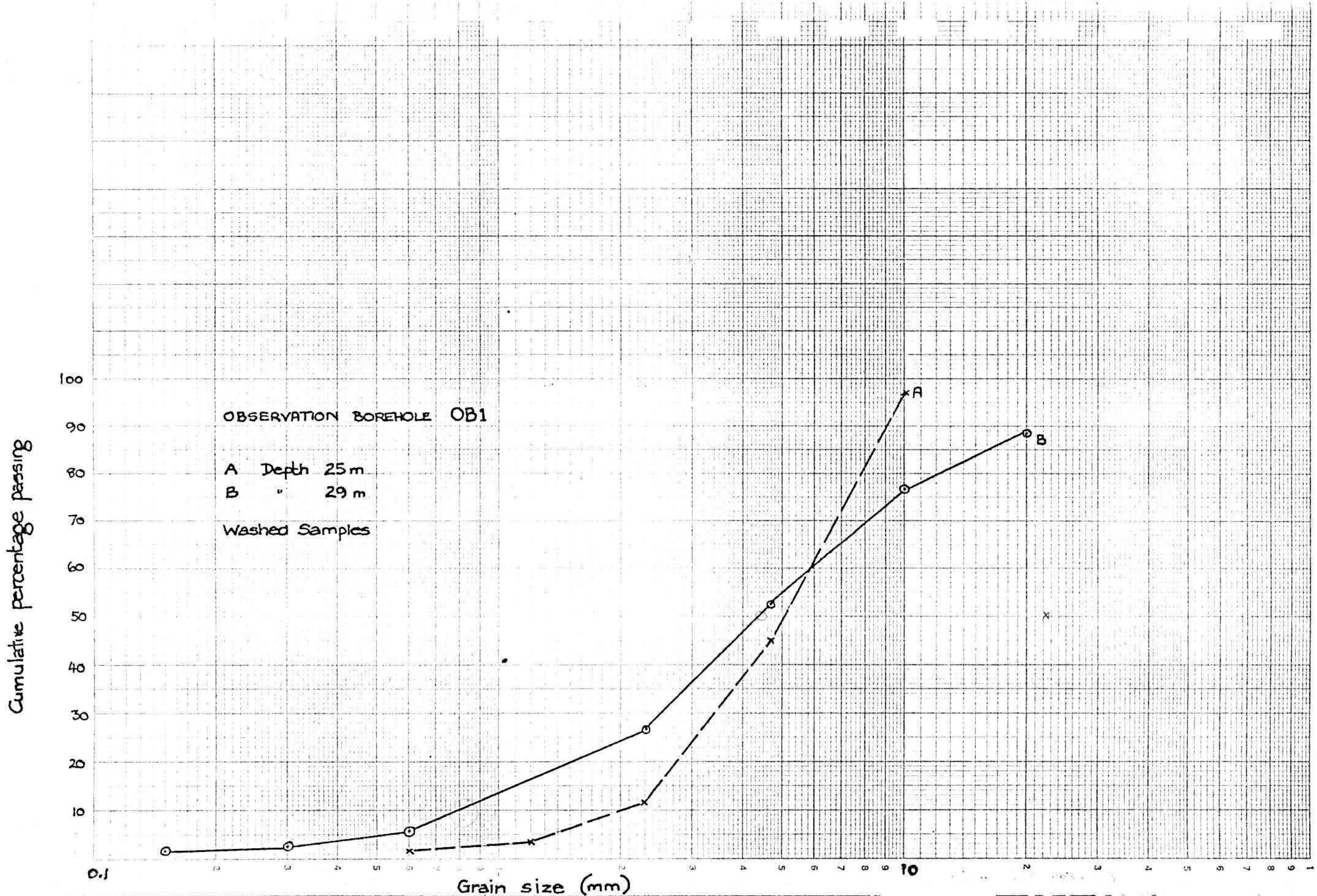
KHAN
OBSERVATION BOREHOLE OB6
Depth 28m
Washed Sample
Cumulative percentage passing
Grain Size (mm)
0·1
10
100
90
80
70
60
50
40
30
20
10


OBSERVATION BOREHOLE OB5
A Depth 21m
B " 27m
C " 37m
Washed Samples
Cumulative percentage passing
Grain Size (mm)
0·1
10
A
B
C



OBSERVATION BOREHOLE OB4
A Depth 17m
B " 25m
Washed Samples
A
B
Cumulative percentage passing
Grain Size (mm)
0.1
10
100
90
80
70
60
50
40
30
20
10


OBSERVATION BOREHOLE OB2
A Depth 18m
B " 24m
C " 36m
Washed Samples
Cumulative percentage passing
Grain Size (mm)
A
B
C
100
90
80
70
60
50
40
30
20
10
0·1
10


OBSERVATION BOREHOLE OB1
A Depth 25 m
B " 29 m
Washed Samples
A
B
Cumulative percentage passing
100
90
80
70
60
50
40
30
20
10
0.1
10
Grain size (mm)

APPENDIX B

GEOPHYSICAL SURVEY OF GHOR SAFI

B.1 INTRODUCTION

A geophysical survey of the proposed wellfield area at Ghor Safi was carried out during November 1978. The results of the geophysical survey were intended for use with the results of the observation borehole drilling programme to aid in the location and design of the production boreholes.

Two geophysical techniques were employed for the survey: electrical resistivity and seismic refraction. It was not found possible to obtain satisfactory results with the seismic refraction method due to the absorption of the seismic energy by the uncon--solidated sediments; consequently, only the resistivity method was used

The area of the survey was approximately 7 km^2. A total of 76 soundings was made in this area and the location of each sounding is shown in Figure B1.

B.2 THE SURVEY

Field practice

Electrical resistivity soundings are made using four electrodes placed in the ground; an electrical current is applied to two of the electrodes, and the voltage difference is measured between the other two electrodes. The electrical resistance of the ground is then the ratio of the observed voltage to the applied current. This is multiplied by the appropriate geometric factor for the electrode configuration to obtain the apparent resistivity of the ground. A succession of apparent resistivity measurements are made with an increasing separation of the electrodes, the centre of the configuration

Errors and limitations of the resistivity method

We have interpreted the resistivity data on the assumption that the observed apparent resistivity curve is produced by an earth consisting of horizontal, homogeneous layers of infinite lateral extent; although these assumptions do not reflect real conditions, they serve as a reasonable approximation thereof.

Resistivity sounding data can produce various resistivity distributions quite different from each other which nevertheless result in apparently similar resistivity curves. Thus the quality of the interpretation of these data depends on the quality of borehole and other geological knowledge available.

Without any geological control, the errors in interpreted resistivities and depths is approximately 25 per cent. This is because minor changes in the apparent resistivity curve can result from large changes in the resistivity/depth function. The error can be even greated if a bed of high resistivity occurs between two beds of moderate resistivity. However, the error can be significantly reduced if control can be established from a nearby borehole.

The recent drilling programme has provided additional geological data which have been used in conjunction with geological logs from existing boreholes (BN302 and BN300) to aid the interpretations. The accuracy of the interpreted data where geological control was available is within ± 10 per cent. Elsewhere geological control has had to be extrapolated, but the errors are unlikely to exceed ± 20 per cent.

The resolution of the resistivity method decreases with depth due to the electrical current becoming more dispersed as the electrode separation increases. Thus, although the geological section from a borehole may show a complex sequence of thin, interbedded layers, this may be interpreted as a single layer by the resistivity method. In addition, what may appear to be a geologically distinct interface may not be recognised by the resistivity method. The converse can also occur where a poorly marked geological interface may have a very

B.3 RESULTS

Geoelectrical sections

A geoelectrical section is a vertical section through the ground on which the interpreted resistivity data are plotted as a series of layers beneath the position of the centre of each sounding. Four sections are shown in Figures B2 to B5.

The geoelectrical sections show the presence of four groups of layers in the area of the survey. The shallowest layer, D, has resistivities ranging from 20 to 350 ohm-m and represents the unsaturated alluvium. Beneath this layer is layer C which represents the main saturated alluvial sequence. Layer C1 represents gravels and has a resistivity varying from 35 to 320 ohm-m. The main low resistivity layer, B, has a resistivity of between 20 and 60 ohm-m and everywhere underlies Layer C. The deepest layers identified, A, have the lowest resistivity, generally less than 20 ohm-m.

Each of the resistivity soundings detected one or more low resistivity layers at depth (Layers A and B). The deepest layer, A, is not continuous and was only identified in two small areas. Layer B, however, was identified throughout the survey area, and is overlain by a layer of higher resistivity, Layer C, which is also continuous throughout the area. The low resistivity layer, B, appears to correlate with a grey clay encountered in the boreholes whilst the higher resistivity layer, C, seems to correlate with the main saturated sequence of gravels.

The correlation of layers is not always unambiguous. Between boreholes OB3 and OB1 the depth to the low resistivity layer decreases, as shown in Figure B2. However, an alternative correlation could have been made with the underlying low resistivity layer which would have suggested that the depth to the low resistivity layer in fact increases. The correlation shown in Figure B2 has been chosen because it is believed that at soundings 7 and 4 the upper low resistivity layer has a resistivity that is only slightly less than that of the layer above and thus has not been recognised.

Depth to base of aquifer

The main low resistivity layer, B, provides a convenient, well defined base to the main alluvial sequence. The depth to this base has been contoured and is shown in Figure 1.2. This shows a depression east of Safi in which the depths to the low resistivity layer reach a maximum of almost 60 m. The edge of this depression is crossed by section G-H (Figure B5). There is also a linear trough extending southwards but apparently not linked to this depression. The depth to the low resistivity layer also increases markedly to the north-west. However, the variations in the depth to the low resistivity layer, although greater than the observational error, are relatively small and the general impression is of an even surface following the present topography of the fan.

The depth to the low resistivity layer decreases markedly in the north-east and south-west of the fan as shown in Figure 1.2. In these areas we believe that the limits of the main aquifer are marked by the 40 m depth contour because once the depth to the low resistivity layer becomes less than 40 m the low resistivity layer becomes rapidly shallower and in addition the resistivity of the main alluvial sequence shows a marked decrease, suggesting a greater clay content.

Resistivity of main aquifer

It is pertinent to consider here the factors which determine the resistivity of a formation. A formula used to described the electrical resistivity of a saturated formation, ρ_r, is:

$$\rho_r = \rho_w / \left(\frac{\phi^m}{a} + \frac{\rho_w}{A} \right)$$

where ρ_w = resistivity of the pore fluids

ϕ = fractional porosity of the formation

a = formation constant related to tortuosity

m = formation constant related to cementation

and A = the matrix resistivity which is a function of the clay content and cation exchange capacity of the formation.

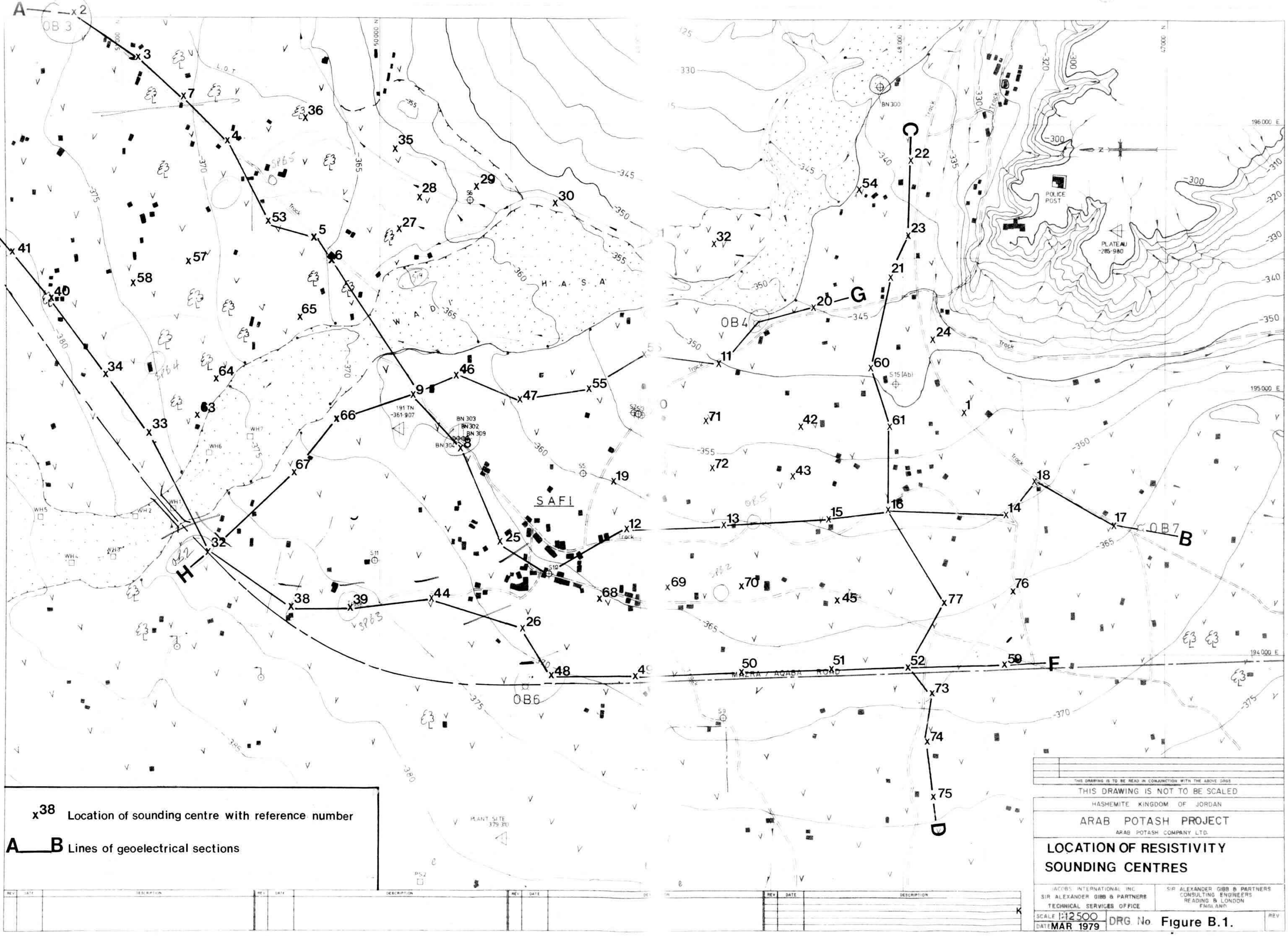
increase in clay content which could be expected to occur down the fan towards the Dead Sea. The resistivity contours show an area of slightly higher resistivity extending approximately along the line of the Wadi Hasa where hydrological measurements have shown that infiltration of undiverted baseflow occurs. Hence it is probable that the variation in resistivity in this part of the fan is mainly due to a decrease in the resistivity of the pore water. However, an increase in clay content would have the same effect and the measured resistivity may be a combination of both factors.

B.4 CONCLUSIONS

The geophysical survey has succeeded in detecting the limits of the aquifer in the north-east and south-west of the survey area. The boundaries have not been detected elsewhere and thus must lie outside the area of the survey.

Low resistivity layers at depth in the south-west and north-east of the area are probably associated with poor quality groundwater. In addition, the decrease in the resistivity values of the main aquifer down the fan probably represents a change in electrical conductivity of the pore water of about 50 per cent.

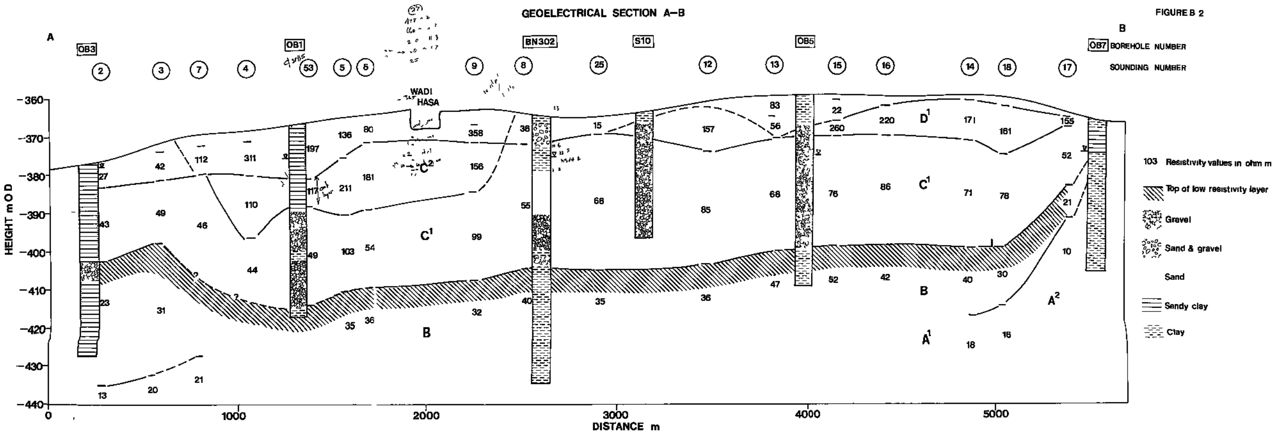
The main areas in which high resistivities have been identified which can certainly be ascribed to a low clay content, and hence a higher permeability, are to the east of Safi and between boreholes OB5 and OB7. However, the first of these areas is also one in which the thickness of saturated gravels is likely to be small.



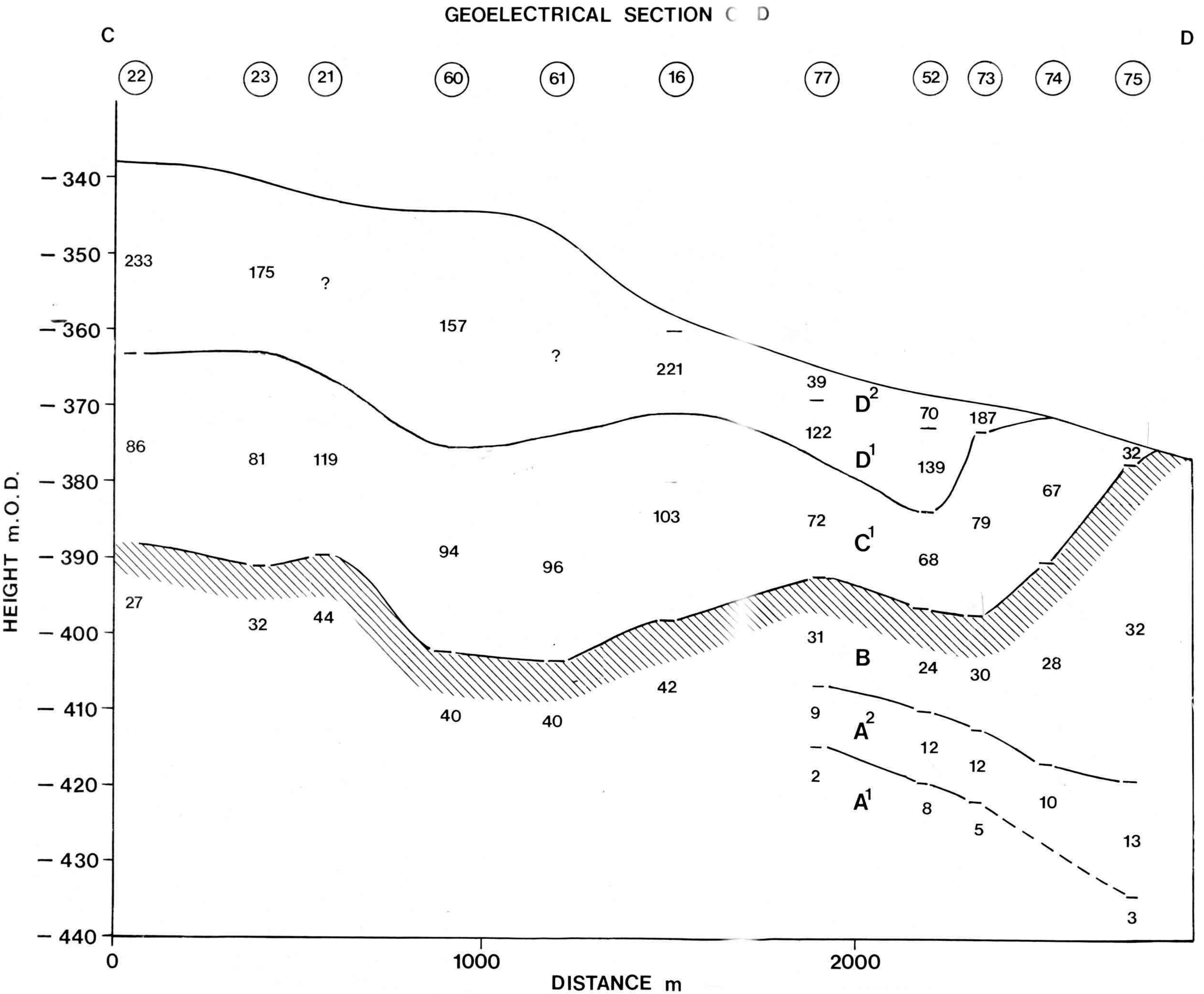
x38 Location of sounding centre with reference number
A—B Lines of geoelectrical sections
SAFI
W A D I H A S A
MAZRA / AQABA ROAD
POLICE POST
PLATEAU -285·980
PLANT SITE 379·310
BN 300
BN 303
BN 302
BN 309
BN 304
191 TN -361·907
OB 3
OB4
OB6
OB7
S15 (Ab)
Track
THIS DRAWING IS TO BE READ IN CONJUNCTION WITH THE ABOVE DRGS
THIS DRAWING IS NOT TO BE SCALED
HASHEMITE KINGDOM OF JORDAN
ARAB POTASH PROJECT
ARAB POTASH COMPANY LTD.
LOCATION OF RESISTIVITY SOUNDING CENTRES
JACOBS INTERNATIONAL INC
SIR ALEXANDER GIBB & PARTNERS
TECHNICAL SERVICES OFFICE
SIR ALEXANDER GIBB & PARTNERS CONSULTING ENGINEERS READING & LONDON ENGLAND
SCALE 1:12500
DATE MAR 1979
DRG. No Figure B.1.

FIGURE B 2

GEOELECTRICAL SECTION A–B

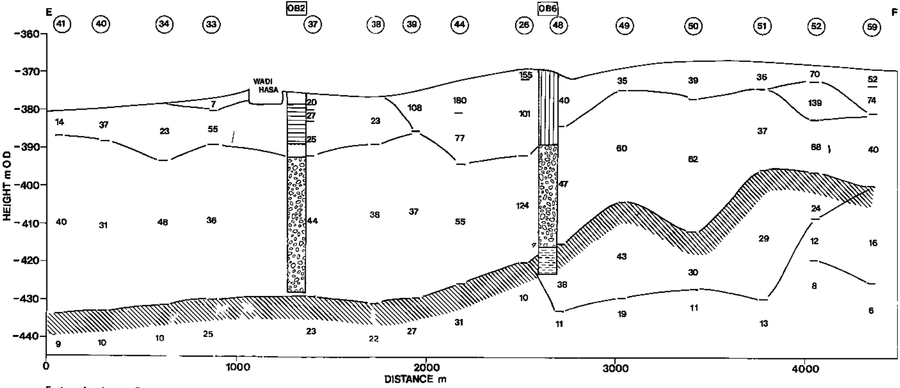


Notes Reference Figure B1 for line of section



Notes: Reference Figure B.1 for line of section
For explanation of symbols see Figure B.2

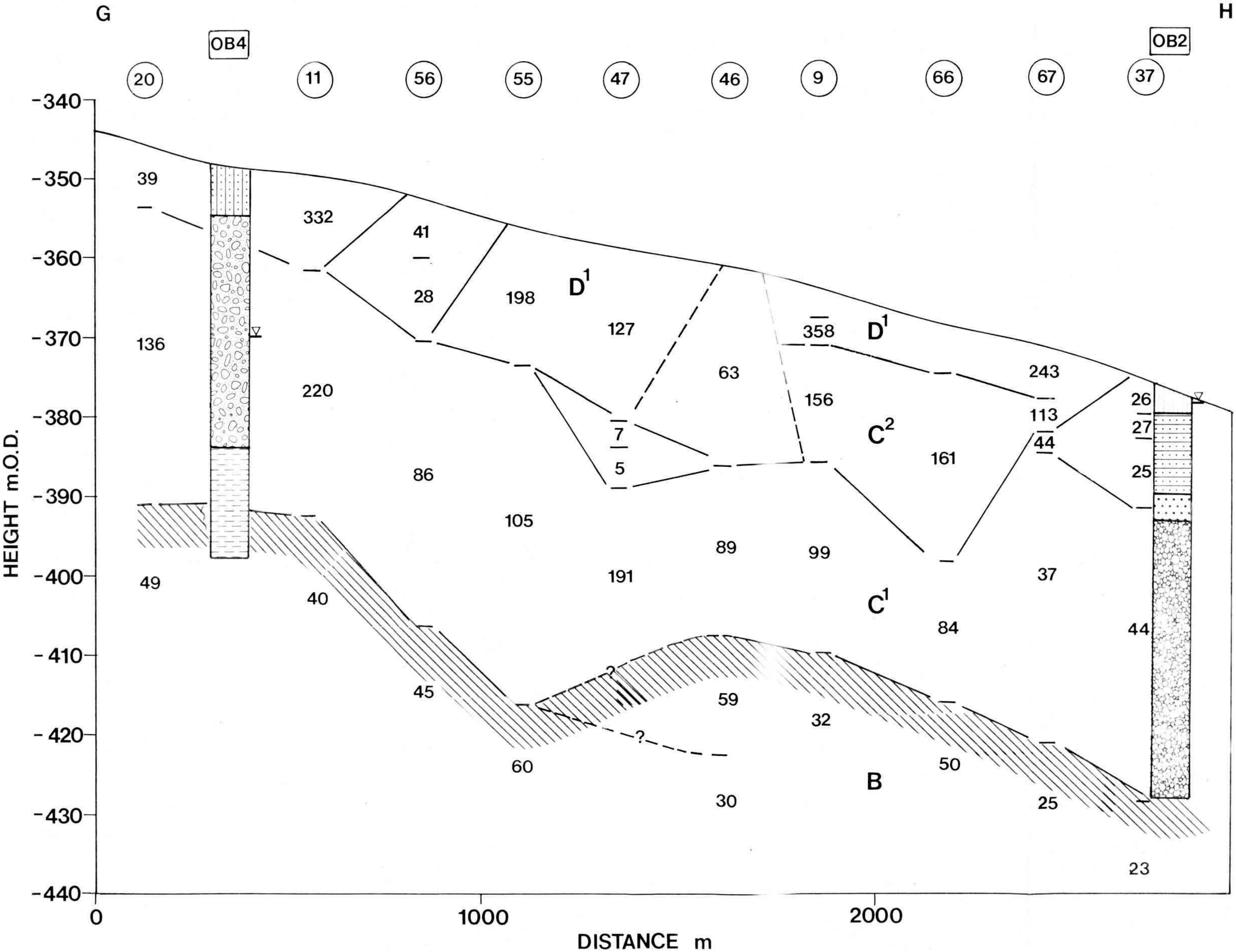
GEOELECTRICAL SECTION E-F



For line of section see Figure B 1

For explanation of symbols see Figure B 2

GEOELECTRICAL SECTION G-H



For line of section see Figure B.1

For explanation of symbols see Figure B.2

LPT   ACCOUNT: 33-24

SAFI V.E.S. 1   GRID REFERENCE 47740 94875

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.820	3000.	1.49	34.25
2.	.820	1000.	3.85	59.00
3.	.495	1000.	1.70	64.74
4.	.427	300.	3.94	69.57
6.	.740	1000.	1.60	81.51
8.	.695	300.	3.66	79.41
12.	.530	300.	1.83	78.10
16.	.755	300.	2.01	80.29
24.	.780	300.	1.48	85.84
32.	.461	100.	1.77	77.20
48.	.467	100.	1.10	71.04
64.	.354	30.	1.94	66.11
96.	.620	30.	1.71	49.91

INTERPRETED MODEL

DEPTHS	.51	1.03	6.34	14.39	33.44	61.63	
RESISTIVITIES	21.	72.	91.	81.	91.	61.	30.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 2   GRID REFERENCE 51625 96420

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.790	3000.	1.48	35.31
2.	.810	1000.	2.23	34.60
3.	.755	1000.	1.37	34.20
4.	.625	300.	2.45	29.56
6.	.680	300.	1.52	25.28
8.	.700	300.	1.53	32.96
12.	.810	300.	1.28	35.74
16.	1.160	300.	1.39	36.14
24.	1.250	100.	2.82	34.02
32.	.740	100.	1.26	34.23
48.	.510	30.	1.73	30.69
64.	.470	10.	2.71	23.19
96.	.690	10.	2.13	18.62

INTERPRETED MODEL

DEPTHS	1.23	6.75	26.47	59.41	
RESISTIVITIES	36.	27.	43.	23.	13.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 3   GRID REFERENCE 50930 96130

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.800	3000.	2.19	51.60
2.	.605	1000.	3.10	64.39
3.	.640	1000.	1.97	58.02
4.	.635	1000.	1.33	52.84
6.	.720	300.	3.20	50.27
8.	.680	300.	2.06	45.68
12.	.580	300.	1.09	42.51
16.	.710	100.	3.60	50.97
24.	.675	100.	1.93	43.12
32.	.870	100.	1.73	39.98
48.	.980	30.	3.86	35.64
64.	.900	30.	2.53	33.91
96.	.487	10.	2.27	28.12

INTERPRETED MODEL

DEPTHS	.37	2.50	9.35	25.96	60.75	
RESISTIVITIES	39.	67.	42.	50.	31.	21.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 4   GRID REFERENCE 50590 95935

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.390	1000.	2.66	42.85
2.	.430	1000.	1.55	45.30
3.	.265	1000.	1.01	71.84
4.	.390	1000.	1.29	83.13
6.	.590	1000.	1.70	108.62
8.	.660	1000.	1.68	127.95
12.	.890	1000.	1.83	155.03
16.	.520	300.	2.97	172.26
24.	.850	300.	1.68	89.41
32.	.930	300.	2.09	135.55
48.	.615	100.	1.60	78.46
64.	.930	100.	1.60	69.18
96.	.720	30.	2.10	52.78

INTERPRETED MODEL

DEPTHS	.74	3.30	12.30	28.00	
RESISTIVITIES	34.	80.	311.	111.	44.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 5   GRID REFERENCE 50240 95590

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.945	3000.	3.39	67.62
2.	.935	3000.	2.57	103.62
3.	.535	1000.	2.76	97.24
4.	.615	1000.	2.43	99.30
6.	.830	1000.	2.18	99.02
8.	.437	300.	3.10	106.97
12.	1.150	1000.	1.88	123.26
16.	1.240	1000.	1.98	160.53
24.	.630	300.	2.50	179.52
32.	.770	300.	2.24	175.47
48.	.780	100.	2.82	109.04
64.	1.090	100.	2.32	85.59
96.	1.230	100.	1.12	54.92

INTERPRETED MODEL

DEPTHS	1.32	9.77	24.66	45.42	
RESISTIVITIES	68.	136.	211.	103.	35.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 6   GRID REFERENCE 50185 95475

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.490	1000.	3.74	47.96
2.	.530	1000.	1.81	42.92
3.	.660	1000.	2.42	69.12
4.	.947	1000.	2.60	69.00
6.	.520	300.	3.62	78.73
8.	.450	300.	2.43	81.43
12.	1.010	1000.	1.33	99.29
16.	.610	300.	2.38	117.67
24.	.550	300.	1.62	133.25
32.	.550	100.	3.37	123.20
48.	.650	100.	2.11	97.90
64.	1.160	100.	2.31	80.08
96.	.640	30.	2.13	60.22

INTERPRETED MODEL

DEPTHS	.63	6.97	24.40	45.00	
RESISTIVITIES	36.	80.	181.	54.	36.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 7   GRID REFERENCE 49700 94780

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.415	1000.	2.63	39.82
2.	.460	1000.	2.11	57.64
3.	.510	1000.	1.78	65.79
4.	.415	1000.	1.21	73.28
6.	.620	1000.	1.44	87.56
8.	.760	1000.	1.48	97.89
12.	.490	300.	2.02	93.25
16.	.800	300.	2.11	79.55
24.	.560	100.	2.34	63.01
32.	.540	100.	1.70	63.30
48.	1.160	100.	1.92	49.92
64.	.775	30.	2.57	40.00
96.	.785	30.	1.33	30.66

INTERPRETED MODEL

DEPTHS	.84	10.49	58.07	
RESISTIVITIES	30.	113.	46.	22.

LPT ACCOUNT: 33-24

SAFI V.E.S. 8 GRID REFERENCE 49700 94780

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.915	3000.	1.70	35.02
2.	1.060	1000.	3.30	39.12
3.	.750	1000.	1.81	45.49
4.	.835	1000.	1.41	42.44
6.	.695	300.	2.43	39.54
8.	.670	300.	1.85	41.64
12.	.875	300.	1.75	45.24
16.	.560	100.	2.76	49.55
24.	1.050	100.	4.00	57.45
32.	.995	100.	2.62	52.94
48.	.650	30.	3.56	49.55
64.	.505	30.	1.90	45.39
96.	.510	30.	1.22	43.29

INTERPRETED MODEL

DEPTHS	.86	2.92	7.53	39.60	
RESISTIVITIES	31.	48.	36.	55.	40.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 9   GRID REFERENCE . 49870 94975

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.328	3000.	1.91	109.76
2.	.302	1000.	3.11	129.41
3.	.280	1000.	2.25	151.47
4.	.225	1000.	1.45	161.97
6.	.420	1000.	2.32	208.24
8.	.244	1000.	1.21	249.27
12.	.415	1000.	1.33	241.64
16.	.316	300.	2.29	218.56
24.	.285	100.	2.99	158.20
32.	.349	100.	2.74	157.85
48.	.930	100.	3.36	108.96
64.	.850	100.	1.14	53.93
96.	.540	30.	2.19	73.39

INTERPRETED MODEL

DEPTHS	1.23	16.53	59.69	
RESISTIVITIES	109.	246.	100.	47.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 10   GRID REFERENCE 48950 94915

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.610	1000.	2.53	26.06
2.	.565	1000.	1.44	32.03
3.	.725	1000.	1.42	36.92
4.	1.340	1000.	2.40	45.01
6.	1.405	1000.	2.49	66.81
8.	1.220	1000.	2.04	84.05
12.	1.240	1000.	1.84	111.88
16.	.750	300.	3.31	133.10
24.	.500	300.	1.74	157.43
32.	.440	100.	3.32	151.71
48.	.395	100.	1.60	122.16
64.	.590	100.	1.42	96.78
96.	.460	30.	1.91	75.14

INTERPRETED MODEL

DEPTHS	1.86	3.39	12.20	40.22	
RESISTIVITIES	24.	58.	335.	124.	41.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 11   GRID REFERENCE 48690 95105

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	1.050	3000.	3.05	54.75
2.	.905	3000.	2.65	110.39
3.	.750	3000.	2.11	159.09
4.	.635	3000.	1.42	168.61
6.	1.085	3000.	2.11	219.94
8.	.510	1000.	2.48	244.43
12.	.850	1000.	3.00	266.11
16.	.835	1000.	1.96	235.98
24.	1.020	1000.	1.67	246.89
32.	.900	300.	3.66	245.30
48.	1.060	300.	2.33	198.88
64.	.745	100.	2.64	142.50
96.	.445	30.	2.06	83.77

INTERPRETED MODEL

DEPTHS	.31	.51	.66	1.07	11.57	43.67	
RESISTIVITIES	17.	59.	202.	817.	332.	220.)	40.

LPT ACCOUNT: 33-24

SAFI V.E.S. 12 GRID REFERENCE 49030 94960

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.710	300.	3.19	8.47
2.	.400	1000.	1.28	40.21
3.	.275	300.	2.93	60.25
4.	.406	1000.	1.42	87.90
6.	.445	1000.	1.39	117.76
8.	.480	1000.	1.25	130.90
12.	.660	300.	3.78	129.55
16.	.575	300.	2.15	112.77
24.	.545	300.	1.45	120.36
32.	1.115	300.	1.98	107.11
48.	.770	100.	2.41	94.39
64.	.940	100.	1.93	82.56
96.	.391	30.	1.27	58.78

INTERPRETED MODEL

DEPTHS	1.56	13.50	43.00	
RESISTIVITIES	40.	158.	93.	35.

LPT ACCOUNT: 33-24

SAFI V.E.S. 13   GRID REFERENCE 48685 94990

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.480	1000.	2.03	26.57
2.	.850	1000.	2.62	38.73
3.	.425	1000.	1.14	50.56
4.	.480	1000.	1.23	64.40
6.	.750	1000.	1.37	68.86
8.	.825	1000.	1.10	67.02
12.	.407	100.	3.27	60.58
16.	.640	100.	3.99	62.67
24.	.845	100.	3.92	69.96
32.	.345	100.	1.19	69.35
48.	.255	30.	1.75	62.09
64.	.355	30.	1.71	58.11
96.	.540	30.	1.63	54.62

INTERPRETED MODEL

DEPTHS	.73	1.12	6.80	12.78	41.50	
RESISTIVITIES	20.	53.	83.	56.	80.	47.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 14   GRID REFERENCE 47600 94465

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.560	1000.	1.98	22.22
2.	1.130	1000.	3.10	34.47
3.	.565	300.	3.70	37.03
4.	.525	300.	3.81	54.72
6.	.470	300.	2.73	65.69
8.	1.140	1000.	2.46	108.47
12.	.475	300.	2.52	120.00
16.	.680	300.	3.28	145.47
24.	1.090	300.	2.26	93.80
32.	.590	100.	2.52	85.88
48.	.530	100.	1.30	73.98
64.	1.265	100.	1.88	59.76
96.	1.070	30.	2.09	35.35

INTERPRETED MODEL

DEPTHS	.75	1.82	12.00	40.95	57.95	
RESISTIVITIES	18.	41.	174.	71.	40.	18.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 15   GRID REFERENCE 48280 94505

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.355	1000.	1.46	25.84
2.	.955	1000.	2.33	30.66
3.	.575	1000.	1.02	33.44
4.	.580	300.	2.16	28.08
6.	.750	300.	1.92	28.95
8.	.900	300.	1.97	33.01
12.	1.140	300.	2.12	42.06
16.	.550	100.	2.87	52.46
24.	1.225	300.	1.69	62.41
32.	1.380	300.	1.55	67.75
48.	1.570	300.	1.26	72.61
64.	1.800	300.	1.08	72.38
96.	1.320	100.	1.48	67.63

INTERPRETED MODEL

DEPTHS .31 .49 .70 1.77 7.02 11.24 39.50

RESISTIVITIES 10. 37. 141. 32. 22. 259. 80.
52.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 16   GRID REFERENCE 48050 94545

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.890	1000.	3.04	21.46
2.	.730	1000.	1.57	27.03
3.	.740	1000.	1.25	31.84
4.	.530	300.	2.91	41.40
6.	.540	300.	2.47	51.73
8.	.700	300.	2.98	64.20
12.	.445	300.	1.60	81.33
16.	.575	300.	1.90	99.66
24.	.600	300.	1.49	112.34
32.	.700	100.	3.93	112.88
48.	.525	100.	1.93	110.87
64.	.445	30.	1.43	38.77
96.	.385	30.	1.42	66.74

INTERPRETED MODEL

DEPTHS	1.01	2.62	3.06	11.58	39.50	
RESISTIVITIES	17.	36.	166.	221.	103.	42.

LPT ACCOUNT: 33-24

SAFI V.E.S. 17 GRID REFERENCE 47190 94480

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.298	300.	2.02	12.78
2.	1.120	1000.	1.81	20.31
3.	.880	1000.	1.74	37.27
4.	1.125	1000.	1.84	41.11
6.	.425	300.	1.91	50.83
8.	.560	300.	3.04	81.86
12.	.480	100.	3.83	60.16
16.	.500	100.	2.71	54.49
24.	.800	100.	2.39	45.05
32.	.440	30.	2.77	37.97
48.	.635	30.	1.81	25.79
64.	1.650	30.	2.42	17.69
96.	1.140	10.	2.41	12.75

INTERPRETED MODEL

DEPTHS	.94	1.63	3.94	19.61	28.67	
RESISTIVITIES	10.	37.	154.	52.	21.	10.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 18   GRID REFERENCE 47490 94645

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.375	300.	3.65	18.35
2.	.525	300.	3.78	27.14
3.	.381	300.	2.13	31.61
4.	.465	300.	2.33	37.78
6.	.540	300.	2.58	54.04
8.	.450	300.	1.97	66.02
12.	.510	300.	1.98	87.82
16.	1.110	300.	3.63	98.63
24.	.990	300.	2.28	104.19
32.	1.255	300.	2.07	99.49
48.	1.175	100.	3.23	82.91
64.	1.310	100.	1.65	50.65
96.	.815	30.	1.58	35.08

INTERPRETED MODEL

DEPTHS	.74	2.76	15.64	41.61	55.37	
RESISTIVITIES	14.	34.	161.	78.	30.	16.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 19   GRID REFERENCE 49105 94655

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.271	1000.	1.73	40.11
2.	.422	1000.	1.55	46.16
3.	.355	300.	3.31	52.73
4.	.390	300.	2.92	56.45
6.	.344	300.	1.92	63.12
8.	.490	300.	2.37	72.94
12.	.373	300.	1.46	88.54
16.	.455	300.	1.58	104.73
24.	.480	100.	3.15	98.96
32.	.465	100.	1.98	85.61
48.	.530	100.	1.44	81.94
64.	.625	30.	4.05	78.17
96.	.840	30.	3.47	74.75

INTERPRETED MODEL

DEPTHS	1.48	6.22	15.24	
RESISTIVITIES	37.	78.	142.	74.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 20   GRID REFERENCE 48336 95305

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.910	3000.	1.89	39.15
2.	.810	1000.	3.02	46.85
3.	.830	1000.	2.13	48.37
4.	.700	1000.	1.29	46.32
6.	.880	300.	3.73	47.94
8.	.540	300.	1.95	54.45
12.	.530	300.	1.48	63.16
16.	.615	300.	1.59	77.97
24.	.835	300.	1.77	95.90
32.	.450	100.	2.26	100.98
48.	.660	100.	2.48	113.33
64.	.873	100.	2.00	92.12
96.	.450	30.	1.93	77.61

INTERPRETED MODEL

DEPTHS	.41	2.49	6.30	45.81	
RESISTIVITIES	32.	49.	39.	136.	49.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 21   GRID REFERENCE 48080 95410

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.321	1000.	1.92	37.58
2.	.570	1000.	1.70	37.48
3.	.610	1000.	1.54	47.59
4.	.770	1000.	1.80	58.75
6.	.860	1000.	1.57	68.82
8.	.915	1000.	1.36	74.71
12.	.880	300.	3.31	85.08
16.	.910	300.	2.81	93.13
24.	.785	300.	1.99	114.68
32.	.780	300.	1.53	118.32
48.	1.345	300.	1.47	98.89
64.	.860	100.	1.87	87.44
96.	1.125	100.	1.32	70.77

INTERPRETED MODEL

DEPTHS	.56	1.22	3.15	46.74	
RESISTIVITIES	38.	30.	57.	119.	43.

LPT ACCOUNT: 33-24

SAFI V.E.S. 22 GRID REFERENCE 47825 95870

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.660	1000.	2.88	27.42
2.	.965	3000.	1.37	53.52
3.	.725	1000.	2.87	74.62
4.	.905	1000.	3.23	89.70
6.	.630	1000.	2.05	122.67
8.	.600	1000.	1.75	146.61
12.	.705	1000.	1.47	157.21
16.	.695	300.	4.00	173.58
24.	.530	300.	2.57	219.37
32.	1.100	300.	3.74	205.08
48.	.740	100.	3.08	125.53
64.	.705	100.	1.77	100.96
96.	.975	30.	3.63	67.37

INTERPRETED MODEL

DEPTHS	.66	1.16	24.58	55.70	
RESISTIVITIES	27.	44.	233.	86.	27.

LPT ACCOUNT: 33-24

SAFI V.E.S. 23 GRID REFERENCE 47835 95580

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	1.060	1000.	3.11	18.43
2.	1.090	1000.	1.92	22.14
3.	1.090	1000.	1.75	30.26
4.	1.080	1000.	1.58	36.77
6.	.745	1000.	1.19	60.22
8.	.945	1000.	1.41	75.00
12.	.695	300.	2.89	94.06
16.	.660	300.	2.24	102.36
24.	.615	300.	1.61	118.43
32.	.390	100.	2.34	120.64
48.	.675	100.	2.30	102.76
64.	.680	100.	1.49	88.11
96.	.790	30.	2.60	59.56

INTERPRETED MODEL

DEPTHS	1.05	2.32	21.92	55.29	
RESISTIVITIES	14.	40.	175.	81.	32.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 24   GRID REFERENCE 47895 95195

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.341	1000.	2.09	38.51
2.	.560	1000.	2.89	64.85
3.	.314	300.	2.56	46.10
4.	.410	300.	2.11	38.80
6.	.510	300.	1.36	30.16
8.	.660	300.	1.36	31.07
12.	.675	100.	3.48	38.87
16.	.580	100.	2.68	46.45
24.	.495	100.	1.88	57.27
32.	.653	100.	2.09	64.35
48.	.910	100.	2.15	71.26
64.	.417	30.	2.38	68.85
96.	.960	30.	3.23	60.88

INTERPRETED MODEL

DEPTHS	.39	2.77	7.18	44.99	
RESISTIVITIES	32.	56.	21.	92.	42.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 25   GRID REFERENCE 49545 94420

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.500	300.	3.64	13.72
2.	.476	300.	2.82	22.33
3.	.425	300.	1.56	20.76
4.	.650	300.	1.80	20.88
6.	.379	100.	2.22	22.08
8.	.785	300.	1.40	26.89
12.	.410	100.	1.85	34.02
16.	.405	100.	1.50	37.23
24.	.570	100.	1.73	45.77
32.	.955	100.	2.38	50.11
48.	.730	100.	1.17	48.34
64.	.880	100.	1.08	49.35
96.	.510	30.	1.26	44.71

INTERPRETED MODEL

DEPTHS   .66   .99   4.29   39.60

RESISTIVITIES   41.   30.   15.   65.   35.

LPT ACCOUNT: 33-24

SAFI V.E.S. 26 GRID REFERENCE 49450 94065

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.640	1000.	3.35	32.89
2.	.650	1000.	2.90	56.07
3.	.865	1000.	3.78	82.37
4.	.985	1000.	3.23	82.41
6.	.760	1000.	1.81	89.78
8.	.685	1000.	1.34	98.33
12.	.680	300.	2.97	98.79
16.	.540	300.	1.78	99.41
24.	.720	300.	1.63	102.42
32.	.625	100.	3.31	106.48
48.	.845	100.	1.83	65.32
64.	.800	30.	3.58	53.99
96.	.465	10.	2.00	25.94

INTERPRETED MODEL

DEPTHS	.32	.57	2.61	22.41	51.00	
RESISTIVITIES	13.	31.	155.	101.	124.	10.

LPT ACCOUNT: 33-24

2-363

SAFI V.E.S. 27 GRID REFERENCE 49920 95580

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.250	3000.	2.29	172.66
2.	.335	3000.	2.00	225.07
3.	.448	3000.	2.33	294.10
4.	.316	1000.	3.98	316.55
6.	.308	1000.	3.24	396.58
8.	.375	1000.	3.12	418.21
12.	.360	1000.	1.25	261.80
16.	.535	300.	3.39	191.10
24.	.349	100.	3.74	161.60
32.	.395	100.	3.28	166.96
48.	.590	100.	1.82	93.03
64.	.422	30.	2.19	62.53
96.	.560	30.	1.41	45.56

INTERPRETED MODEL

DEPTHS	1.05	1.77	5.30	11.33	56.71	
RESISTIVITIES	138.	477.	661.	251.	80.	25.

LPT ACCOUNT: 33-24

-362

SAFI V.E.S. 28 GRID REFERENCE 49850 95372

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.354	3000.	1.58	84.13
2.	.381	1000.	3.74	123.35
3.	.341	1000.	2.87	158.65
4.	.330	1000.	2.57	196.11
6.	.265	1000.	1.71	243.27
8.	.270	1000.	1.31	243.88
12.	.170	300.	1.53	203.58
16.	.160	100.	2.57	161.48
24.	.105	30.	2.90	124.95
32.	.178	30.	2.90	98.27
48.	.110	10.	2.92	80.06
64.	.087	3.	3.95	54.77
96.	.117	3.	2.35	36.35

INTERPRETED MODEL

DEPTHS	.96	1.66	5.37	12.95	58.92	
RESISTIVITIES	66.	278.	408.	134.	78.	16.

WH?

LPT   ACCOUNT: 33-24

SAFI V.E.S. 29   9.356 GRID REFERENCE 49635 95745

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.047	10000.	1.38	1844.85
2.	.061	3000.	2.66	1643.93
3.	.031	1000.	2.41	1489.42
4.	.047	1000.	1.94	1037.39
6.	.044	300.	2.90	745.41
8.	.041	300.	1.51	555.37
12.	.051	100.	2.20	325.25
16.	.081	100.	2.09	259.39
24.	.051	30.	1.82	161.44
32.	.081	30.	1.10	81.91
48.	.100	30.	1.10	99.53
64.	.225	30.	1.60	85.79
96.	.208	10.	2.16	62.64

INTERPRETED MODEL

DEPTHS	2.02	3.98	6.82	15.59	54.04	
RESISTIVITIES	1890.	1194.	391.	273.	107.	38.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 30   ≈ -356   GRID REFERENCE 49310 95700

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.200	10000.	1.55	486.95
2.	.168	3000.	2.24	502.65
3.	.205	3000.	1.50	413.77
4.	.132	1000.	1.92	365.57
6.	.220	1000.	1.63	279.32
8.	.265	1000.	1.26	239.00
12.	.186	300.	1.41	171.47
16.	.234	100.	3.30	141.77
24.	.150	30.	4.00	120.64
32.	.200	30.	3.72	112.19
48.	.316	30.	3.41	97.64
64.	.142	10.	3.05	86.37
96.	.148	10.	1.68	68.47

INTERPRETED MODEL

DEPTHS	.64	2.34	6.46	31.92	59.38	
RESISTIVITIES	480.	559.	259.	120.	83.]	46.

LPT   ACCOUNT: 33-24

2-350

SAFI V.E.S. 31   GRID REFERENCE 48965 95560

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.211	10000.	1.53	455.61
2.	.102	3000.	1.47	543.31
3.	.077	1000.	2.17	531.21
4.	.087	1000.	2.09	603.76
6.	.155	1000.	2.24	544.81
8.	.111	300.	3.76	510.81
12.	.110	300.	2.05	421.54
16.	.059	100.	1.58	269.22
24.	.050	30.	1.74	157.43
32.	.060	30.	1.37	137.73
48.	.040	10.	1.68	126.67
64.	.315	30.	2.75	105.32
96.	.119	10.	1.94	98.33

INTERPRETED MODEL

DEPTHS   .41   .91   2.78   7.77   11.49   14.02   19.13
57.24

RESISTIVITIES   355.   666.   523.   692.   310.   110.   51.
131.   83.

2-407

LPT   ACCOUNT: 33-24

SAFI V.E.S. 32   GRID REFERENCE 48720 95535

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.144	3000.	1.83	239.55
2.	.121	1000.	1.46	151.63
3.	.172	1000.	1.27	139.18
4.	.186	300.	3.42	138.64
6.	.202	300.	2.83	158.45
8.	.122	300.	1.42	174.80
12.	.125	100.	3.02	182.16
16.	.108	100.	2.32	215.96
24.	.174	100.	3.14	272.13
32.	.141	100.	2.04	290.90
48.	.186	100.	1.83	296.73
64.	.204	100.	1.45	285.82
96.	.178	30.	1.85	188.07

INTERPRETED MODEL

DEPTHS	.61	.87	3.31	13.11	42.60	58.60	
RESISTIVITIES	350.	175.	113.	201.	477.	228.	52.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 33   GRID REFERENCE 50870 94860

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.650	300.	2.88	8.35
2.	1.060	300.	2.60	9.25
3.	1.060	300.	1.70	9.07
4.	1.200	300.	1.58	9.93
6.	1.220	100.	2.82	8.71
8.	.735	100.	2.93	20.04
12.	.770	100.	2.50	24.48
16.	.800	100.	1.73	21.74
24.	.840	100.	1.60	28.72
32.	.830	100.	1.28	31.01
48.	1.010	100.	1.17	34.94
64.	1.140	30.	3.23	34.18
96.	1.340	30.	2.32	31.33

INTERPRETED MODEL

DEPTHS	.43	.99	3.85	12.23	56.55	
RESISTIVITIES	6.	12.	7.	55.	36.	25.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 34   GRID REFERENCE 51060 95070

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.337	300.	1.09	6.10
2.	.415	100.	2.83	8.57
3.	.412	100.	2.36	10.80
4.	.510	100.	2.59	12.76
6.	.520	100.	2.18	15.80
8.	.610	100.	2.18	17.96
12.	.550	100.	1.39	19.06
16.	.590	100.	1.28	21.81
24.	.590	100.	1.07	27.35
32.	1.230	100.	1.88	30.73
48.	1.175	100.	1.30	33.37
64.	1.380	30.	3.76	32.87
96.	1.020	30.	1.27	22.53

INTERPRETED MODEL

DEPTHS	1.18	15.16	53.00	
RESISTIVITIES	5.	23.	48.	10.

LPT   ACCOUNT: 33-24

-36'

SAFI V.E.S. 35   GRID REFERENCE 49945 95890

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.070	3000.	1.93	519.71
2.	.129	3000.	1.19	347.77
3.	.306	3000.	1.50	277.20
4.	.244	1000.	2.98	306.95
6.	.335	1000.	2.88	324.10
8.	.309	1000.	1.63	265.15
12.	.311	300.	2.13	154.92
16.	.184	100.	2.27	124.02
24.	.287	100.	2.20	115.59
32.	.328	100.	1.69	103.60
48.	.272	30.	3.01	100.12
64.	.340	30.	1.50	53.22
96.	.565	30.	1.04	33.31

INTERPRETED MODEL

DEPTHS	.99	7.69	45.34	58.26	
RESISTIVITIES	517.	250.	80.	35.	12.

LPT   ACCOUNT: 33-24

.344

SAFI V.E.S. 36   GRID REFERENCE 50275 96005

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.285	10000.	1.53	337.31
2.	.175	3000.	1.65	355.45
3.	.266	3000.	1.47	312.51
4.	.169	1000.	2.15	319.74
6.	.161	1000.	1.29	302.06
8.	.201	300.	4.01	300.84
12.	.314	300.	3.44	247.81
16.	.257	300.	1.89	221.79
24.	.263	100.	2.99	171.44
32.	.285	100.	1.66	117.11
48.	.314	30.	2.26	65.12
64.	.158	10.	2.01	51.16
96.	.428	10.	2.79	39.32

INTERPRETED MODEL

DEPTHS	1.66	7.12	16.38	28.32	
RESISTIVITIES	328.	313.	229.	94.	35.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 37   GRID REFERENCE 50515 94460

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	1.280	1000.	2.14	10.50
2.	.710	300.	2.48	13.17
3.	.600	300.	1.50	14.14
4.	.610	300.	1.30	16.07
6.	.670	100.	3.52	19.81
8.	.835	100.	3.75	22.57
12.	.790	100.	2.26	21.57
16.	.720	100.	1.66	23.18
24.	.870	100.	1.54	26.69
32.	.755	100.	1.22	32.49
48.	1.360	100.	1.45	32.16
64.	1.150	30.	3.22	33.78
96.	1.135	30.	1.91	30.45

INTERPRETED MODEL

DEPTHS	.90	4.08	7.23	16.10	53.00	
RESISTIVITIES	9.	20.	27.	25.	44.	23.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 38   GRID REFERENCE 50240 94250

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.950	1000.	2.17	14.35
2.	.670	300.	2.73	15.36
3.	.970	300.	2.89	16.85
4.	.840	300.	1.95	17.50
6.	.505	100.	2.57	19.19
8.	1.210	300.	1.55	19.32
12.	.880	100.	2.46	21.08
16.	.810	100.	1.82	22.59
24.	1.065	100.	1.95	27.61
32.	1.120	100.	1.64	29.44
48.	1.190	100.	1.27	32.19
64.	.910	30.	2.45	32.48
96.	1.065	30.	1.68	28.55

INTERPRETED MODEL

DEPTHS	2.44	12.69	60.23	
RESISTIVITIES	14.	23.	38.	22.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 39   GRID REFERENCE 50055 94195

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.495	300.	3.23	12.30
2.	.770	300.	2.51	12.29
3.	.750	300.	2.04	15.38
4.	.940	300.	2.62	21.02
6.	.900	300.	2.29	28.78
8.	.950	300.	2.42	38.41
12.	.680	300.	1.53	50.89
16.	.935	300.	1.63	52.58
24.	1.090	100.	3.37	46.62
32.	1.060	100.	2.32	44.01
48.	1.435	100.	1.87	39.30
64.	.770	30.	2.44	38.23
96.	.550	10.	3.00	32.90

INTERPRETED MODEL

DEPTHS	.53	1.95	2.48	9.91	54.00	
RESISTIVITIES	17.	8.	50.	108.	37.	27.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 40   GRID REFERENCE 51285 95340

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.700	300.	3.39	9.13
2.	.640	300.	3.17	18.67
3.	.650	300.	3.20	27.84
4.	.750	300.	2.89	29.05
6.	1.390	300.	3.42	27.83
8.	.710	300.	1.43	30.37
12.	1.400	300.	1.98	31.99
16.	.820	100.	2.52	30.89
24.	1.330	100.	2.52	28.57
32.	.890	100.	1.28	28.92
48.	.850	30.	2.64	28.10
64.	.860	30.	1.86	26.09
96.	.810	10.	2.73	20.33

INTERPRETED MODEL

DEPTHS	.71	1.19	7.63	53.00	
RESISTIVITIES	9.	27.	37.	31.	10.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 41   GRID REFERENCE 51440 95510

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.710	1000.	1.37	12.12
2.	.620	300.	2.81	17.09
3.	.720	300.	1.84	14.45
4.	.725	300.	1.51	15.70
6.	.755	100.	3.22	16.08
8.	.690	100.	2.47	17.99
12.	.760	100.	2.11	20.93
16.	.700	100.	1.56	22.40
24.	.740	100.	1.34	27.31
32.	.760	30.	3.69	29.29
48.	.790	30.	2.77	31.72
64.	.830	30.	2.17	31.54
96.	.775	10.	2.78	21.64

INTERPRETED MODEL

DEPTHS	.43	3.58	6.74	53.00	
RESISTIVITIES	9.	17.	14.	40.	9.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 42   GRID REFERENCE 48390 94865

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.850	3000.	1.57	34.82
2.	1.020	1000.	1.94	23.90
3.	.975	1000.	1.30	25.13
4.	.790	300.	2.71	25.86
6.	.730	100.	1.83	9.45
8.	.610	100.	3.86	31.81
12.	.475	100.	2.64	41.91
16.	.580	100.	2.93	50.79
24.	.585	100.	2.32	59.80
32.	.635	100.	2.01	63.64
48.	.475	30.	3.03	57.72
64.	.630	30.	3.23	61.85
96.	1.410	100.	1.34	57.32

INTERPRETED MODEL

DEPTHS	.49	.76	3.25	9.08	33.24	
RESISTIVITIES	55.	27.	20.	43.	86.	46.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 43   GRID REFERENCE 48405 94660

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.495	1000.	2.93	37.19
2.	.640	1000.	1.62	31.81
3.	.515	300.	2.70	29.65
4.	.505	300.	1.95	29.11
6.	.535	300.	1.41	29.81
8.	.585	300.	1.34	34.54
12.	.800	300.	1.55	43.83
16.	.775	300.	1.34	52.15
24.	1.050	300.	1.45	62.47
32.	.710	100.	2.74	77.59
48.	.975	100.	2.23	68.98
64.	.535	30.	2.91	65.62
96.	.550	30.	1.68	55.27

INTERPRETED MODEL

DEPTHS	.96	6.31	29.41	57.29	
RESISTIVITIES	41.	25.	106.	64.	35.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 44   GRID REFERENCE 49800 94205

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.930	1000.	1.73	11.69
2.	1.170	1000.	1.78	19.12
3.	.710	300.	3.31	26.36
4.	.745	300.	3.08	31.17
6.	1.030	300.	3.26	35.80
8.	1.075	300.	3.00	42.08
12.	1.040	300.	2.63	57.20
16.	.905	300.	2.11	70.32
24.	1.140	300.	2.03	80.56
32.	.587	100.	2.18	74.67
48.	.705	100.	1.32	56.47
64.	.490	30.	1.75	43.08
96.	.750	30.	1.64	39.45

INTERPRETED MODEL

DEPTHS	.70	2.40	8.60	21.90	53.20	
RESISTIVITIES	9.	19.	171.	77.	55.	31.

LPT ACCOUNT: 33-24

SAFI V.E.S. 45 GRID REFERENCE 48250 94170

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.449	1000.	1.32	18.47
2.	.469	300.	2.97	23.87
3.	.465	300.	2.16	26.27
4.	1.240	1.	1.35	.03
6.	.505	300.	1.57	35.16
8.	.430	100.	3.28	38.34
12.	.435	100.	2.48	42.99
16.	.600	100.	2.67	44.74
24.	.550	100.	2.01	55.11
32.	.780	100.	2.39	61.61
48.	.650	100.	1.28	59.39
64.	.495	30.	2.19	53.37
96.	1.110	30.	3.10	50.54

INTERPRETED MODEL

DEPTHS	1.42	8.22	47.41	
RESISTIVITIES	16.	46.	66.	41.

LPT ACCOUNT: 33-24

SAFI V.E.S. 46 GRID REFERENCE 49700 95045

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.580	1000.	3.14	34.02
2.	.635	1000.	2.82	55.81
3.	.680	1000.	2.58	71.52
4.	.740	1000.	2.22	75.40
6.	.610	300.	3.83	71.01
8.	.590	300.	2.75	70.29
12.	.565	300.	1.65	66.06
16.	.458	100.	2.75	60.36
24.	.950	100.	3.85	61.11
32.	.535	100.	1.76	66.14
48.	.760	100.	1.74	69.05
64.	.985	100.	1.59	64.91
96.	.359	10.	3.10	52.09

INTERPRETED MODEL

DEPTHS	.46	.74	2.61	25.39	46.81	62.61	
RESISTIVITIES	19.	49.	110.	64.	89.	59.	30.

LPT ACCOUNT: 33-24

SAFI V.E.S. 47 GRID REFERENCE 49445 49930

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.590	1000.	2.50	26.62
2.	.550	1000.	1.12	25.59
3.	1.285	1000.	2.23	32.71
4.	.710	1000.	1.24	43.89
6.	1.150	1000.	2.00	65.56
8.	.665	300.	3.87	87.76
12.	.585	300.	3.09	119.48
16.	1.195	1000.	1.73	145.54
24.	.310	100.	3.29	160.04
32.	.375	100.	1.93	103.48
48.	.825	100.	1.66	60.68
64.	.725	30.	3.59	59.74
96.	.515	30.	2.16	75.90

INTERPRETED MODEL

DEPTHS .64 .89 1.69 2.58 4.12 22.07 25.62
30.07

RESISTIVITIES 32. 20. 11. 72. 960. 128. 7.
5. 191.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 48   GRID REFERENCE 49365 93915

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.615	1000.	1.92	19.62
2.	.790	1000.	1.45	23.06
3.	.560	300.	2.47	24.94
4.	.600	300.	2.08	26.14
6.	.550	300.	1.48	30.43
8.	.665	300.	1.43	32.43
12.	1.050	300.	1.63	35.11
16.	.735	100.	2.79	38.16
24.	1.260	100.	3.53	42.25
32.	1.135	100.	2.46	43.58
48.	.635	30.	3.99	56.85
64.	.390	30.	1.27	39.28
96.	1.095	30.	1.53	25.28

INTERPRETED MODEL

DEPTHS	1.76	13.23	45.00	62.50	
RESISTIVITIES	18.	40.	47.	38.	11.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 49   GRID REFERENCE 49020 93905

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.750	1000.	1.59	13.32
2.	.740	1000.	1.30	22.08
3.	.660	300.	3.03	25.96
4.	.560	300.	2.03	27.33
6.	.760	300.	2.13	31.70
8.	.625	300.	1.65	39.81
12.	.710	300.	1.70	54.16
16.	.760	100.	3.56	47.09
24.	.490	100.	1.74	53.55
32.	.135	30.	1.24	55.40
48.	.525	30.	.30	5.20
64.	.410	30.	1.64	48.25
96.	.380	10.	2.31	36.67

INTERPRETED MODEL

DEPTHS	.32	.55	6.20	34.50	
RESISTIVITIES	6.	14.	35.	59.	43.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 50   GRID REFERENCE 48620 93925

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.490	1000.	1.17	15.00
2.	.685	1000.	1.16	21.28
3.	.910	1000.	1.41	29.21
4.	.545	300.	2.21	30.57
6.	.790	300.	2.57	36.79
8.	1.130	300.	2.51	33.50
12.	.580	100.	3.12	40.56
16.	.650	100.	2.81	43.46
24.	.610	100.	1.98	48.95
32.	.730	100.	1.91	52.61
48.	.765	100.	1.26	49.67
64.	.600	30.	2.15	43.23
96.	.560	10.	2.71	29.19

INTERPRETED MODEL

DEPTHS	.83	9.05	44.64	60.08	
RESISTIVITIES	12.	39.	62.	30.	11.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 51   GRID REFERENCE 48265 93945

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.860	1000.	3.31	24.18
2.	.482	300.	3.47	27.14
3.	.790	300.	3.95	28.27
4.	.780	300.	2.81	27.16
6.	.730	300.	1.97	30.52
8.	.337	100.	2.17	32.37
12.	.480	100.	2.18	34.24
16.	.465	100.	1.55	33.51
24.	.459	30.	3.57	35.19
32.	.405	30.	2.34	34.85
48.	.462	30.	1.58	30.94
64.	.945	30.	2.33	29.74
96.	.560	10.	2.07	22.30

INTERPRETED MODEL

DEPTHS	1.79	6.57	28.93	62.05	
RESISTIVITIES	23.	36.	37.	29.	13.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 52   GRID REFERENCE 47990 93945

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.620	1000.	2.71	27.46
2.	.630	1000.	1.79	35.70
3.	.700	1000.	1.62	43.62
4.	.635	1000.	1.27	50.27
6.	.520	300.	2.75	59.81
8.	.570	300.	2.83	74.87
12.	.825	300.	3.21	88.01
16.	.685	300.	2.17	95.54
24.	.575	100.	3.37	88.38
32.	.530	100.	2.01	76.25
48.	.335	30.	1.70	45.91
64.	.458	30.	1.33	35.03
96.	1.035	30.	1.12	19.58

INTERPRETED MODEL

DEPTHS	1.19	4.50	14.80	28.77	41.41	51.48	
RESISTIVITIES	24.	70.	139.	68.	25.	12.	8.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 53   GRID REFERENCE 50425 95625

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.428	3000.	1.26	55.49
2.	.710	3000.	2.03	107.79
3.	.440	1000.	2.89	123.81
4.	.530	1000.	2.91	137.99
6.	.535	1000.	2.02	142.34
8.	.680	1000.	2.11	155.97
12.	.545	300.	3.93	163.11
16.	.690	300.	3.64	159.10
24.	.495	300.	1.48	135.26
32.	.590	100.	3.18	108.37
48.	.565	30.	3.62	57.97
64.	.900	30.	3.84	51.47
96.	.650	30.	1.63	45.38

INTERPRETED MODEL

DEPTHS	.34	.58	.92	14.80	22.40	
RESISTIVITIES	22.	50.	279.	198.	117.	49.

LPT ACCOUNT: 33-24

SAFI V.E.S. 54 GRID REFERENCE 49170 95260

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.420	1000.	2.08	31.12
2.	.302	1000.	3.36	139.81
3.	.242	1000.	2.08	162.01
4.	.330	1000.	2.04	155.37
6.	.487	1000.	2.09	161.79
8.	.365	1000.	1.27	174.90
12.	.368	300.	3.20	196.69
16.	.378	300.	2.97	236.97
24.	.400	300.	2.01	227.33
32.	.440	300.	1.46	200.15
48.	.417	100.	1.93	139.59
64.	.380	30.	3.02	95.87
96.	.472	30.	1.44	55.21

INTERPRETED MODEL

DEPTHS	.59	3.47	6.22	22.20	30.04	42.82	
RESISTIVITIES	87.	171.	131.	318.	165.	70. /	25.

LPT ACCOUNT: 33-24

SAFI V.E.S. 55 GRID REFERENCE 4920 95000

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.360	3000.	1.85	96.87
2.	.281	1000.	2.88	128.79
3.	.395	1000.	2.65	126.46
4.	.289	1000.	1.27	110.44
6.	.440	1000.	1.46	125.09
8.	.665	1000.	2.97	224.49
12.	.478	300.	3.53	167.04
16.	.500	300.	2.73	164.67
24.	.471	300.	1.42	136.39
32.	.365	100.	2.43	133.86
48.	.670	100.	2.57	115.69
64.	.650	100.	1.78	110.12
96.	.366	30.	1.76	87.02

INTERPRETED MODEL

DEPTHS	.34	1.57	5.38	17.26	60.35	
RESISTIVITIES	49.	155.	117.	198.	105.	60.

LPT ACCOUNT: 33-24

SAFI V.E.S. 56 GRID REFERENCE 48985 95130

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.395	3000.	1.48	70.63
2.	.645	1000.	3.13	60.98
3.	.473	1000.	1.30	51.81
4.	.530	300.	3.91	55.62
6.	.495	300.	2.04	46.61
8.	.600	300.	1.63	40.97
12.	.381	100.	1.88	37.20
16.	.635	100.	2.35	37.20
24.	.540	100.	1.58	44.12
32.	.448	100.	1.13	50.71
48.	.620	100.	1.28	62.26
64.	.355	30.	2.01	68.30
96.	.515	30.	2.41	84.68

INTERPRETED MODEL

DEPTHS	1.48	6.38	17.13	53.11	
RESISTIVITIES	77.	41.	29.	86.	145.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 57   GRID REFERENCE 50750 95470

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.415	1000.	1.87	28.31
2.	1.115	1000.	2.93	33.02
3.	.560	1000.	1.95	65.64
4.	.850	1000.	3.25	96.10
6.	1.155	1000.	2.43	79.32
8.	1.095	1000.	2.07	95.02
12.	1.030	300.	3.20	70.27
16.	1.140	300.	2.28	60.32
24.	.625	100.	1.92	46.32
32.	.945	100.	1.74	37.02
48.	.575	30.	2.15	33.83
64.	1.150	30.	2.83	29.69
96.	.695	10.	2.95	25.60

INTERPRETED MODEL

DEPTHS	.49	.86	8.32	34.90	
RESISTIVITIES	20.	36.	112.	38.	22.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 58   GRID REFERENCE 50880 95370

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.401	1000.	1.36	21.31
2.	.660	300.	3.35	19.14
3.	.955	300.	2.65	15.69
4.	.970	300.	2.20	17.10
6.	.550	100.	2.83	19.40
8.	.457	100.	2.07	22.77
12.	.750	100.	2.53	25.43
16.	.685	100.	2.03	29.79
24.	.590	100.	1.47	37.57
32.	.980	100.	1.53	31.39
48.	.665	30.	2.22	30.20
64.	1.020	30.	2.48	29.33
96.	1.040	30.	1.40	24.36

INTERPRETED MODEL

DEPTHS	.90	3.69	48.54	
RESISTIVITIES	24.	14.	34.	17.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 59   GRID REFERENCE 47680 93965

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.590	1000.	1.88	20.02
2.	.545	1000.	1.04	23.98
3.	.610	300.	3.14	29.11
4.	.515	300.	2.31	33.82
6.	.535	300.	1.82	38.47
8.	.545	300.	1.71	47.31
12.	.645	300.	1.47	51.55
16.	.655	100.	3.55	54.49
24.	.520	100.	1.57	45.53
32.	.695	100.	1.38	39.92
48.	.385	30.	1.24	29.14
64.	.575	30.	1.13	23.71
96.	.660	10.	1.43	13.07

INTERPRETED MODEL

DEPTHS	1.42	5.67	12.24	31.32	56.59	
RESISTIVITIES	18.	52.	74.	40.	16.	6.

LPT ACCOUNT: 33-24

SAFI V.E.S. 60 GRID REFERENCE 48125 95090

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.515	1000.	2.48	30.26
2.	.490	1000.	1.29	33.08
3.	.580	300.	3.42	33.34
4.	.650	300.	3.35	38.86
6.	.570	300.	2.54	50.40
8.	.575	300.	2.30	60.32
12.	.745	300.	2.47	74.99
16.	.750	300.	2.26	90.88
24.	.620	300.	1.57	114.56
32.	.630	100.	3.59	114.57
48.	.500	100.	1.85	111.59
64.	.790	100.	2.09	106.38
96.	.815	30.	3.57	79.27

INTERPRETED MODEL

DEPTHS	3.66	29.72	57.56	
RESISTIVITIES	31.	157.	94.	40.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 61   GRID REFERENCE 48040 94860

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.310	300.	2.97	18.06
2.	.465	300.	2.30	18.65
3.	.435	300.	1.63	21.19
4.	.348	100.	3.93	28.38
6.	.315	100.	2.93	35.07
8.	.500	300.	1.38	41.62
12.	.386	100.	2.71	52.94
16.	.335	100.	2.00	60.02
24.	.895	300.	1.39	70.26
32.	1.270	300.	1.60	75.99
48.	.655	100.	1.83	84.26
64.	.645	100.	1.36	84.79
96.	.675	30.	3.18	85.25

INTERPRETED MODEL

DEPTHS	.68	2.19	4.63	56.29	
RESISTIVITIES	18.	16.	42.	96.	79.

LPT ACCOUNT: 33-24

SAFI V.E.S. 63 GRID REFERENCE 50715 94895

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	MULTIPLIER	APPARENT RESISTIVITY
1.	.310	3000.	2.57	156.27
2.	.285	3000.	1.64	216.94
3.	.400	1000.	3.29	155.04
4.	.600	1000.	3.03	126.92
6.	.585	1000.	1.41	90.86
8.	.640	300.	3.31	77.99
12.	.565	100.	3.95	52.71
16.	.470	100.	1.77	37.86
24.	.482	30.	3.90	36.60
32.	.595	100.	1.14	38.52
48.	.385	30.	1.66	39.01
64.	.372	10.	3.48	37.62
96.	.374	10.	2.24	36.13

INTERPRETED MODEL

DEPTHS	.37	3.07	6.57	25.60	48.50	
RESISTIVITIES	141.	221.	66.	33.	40.	31.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 64   GRID REFERENCE 50640 95030

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	1.100	3000.	2.93	50.21
2.	.970	1000.	2.18	28.24
3.	.720	300.	2.55	20.03
4.	.720	300.	2.10	21.99
6.	.960	300.	2.12	24.98
8.	.880	300.	1.89	32.39
12.	.630	100.	3.09	36.98
16.	.880	300.	1.18	40.44
24.	.355	100.	1.16	49.27
32.	.282	30.	2.55	54.54
48.	.305	30.	2.03	60.22
64.	.510	30.	2.85	67.41
96.	.690	30.	1.68	44.06

INTERPRETED MODEL

DEPTHS	.66	.98	4.14	20.66	43.01	59.00	
RESISTIVITIES	69.	45.	14.	66.	83.	59.	25.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 65   GRID REFERENCE 50315 95250

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.314	1000.	2.65	53.03
2.	.352	1000.	1.74	62.12
3.	.497	1000.	1.33	50.44
4.	.345	300.	2.83	61.85
6.	.625	300.	2.75	49.76
8.	.600	300.	2.06	51.77
12.	.305	100.	2.40	59.33
16.	.590	100.	3.74	63.73
24.	.473	100.	2.11	67.27
32.	.373	100.	1.34	72.23
48.	.296	30.	2.20	67.25
64.	.570	30.	2.71	57.36
96.	.610	30.	2.22	65.86

INTERPRETED MODEL

DEPTHS	.32	2.54	5.50	44.14	63.40	
RESISTIVITIES	43.	60.	46.	69.	50.	76.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 66   GRID REFERENCE 50175 94880

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.335	1000.	2.62	49.14
2.	.359	1000.	3.08	107.81
3.	.635	3000.	2.09	186.12
4.	.805	3000.	1.97	184.51
6.	.458	1000.	2.68	220.60
8.	.340	1000.	1.55	229.15
12.	.945	1000.	2.85	227.39
16.	.525	300.	3.68	211.40
24.	.320	300.	1.35	190.85
32.	1.015	300.	2.64	156.89
48.	.413	100.	1.66	121.22
64.	.395	30.	3.06	93.46
96.	.940	30.	3.65	70.26

INTERPRETED MODEL

DEPTHS	.97	1.59	6.14	29.45	48.00	
RESISTIVITIES	61.	148.	402.	161.	84.	50.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 67   GRID REFERENCE 50340 94675

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.318	3000.	3.33	197.39
2.	.206	1000.	3.36	204.97
3.	.285	1000.	2.58	170.64
4.	.320	1000.	2.40	188.50
6.	.300	1000.	1.68	211.12
8.	.315	300.	3.49	167.07
12.	.137	100.	2.08	114.47
16.	.417	100.	3.34	80.52
24.	.240	30.	3.07	57.87
32.	.315	30.	2.48	47.49
48.	.495	30.	2.32	42.41
64.	.515	30.	1.62	37.95
96.	1.085	30.	2.89	48.20

INTERPRETED MODEL

DEPTHS	2.31	6.46	11.42	13.67	50.00	
RESISTIVITIES	202.	243.	113.	44.	37.	25.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 68   GRID REFERENCE 49160 94190

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.650	3000.	1.29	37.41
2.	.555	1000.	2.59	58.64
3.	.670	1000.	2.17	61.05
4.	.650	1000.	1.56	60.32
6.	.456	300.	2.14	53.08
8.	.550	300.	2.14	58.67
12.	.790	300.	2.29	65.57
16.	.455	100.	3.02	66.73
24.	.910	100.	3.78	62.64
32.	.645	100.	1.79	55.80
48.	.505	30.	2.82	50.52
64.	1.040	30.	3.78	43.85
96.	.421	10.	2.01	28.80

INTERPRETED MODEL

DEPTHS	.44	2.50	6.86	44.50	61.10	
RESISTIVITIES	20.	75.	52.	70.	44.	13.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 69   GRID REFERENCE 48875 94230

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.415	1000.	1.68	25.44
2.	.405	300.	3.63	33.79
3.	.487	300.	3.01	34.95
4.	.387	300.	1.87	36.43
6.	.540	300.	1.96	41.05
8.	.500	300.	1.60	48.25
12.	.640	300.	1.52	53.72
16.	.635	100.	3.73	59.05
24.	1.060	300.	1.42	60.60
32.	.640	100.	1.89	59.38
48.	.435	30.	2.87	59.69
64.	.450	30.	2.13	57.10
96.	.468	10.	2.92	37.63

INTERPRETED MODEL

DEPTHS	.82	6.03	46.08	62.42	
RESISTIVITIES	20.	46.	71.	46.	16.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 70   GRID REFERENCE 48640 94250

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.455	1000.	2.78	38.39
2.	.510	1000.	2.10	51.74
3.	.560	1000.	1.63	54.87
4.	.482	300.	3.99	62.41
6.	.515	300.	3.30	72.47
8.	.446	300.	2.15	72.69
12.	.477	300.	1.56	73.98
16.	.500	100.	3.92	78.82
24.	.615	100.	3.28	80.30
32.	.870	100.	3.73	86.20
48.	.660	100.	1.93	88.19
64.	.845	100.	1.85	88.04
96.	.520	30.	1.81	62.99

INTERPRETED MODEL

DEPTHS	.89	14.50	46.00	
RESISTIVITIES	32.	78.	145.	34.

LPT ACCOUNT: 33-24

SAFI V.E.S. 71 GRID REFERENCE 48750 94865

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.495	1000.	2.07	26.28
2.	.505	300.	3.56	26.58
3.	.517	300.	3.63	39.70
4.	.502	300.	2.47	37.10
6.	.302	300.	1.31	49.06
8.	.408	300.	1.77	65.42
12.	.485	300.	1.81	84.41
16.	.560	300.	1.78	95.86
24.	.675	300.	1.70	113.94
32.	1.055	300.	2.23	127.50
48.	.341	100.	1.38	122.05
64.	.336	30.	3.18	114.17
96.	.345	30.	1.25	65.56

INTERPRETED MODEL

DEPTHS	.55	2.05	4.85	28.28	56.04	
RESISTIVITIES	27.	21.	67.	190.	98.	20.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 72   GRID REFERENCE 48740 94690

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.430	1000.	1.71	24.99
2.	.477	300.	3.34	26.40
3.	.486	300.	2.44	28.39
4.	.348	300.	1.75	37.92
6.	.370	300.	1.71	52.27
8.	.550	300.	2.38	65.25
12.	.690	300.	2.06	67.53
16.	.486	300.	1.55	96.19
24.	.850	300.	2.01	106.98
32.	.870	300.	1.64	113.70
48.	.495	100.	1.58	96.27
64.	.655	100.	1.35	82.88
96.	.815	30.	2.85	63.28

INTERPRETED MODEL

DEPTHS	2.26	4.00	28.96	56.26	
RESISTIVITIES	25.	72.	154.	66.	32.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 73   GRID REFERENCE 47880 93850

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.321	1000.	1.59	31.12
2.	.715	1000.	3.27	57.47
3.	.444	1000.	1.83	77.69
4.	.442	1000.	1.78	101.21
6.	.505	1000.	1.31	97.79
8.	.366	300.	2.93	120.72
12.	.380	300.	1.64	97.62
16.	.311	100.	2.93	94.71
24.	.505	100.	2.90	86.60
32.	.655	100.	2.17	66.61
48.	.635	30.	2.91	41.46
64.	.520	30.	1.17	27.14
96.	.740	10.	1.75	14.26

INTERPRETED MODEL

DEPTHS	.69	.96	3.68	28.52	43.15	52.94	
RESISTIVITIES	21.	39.	188.	79.	30.	12.	5.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 74   GRID REFERENCE 47895 93660

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.370	1000.	2.72	46.19
2.	.370	1000.	1.44	48.91
3.	.405	300.	3.10	43.28
4.	.295	300.	1.97	50.35
6.	.302	300.	1.43	53.55
8.	.345	300.	1.39	60.76
12.	.262	100.	1.98	56.98
16.	.510	100.	2.90	57.16
24.	.370	100.	1.32	53.80
32.	.369	30.	2.74	44.79
48.	.322	10.	3.39	31.75
64.	1.350	30.	2.77	24.75
96.	.775	10.	2.15	16.73

INTERPRETED MODEL

DEPTHS	3.34	18.63	45.33	
RESISTIVITIES	45.	68.	28.	10.

LPT ACCOUNT: 33-24

SAFI V.E.S. 75 GRID REFERENCE 47885 93450

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.367	1000.	3.28	56.15
2.	.370	300.	3.12	31.79
3.	.254	100.	2.70	20.04
4.	.495	100.	3.09	15.69
6.	.241	100.	1.11	17.36
8.	.345	100.	1.24	18.07
12.	.296	30.	3.03	23.15
16.	.590	100.	1.43	24.37
24.	.337	30.	1.99	26.71
32.	.301	30.	1.38	27.65
48.	.620	30.	1.79	26.12
64.	.560	10.	3.00	21.54
96.	.515	3.	2.53	8.89

INTERPRETED MODEL

DEPTHS	.92	1.75	3.30	44.16	59.63	
RESISTIVITIES	73.	20.	8.	32.	13.	3.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 76   GRID REFERENCE 47580 94240

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	1.120	1000.	3.24	18.18
2.	1.120	1000.	2.00	22.44
3.	.790	1000.	1.13	26.96
4.	1.035	1000.	1.39	33.75
6.	.970	300.	3.98	46.40
8.	.640	300.	2.37	55.84
12.	.910	300.	2.82	70.10
16.	.515	100.	3.93	76.72
24.	1.170	300.	1.42	54.91
32.	1.000	100.	1.64	32.97
48.	.525	10.	2.16	12.41
64.	1.115	10.	2.78	10.03
96.	.260	1.	3.01	6.98

INTERPRETED MODEL

DEPTHS	1.14	2.80	13.81	21.73	27.40	
RESISTIVITIES	18.	42.	90.	40.	16.	3.

LPT   ACCOUNT: 33-24

SAFI V.E.S. 77   GRID REFERENCE 47845 94185

ELECTRODE SPACING	CURRENT (AMPS)	VOLTAGE RANGE	VOLTAGE MULTIPLIER	APPARENT RESISTIVITY
1.	.560	1000.	1.83	20.53
2.	.510	300.	3.55	26.24
3.	.600	300.	3.09	29.12
4.	.780	300.	3.93	37.99
6.	.430	300.	2.03	53.39
8.	.465	300.	2.23	72.32
12.	.540	300.	2.08	87.13
16.	.485	300.	1.37	85.19
24.	.380	100.	2.13	84.53
32.	.351	100.	2.13	122.01
48.	.351	100.	1.45	124.59
64.	.595	30.	3.96	80.29
96.	1.485	30.	3.97	48.38

INTERPRETED MODEL

DEPTHS	1.06	2.66	14.20	28.81	42.70	50.72	
RESISTIVITIES	20.	39.	123.	72.	31.	9.	2.

APPENDIX C

HYDROLOGICAL MEASUREMENTS, 1977/78

C.1 WADI HASA

The total flow of the Wadi Hasa is made up of winter flood flows of short duration superimposed upon a large perennial baseflow derived from high-level springs rising in the eastern highlands. Flood flows are measured by the NRA at a gauging station established for this purpose at the point where the wadi emerges from the escarpment. A large proportion of the baseflow is diverted just downstream of the NRA gauging station for irrigation.

Locations were selected upstream of the NRA gauging station to measure total flow and on the irrigation canal to measure diverted flow. The undiverted flow which continues down the wadi channel has been calculated as the difference between these measurements. The flow measurements from May 1977 to November 1978 are given in Table C.1 and plotted in Figure C.1.

Surveys have been carried out to estimate the losses of undiverted flow along the channel from the NRA gauging station to the Aqaba roadbridge as well as the general distribution of diverted flow and the extent to which the irrigation canals are lined.

Total flow

The total flow of the Wadi Hasa is measured by the float method. It is necessary to apply a correction factor to these measurements to allow for differing flow velocities at the surface and the channel bottom. We are not certain whether a correction factor has been applied consistently to the field measurements and some revision may be required when the field data have been checked.

Flows range from about 0.4 to 1.4 m^3/s, averaging about 1 m^3/s (31.5 million m^3/year) over the 18 months of record. This record of total flow cannot necessarily be equated directly with baseflow as it is likely that some remnant flood flows may be included in the measurements during the winter months. Nonetheless the total flow measurements do suggest a seasonal variation in baseflow.

Diverted flow

A current meter is used to measure the flow diverted from the wadi channel into the main irrigation canal. The average volume of diverted flow over the period May 1977 to October 1978 was 730 l/s.

Not all of the total flow is diverted, the average being about 65 per cent of total flow. The proportion of total flow diverted into the irrigation canal is influenced by the occurrence of flood flows (to avoid silting), the efficiency of the loose-rock bund to divert flow and the capacity of the irrigation canal itself.

The irrigation channel usually flows at full capacity. Earlier flow measurements at the distribution box may have therefore underestimated the total baseflow and suggested a relatively constant baseflow. As the capacity of the irrigation canal is a major factor controlling the volume of total flow that can be diverted, it is not possible to relate flow measured at the distribution box with rainfall. The measurements at this location are of the minimum, reliable baseflow.

A knowledge of how the flow diverted for irrigation is distributed areally over the fan would help to assess the recharge available to the proposed wellfield from this source. As it is not practical to examine the distribution in detail, we have chosen to divide the irrigated area of the fan, using aerial photographs, into three roughly equal areas each supplied by a major channel (Figure C.2). A preliminary survey was then carried out, on the 15 November 1978, to estimate the proportion of diverted flow to each sub-area. It was found that 50 per cent of the diverted flow irrigates the area south of 48^{o}N, the remaining 50 per cent being equally distributed to the area north of the wadi channel and to the area between the wadi channel and 48^{o}N.

The large proportion of flow to the southern area seems high, considering each area has roughly similar areas under cultivation. Further surveys are needed to confirm whether this distribution of diverted flow varies during the year.

Undiverted flow

The average undiverted baseflow for the period May 1977 to October 1978 was 320 l/s (ranging from about 100 to 700 l/s), about 35 per cent of the total flow. Significant volumes of undiverted baseflow are now known to continue throughout the year, whereas it was previously believed that undiverted baseflow occurred mainly during the 'non-irrigation season', when irrigation demands are smaller. We now believe that a significant proportion of the total baseflow is not diverted because the diversion structures are not capable of diverting all of the total baseflow available. Thus the undiverted baseflow must form an important, previously unrecognised, source of recharge.

Surveys were made on the 15 November and 2 December 1978 to measure the losses of undiverted baseflow along the wadi channel from below the gauging station to the Aqaba roadbridge, a distance of some 4 km. The main intervening diversion is to an unlined canal (from which water is then abstracted by sumps) to irrigate a small area just east of the north bank siphon canal (Figure C.2). At the Aqaba roadbridge the remaining flow in the channel is used for irrigation.

The results of the surveys of undiverted baseflow are as follows in litres per second, after applying a correction factor for the float method of 0.7:

	15 November 1978	2 December 1978
Undiverted flow input	215	175
Diversion for irrigation	(35)	35
Remaining flow at Aqaba roadbridge	25	35
Loss of undiverted flow along channel due to infiltration and evaporation	155	105

The volume of loss, without accounting for direct evaporation (? 5-10 l/s/km), is about 40 l/s/km and this is similar to losses along the Wadi Karak as it crosses Ghor Dhira. The annual infiltration from undiverted flow could be several million m^3, most of which will contribute to where the wellfield is located. Further surveys would usefully provide more information on this important source of recharge.

C.2 FAN-EDGE SPRINGS

A temporary weir was installed to measure the collected flow from a number of seepages which rise about one kilometre north-west of Safi. Due to interference with the weir only two flow measurements have been possible, 42 and 28 l/s, in September 1977 and January 1978 respectively.

C.3 WATER LEVEL FLUCTUATIONS

The only boreholes suitable for routine water level measurements at Ghor Safi are S6 and the group BN309/302/303/304 (see Figure 2.1). Routine water level measurements began at these boreholes in the spring of 1977. Water-levels had not been measured previously on any regular basis.

Water level hydrographs for S6 and BN302 are shown in Figure C.3. At S6 the measuring datum was altered by 1.3 m in September 1977 and the preceding measurements of water levels have been readjusted accordingly. The water level dippers were recalibrated in August 1977 and a new dipper has been in use since October 1978. Consequently the correlation between the sets of measurements in each of the following periods is not wholly reliable: April to August 1977, September 1977 to September 1978, and from October 1978 to February 1979.

The highest water levels occur in August and during the winter months of December or January. The rise in water level from June to August probably relates to irrigation practices and the rise in water level about November - December suggests recharge from winter flood flows.

Water levels at S6 rose by 0.7m between June and August 1977 but by only 0.08m in the same period of 1978, although a rise of 0.3m occurred in the latter period at BN 302. The rise in water level in the winter is more rapid and amounted to 0.265m and 0.45m at BN 302 in December 1977 and December 1978 respectively. It is not yet possible to judge whether the changes in water levels at S6 and BN 302 are typical of the aquifer as a whole.

TABLE C.1

FLOW MEASUREMENTS 1977/78 (litres/second)

Date	W. Hasa Total Flow	W. Hasa Diverted Flow	W. Hasa Undiverted[(1)] Flow	Fan-edge spring
1977 May 28	1088	580	508 (47)	
Jun 2	762	625	137 (18)	
16	870	670	200 (23)	
Jul 25	923	686	237 (26)	
27				
Aug 2	820	619	201 (24)	
3				
15	840	630	210 (25)	
23				
Sep 17				
18	942	794	148 (16)	
28				42
Oct -				
Nov 7	1140	510	630 (55)	
30				
Dec 1	1204	798	406 (34)	
22	1220	523	697 (57)	
1978 Jan 7				28
9	1125	756	369 (33)	
31	1103	930	173 (16)	
Feb 13	1370	844	526 (38)	
Mar 26	1065	967	98 (9)	
Apr -				
May 21	1020	690	330 (32)	
Jun -				
Jul 11	959	692	267 (28)	
Aug 20	948	677	271 (29)	
Sep 27	982	822		
Oct 17	1137	746	391 (34)	
18				

Notes: (1) Undiverted flow computed by difference. Figures in parentheses are the percentage of total flow not diverted at the irrigation offtake.

WADI HASA – FLOW MEASUREMENTS, 1977/78

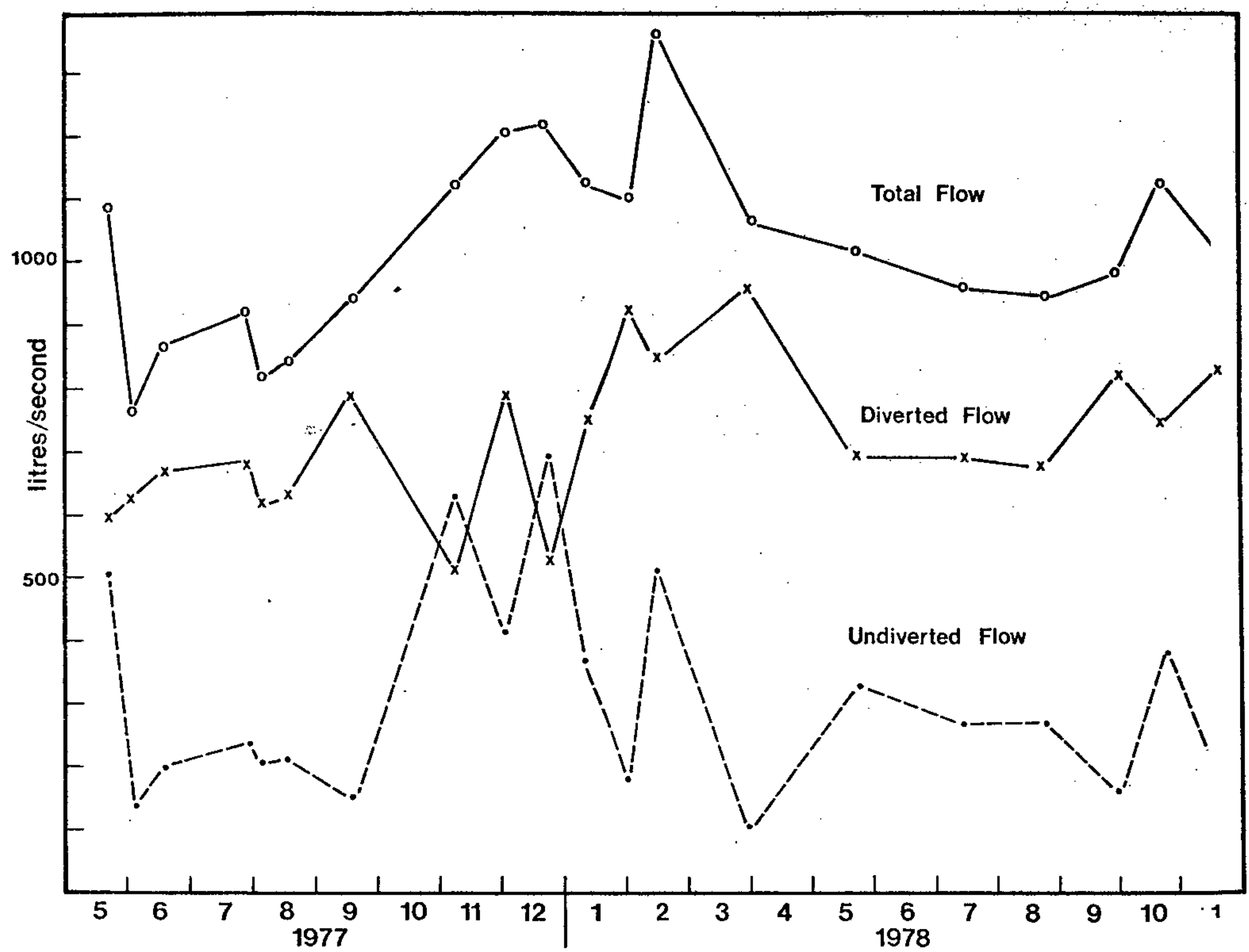


Figure C.2

GHOR SAFI ~ DISTRIBUTION OF WADI HASA FLOW

(November 15, 1978)

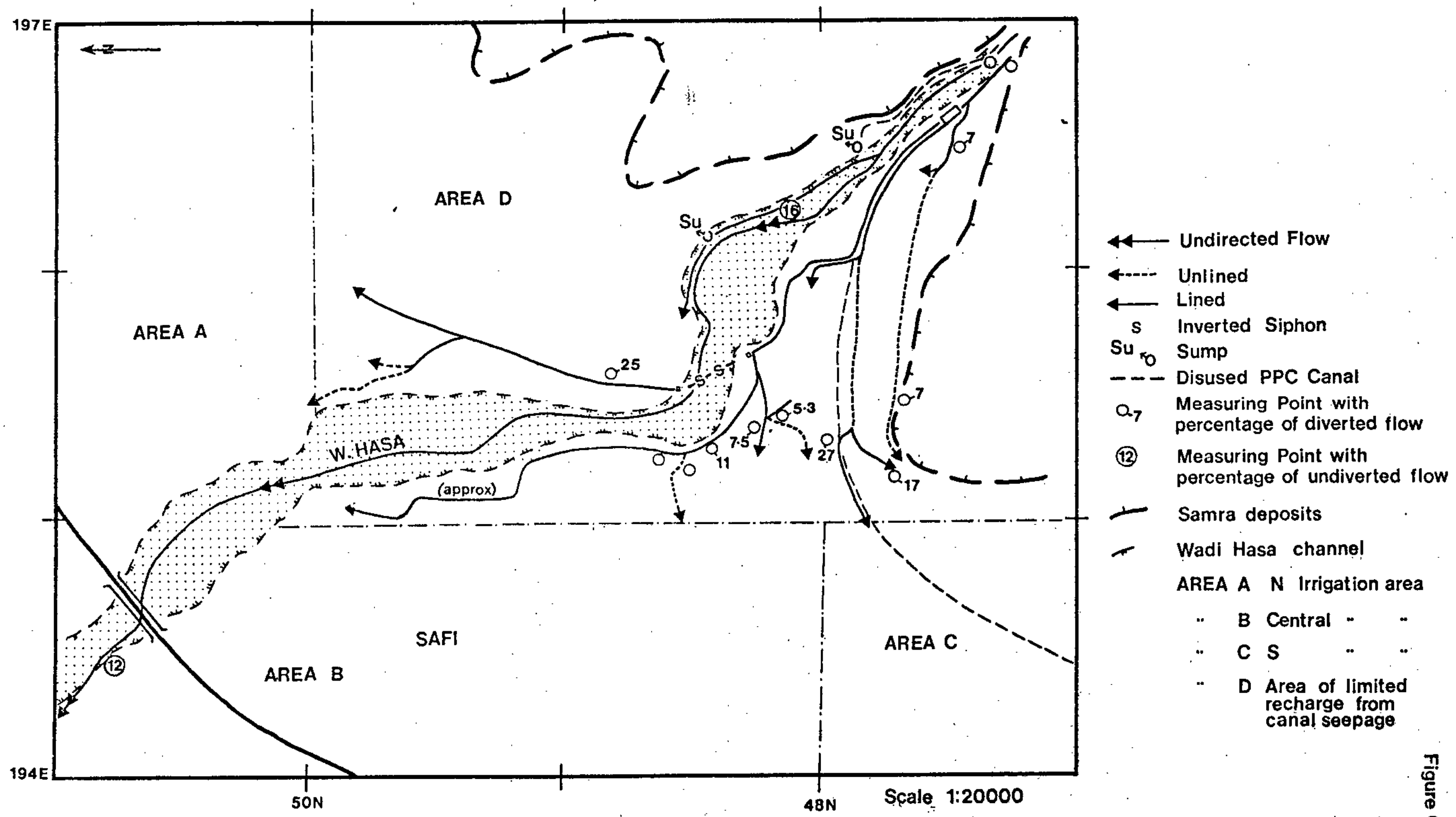
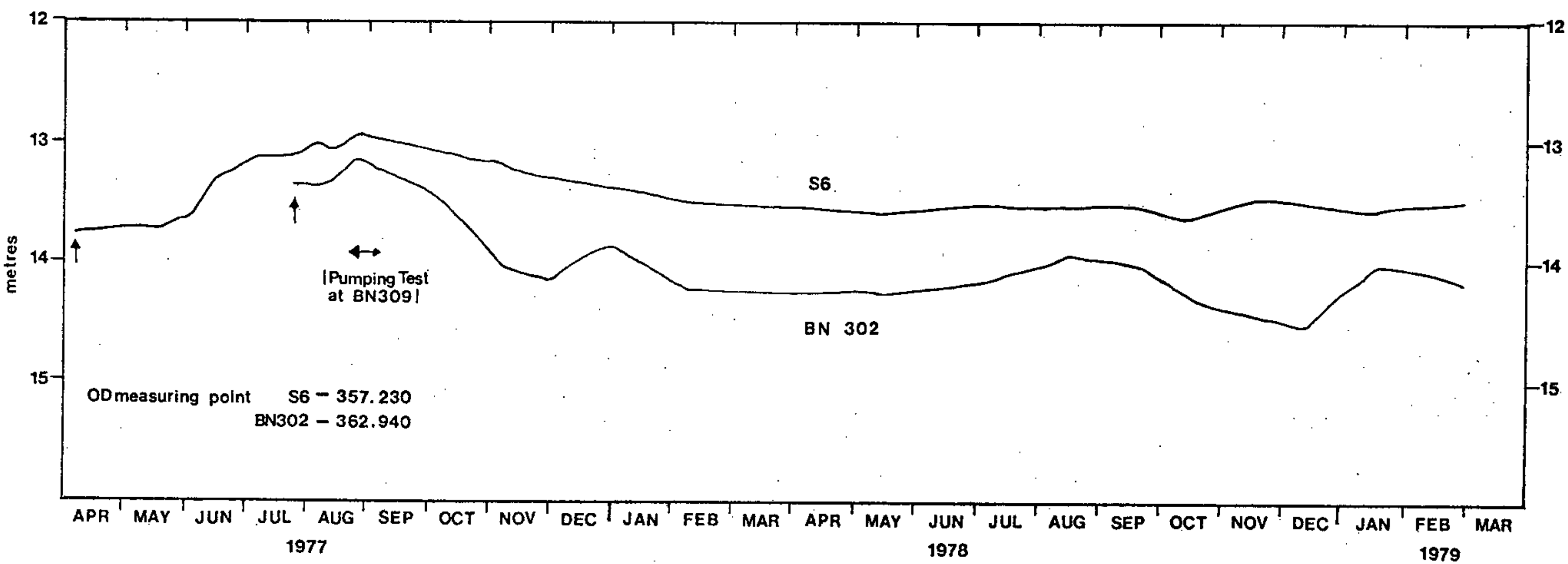


FIGURE C.3

WATER LEVEL HYDROGRAPHS, BOREHOLES S6 AND BN 302

(metres below measuring point)



Notes: Measurements at S6 prior to September 1977 have been corrected for 1.3m change in datum