SULTANATE OF OMAN

MINISTRY OF DEVELOPMENT

WATER RESOURCES SURVEY OF NORTHERN OMAN

INTERIM REPORT

VOLUME 1

APRIL 1974

HYDROLOGICAL AND HYDRO-GEOLOGICAL STUDIES

BY

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LONDON

IN ASSOCIATION WITH

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2nd May 1974

H.E. The Minister,
Ministry of Development,
P.O. Box 550/551,
Muscat.
Sultanate of Oman.

Excellency,

WATER RESOURCES SURVEY OF NORTHERN OMAN
INTERIM REPORT

In accordance with our agreement we have pleasure in submitting our first Interim Report.

This report is largely factual in substance and deals with the work and studies we have carried out in the past year, since we commenced the Survey. Where it has been possible to draw interim conclusions on the basis of data presently available, we have done so, but generally this has not been possible at this stage of the survey.

The field work for the survey has been carried out by our own staff, by staff of the Institute of Hydrology, Wallingford, U.K., by staff of ILACO, Arnhem, Holland, and by staff of Sogréah, Grenoble, France.

The Report is divided into the following five chapters:-

Chapter 1	:	General. This gives a brief description of the area covered by the survey. It gives information of supporting investigations and explains the methods we have adopted to carry out the survey.
Chapter 2	:	Hydology. This covers the work carried out in the ˙eld to date.

H. E. The Minister,
Sultanate of Oman. 2nd May 1974

Chapter 3	:	Hydro-geology. This gives details of work carried out in the field and refers to complementary studies and evaluations made on the basis of the field-work.
Chapter 4	:	Soils and Land Classification. This contains detailed description of soils and soil quality.
Chapter 5	:	Agriculture and Agro-economy. This shows the present state of agriculture.

The report is divided into two Volumes for ease of reference and handling. Chapters 1, 2 and 3 are contained in Volume 1 with a separate volume containing Appendices to Volume 1. Chapters 4 and 5 are contained in Volume 2. The Report is illustrated by a large number of figures and diagrams bound into the text and by eight drawings which are placed at the end of Volume 1.

During the course of the survey we have become increasingly concerned at the rapid deterioration in water quality in wells along the coastal area and in particular in the area of the Rumais Agricultural Experimental Farm. We refer to our letter addressed to you, dated 13th June 1973, which set out our fears for this particular area, but since that time further wells have been drilled there and the withdrawal of water from the aquifer has increased.

Our record of tests we have been conducting show that the salinity of water from the Rumais wells has been more than doubled over a period of only seven months. This is a very serious situation, and although we appreciate that there has been a lack of winter rainfall which might have had some effect upon the water quality, we strongly advise that immediate steps are taken to control, to regulate and to measure all water withdrawn from the ground, not only in the Rumais area but throughout the whole Batinah plain.

H. E. The Minister,
Sultanate of Oman. 2nd May 1974

Further exploration borehole drilling and test pumping, and geophysical and thermoprobe survey will commence shortly, the results of which will enable us to be more precise in our conclusions and to make recommendations for the future.

We have been greatly helped in our work by the generous assistance of your Department and of the office of the Economic Adviser to the Government as well as of other Government Departments. In addition we would like to acknowledge the help given to our field team by the management and technical staff of P. D. (O)., by the Director of Public Health, and the local Walis and Agricultural Extension Officers within our area of survey.

Yours faithfully,
For SIR ALEXANDER GIBB & PARTNERS

J. V. [signature]

WATER RESOURCES SURVEY OF NORTHERN OMAN

INTERIM REPORT

VOLUME 1

HYDROLOGICAL AND HYDROGEOLOGICAL STUDIES

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WATER RESOURCES SURVEY OF NORTHERN OMAN

VOLUME 1

HYDROLOGICAL AND HYDRO-GEOLOGICAL STUDIES

1. GENERAL NOTES

1.1 INTRODUCTION

The Sultanate of Oman lies between the latitudes of 16°N and 26°N, and only in the extreme South and in the North will the climate, the soils and the water supply support agriculture. Between these two extremes there is largely desert.

The area covered by this present Water Resources Survey lies in the Northern part of Oman and straddles the Tropic of Cancer which passes close to the South of Muscat, the Capital City. The area extends, in broad terms, along the coast from Muscat to Al Khaburah, and inland from Ibri to Adam and to the watershed East of the Wadi Semail. The total area is some 17000km^2 and is shown on Sketch Map No. 1.

The area is abruptly divided into two distinct regions by a range of high mountains, the Jebel Akhdar, which rises to a maximum height of 3 000 m. To the North of the Jebel, from the foothills to the sea, stretches the Batinah Plain varying in width from some 25 km at its widest point near Sib to only 10 km at Al Khaburah. This plain has a fringe of cultivated land along the sea coast and for 1 or 2 km inland, but the remainder is largely stony desert with some simple scrub vegetation.

No!

To the South of the Jebel lies an arid desert with rock outcrops leading eventually to the sands of the Rhub al Khali or Empty Quarter.

Close to the foot of the Jebel, both in the North and in the South are small towns or villages sited in more or less fertile areas fed by water from the Jebel. The principal villages on the Northern side of the Jebel are Nakhl, Awabi and Rostaq and those on the Southern side are Izki, Nizwa, Al Hamara, Bahla and Ibri.

The cultivated area along the sea coast and the areas around the towns and villages footing the Jebel Akhdar are the only areas which presently support agriculture, although there is evidence that even these areas are not fully exploited and that land, apparently cultivated and irrigated in the past, is now no longer worked.. This will be discussed further in Volume 2 of this Report.

The primary source of water in the area is from rain falling in the mountains, but the past year has been particularly dry and during the period of study up to the end of February, 1974 no rainfall of significant magnitude had fallen. This fact has had an effect upon the substance of this Interim Report in that until such rain events are observed and recorded, their effect upon the water balance of the area cannot fully be assessed.

Al Khawd

There are no previous records of runoff from a rain event in the Jebel but it can be assumed from similar situations elsewhere that runoff from significant rainfall would be a violent event, lasting for a relatively short period.

In the past, in Oman, rain has been accepted as a God given, natural benefice, and there had not been any reason to measure this bounty nor to check its periodicity. It is then, inevitable, that there are no records of rainfall within the area of survey, nor in the Jebel Akhdar in particular. However, the Petroleum Development (Oman) Company (PDO) have some records of rainfall at their base in Mina al Fahal made over the past few years, and these records have been made available to us. It was essential that provision should be made as a first priority, to measure rainfall in the Jebel and to record the amount of water flowing in certain wadis as a measure of the runoff from the Jebel, and this is described later.

Considerable assistance was given by management and Technical Staff of P.D. (O) in the geology of the area, and although their interests lie particularly in deeper lithology, their experience of more shallow strata has proved invaluable. Even with such guidance there was still no detailed information available of the lithology of the Batinah Plain, an area which, it was claimed by two earlier geological studies, contained a large potential of potable water in extensive aquifers. This assumption is, unfortunately, proving to be over-optimistic as will become apparent in later chapters of this report.

Information on the lithology of the Batinah was to be gained however in some degree, through a contract to drill one hundred water wells in the Batinah area, which the drilling Contractor, Geoprosco International Limited had negotiated directly with the Government of Oman early in 1972. By the time that this Water Resources Survey had been put into operation, in February 1973, some fifty wells had been drilled, and it was evident that such uncontrolled and indiscriminate drilling and abstraction of water within a limited area, could produce damage of a lasting nature to the quality of water in the aquifers. This, unfortunately, has indeed been found to be already taking place, in areas where excessive pumping is carried on.

At this time, the newly appointed Economic Adviser to the Government, having appreciated the dangers inherent in the effects of the drilling Contract, asked Sir Alexander Gibb & Partners to assume responsibility for directing the contract. This was agreed to, and it was further agreed that the aims of the contract would henceforward be directed particularly towards investigating the lithology and hydrology of the Batinah, rather than solely to producing water wells.

The remaining boreholes were therefore arranged to give the maximum amount of information both of lithology and of the quality of water and details of the water table, within a somewhat limited area and even though some boreholes were directed by Government to be drilled at special, specific locations not connected with the survey, a background of data has been built up which enables a more precise programme of drilling to be set out for a future exploratory drilling contract about to be arranged.

1.2 INSTRUMENTS

All of the instruments purchased for this Survey in the early part of 1973 have been installed and have been in operation for some time.

It is, however, unfortunate that some of the standard raingauges set in the Jebel Akhdar have been removed by persons unknown, and even when they were replaced by less attractive fibre-glass substitutes, some of these too have been taken away. This will have a serious effect upon the results of the survey.

Four synoptic meteorological stations have been set up, two North of the Jebel Akhdar and two South of the Jebel. The locations where the stations have been sited, and the personnel who have agreed to record the observations are as follows :

1. At Rumais, the station is set on the perimeter of the Government Experimental Farm, and senior staff at the Farm have agreed to take the readings. The Station became operational on 23rd December 1973.

2. At Rostaq, the station is established in the grounds of the Hospital. All of the instruments have been installed but it was found difficult, in the event, to find persons who were able and willing to be responsible for recording the readings. This difficulty is now overcome and the station is in operation.

3. At Nizwa, the station is sited at the boundary of the Government Experimental Farm. Here also, all the instruments are installed but it is proving difficult to find persons to make the readings.

4. At Sayq, in the high Jebel, a station has been set up within the Army Camp and the observations are being recorded by the Civil Development Officer. This station became operational on 9th December 1973.

A Contract was let to the Arab Development Company for the Civil Engineering Work in connection with the Wadi gauging stations. The work was to have been completed by the end of 1973, but to date only 50% of the sites are completed and these are all on the Northern side of the Jebel.

The gauging stations consist of a $9^5/_8$ ins. diameter steel tube, set into a concrete base in the wadi bed, and supported, where this is possible, by steel straps fastened into the rock at the side of the wadi.

An automatic water-level recording gauge is mounted on a platform at the top of the tube, which itself is sufficiently long to extend above the expected level of flood waters, and the float which operates the level recorder hangs inside the tube. The tube is set some 2 m. into the wadi bed so as to record any subsurface variations in water level.

The locations in which raingauges are sited are shown by map grid reference in Table 2.1 and those for the Wadi gauging station are shown in Table 2.3.

1.3 MAPS AND AERIAL PHOTOGRAPHY

The area of survey is covered by topographic maps to the scales 1:100 000 and 1:250 000 and copies of these have been obtained in England from the Development of Overseas Survey. Aerial photography was carried out in 1968 by the Royal Air Force and copies of the photographs to the scale 1:60 000 have been obtained.

Further sorties were flown by the R.A.F. in 1972 in specific but scattered areas and copies of photographs made at that time, to the scale 1:20 000 were obtained.

A further air photographic coverage of the area was made by the R.A.F. in November/December 1973, but to date the results have not come to hand.

The topographic maps have proved to be of very great value to the team, except that since they are based upon aerial photographic survey made circa 1960, the new Matrah to Sohar coastal road is not shown, and this causes difficulties in pinpointing the locations of wells, wadis, villages etc., which are situated adjacent to the new road.

The aerial photography to the scale 1:60 000 covers almost all of the survey area and these photographs have been used in various formats for locating specific details of areas on the ground. They have been used particularly for the Village Surveys and in the Soils and Agricultural Studies. There are, of course, discrepancies between the photography flown 5 years ago and the present day detailed topography, and it was for this reason that a firm request was made for a new aerial photographic coverage to be made. This up-to-date photography is most important to the Soils and Agricultural Study steams and until it is to hand, it will not be possible to finalise these sections of our Report.

1.4 DRILLING CONTRACT

The Contract negotiated by Geoprosco International Limited with the Government in 1972 to drill 100 water wells in the Batinah area, and which was extended under a Supplementary Agreement in 1973 to include a further 24 boreholes, has been completed.

The direction of this Contract was passed over to Sir Alexander Gibb and Partners in February 1973 at the request of the Government, and from that time it was possible to obtain data from drilling the boreholes useful to the Survey. The Contract itself imposed certain restrictions on the amount of data that could be obtained, but when the Contract was extended, provision was made for the provision of more information from the boreholes.

A separate Report has been submitted to Government dealing with this Drilling Contract and further reference to it now is unnecessary, except that well data sheets for all boreholes are included in Appendix C.

1.5 STAFF AND HOUSING

The team in Oman has remained constant for the past year, but now P.A. Greenway the Engineer in Charge, has handed over his responsibility to J.S. Clark who assumed the duties of Engineer in Charge of the survey team as from 8th February, 1974.

J.C. Dickie, who has been in charge of the Drilling Contract being carried out by Geoprosco International Limited, completed his duties when the Contract was completed in March, and departed from Oman on 1st April, 1974.

Staff housing has caused many problems and only two members of the team are satisfactorily accommodated. The two blocks of Flats being constructed for staff, are still not completed, some three months after the date promised by the Contractor, and at the date of this Report there is no indication of when they will be ready to be occupied.

1.6 ASSOCIATED CONSULTANTS

Sir Alexander Gibb and Partners are being assisted in the Hydrological and Hydrogeological aspects of their survey by the Institute of Hydrology, Wallingford, in the Soils and Land Classification studies by Sogreah, Consulting Engineers, Grenoble, and in the Agricultural and Agro-Economic studies by ILACO, Consulting Engineers, Arnhem.

1.7 STRATEGY

In a semi arid area the availability of fresh water is the limiting factor in development particularly in agriculture, which is by far the largest user. A soundly based water resources survey is essential, and it should consider not only the extent of the water resource available but also the pattern of existing water use and the changes that occur as a consequence of development.

The area being studied comprises some 17000 km^2 which includes the Jebel Akhdar range and the broad areas of alluvium to the north and south of the mountains. In the east of our area the Wadi Samail, the largest single Wadi basin, has perennial flow which is exploited in part for the water supply of the Muscat and Muttrah area, while the boundary to the west is defined by the Wadi Hawqayn and the Wadi Sayfam.

The major source of water is rainfall on the Jebel Akhdar range. Part of this rainfall becomes runoff in the wadis draining the mountain basins; of the remainder some is lost by evaporation and some infiltrates into the massive limestones to feed the springs issuing at the foot of the mountains. Floods in the wadis, which can be substantial after a rain storm, flow across the alluvial plains sometimes reaching the sea in the north, and deep into the desert area to the south. These flows are probably a significant source of recharge to the acquifers in the alluvium. However, the quantity of recharge depends upon the geological characteristics of the alluvium as well as the duration and extent of the wadi flows themselves.

The strategy of the survey has three main aspects. Firstly the overall input of rainfall to the area must be determined and the proportion of it which becomes wadi flow and as such is potentially available for recharge to natural storage. Secondly the complex lithology of the alluvial areas must be explored so that the extent and the characteristics of the natural aquifers can be defined. Lastly the existing pattern of water use must be surveyed to determine which sources are exploited and the efficiency of the methods used.

To meet the first objective a network of raingauges have been established over the whole region with emphasis on the Jebel and its foothills, the area which has the highest rainfall. In addition each major wadi has a gauging station. In some of these wadis a second gauging station is established so that a record of the outflow to the desert or the sea may be made. The continuous record of water level during a runoff event will enable the total volume of water leaving the drainage basins on the Jebel to be determined. Meteorological stations have been established at Saik, Nizwa, Rumais and Rostak where the intensity of rainfall and the meteorological factors which govern the water use of crops, will be measured.

The exploration of the alluvial areas involves a large scale drilling programme whereby the complex lithology of the alluvium, the position and extent of major aquifers and their water bearing capacity can be determined. Continual monitoring of water table levels in the boreholes enables an assessment of the extent of recharge during a runoff event in the wadis to be made and also the manner in which the water table declines during a prolonged dry period. Water quality is important both as an indicator of the origin and possibly the age of the water and of its suitability for abstraction.

The final aspect of our field work is the survey of water sources and the extent to which they are exploited in all the villages in our study area. The existing level of water use could, in many areas, be a substantial proportion of the perennially available water. Certainly current water use must be taken into account in the water budget for each major basin. Here also water quality determined by full chemical analysis is used to help define the source of the water be it from springs or aflaj or from wadi gravels. In some coastal areas particularly, it is found that the increasing use of water as more pumps are installed is leading to a deterioration in water quality. Thus we are extending our village survey programme to include continual monitoring of these changes in selected sample areas. Also there is a need for some direct study of the water requirements of crops so that some control of water use can be considered before any permanent deterioration occurs.

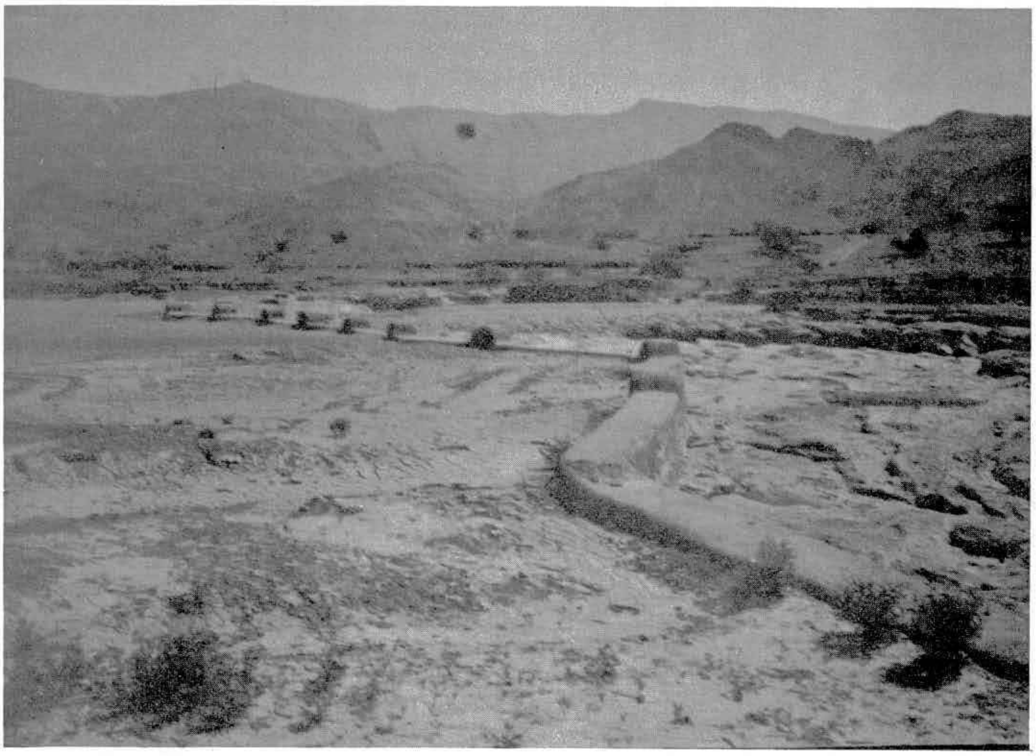
In the long term the availability of water is limited by the extent of natural replenishment of the aquifers, although, if it is found that the losses of water to the sea and out of the area to the south are significant, some of these losses might be avoided by enhancing recharge or by building surface reservoirs for additional storage. The key question in any event concerns the average input to the area. It will, of course, be impossible to provide a final answer to this question in three years and the collection of data must continue long into the future. Emphasis during the survey period must be toward understanding the process of runoff and recharge. Unfortunately this last winter season has been dry and what little rain has fallen has had little effect on the groundwater storages.

The following sections of this report describe in detail the work carried out during the first year of the survey. Inevitably much of the year has been taken up with detailed reconnaissance and with the siting and installation of instruments. Fortunately the existing drilling contract with Geoprosco International has enabled us to explore the alluvium of the Batinah more quickly than would have been possible otherwise. Also our survey of villages has made substantial progress in this first year and we have concentrated on the area of the Sib fan and the Wadis Samail and Bani Kharus.

TYPICAL LOCATIONS CHOSEN FOR THE ERECTION OF WADI GAUGING STATIONS

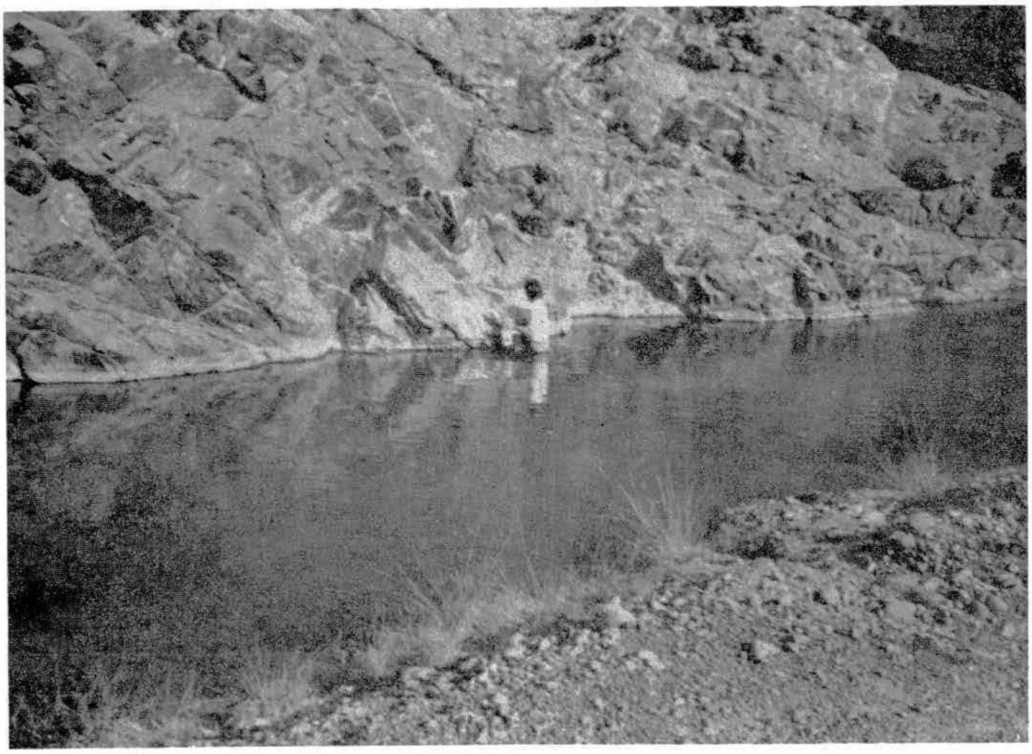
S1 WADI BAHLA AT BAHLA

N5 WADI BAHLA AT BISYAH

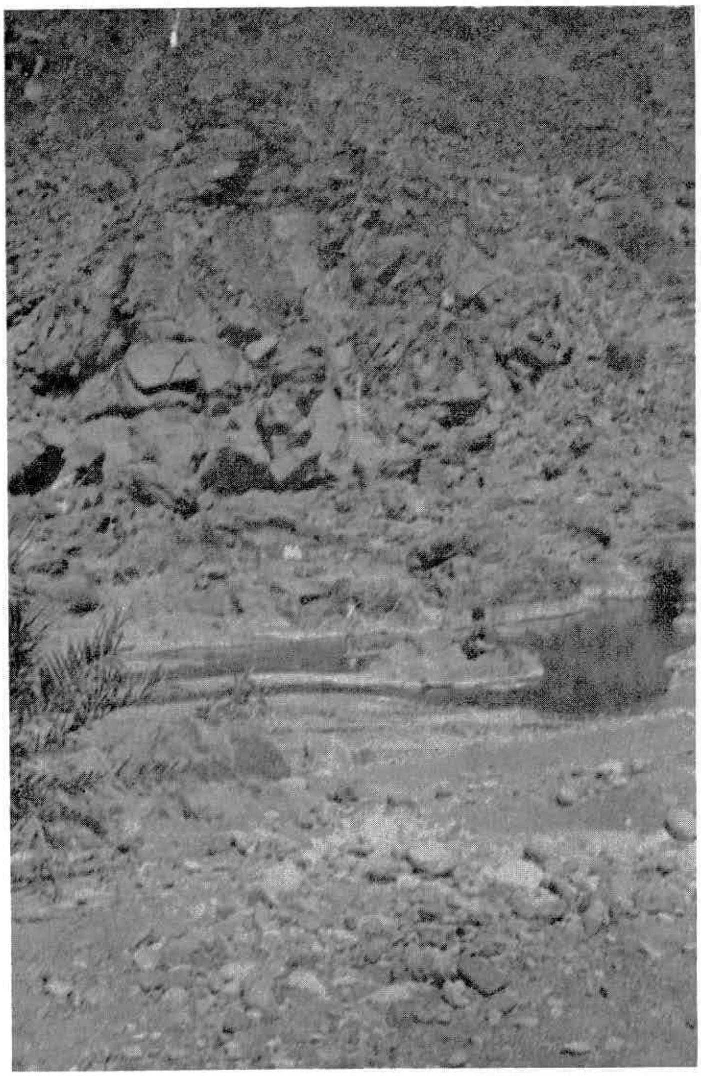


S5 WADI NIZWA ABOVE NIZWA

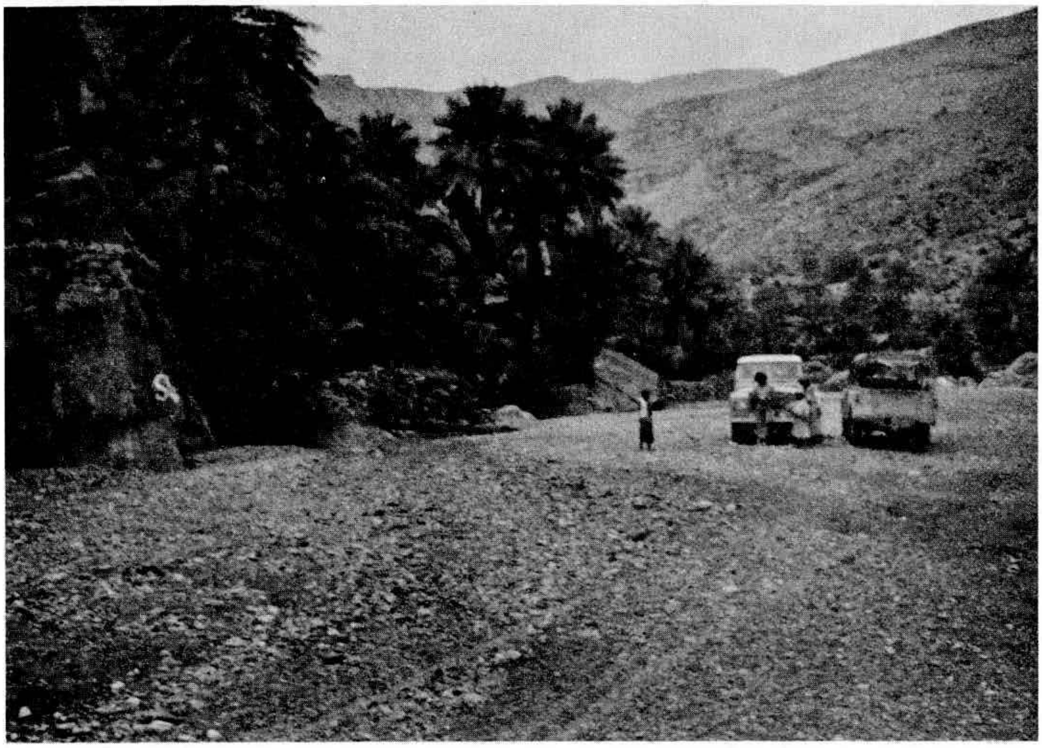
N5 WADI SABT NEAR MAHANI



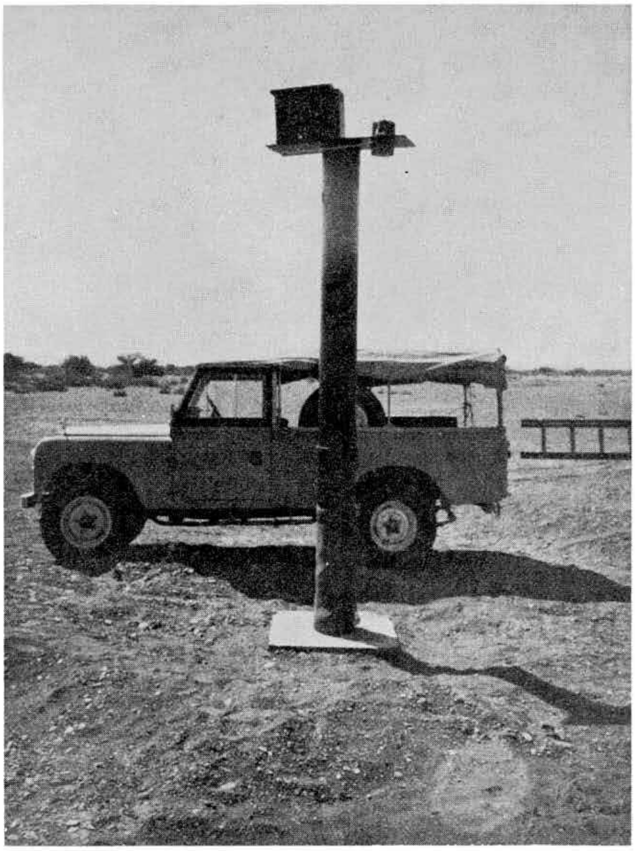
N1 WADI SEMAIL BELOW FANJA



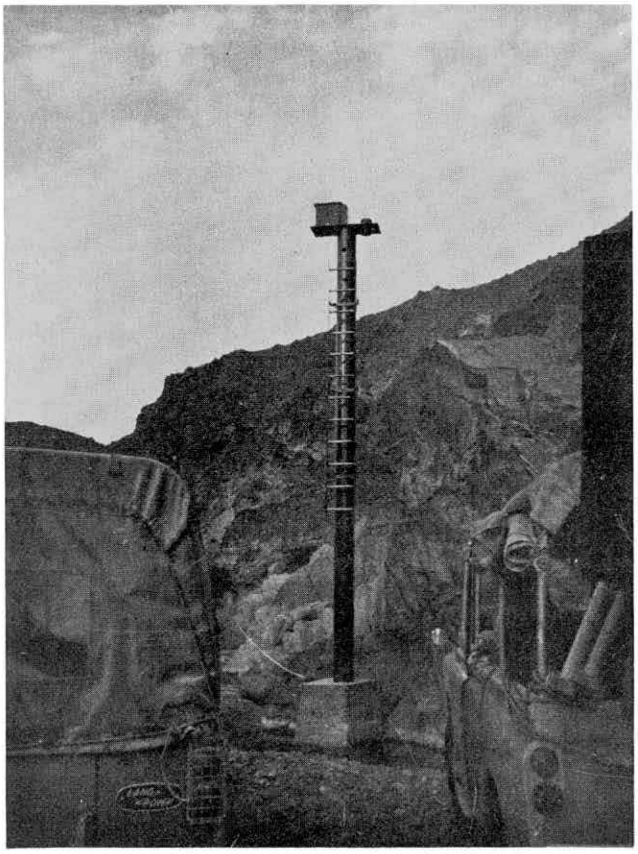
N6 WADI BANI KHARUS NR LABIJAH



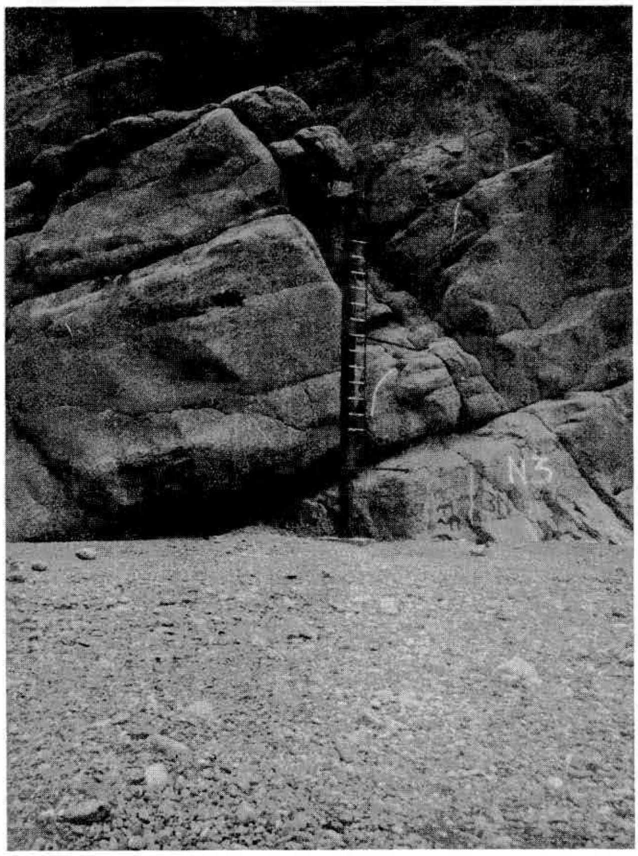
S4 WADI NAKHR NEAR GHUL



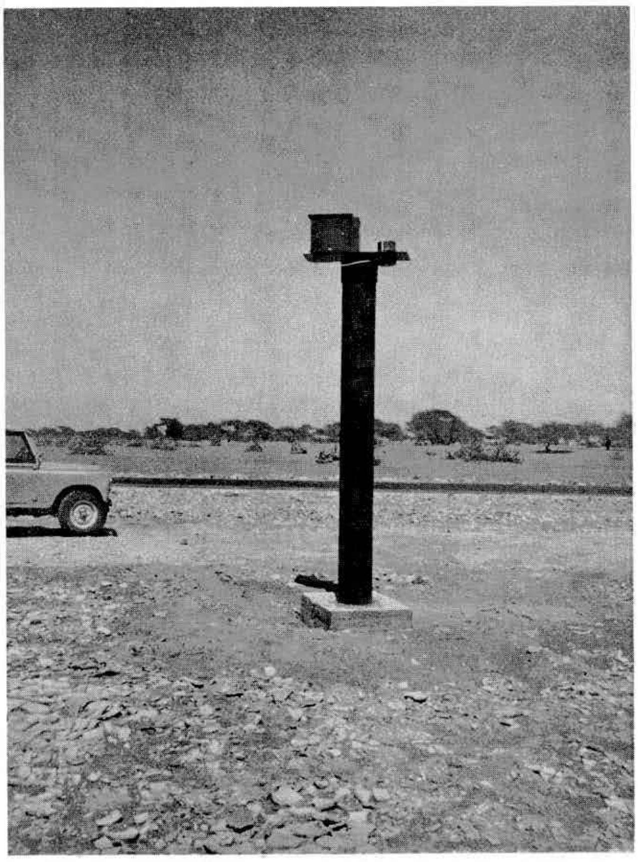
Water level recording instrument in the Wadi Bani Kharus, near the main Matrah to Sohar road.



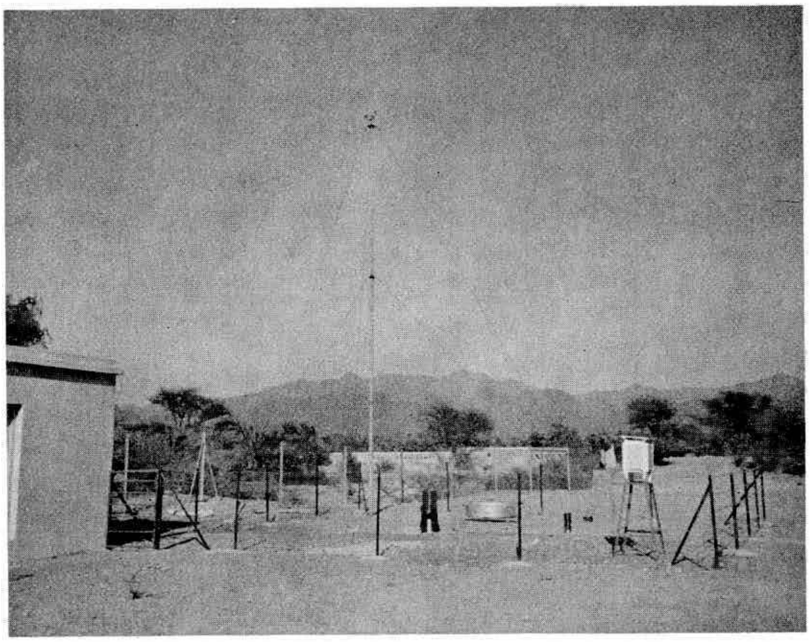
Water level recording instrument erected on a 30 ft. high tube in the Wadi Semail, below Fanjah Guaging Station N1.



WADI GAUGING STATION N3

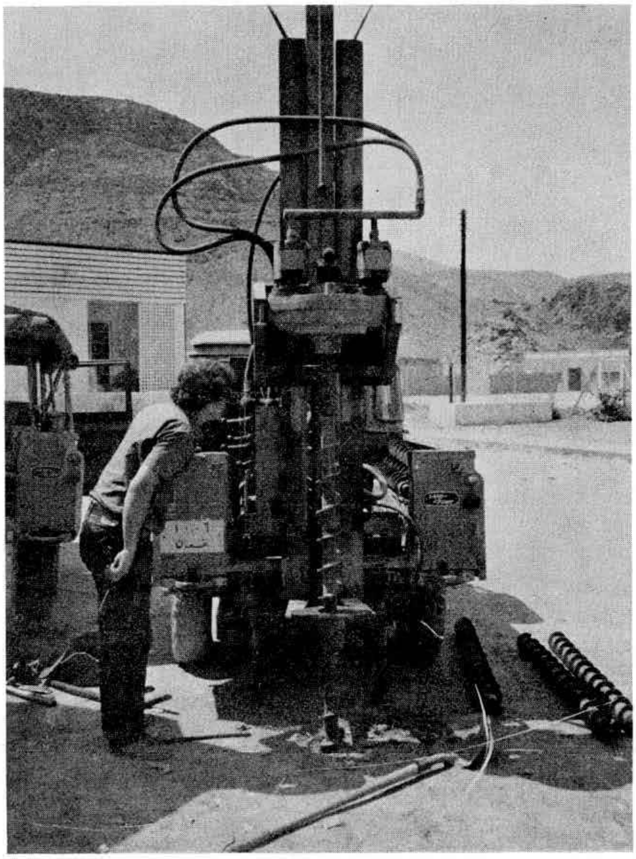


WADI GAUGING STATION N8



The synoptic meteorological station set up at Rostaq. This is one of four such stations already set up and operating in the area, at Rumais, Nizwa, Sayk and Rostaq.

It is proposed that one further station will be set up near Bahla in the Wadi Quryat : this is as a result of the growing importance of this area for the development of agriculture.



Hands - England hydraulically operated drilling rig, mounted on a long wheel based Mk III Landrover.

This rig will be used by the survey team in connection with the geophysical investigations to be carried out.

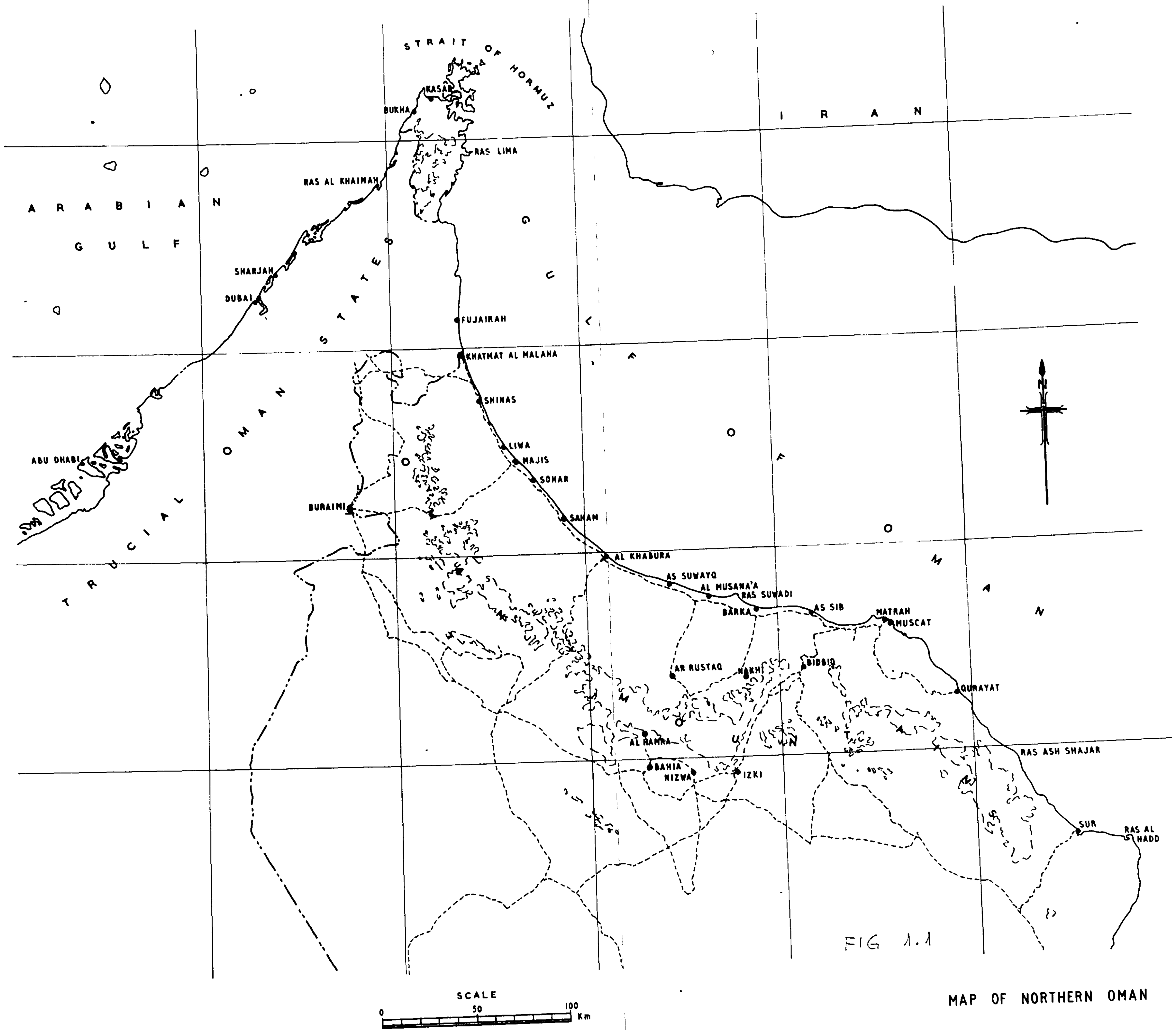
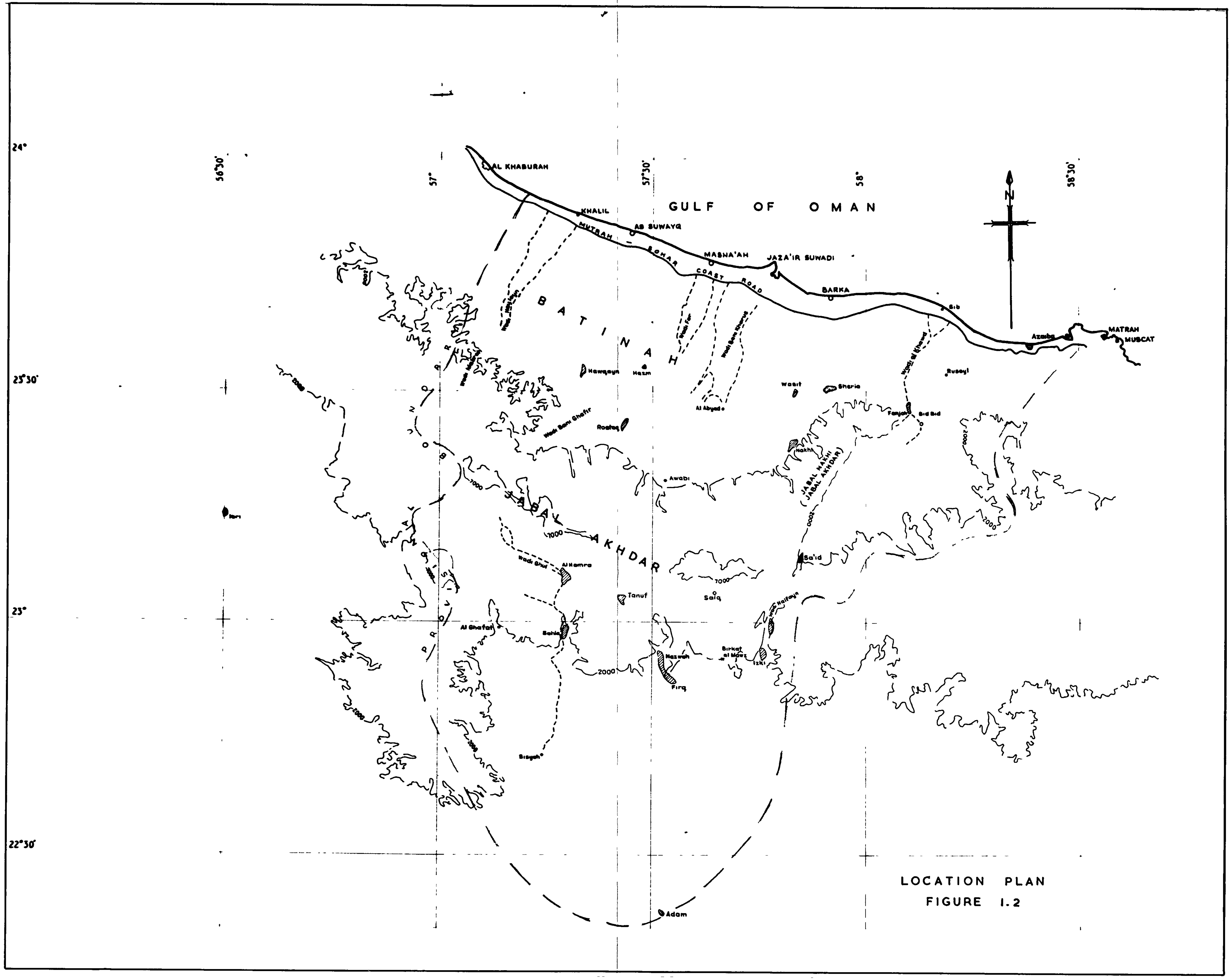


FIG 1.1

MAP OF NORTHERN OMAN



LOCATION PLAN
FIGURE 1.2

2. HYDROLOGY AND METEOROLOGY

2.1 MEASUREMENT OF RAINFALL

It is usual to find that rainfall increases with altitude. Thus the high mountain areas should receive substantially more rain than the surrounding plains. We need to know how much the rainfall increases with altitude and whether there are systematic variations with position north or south of the main watershed or along the range in the east-west direction.

Access is the principal problem in the Jebel itself. The initial planning envisaged regular helicopter flights to read and service the rain gauges on the Jebel. However this support is proving difficult to arrange on a regular monthly basis and the siting of gauges must be reconsidered to make access easier so that they can be visited from Saik or Al Hamra on foot or by donkey.

The raingauge network comprises 6 standard rain gauges on the Jebel itself and 14 gauges at lower altitudes in the surrounding villages. These other gauges have been sited where observers could be found to read them daily during periods of rain. They will also be visited monthly by the survey team to collect the records and for routine inspection. A full list of the existing network is given in Table 2.1.

No

Recording raingauges have been sited at the meteorological stations at Rumais, Rostaq, Nizwa and Saik. These gauges give a continuous record of rainfall on a daily chart whereby the duration of rainfall and its intensity can be determined.

The six raingauges on the Jebel were sited on 1 October 1973 and of these five were reported missing when the next helicopter flight was made on 17 November 1973. They were replaced on 18 January 1974 and 18 February 1974 and as yet it has not been possible to arrange a flight to inspect them. The gauges in the villages to the north of the Jebel were sited in January 1974 and those to the south in March 1974. The recording gauges became operational as observers were found for the meteorological stations; Saik in August 1973, Rumais in December 1973, Nizwa in February 1974 and Rostaq in March 1974. No rain has been recorded at Rumais from 19 December 1973 to 31 January 1974. The only rainfall at Saik from 25 August to 31 December 1973 fell in September and the data are shown in Table 2.2.

2.2 MEASUREMENT OF WADI-FLOWS

Perennial surface flow is uncommon; apart from the Wadi Samail above Al Khawd, it occurs only when a rock bar forces the flow in the wadi gravels to the surface. Even so there is only one site, the Wadi Bahla at Bahla, where the rock bar is clear of gravels and the total flow is on the surface. At all other sites there is a subsurface component of flow in the gravels of the wadi. This makes the measurement of base flow difficult.

During periods of heavy rainfall on the Jebel we expect large surface flows in the wadis, lasting for a few hours. It is important that we should be able to estimate the total volume of flow as it is this volume which is potentially available for recharge in the alluvial plains. Thus we need to know the shape of the flood hydrograph and it follows that we must establish a water level recorder at each site.

The recorders are float actuated, the float being inside a twelve inch diameter standpipe. In order to monitor the water table in the wadi gravels as well as flood water levels, we have set the standpipe into the gravels by about 2 m at each site. In total we are installing 18 recorders at the sites listed in Table 2.3. By the beginning of March 1974 the standpipes had been completed north of the Jebel and recorders were being installed. The Contractor is now working at the sites to the South of the Jebel.

Most of the gauging sites are located within the rocks of the foothills to the Jebel, or within the Jebel itself, and because the wadi beds form the only reasonable means of access, it becomes impossible to visit the sites during times of flood flow, and direct measurement of flow is not feasible. Consequently we shall use indirect methods to determine the relationship between water level and flow. The gauging sites will be carefully surveyed and Mannings equation will be used to estimate flows.

2.3 METEOROLOGICAL STATIONS

The transpiration of water by plants and the evaporation of water directly from wet soil is controlled largely by the prevailing meteorological conditions. Consequently meteorological records are essential to any estimate of the water use of the crops in the survey area. Meteorological stations have been set up in the experimental farms at Rumais and Nizwa, and it is proposed to set up a station on the Wadi Quryat farm. In addition stations have been set up at Saik which is at a much higher altitude and at Rostaq where there is a large area under cultivation.

Each station is equipped with instruments to measure the variables required in the Penman equation which is one of the best methods available for estimating the potential evaporation. Solar radiation is measured directly by Kipp Solarimeter attached to a Lintronic integrating counter which gives a total for each day. A Campbell-Stokes sunshine recorder is used as a secondary measure of radiation. Wind speed is measured in the form of wind run in kilometres per day by an anemometer at a height of 10 m above ground level. Finally the wet and dry bulb temperatures and the maximum and minimum temperatures are recorded when the station is visited at 0900 hours local time each day.

Complete records are now available from Rumais since 23 December 1973 and from Saik since 9 December 1973. The Nizwa station became operational in February 1974 and the Rostaq station during March 1974. The records which have been collated by the Muscat Office are shown in Tables 2.4 - 2.6. Note that the wind run figures are cumulative. Some additional data from a station at Darseit operated by Sir William Halcrow and Partners are shown in Tables 2.7 - 2.9. All these data are currently being checked for consistency and further analysis is being carried out at the Institute of Hydrology using the routine computer programs developed there.

TABLE 2.1

SITES OF RAINGAUGES

Site	Grid Reference
Rumais (meteorological station)	FB 000 180
Bid Bid	FA 146 920
Izki	EA 790 385
Nakhl	EA 850 868
Awabi	EA 541 763
Rostaq (meteorological station)	EA 435 875
Hawqayn	EB 340 040
Khatum	EA 702 970
Nizwa (meteorological station)	EA 541 375
Al Hamra*	
Bahla*	
Bisyah*	
Al Ghafat*	
Saik (meteorological station)	EA 660 510
Ghubrah bowl	EA 768 697
Above Ghubrah bowl	EA 742 567
Wadi Bani Kharus	EA 586 605
Misfah	EA 354 648
Wadi Sahtan	EA 326 674
Wadi Nakhr	EA 152 673

*These gauges are being sited during March 1974.

SULTANATE OF OMAN
WATER RESOURCES SURVEY
METEOROLOGICAL FORM No.3

RECORDING GAUGE. RAINFALL.
(mm)

Month SEPTEMBER Year 1973 SAIK

DAY \ HOUR	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8.	Total in Recording Gauge	Total in Standard Gauge			
1							0·3																		0·3	0·3			
2																										T			
3																													
4																										T			
5									12·2																12·2	12·2			
6																													
7																													
8																													
9																										T			
10																													
11																													
12																													
13																													
14																													
15																													
16																													
17																													
18								0·4																	0·4	0·4			
19																													
20																										T			
21																										T			
22																										T			
23																										T			
24																													
25																													
26																													
27																										T			
28										6·0															6·0	6·0			
29																													
30																													
31																													
Total																									18·9	18·9			

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TABLE 2.3

SITES OF WADI GAUGING STATIONS

Site		Grid Reference
Wadi Samail	Fanjah	FA 135 995
	coast road	FB 170 170 (approx)
Wadi Bani Kharus	Awabi	EA 540 755
	Labijah	EA 682 910
	coast road	EB 720 247
Wadi Sabt	Mahani	EA 691 818
Wadi Sahtan	Tabaqah	EA 315 856
Wadi Bani Ghaffir	Al Madinah	EA 294 967
	coast road	EB 417 345
Wadi Halfayn	Izki	EA 783 359
Wadi Muaydin	Birkar Mawz	EA 687 374
Wadi Nizwa	Nizwa	EA 562 404
Wadi Nakhr	Ghur	EA 209 600
Wadi Misfah	Al Hamra	EA 305 566
Wadi Bahla	Bahla	EA 298 392
	Bisyah	EA 270 160
Wadi Al Ala	Al Ala	EA 122 515
Wadi Sayfam	Mudri	EA 284 072

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SULTANATE OF OMAN **TABLE 2·4**

WATER RESOURCES SURVEY

METEOROLOGICAL FORM No.1.

Station......Rumais......

Month...December...... Year...1973......

Day	Maximum temp °C	Minimum temp °C	Dry bulb temp °C	Wet bulb temp °C	Run of wind Km/day	Sunshine hrs.	Radiation counts.	Totals
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23	25.3	11.5	24.2	19.0	7728.53	5.0	400	
24	25.5	11.0	21.8	15.8	7986.01	9.6	3221	
25	25.8	13.0	22.5	17.0	8193.61	9.6	4582	
26	25.0	11.5	21.9	15.5	8412.20	9.6	4569	
27	24.4	4.5	21.3	14.8	8621.42	8.7	3876	
28	43.7+	9.5	20.8	1.5+	8812.30	9.7	4708	
29	24.7	11.5	19.3	15.0	9060.42	8.2	4416	
30	25.8	11.5	21.0	15.2	9230.41	9.6	4588	
31	25.7	15.2	21.6	17.7	9434.50	9.2	4722	
Total								

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SULTANATE OF OMAN **TABLE 2·5**

WATER RESOURCES SURVEY

METEOROLOGICAL FORM No.1.

Station....Rumais....

Month....January.... Year....1974....

Day	Maximum temp °C	Minimum temp °C	Dry bulb temp °C	Wet bulb temp °C	Run of wind Km/day	Sunshine hrs.	Radiation counts.	Totals
1	24.6	14.5	22.4	18.0	9647.94	9.6	4599	
2	24.4	15.0	22.5	17.4	9844.21	9.7	4637	
3	24.7	13.7	21.5	16.8	0065.12	8.6	4822	
4	24.6	13.0	22.1	16.0	0313.32	9.6	4766	
5	24.4	12.5	21.2	16.9	0528.22	9.5	4577	
6	25.3	14.7	21.8	17.5	0727.21	9.5	4811	
7	24.4	11.0	21.5	16.3	0943.58	9.9	4788	
8	24.7	12.7	21.0	16.2	1194.55	9.7	4909	
9	25.1	13.5	21.7	18.5	1409.47	9.7	4822	
10	25.4	14.0	23.0	20.0	1602.68	9.6	4666	
11	25.5	15.0	23.0	18.5	1787.20	8.1	4767	
12	25.2	13.0	20.4	15.7	2029.14	8.0	3998	
13	24.7	14.5	21.4	14.6	2237.92	8.3	4484	
14	23.0	11.5	20.3	15.4	2499.56	9.0	4592	
15	23.9	11.8	21.4	15.8	2843.82	5.7	4648	
16	25.8	16.0	23.5	18.0	2953.41	4.5	3851	
17	30.7	16.0	22.8	19.8	3133.96	8.6	3172	
18	25.4	13.9	22.0	20.3	3375.18	9.8	4473	
19	25.9	21.0	19.8	13.8	3695.62	6.6	4601	
20	21.5	13.4	16.8	12.7	4097.51	6.1	4318	
21	21.3	10.8	19.4	14.9	4313.50	8.8	3973	
22	24.7	14.2	20.8	16.9	4579.91	8.4	4451	
23	24.8	16.2	21.8	19.0	4797.77	6.2	4131	
24	25.7	15.7	22.0	20.0	5099.69	9.3	4088	
25	28.6	17.4	20.5	14.9	5488.84	3.0	4494	
26	20.5	12.3	18.4	12.8	5994.71	9.2	3678	
27	21.1	10.2	19.0	14.5	6275.66	9.6	4800	
28	21.3	10.8	19.8	15.7	6466.56	9.5	4894	
29	22.4	10.7	20.7	15.4	6656.03	9.4	4721	
30	23.6	13.7	22.0	17.0	6834.48	9.3	4441	
31	24.3	13.7	21.5	18.7	7041.81		4333	
Total								

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SULTANATE OF OMAN **TABLE 2·6**

WATER RESOURCES SURVEY

METEOROLOGICAL FORM No.1.

Station....Saiq.........................

Month.December......... Year.1973.......

Day	Maximum temp °C	Minimum temp °C	Dry bulb temp °C	Wet bulb temp °C	Run of wind Km/day	Sunshine hrs	Radiation counts.	Totals
1						9.4		
2						9.4		
3						9.4		
4						5.8		
5						5.7		
6						8.4		
7						10.5		
8						10.5		
9	18.0	7.5	16.5	9.5		10.2	5883	
10	21.0	13.0	15.0	14.0		10.4	5756	
11	18.5	12.0	12.5	6.0		10.5	5884	
12	15.0	7.0	7.5	7.0		9.2	5971	
13	14.0	8.5	10.0	10.0		10.4	5884	
14	15.5	12.5	14.0	11.0		10.5	5828	
15	16.5	5.5	9.5+	10.0+		10.5	5807	
16	15.5	11.5	14.0	6.5		10.5	6167	
17	22.0	7.0	15.0	9.0		10.5	5922	
18	19.0	6.5	15.0	10.0		10.5	6075	
19	18.5	7.5	13.0	10.0		10.5	5944	
20	17.5	9.5	14.0	9.5		10.5	5955	
21	16.0	7.5	11.0	10.0		10.1	5829	
22	19.5	6.5	10.0 +	20.0 +		9.4	5863	
23	14.0	8.0	14.0	10.0		8.0	5747	
24	15.0	11.0	2.0 +	1.0 +		10.2	5891	
25	18.0	5.5	11.0	7.0		9.2	5548	
26	14.5	6.0	12.0	7.5		9.7	5266	
27	18.0	7.0	12.5	7.0		10.4	5441	
28	16.5	6.0	15.0	9.5		8.1	5681	
29	19.0	5.0	16.0	9.0		10.3	5064	
30	17.0	15.0	11.5	7.5		10.4	5555	
31	15.0	5.0	12.5	10.0		10.4	5981	
Total								

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SULTANATE OF OMAN **TABLE 2·7**
WATER RESOURCES SURVEY
METEOROLOGICAL FORM No.1.

Station..Darseit..........................

Month..November........ Year..1973.........

Day	Maximum temp °C	Minimum temp °C	Dry bulb temp °C	Wet bulb temp °C	Run of wind Km/day	Sunshine hrs.	Radiation counts.	Totals
1	26.5	20.5	27.0	18.0	35			
2								
3	33.0	22.0	28.0	20.5	271			
4	33.0	21.5	26.0	18.0	108			
5	31.0	22.0	26.5	21.0	141			
6	32.0	22.0	27.0	24.0	192			
7	28.5	24.0	28.5	22.0	167			
8	31.0	25.0	26.0	21.0	215			
9								
10	28.0	21.0	24.0	18.0	313			
11	27.5	19.0	23.0	18.0	131			
12	27.0	19.0	23.0	19.0	114			
13	27.0	16.0	21.0	16.0	106			
14	27.0	17.0	22.0	17.0	125			
15	27.5	17.0	21.0	17.0	151			
16								
17	28.0	16.5	24.0	19.0	267			
18								
19								
20	29.0	19.0	24.0	22.0	406			
21	28.0	20.0	25.0	21.0	143			
22	27.0	22.0	25.0	22.5	149			
23								
24	28.5	19.0	23.0	21.0	279			
25	27.0	20.0	23.0	21.0	166			
26	27.5	20.0	23.5	20.0	158			
27	28.5	22.0	23.5	22.5	146			
28	26.5	22.0	25.0	19.0	220			
29	27.5	21.0	24.0	20.0	134			
30								
31								
Total								

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SULTANATE OF OMAN TABLE 2·8

WATER RESOURCES SURVEY

METEOROLOGICAL FORM No.1.

Station: Darseit

Month: December Year: 1973

Day	Maximum temp °C	Minimum temp °C	Dry bulb temp °C	Wet bulb temp °C	Run of wind Km/day	Sunshine hrs.	Radiation counts.	Totals
1	26.5	17.0	21.5	18.5	288			
2	26.0	18.0	21.0	18.0	127			
3	26.5	19.5	22.5	21.0	105			
4	28.0	19.0	22.0	20.0	211			
5	27.0	19.5	22.0	20.0	165			
6	27.0	19.0	22.5	19.5	104			
7								
8	27.5	18.0	22.5	20.0	238			
9	26.5	18.0	21.0	19.0	134			
10	28.5	18.5	21.0	18.5	144			
11	28.0	20.5	22.5	20.0	186			
12	25.0	18.5	20.5	18.5	130			
13	26.0	19.0	22.0	20.0	148			
14								
15	25.5	20.0	19.5	16.0	324			
16	21.5	15.0	17.5	13.5	190			
17	24.0	14.0	17.5	14.0	145			
18	24.5	16.5	20.0	17.0	201			
19	25.0	16.5	19.0	16.5	197			
20	25.0	16.0	18.0	15.0	102			
21	25.0	18.0	21.0	18.5	150			
22	24.5	17.0	20.0	18.0	112			
23	25.0	17.0	20.0	17.0	138			
24	26.5	16.0	17.0	14.0	184			
25								
26	26.0	15.0	18.0	14.5	248			
27	24.0	15.0	22.0	17.0	109			
28								
29	25.0	15.0	21.5	16.0	329			
30	25.0	15.0	18.0	17.0	196			
31	27.0	18.0	20.0	19.0	183			
Total								

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SULTANATE OF OMAN **TABLE 2·9**

WATER RESOURCES SURVEY

METEOROLOGICAL FORM No.1.

Station..Darseit..........

Month..January........ Year.1974.......

Day	Maximum temp °C	Minimum temp °C	Dry bulb temp °C	Wet bulb temp °C	Run of wind Km/day	Sunshine hrs.	Radiation counts.	Totals
1								
2								
3								
4								
5								
6								
7	24.5	15.0	18.0	17.0	1145			
8	26.0	16.0						
9	25.0	17.0	20.0	17.0	322			
10	27.0	18.0	21.0	19.0	169			
11								
12	26.0	19.0	20.0	17.0	330			
13	23.0	17.0	21.0	17.0	138			
14	23.0	15.0	18.0	15.0	156			
15	24.5	17.0	19.5	16.0	211			
16	26.0	18.5	22.0	18.0	162			
17	28.0	18.5	20.0	18.5	123			
18								
19	30.0	19.0	20.5	18.0	598			
20	26.0	17.0	18.0	15.0	385			
21	26.5	15.0	18.0	15.0	152			
22	23.5	17.0	18.5	17.0	266			
23	25.0	18.5	22.0	20.0	234			
24	25.5	20.0	21.0	19.0	428			
25								
26								
27	26.5	15.5	18.0	14.0	832			
28	21.0	15.0	18.0	15.0	146			
29	22.0	15.0	16.0	14.0	126			
30	24.5	16.0	18.0	15.0	149			
31	24.0	17.5	19.0	17.0	221			
Total								

3. GROUNDWATER INVESTIGATIONS

3.1 INTRODUCTION

The exploration of potential aquifers with the assessment of their water bearing characteristics is a most important aspect of the water resources survey. In our reconnaissance report of July 1973, we discussed the distribution of the water bearing formations and we recommended that our three year study period should be devoted almost exclusively to the exploration of the Quaternary and Recent sediments. Only through the village survey would we identify and measure the existing sources of water from the Tertiary and Permo-Cretaceous hard rock areas. Our major concern therefore is with the alluvial plains both north and south of the Jebel and of these, the Batinah plain would appear to offer the greatest potential.

An extensive drilling programme is central to the study. As the boreholes are drilled the lithology of the sediments can be monitored; after development the quality of the water can be determined throughout the depth of the borehole by logging conductivity. Other logging techniques, gamma, resistivity and self-potential give supporting evidence of lithology and aquifer properties. Pumping tests enable determination of the hydraulic aquifer properties to be made, and finally, the continued observation of water level together with levels in neighbouring boreholes and observation wells enables the response of the aquifer to recharge events and to continued abstraction through prolonged dry periods to be assessed.

On the Batinah plain we have been able to make extensive use of the existing water well construction programme which was established prior to the commencement of this survey. Although this Well Drilling Contract did not lend itself directly to detailed scientific investigations we have been able to improve certain aspects of the work. A three stage step-drawdown pumping test procedure has been introduced. Records of penetration rate and strata samples have been obtained at 1 m interevals. Well screen construction has been improved by using a larger open area screen. We have also been able to site some 30 wells, about 25 per cent of the total, between the coast road and the foothills of the Jebel Akhdar.
So far as possible, the original objective of the Government programme has been met by locating boreholes along the roads connecting the coast with the inland villages. However, some of these boreholes have been sited in order to determine strata details rather than to produce water, and in some cases we have exceeded the 70 m depth of the original contract, whilst in others

we have drilled through relatively thin sediments to determine depth to bedrock. The final four boreholes of the drilling programme have now been constructed. These are 300 m deep fully screened boreholes designed specifically to provide water quality data at all depths and they are not suitable for supply purposes.

One further aspect of the groundwater study is the interpretation of the aerial photographic cover from which can be distinguished recent from less recent alluvial deposits. In some wadi fans up to four stages of alluvial deposition can be recognised from surface features alone. This interpretation, which is being confirmed by field observation, is a useful indicator in planning the exploratory drilling programme.

3.2 WATER LEVEL OBSERVATIONS

Since July 1973 observations of water level in a network of boreholes and wells have been made throughout the study area. On the Batinah, our network is based on the boreholes constructed under the existing contract supplemented, where coverage is inadequate, by existing wells usually hand-dug. To the south of the Jebel there has been no systematic drilling programme and our current network is based upon some Arab Development Company wells and a larger number of relatively shallow hand-dug wells. The locations of all wells in the network are shown in Figure 3.1.

Our objective in establishing the network as rapidly as possible is to provide background data on the decline in water levels prior to the expected winter rains. However, rainfall has been negligible throughout most of the study area and water levels continue to decline. As a consequence we are not yet in a position to rationalise the network and the routine observations continue to be demanding on man-power.

The records to date are reproduced in the form of groundwater hydrographs in the Appendix to this section of the report. The depths of water table are measured from a datum marked on the well head and these datum marks are currently being surveyed so that water table levels can be related to a common datum.

The well hydrographs for the western part of the Batinah, Figures B1-B3, show some minor effects of rainfall in July but have tended to fall through the rest of the year. The wells nearer the coast, shown at the top of each Figure, indicate little change in level with a tendency to some recovery; those further inland show a more substantial decline although in no case is there a dramatic fall in level.

Hydrographs for wells in the central Batinah are shown in Figures B4-B7. A similar distribution of change is found in this zone. The minor recoveries in levels along the coast pre-date the light winter rainfall and may reflect reduced evaporation losses or regional reductions in abstraction rather than real recharge. The hydrograph of Borehole JT 56 illustrates natural recovery in water level due probably to a well development phenomenon.

Groundwater levels in the Sib area and in the Wadi Samail, Figures B8-B13, are changing very little, less than 0.5 m in most cases. The exceptions are the observation wells associated with the P.D.(O) well field which show a continuing decline in level at a rate of 0.25 m per month.

South of the Jebel, there would appear to be two distinct patterns of behaviour. In the piedmont areas north of Bahla and Nizwa there is a fairly rapid decline in water levels. This is illustrated in Figure B14 for the Bahla basin and Figure B16 (upper two hydrographs) for the Nizwa basin. Below Bahla and Nizwah and in the other alluvial areas below the ophiolite hills, the response is similar to that in the Batinah; small changes indicative of low transmissivity.

Water level recorders have been installed on several wells in order to provide some evidence of the small scale fluctuations. Representative hydrographs for a 2 week period are given in Figure B18. The semi-diurnal tidal effects shown in many of the wells are surprisingly small.

3.3 PUMPING TESTS ON BOREHOLES IN THE BATINAH AREA

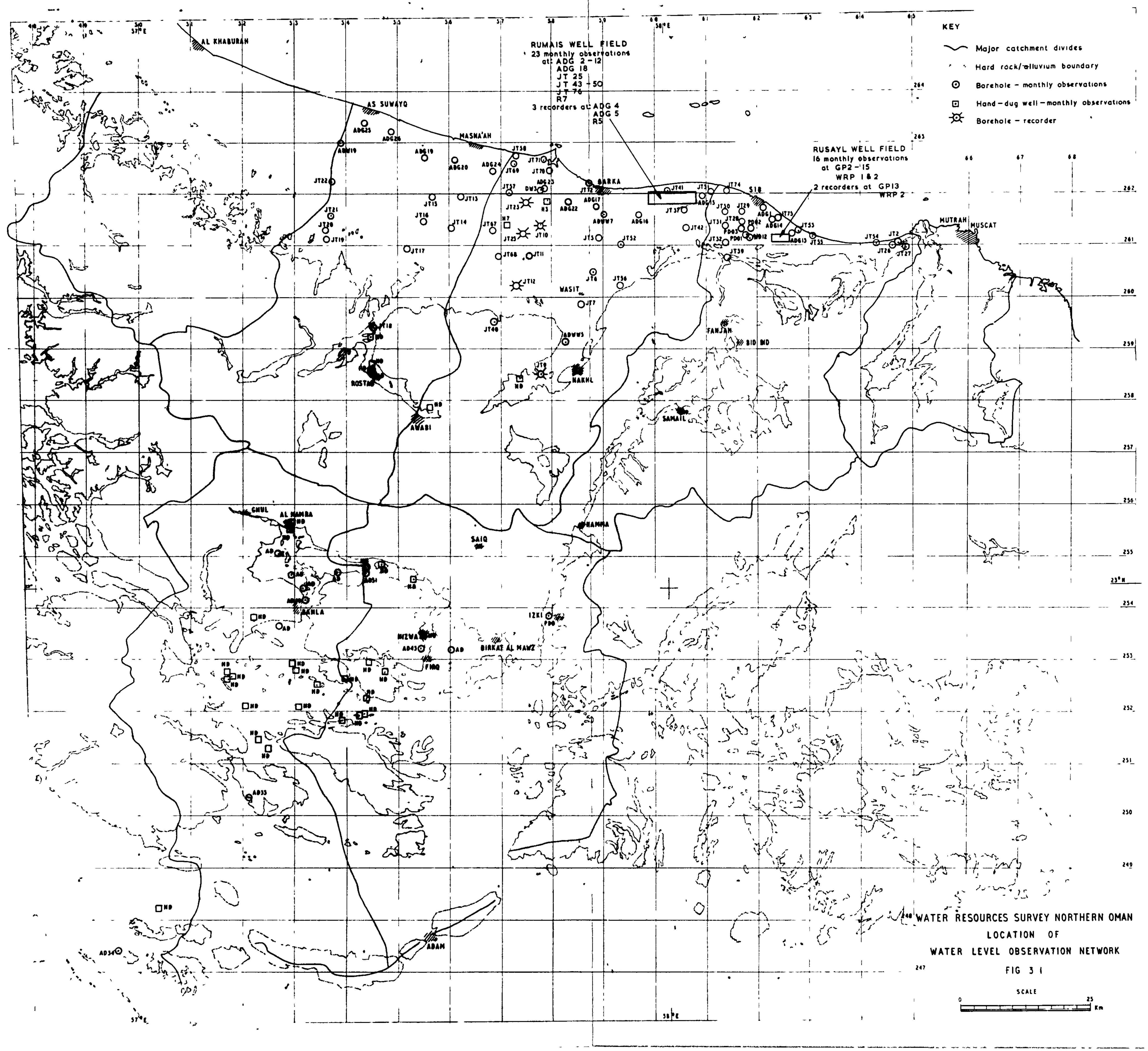
The step-drawdown pumping tests have been analysed in order to assess yields from the boreholes in the Batinah area. Figure 3.2 shows the yield/depression characteristics. The results can be grouped into five classes and we show the geographical distribution of these groups in Figure 3.3. Class 1 is defined by a drawdown of less than 1 m for a yield of up to 12 l/sec; classes 2 to 5 by drawdowns of up to 3 m, 10 m, 20 m and over 20 m respectively, for the same yield.

Class 1 and 2 boreholes are generally located in the east between the coast and the + 10 m groundwater contour. In this area the water table stands well above the base of the uncemented and marl-free gravels. By contrast boreholes in classes 4 and 5 are in areas of older, heavily cemented gravels and where the alluvium overlies shallow Tertiary limestones. In these areas many of the wells have failed to yield 5 1/sec and several dry wells were drilled.

The results of our study to date are not encouraging. Previous reports based on superficial studies have suggested that there could be many tens of metres of water-bearing Quaternary and Recent gravel sediments creating a storage zone for exploitation of groundwater. Our studies are indicating that much of the Batinah is underlain by marly and lime cemented gravels of little groundwater significance since they contain brackish water. The extent of existing development and the potential for future development of this source appears to be related to the occurrence of good quality groundwater within relatively uncemented and marl free gravels associated with the modern wadi channels. At the coast it appears that most of this freshwater is being taken by the existing wells in the cultivated area and this emphasises the value of our village survey work reported in Section 4.

Because of the nature of the water-well construction programme and because of the complex lithology of the Batinah area, it has not always been possible to achieve a consistent standard of well development. Consequently some of the pumping test results show well improvement characteristics compatible with development continuing during pump testing.

Recent gravels flooring the wadis between the mountains and the Tertiary limestone do not generally contain marls and clays although in places they form gravel conglomerates. The extent of the secondary carbonate deposition is however insignificant by comparison with the secondary carbonates present in the coastal plain sediments. The dry wells, and the class 4 and 5 situation, results from extensive induration of the alluvium, presumably derived during previous pluvial conditions, by carbonate rich groundwater. The origins of this carbonate material are undoubtedly the Tertiary strata. The presence of white marls, limestone marl and clay in the gravels of the Batinah from the Tertiary outcrop to the coast, and from As Suwayq to Azaiba, is the dominating characteristic of the coastal plain.



WATER RESOURCES SURVEY NORTHERN OMAN

LOCATION OF

WATER LEVEL OBSERVATION NETWORK

FIG 3 1

Figure 3.2

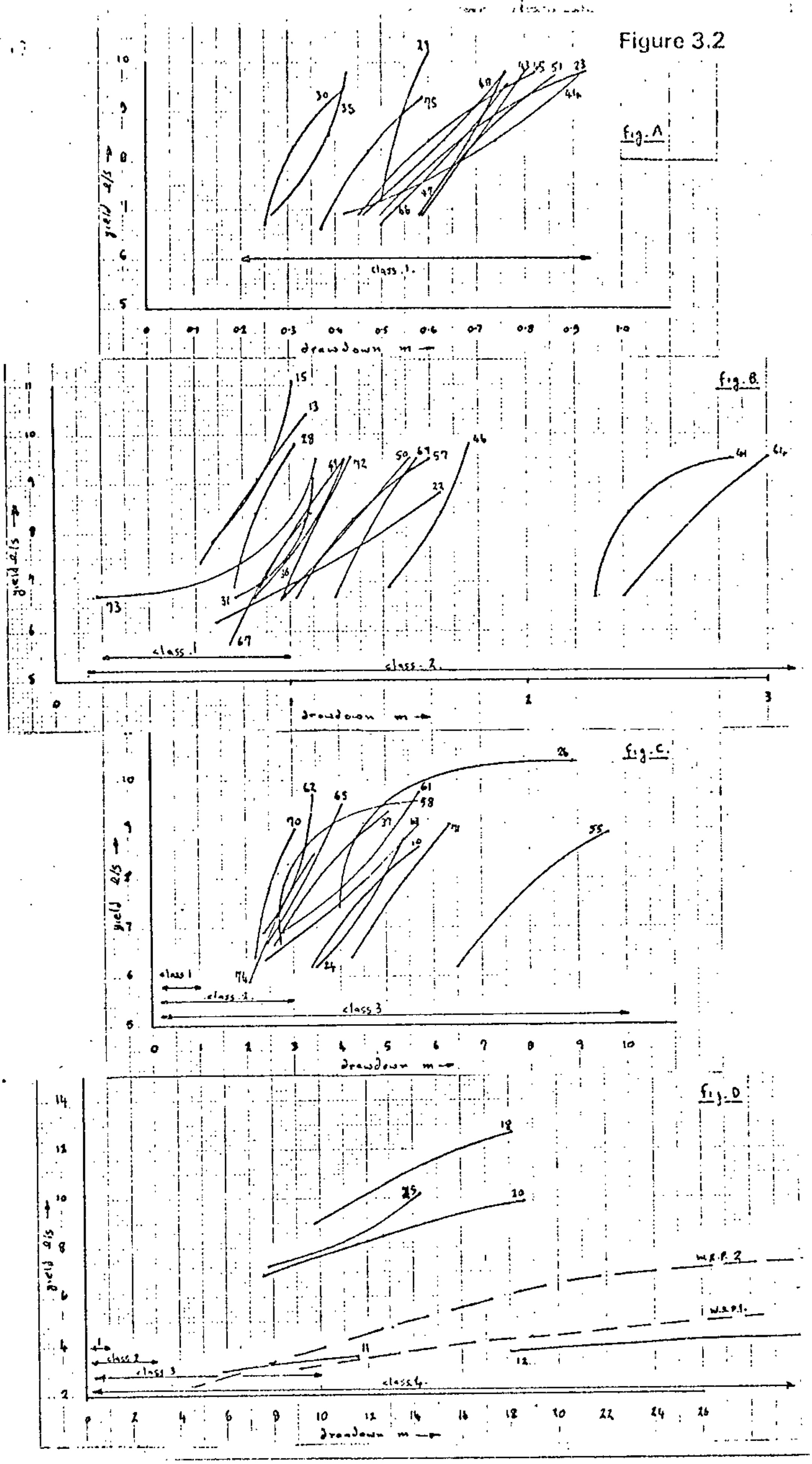
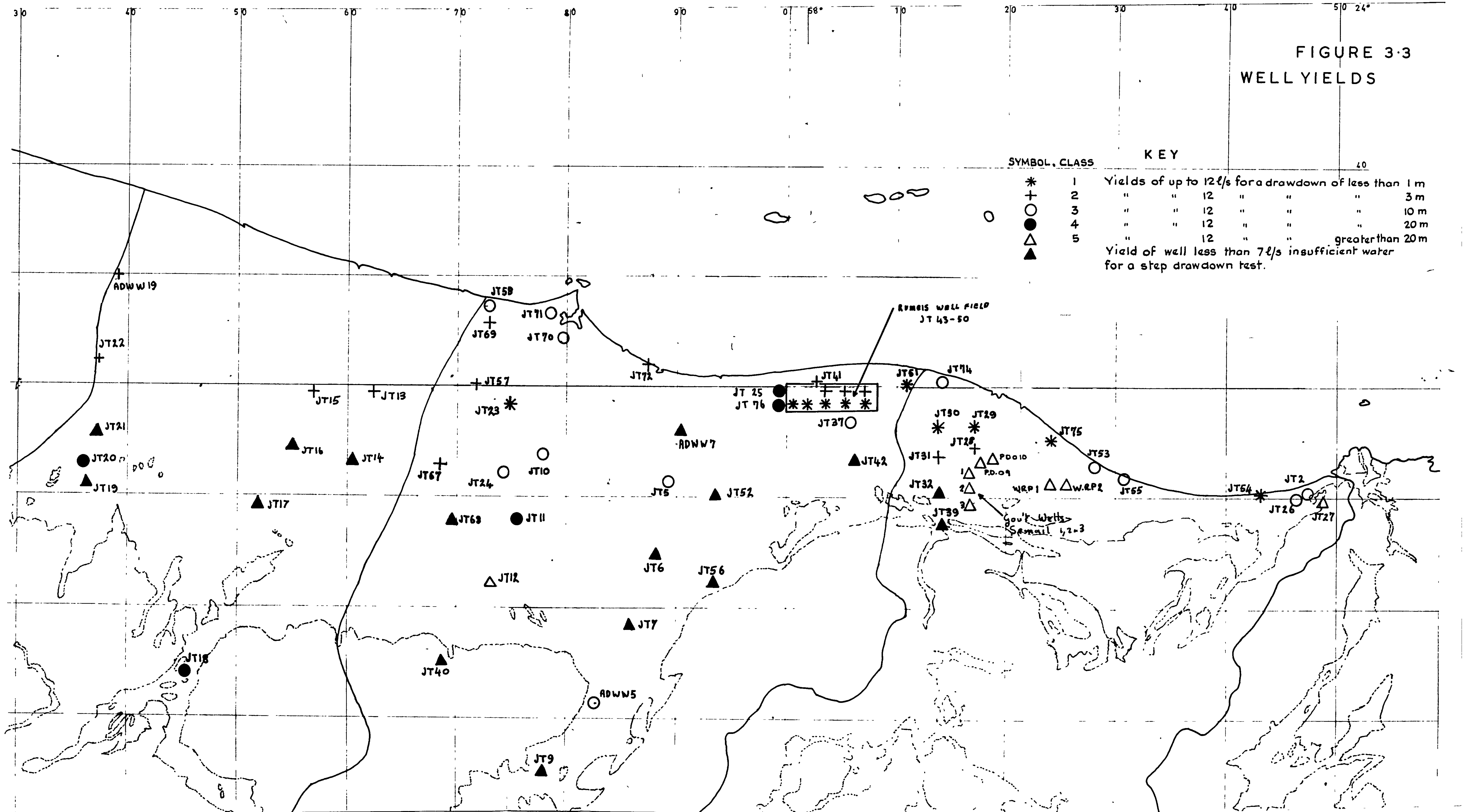


fig. A
yield l/s
drawdown m
class 1
fig. B
class 1
class 2
fig. C
class 1
class 2
class 3
fig. D
W.R.P. 2
W.R.P. 1
class 1
class 2
class 3
class 4

FIGURE 3·3

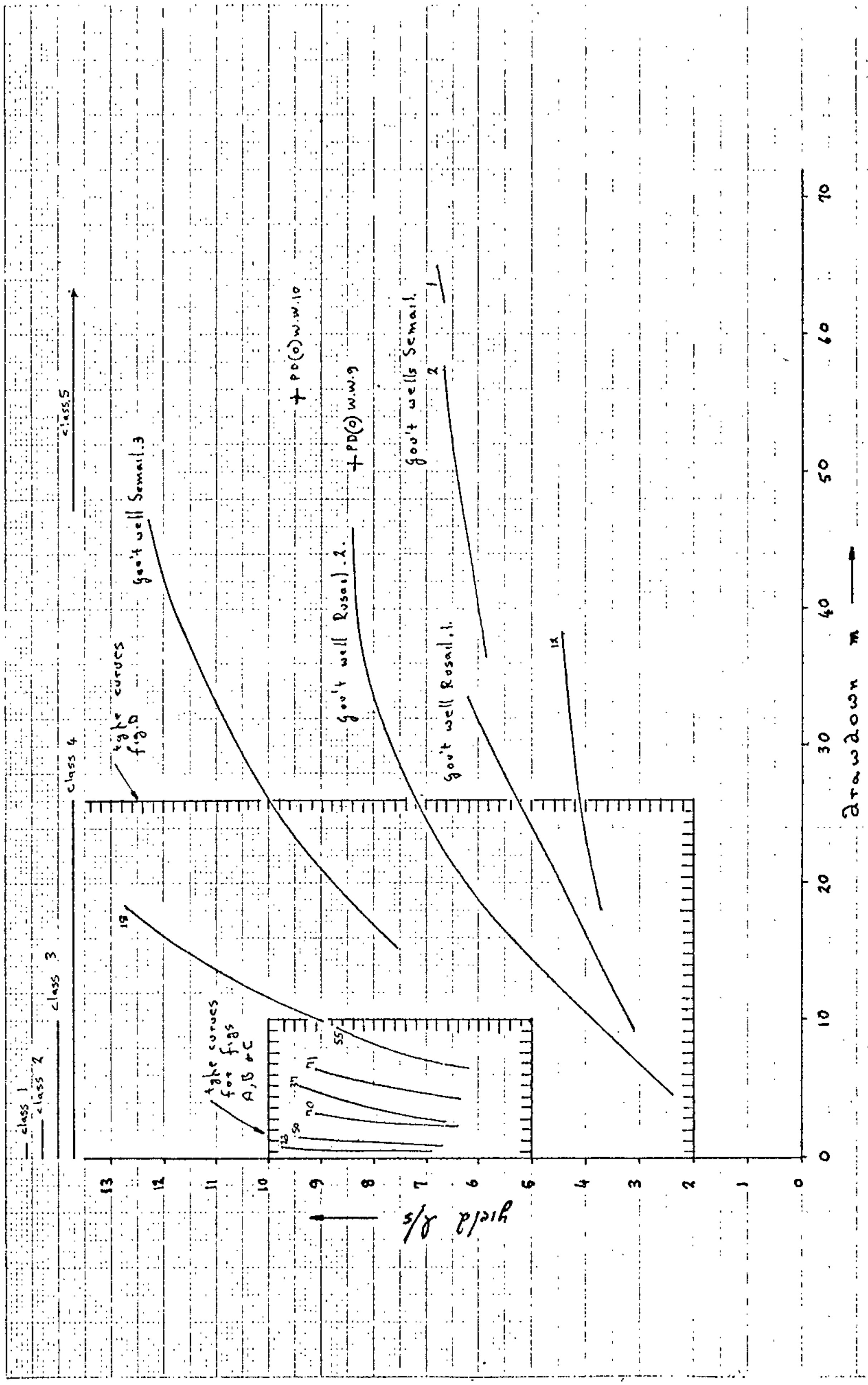
WELL YIELDS



The high yielding wells occur where the water table stands well above the top of the "uncemented" or clayey gravels, in a relatively narrow zone where the modern wadi fans have deposited up to 70 m of clean gravels not yet subjected to secondary carbonate deposition. Silts mixed with gravel are characteristic of fairly modern coastal sediments, and well yields and aquifer properties become poorer throughout the immediate coastal strip.

Figure 3.4 has been prepared to show the family of yield/ depression curves for the Batinah. The yield characteristics of the Government wells in the Wadi Samail area are shown in order to illustrate the relative failure to deep wells in the lime cemented alluvium. These are some of the poorest water wells in the whole of the Batinah. To date we have been unable to locate any good aquifer conditions except in wells situated in modern wadi sediments.

Figure 3.4



class 1
class 2
class 3
class 4
class 5
type curves fig. D
type curves for figs A, B & C
Gov't well Semail.3
Gov't well Rosail.2
Gov't well Rosail.1
Gov't wells Semail.
PD(o) w.w.9
PD(o) w.w.10
drawdown m
yield l/s

4. VILLAGE SURVEYS

4.1 INTRODUCTION

Earlier in this report, we outlined the importance of a survey of current water use and of the sources that are being exploited. We envisaged collecting information on numbers of wells, springs and aflaj with some integrated measure of total output and taking samples from all sources both as a means of identifying the source and of monitoring water quality for agriculture. However it soon became apparent that in many areas we are observing a dynamic situation. More wells are being fitted with pumps, more water is being abstracted and there are consequent deleterious changes in water quality. This is particularly the case along the coast and we have consequently intensified our survey and set up a procedure for revisiting selected areas to monitor changes in water quality.

Our survey to date has covered the coastal villages of the Wadi Samail together with the inland villages up to Bid Bid, the inland villages in the Wadi Bani Kharus and, in a preliminary survey, the villages of the Bahla basin. By far the greatest effort has gone into the mapping of the coastal agricultural area of the Wadi Samail. This was carried out as a first priority in view of the pressures rapidly building up for exploitation of the groundwater resources of the area.

The basis for compilation of statistics relating to water availability, its source and use, has been field mapping using 1:12 000 scale enlargements of the 1968 1:60 000 photographic coverage. For convenience each photographic enlargement of a village or agricultural area has been numbered and data relating to all wells, springs and aflaj catalogued and referenced to this field sheet reference. Figure 4.1, shows the location and index numbers of the photographic coverage, and areas of preliminary and completed coverage are indicated. The coastal plain west of Sib was not included in the original 1968 1:60 000 aerial survey although 1 20 000 scale photographs have recently been made available.

4.2 WADI SAMAIL - SIB COASTAL AREA

An area some 22 km in length has been mapped. Over 800 hand dug wells have been located and catalogued. The following details are recorded in a card index held in the Survey Office :

Location
Water use
Rate and duration of pumped abstraction
Well dimensions
Static water level
Groundwater temperature
Groundwater conductivity

It was found necessary to introduce a sampling procedure in view of the time needed to locate, gain access to and document every well. In consequence we estimate that at least a further 250 domestic wells exist in the villages, and between 50 and 100 wells in private gardens. In total, 1,100 hand-dug wells exist, 600 are fitted with pumps, a few are provided with two pumps.

Most of the pumps are capable of yielding up to 23 litres/sec (300 gpm) and some were being used for up to 8 hours per day. During the period of our survey (October–December) they were being used on average for about 3 hours per day and we estimate that the average yield was some 12/ l/sec (150 gpm). This would indicate a total daily abstraction of groundwater of the order of 70 000 m^3 (16 million gallons) which implies an annual abstraction of at least 25×10^6 m^3 (5.5×10^9 gallons), a figure comparable with the average surface flow at Al Khawd.

Our survey collected numerous reports of progressive increases in groundwater salinity. Some date gardens are being abandoned and yields are poor in some other areas. Some well owners reported large increases in salinity during the past fifteen years and many wells appear to have become saline following installation of a pump. Three processes may be responsible for the deterioration in quality :

1. migration of salt water inland from the coast as a result of a head decline in the aquifer due to well abstractions.

2. recharge of excess irrigation water carrying leached solutes to the water table.

3. skimming of a thin freshwater layer by the shallow hand-dug wells followed by upwelling of brackish water.

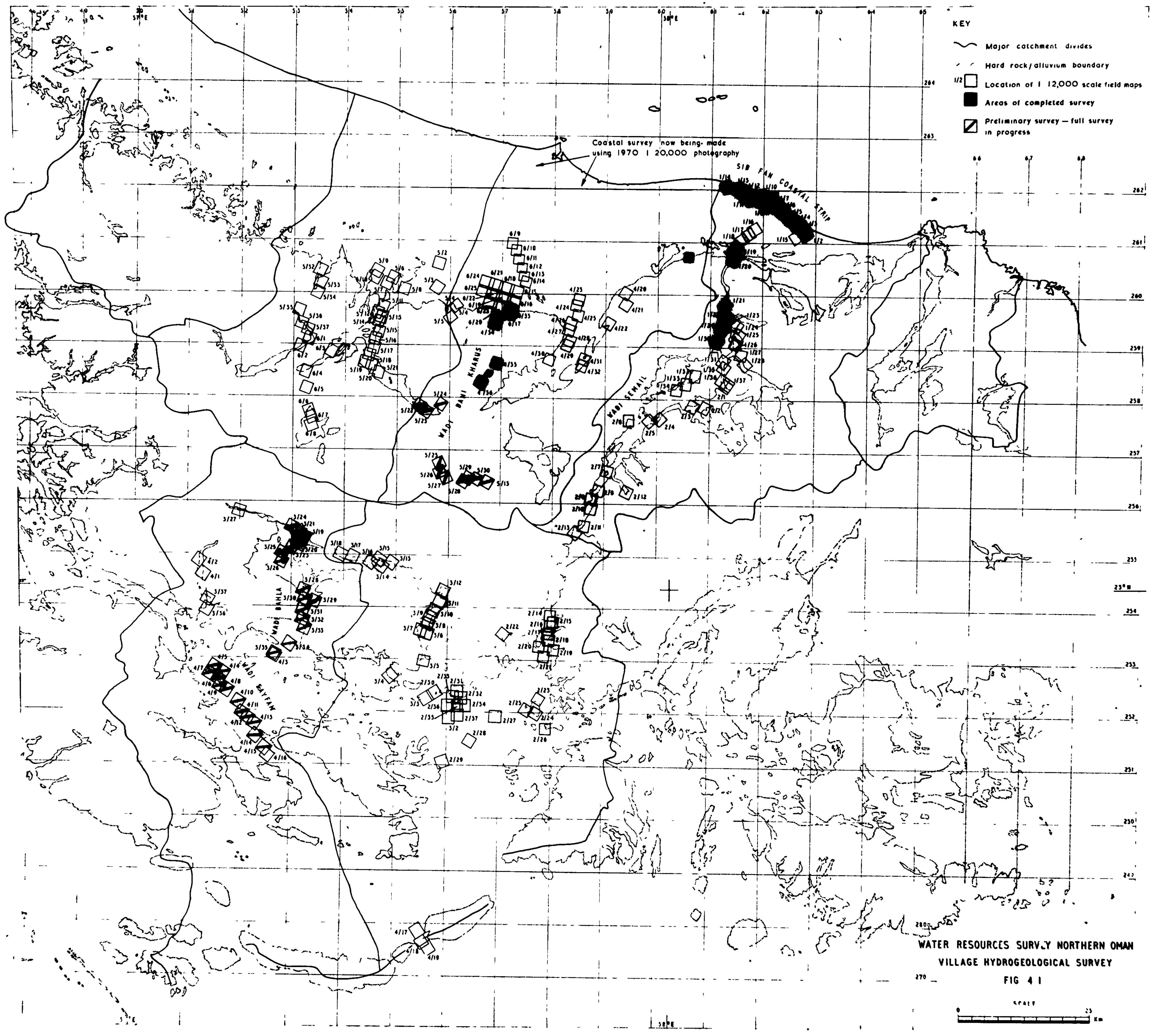
We cannot be sure yet which of these processes is the principal cause of the increasing salinity although it is likely that all three are contributing to the problem.

Figure 4.2 shows the distribution of the cultivated area with respect to the main surface sedimentary features of the Wadi Samail. The main pumping capacity is located around Sib where 400 wells abstract groundwater from the modern alluvial fan of the wadi. To the west of Sib a progressively narrower and poorer agricultural area has been developed in an area underlain by older sediments and fans of previous channels of the Wadi Samail. East of Sib a cultivated area has been developed along a coast of the minor Wadi Rusail.

The extent of the cultivation and the numbers of wells probably reflect the availability of groundwater. The Wadi Samail has virtually perennial surface flow at Al Khawd and there is evidence to suggest that this flow is contained as groundwater within the area of the modern fan. The Wadi Rusail is an ephemeral stream subject to occasional floods. These appear to originate in the low Jebel and provide some recharge to the alluvium. However to the west of Sib the surface drainage pattern arises from low hills within the old alluvial tract of Wadi Samail. Runoff and recharge of groundwater are dependent upon rainfall on the plain, rather than in the Jebel, or to leakage from the modern wadi or from flooding along the old watercourse. Scattered, less intensive cultivation occurs in the coastal area bordering these older sediments, and the gardens contain fewer wells and yield poorer quality water than those to the east.

Groundwater quality, expressed as the conductivity of well water, is shown in the form of the 1,000 µmho and 5000 µmho contours in Figure 4.2. These correspond to total dissolved solids of about 650 mg/l and 3,500 mg/l respectively. In the cultivated area around Sib, the gardens lie between the 1000 µmho contour and 5000 µmho contour, the latter currently being located near to the coast in the centre of the fan but running inland to the east and west where it is to be found beneath the gardens at Hayl and Ghursheba. We have recorded groundwater conductivities of up to 30 000 µmhos in places between the 5000 µmho contour and the shore. This is approaching the conductivity of seawater, 40 000 µmhos, but does not in our opinion necessarily prove active sea water intrusion. Coastal sabkhas are common along this part of the Batinah and the saline groundwater could represent the natural position of the interface since the water table is normally within about 2 m of the surface and inter-dunal areas can be close to sea level. We have installed observation boreholes along the coast to examine water table fluctuations whereby we can determine whether a decline in head is occurring.

We have carried out some exploratory work at depth in the aquifer inland from the agricultural areas. Two 300 m deep fully screened boreholes were drilled as part of the final work in the water well contract. The positions of these wells, DW1 and DW2 are shown on Figure 4.2. DW1 is located in the centre of the modern fan due south of Sib while DW2 is to the west in the centre of the old Samail fan. These boreholes indicate some 100 m to 120 m of gravel sand and boulders overlying 200 m of clayey and silty gravels with some sandy gravel horizons. Fluid conductivity logs have been made following extensive well development.



WATER RESOURCES SURVEY NORTHERN OMAN
VILLAGE HYDROGEOLOGICAL SURVEY
FIG 4.1

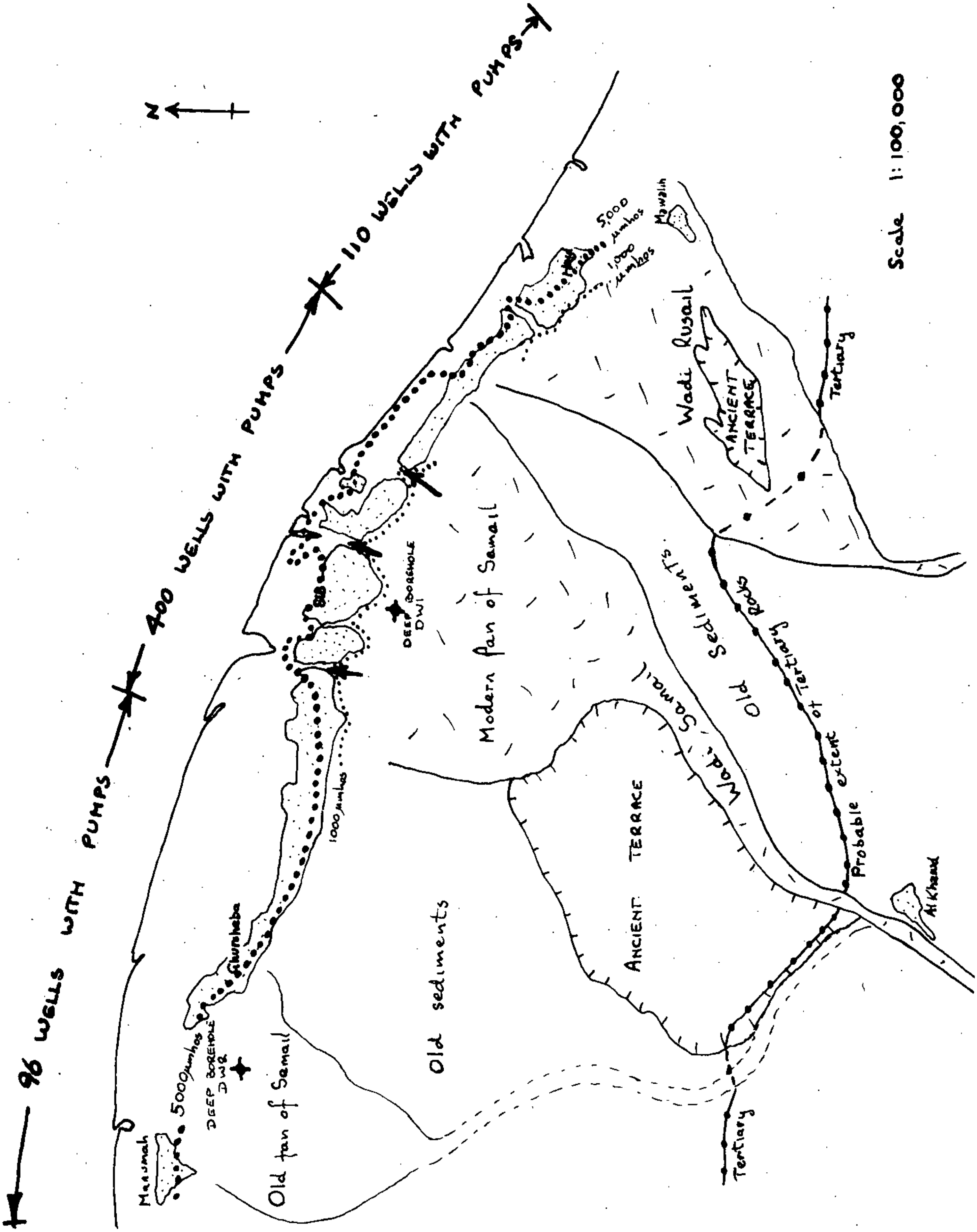
Currently we are re-logging the wells in order to determine when equilibrium will be re-established. DW1 indicates the presence of only 25 m of freshwater with a conductivity of 800 µmhos above groundwater of up to 5 500 µmhos (total dissolved solids of about 3 500 mg/l). DW2 indicates that the upper layers of groundwater contain dissolved solids of about 2 500 mg/l and shows the presence of brackish water at 48 m below surface. Fluid conductivities of 6000 µmhos are being recorded at 60 m, equivalent to a dissolved solids content of about 4 000 mg/l., in the gravels overlying the silty and marly beds.

It seems likely that this brackish water may be connate groundwater, or even trapped but subsequently diluted sea water from an earlier marine intrusion. Chemical data is still being collected to attempt to determine its origin. A borehole water sampler is necessary in order to provide 'in-situ' sampling facilities and currently conductivity logs in all boreholes in the area are being made.

The occurrence of a relatively thin freshwater layer above brackish groundwater could account for the salinity build-up beneath the cultivated area. The shallow wells, normally penetrating about 2 m below the water table, would tend to skim off the fresh water and in the absence of any confining layers, allow an upwelling of the underlying brackish groundwater. Under these circumstances the 5 000 µmho contour would indicate the approximate position of complete abstraction of the fresh water layer, seaward conductivities in excess of 5 000 µmhos being caused by solute build up due to leaching, mixed with saline instrusion of sea water following any fall in water levels.

The survey results show that some groundwater flow to the sea could still be occurring in the upper layers of the aquifer. Low conductivity groundwater is present beneath the main wadis of the Samail cutting through the gardens to the coast. Furthermore the position of the 5 000 µmho contour in the eastern half of the modern fan is relatively close to the shore. This would be in keeping with the concepts of containment of the Samail water to the modern fan and the apparent relationship between base flow input and groundwater abstractions for irrigation. A component of groundwater recharge must occur as a result of the occasional flooding of the Samail in response to rainfall in the Jebel Akdhar. Currently the evidence would tend to suggest that flood recharge is not a major contributor to groundwater recharge but until we have been able to observe a runoff event further quantitative observation is speculative.

SIB COASTAL AREA



The detailed information collected during the survey has been compiled on overlays to the 1:12 000 scale photographic cover. The overlays together with some descriptive test are reproduced as an Appendix to this section.

4.3 INLAND VILLAGES - WADI SAMAIL AND WADI BANI KHARUS

A detailed field survey has been completed in the Wadi Samail from Al Khawd to Fanjah including the area of the Wadi Hamim. Also a less detailed reconnaissance survey was carried out of the villages of the Wadi Bani Kharus basin upstream of Khatum. However the information requires further collation and analysis before it can be presented in a form consistent with our coverage of the coastal area of the Wadi Samail.

The area of Al Khawd, Fanjah and the Wadi Hamim has a complex geology. There are some springs and wells but the major sources of water are aflaj in the wadi gravels. The water is hard but otherwise is of good quality for both agricultural and domestic use. By contrast the water from the few wells mainly in the serpentinites tends to be brackish.

In the Wadi Bani Kharus the villages from Khatum to Istal derive their water mainly from the wadi gravels. Quality is good although, unlike the Wadi Samail villages, there were indications that severe shortages are experienced in some years. Above Shaww, the villages rely on spring flows from the limestone. In many cases screes and conglomerates obscure the location of the springs. This area will be subject to detailed survey during 1974.

4.4 VILLAGES IN THE BAHLA BASIN

In February this year, a reconnaissance survey was carried out of the major water sources in this basin in order to define the programme of detailed survey which is now being carried out.

The major concern at this stage is the quantity of water passing out of the upper part of the Bahla basin through the town of Bahla itself. The town is situated in a gap between gabbro and peri-dotite hills which constrict the wadi bringing the flows in the wadi gravels to the surface. There is probably some constriction on groundwater levels such that the water table is reasonably near the surface in the agricultural areas of the town.

Three aflaj with a combined flow of about 150 l/s were identified and numerous wells in the northern area of the town were observed. The contemporary flow in the wadi was only 10 l/s and there was little evidence of return flow to the wadi from the agricultural areas. Thus, at present, the upper part of the basin would appear to be contributing little to the groundwater resources of the area to the south.

During and after the detailed survey we shall continue to monitor the flows in the major aflaj and the output from a sample of wells throughout the whole basin. Only in this way can the normal seasonal variation in flows and the response of aflaj and groundwater levels to the rainfall input be determined.

APPENDIX A

COASTAL AREA SURVEY OF WADI SAMAIL

MAWALIH   Figure A2   Sheet 1/2

Groundwater occurs at a depth of about 6 or 7 m beneath the date gardens of the village. Seven wells, about 2 m square, are used for irrigation purposes. Six of these are fitted with pumps and provide water used for growing lemons, onions, maize and mangoes in and around the date gardens. Large areas surrounding the village have been settled during recent years. Four small wells provide domestic supplies but none of these is yet fitted with a pump.

Boreholes JT 53 and ADG 13 provide strata details for the area. 33.5 m of fine gravel with some sand were recorded at ADG 13 prior to the start of our study. JT 53 samples have been examined and indicate the following sequence :

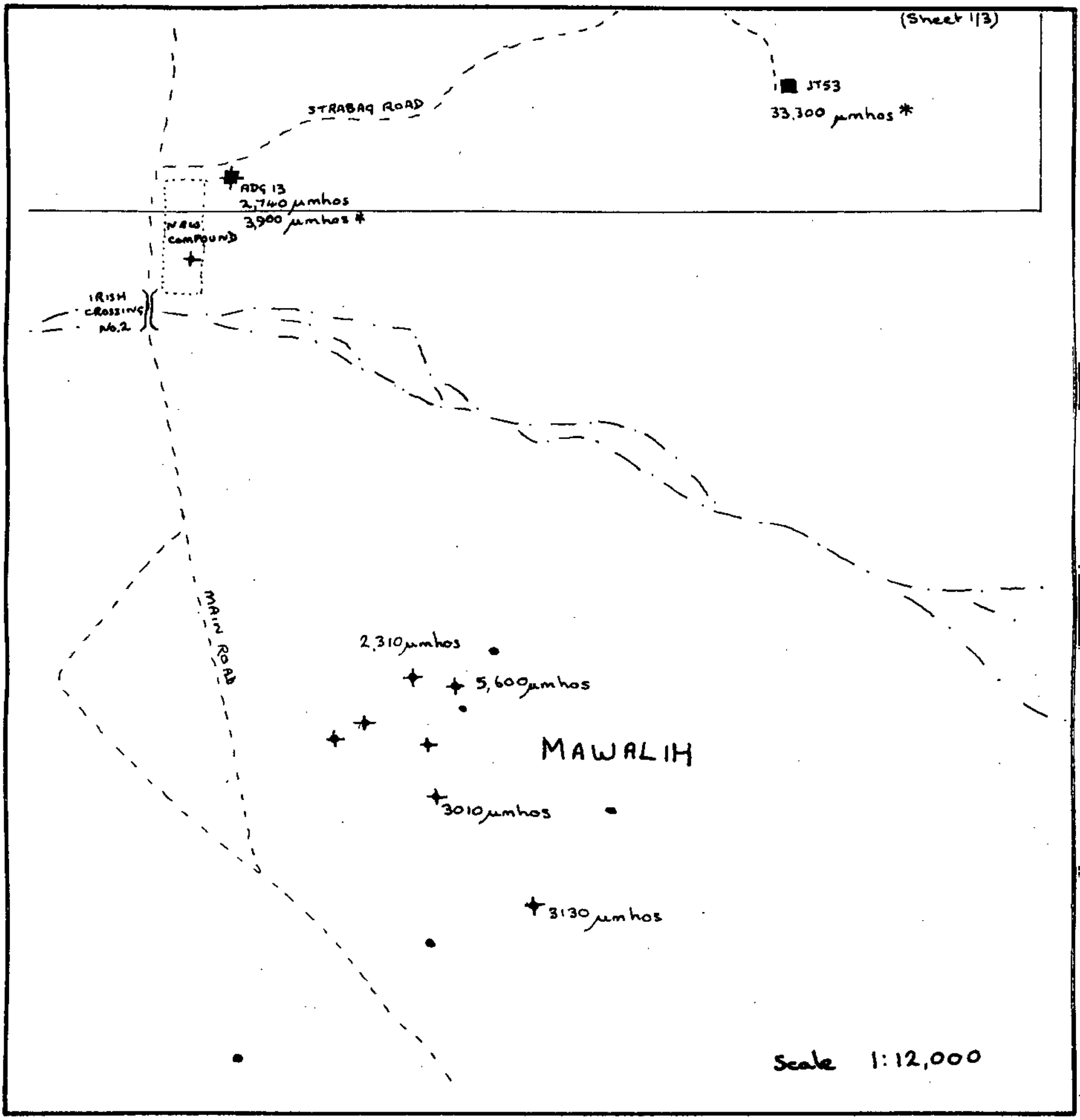
0- 7 m	Sand and Clay
8-25 m	Gravel
26-41 m	Sandy clay and gravel/sand
42-72 m	Gravel, gravel and clay, and gravel with boulders.

Brackish or saline groundwater underlies the area. Borehole ADG 13 and the wells nearest the road produce the best quality water. Field evidence shows that fluid conductivity increases across the village while JT 53 produced water that was approaching sea water in composition.

Water Quality (mg/ l)

	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	EC umho/cm
ADG 13	152	176	545	11	84	310	1300	9	2710
MAWALIH	130	190	1120	31	78	590	2000	25	4250
JT 53	800	1370	9550	360	84	2580	18450	17	33300

FIGURE A 2



VILLAGE SURVEY
SHEET 1/2

MAWALIH

Domestic well •

Well with pump ✦

Borehole ■

Groundwater conductivity in μmhos at 25°C (Field) — — — —

Conductivity at 20°C (Laboratary) *

Most of the 56 wells in and around this village are fitted with pumps and produce a brackish water used for irrigating dates, mangoes, bananas and sorghum. There would appear to be general dissatisfaction regarding water quality and reports were received of good wells turning brackish when fitted with pumps, of date gardens and wells being abandoned on the coastal side of the village, and of domestic water supplies being taken only from wells in the vicinity of the road.

The village survey map shows the distribution of wells and the fluid conductivity of groundwater in the hand-dug wells. Along the main road, where conductivity is less than 1 000 umhos, a few wells yet exist and agricultural development has not yet taken place. Beneath the gardens, within a short distance of the road, the quality of groundwater rapidly deteriorates and the concentration of most salt rapidly increases. All of the pumped wells in the gardens yield groundwater with a conductivity greater than 1000 umhos; this implies chlorides in excess of 200 mg/1 and total dissolved solids of at least 800 mg/1. There is some evidence to suggest that water of a better quality underlies the main wadi channel but the general conclusion that may be drawn from the water quality data suggests that the seaward flow of groundwater is balanced by abstractions and natural evaporation and transpiration losses. A representative sample taken from a well located in the centre of the gardens is given below.

Hayl - Well 1/3 - 20

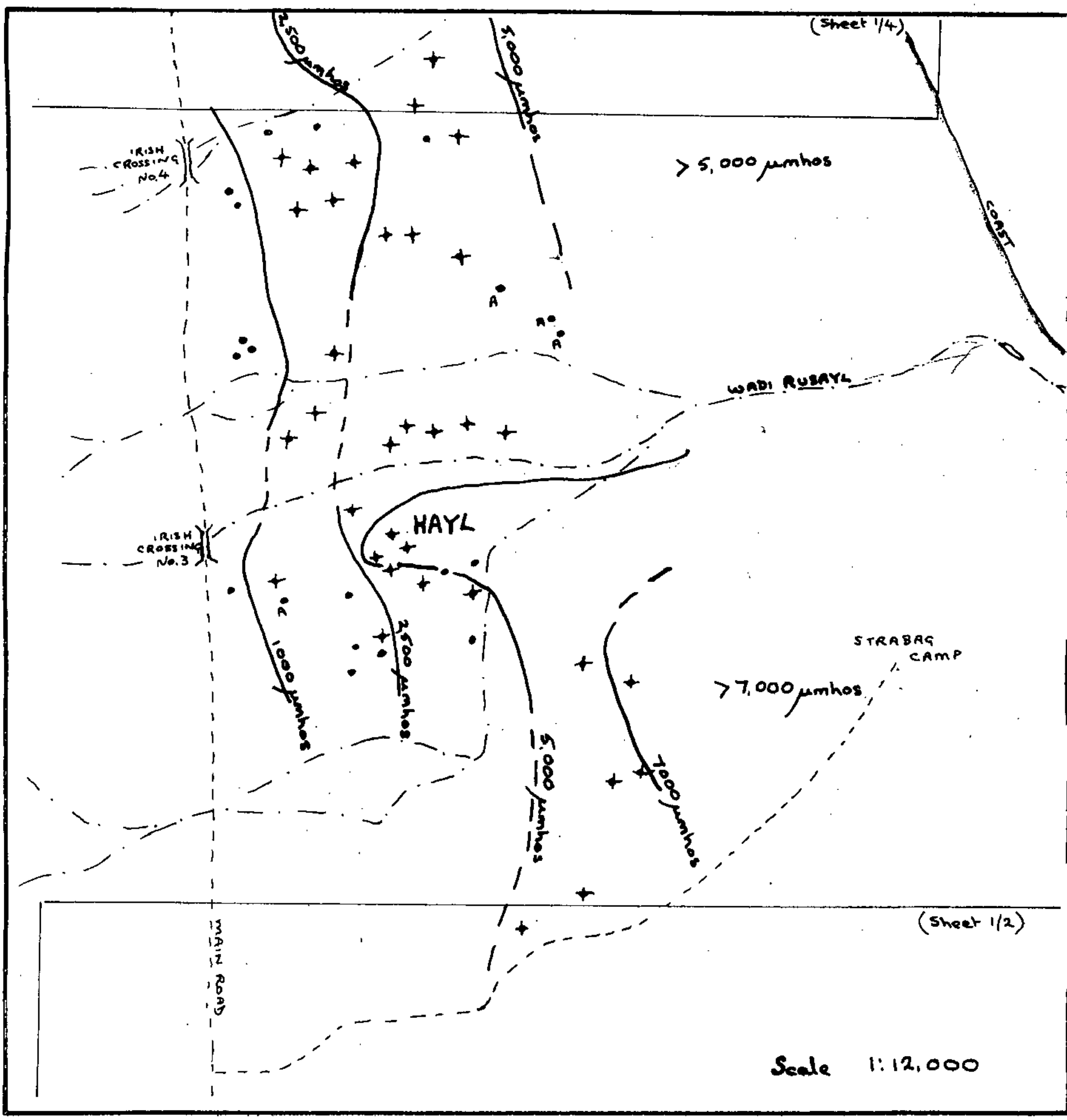
Water Quality

Conductivity umhos	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	TDS
	mg/1								
2650[1] / 3600[2]	146	204	400	170	102	240	1320	9	2680

1 Field measurement at 25°C

2 Laboratory measurement at 20°C

FIGURE A 3



VILLAGE SURVEY
SHEET 1/3

HAYL

Domestic well •

Well with pump ✦

Abandoned well A•

Groundwater conductivity in μmhos at 25°C ——— — —

WADI ABUDAH   Figure A4   Sheet 1/4

Unlike the Hayl area, where villagers walk over a mile for good drinking water, groundwater quality is much better in the adjacent Wadi Abudah area. Wells over 100 years old were reported to be in use and villagers claimed that these were some of the best in this part of the coast.

Groundwater quality, expressed in terms of conductivity, shows that most of this area is underlain by water with a conductivity of less than 2 500 umho. Only 20% of the 62 wells fitted with pumps occur between the coast and the 2 500 umho contour. The local picture may be somewhat optimisitc and the close proximity of the 2 500 umho and the 5 000 umho contours suggest a condition where water quality could rapidly deteriorate. A sample of water taken from a well in the centre of this area yielded the following analysis :

Wadi Abudah - Well 1/4 - 21

Water Quality

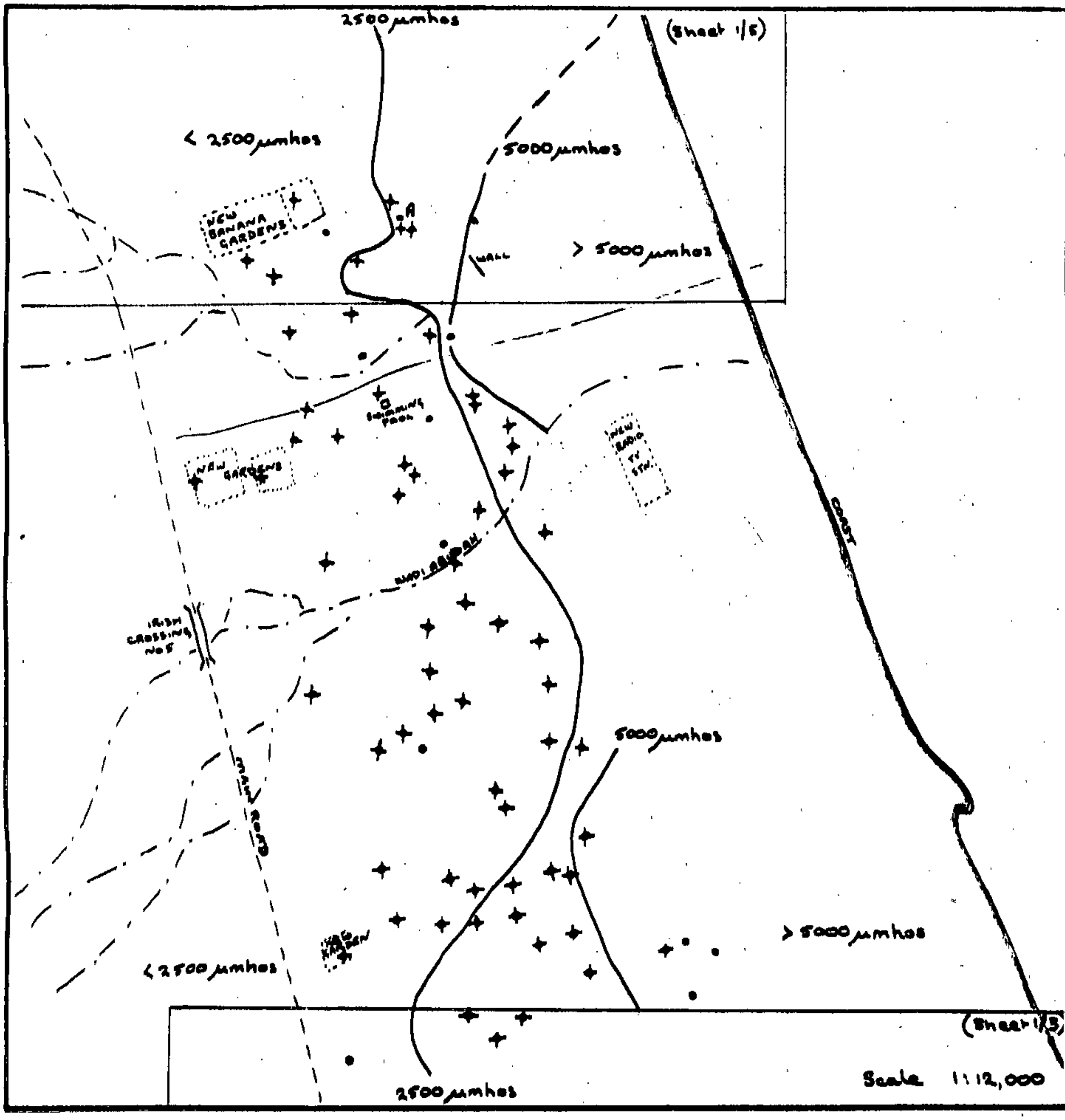
Conductivity	mg/1									
umhos	Ca	Mg	Na	K	HCO_3	SO_4	C1	NO_3	TDS	Boron
2 000 *	26	72	385	16	210	280	395	11	1440	2.5

* Laboratory determination at 20°C

By comparison with the Hayl sample most ions are present in lower concentrations. A considerable reduction in chloride content should be noted. Boron concentration is sufficiently high to render this particular well unsuitable for the irrigation of boron sensitive, or even semi-tolerant, crop.

Groundwater occurs at depths of 2.5 m to 7.5 m. Pumps were delivering about 11 l/s (150 gpm) and were being used for periods of 3 hours to 8 hours per day.

FIGURE A 4



VILLAGE SURVEY
SHEET 1/4

WADI ABUDAH

Domestic well •
Well with pump ✦
Abandoned well A•
Groundwater conductivity in μmhos at 25°C — — — —

EASTERN WADI SAMAIL Figure A5 Sheet 1/5

The improvement in water quality continues within the area covered by survey sheet 1/5. The 5 000 umho contour is close to the coast, suggesting a more normal fresh/saline interface. This eastern part of the coastal fan of the Wadi Samail must be receiving a more significant groundwater flow than those coastal areas in the Wadi Rusayl. Over 50 wells are fitted with pumps but these are distributed throughout a fairly large area and there would appear to be no evidence of a deteriorating water quality. A marked groundwater flow of good quality water appears to exist beneath the Wadi Luwam which forms the western boundary of this survey area.

A chemical analysis of groundwater from a well in the vicinity of the main road is given below. This is a particularly good quality water and is probably typical of groundwater on the landward side of the coastal gardens.

Well 1/5 - 14

Water Quality

Conductivity	mg/1								
umhos	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	TDS
1620[1])) 1350[2])	28	100	148	6	138	170	280	5	940

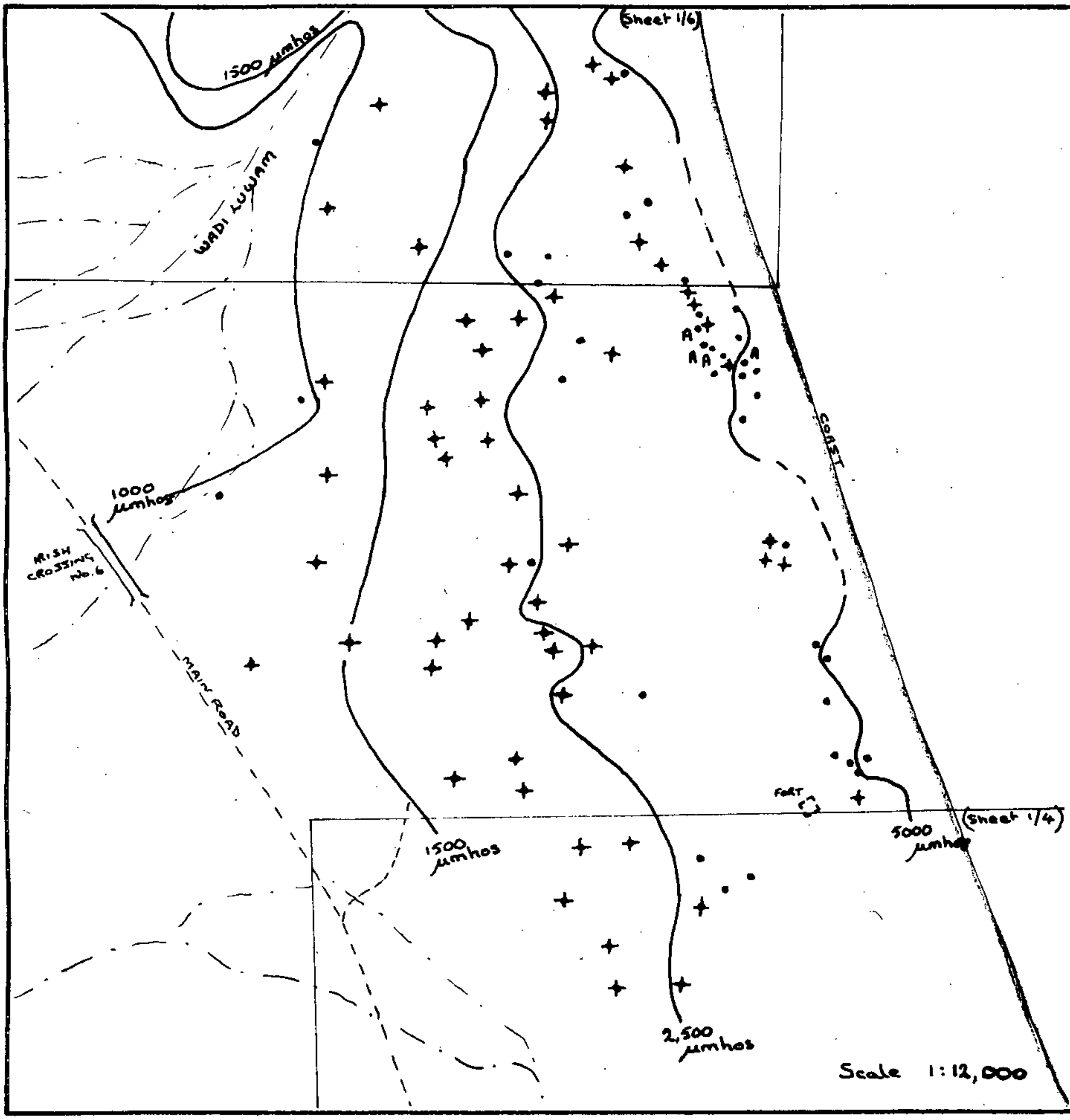
1 Field measurement at 25°C

2 Laboratory measurement at 20°C.

WADI LUWAM Figure A6 Sheet 1/6

Nearly 150 wells were located in this area of which 104 were fitted with pumps. Several large residences surrounded by gardens with a great variety of trees and flowers occur in the northern part. It seems likely that large quantities of water were being abstracted in these gardens but access to the grounds could not be arranged at the time of the survey. The general form and distribution of the groundwater conductivity suggests that they were located in an area of good quality groundwater associated with a sub-surface flow beneath the Wadi Buhayyis.

FIGURE A 5



VILLAGE SURVEY
SHEET 1/5

EASTERN WADI SAMA'IL

Domestic well •
Well with pump ✦
Abandoned well A•
Groundwater conductivity in µmhos at 25°C ———— — —

The coastal belt contained wells yielding a very salty water and landward replacement wells were reported to have been constructed during the past 20 years. Perhaps one third of the wells were seldom used except for dates, which have a high salt tolerance, and villagers obtained drinking water from fresh water wells in the wadi bed.

Very large variations in conductivity were recorded in the wells of the coastal gardens. The 5 000 umho and 10 000 umho contours shown on the enclosed diagram of the area are intended to indicate the approximate positions only. Variations of up to 10 000 umhos were observed between adjacent wells and the complexity of the chemistry suggests either that the abstractions in these gardens are now exceeding the quantity of fresh water flowing to the sea or that the landward wells are intercepting groundwater previously available to the older gardens. Areas liable to suffer a progressive deterioration in quality have been indicated on the survey sheet.

An analysis of groundwater taken from well 1/6 46 is given below. The sample, taken from a well adjacent to the gardens in the inland area, should be typical of the better quality groundwater in the area.

Water Quality

mg/l

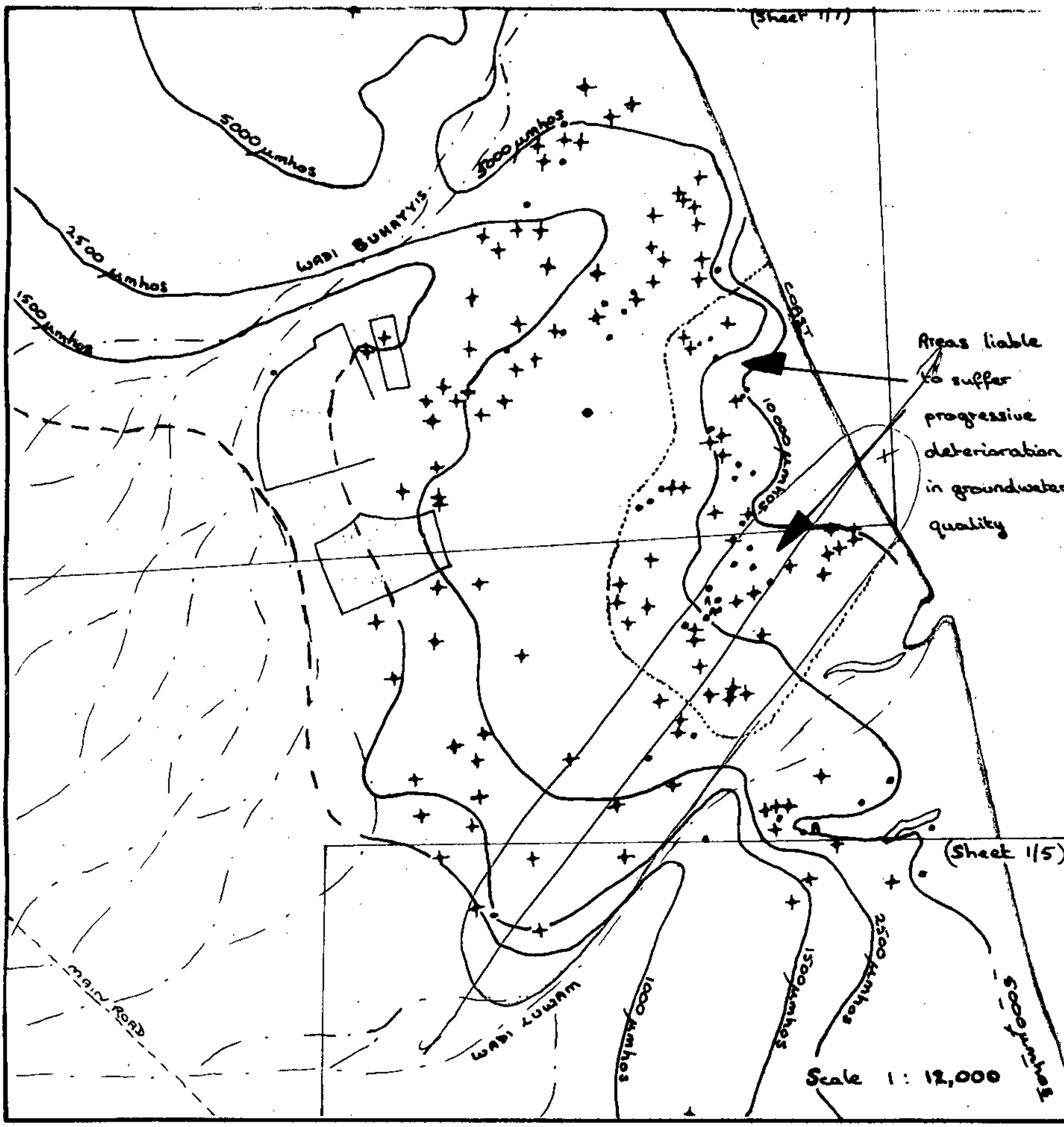
Conductivity umhos	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	TDS
2075[1])) 1350[2])	45	115	235	7	192	270	360	4	1270

1 Field measurement at 25°C

2 Laboratory measurement at 20°C

Depth to water table varies in a similar fashion to the chemistry. The inland wells with the best quality water intersect the water table at depths of 6 m to 8 m below surface. The water table is at about 3 m in the central areas but is within 2 m of the surface in the brackish and saline areas along the coast.

FIGURE A 6



VILLAGE SURVEY
SHEET 1/6

WADI LUWAM

Domestic well •

Well with pump ✦

Abandoned well A•

Groundwater conductivity in µmhos at 25°C ——— — —

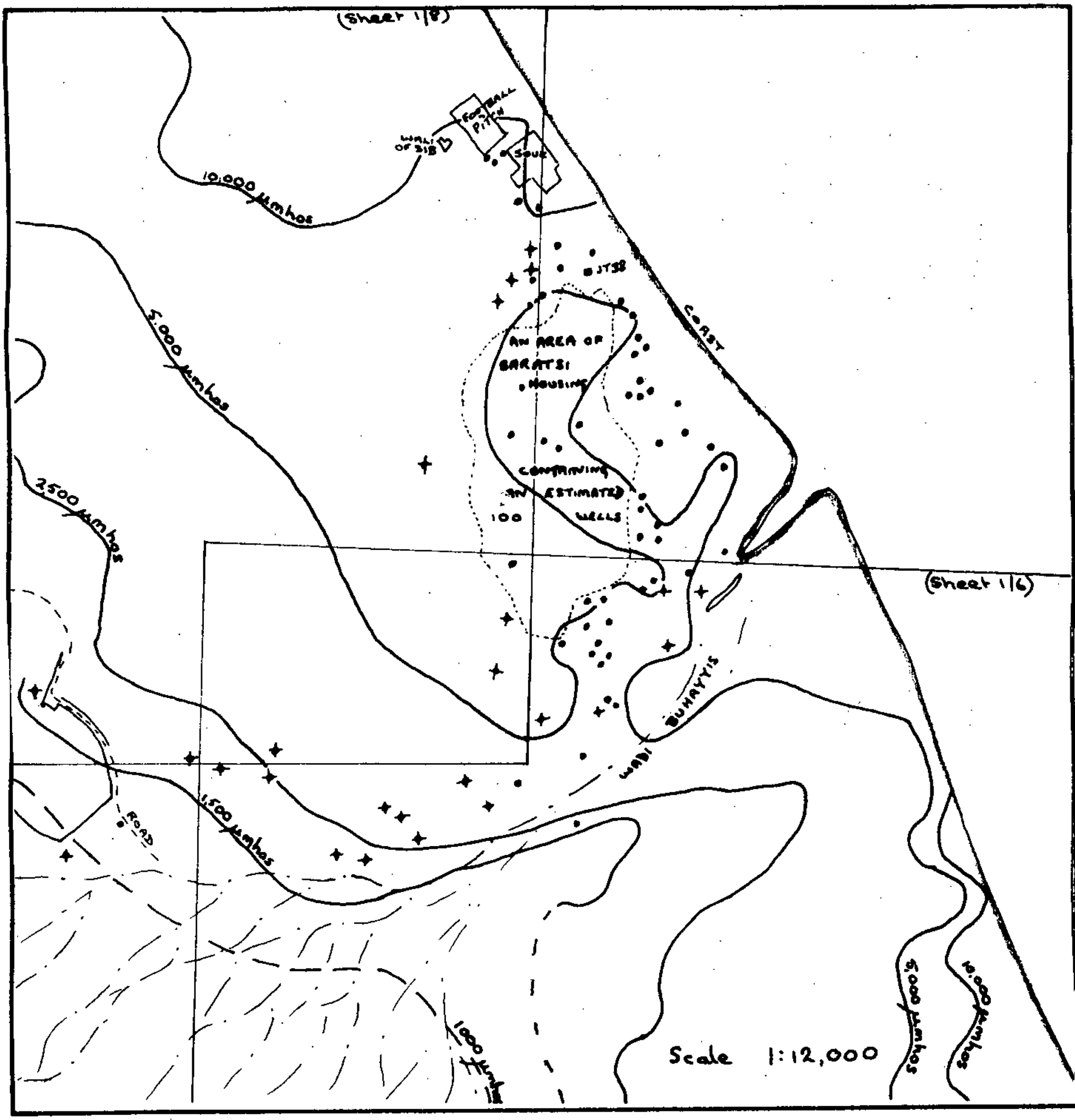
WADI BUHAYYIS Figure A7 Sheet 1/7

The area of survey covered by sheet 1/7 on the western bank of the Wadi Buhayyis is on the fringe of the village of Sib. 76 wells were registered in a relatively small area and it was estimated that at least 100 other wells provided domestic supplies to a large area of barasti housing (dwellings constructed from interwoven palm fronds) between the wadi and the Souk at Sib. A relatively small number of pumps were fitted to the wells, 26 out of a total of perhaps 180-200 wells. The depth to water level varied between about 7 m inland to about 2.5 m at the coast.

Good quality water is to be found only in the inland wells and along the Wadi Buhayyis. The salinity pattern is again complex in the coastal area and beneath the area of barasti housing. The salinity pattern suggests that recirculation and possible local pollution is the cause of the problem and that groundwater abstraction is relatively low in the area. However, the wells in this area are on the eastern fringe of the main centre of cultivation in this part of the Batinah and the groundwater quality is likely to be influenced by pumping in the gardens to the west.

Chemical analyses have been made on two water samples in this area. They were taken from a waterhole in the bed of the wadi and from an adjacent well on the western bank and provide a useful comparison indicating the lower dissolved solids content of the wadi bed groundwater. The chemical and mineral analysis of the wadi source indicate a hard water, but nevertheless, a pure and wholesome supply. By comparison the well sample contains a total dissolved solids concentration well in excess of the "maximum allowable" content recommended in the World Health Organisation International Standards. Rigid standards cannot of course be established but one of the major features of the village survey of this part of Batinah is the relatively high and unexpected dissolved solid content of groundwater from beneath the gardens and the villages. Many of the wells supply water which will taste saline and the common practice of drawing domestic water supplies from the wadi bed gravels some distance from the villages demonstrates the unsuitability of many sources of water.

FIGURE A 7



VILLAGE SURVEY
SHEET 1/7

WADI BUHAYYIS

Domestic well •
Well with pump ✦
Borehole ■
Groundwater conductivity in µmhos at 25°C. ———— — —

Water Quality (mg/l)

Conductivity umhos	Ca	Mg	Na	K	CO_3	SO_4	Cl	NO_3	TDS
Waterhole sample 1/7 A									
1010[1]) 850[2])	34	54	80	6	69	78	202	7	560
Well sample 1/7 1									
5730[1]) 5100[2])	145	358	600	21	120	410	1800	4	3500

[1] Field sample at 25°C

[2] Laboratory sample at 20°C

SIB Figure A8 Sheet 1/8

146 wells were individually located and examined during the survey of this area. 109 wells were fitted with pumps and it is estimated that an additional 200 domestic wells probably exist in the barasti housing between the main date gardens and the coast.

The coastal area groundwater is consistently brackish or even saline. A detailed conductivity survey along two sections across the village showed a general tendency for increasing conductivity toward the coast but gave results ranging from 6000 umho to 15 500 umho. A pattern of inland re-siting of wells was recorded, domestic water supplies were being obtained from a well in the wadi to the west of Sib while cultivation in this zone was limited to dates.

The main garden area is at its widest between the village and the Palace. Most of the pumped wells are located in this zone. Ornate gardens, some with swimming pool, are common and groundwater abstraction is probably at its greatest in this vicinity. On the basis of pumping capacities this would seem to be in the order of 25 000 m^3/day to 30 000 m^3/day.

The depth to water level decreases from about 10 m in the extreme south of the sheet to about 2.5 m – 3 m at the coast. Details of the sediments in this area have been obtained from a 300 m deep borehole constructed immediately to the south of the mapped area of sheet 1/8. This borehole recorded the following sequence :

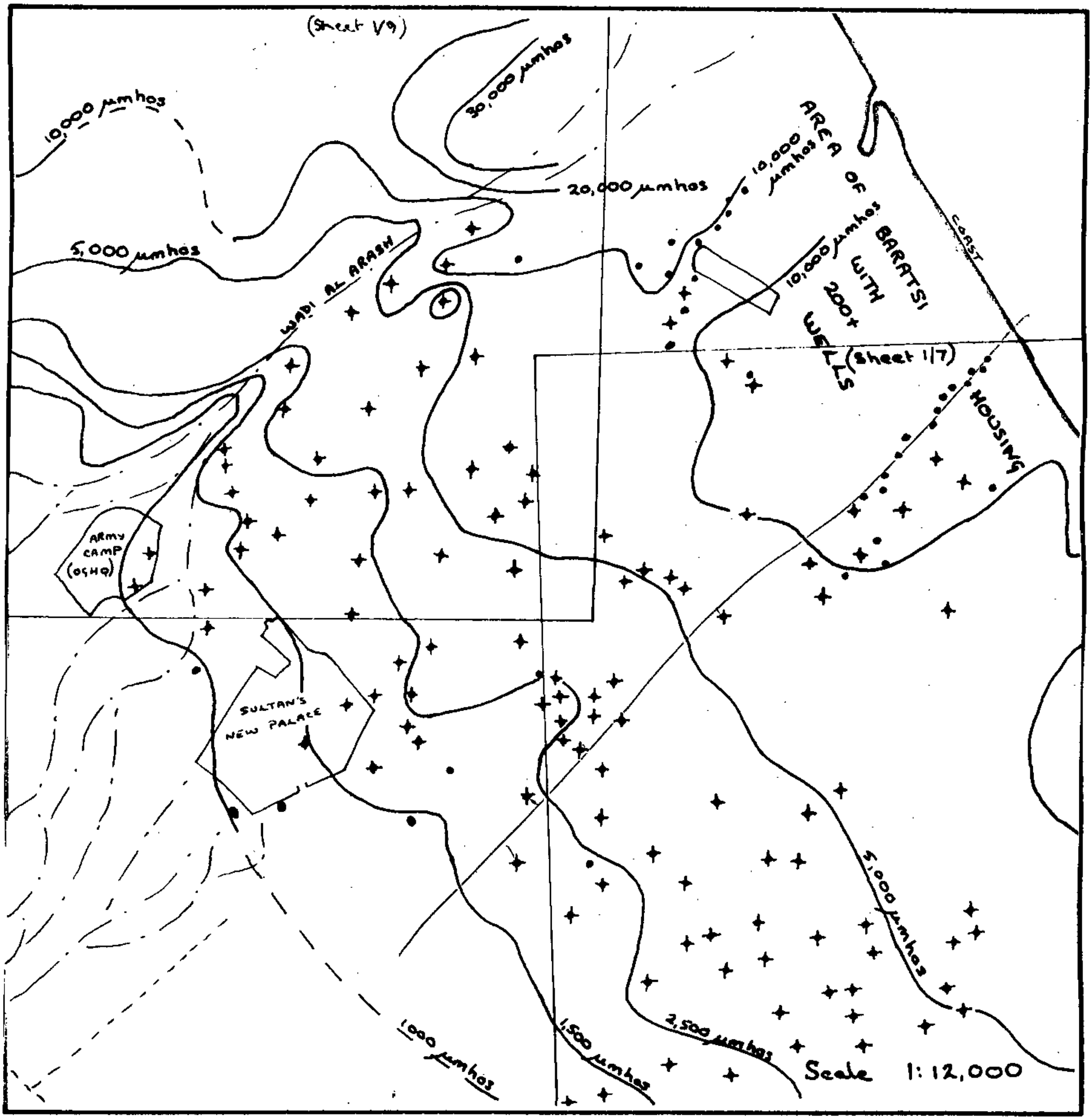
0– 72 m	Gravels, boulders and sand
73– 84 m	Fine to medium grained sand
85–104 m	Coarse sand and fine gravels
105–116 m	Sand and fine gravel with some lime cement
117–134 m	Fine to medium gravel and red/brown clays
135–166 m	Gravels with brown clay and white marls
167–216 m	Sands and gravels with clay and marl
217–224 m	White marls
225–300 m	Lime cemented sands and fine gravels with marls and clay

Fluid conductivity measurements made in the borehole prove the existence of a freshwater layer of only 25 m thickness. Between 35 m and 85 m below surface the salinity of the groundwater gradually increases from about 800 umhos to about 5 ooo umhos. Repeated logging of the borehole is being carried out but to date there has been no evidence of fresh water below a depth of 35 m. The occurrence of brackish water below about 105 m appears to be related to the presence of clay, marl and lime-cement in the sands, gravels and conglomerates of these older sediments. Between 35 m and 105 m there would appear to be little lithological reason for the increase in salinity.

The rapid deterioration in water quality beneath the date gardens of the coast probably occurs as a result of several processes. If the abstraction of the fresh water by the hand-dug wells exceeds the seaward flow then the underlying older and brackish water will be brought to the surface. Salinity will be further increased by recharge of excess irrigation water carrying high dissolved solids and further complicated by the possibility of landward migration of sea water. The appearance of a natural groundwater fresh/brackish interface complicates the problems of the water resources of the Batinah. Further investigations must be carried out to examine the geometry of the apparently thin fresh groundwater layer and to examine the behaviour of the interface under the influence of the large regional abstractions.

Chemical analyses of samples collected by our survey team together with other data collected in connection with the Palace irrigation project are given below. At this stage it is not possible to determine whether the differences in composition in the Palace and Bandsmans Wells are due to real changes in the position of the interface or to inter-laboratory and sample procedure variations. Large differences in the chloride content, 183 mg/1 to 380 mg/1, would seem to indicate changes in the position of the brackish interface. Attention should be drawn to the high boron content of some of these analyses which indicate a groundwater of unsuitable quality for irrigation of such boron sensitive crops as citrus fruit.

FIGURE A 8



VILLAGE SURVEY
SHEET 1/8

SIB

Domestic well •
Well with pump ✦

Groundwater conductivity in μmhos at 25°C ——— — —

VILLAGE SURVEY - SIB (SHEET 1/9) WATER QUALITY

mg/l

	Conductivity u mhos	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	B	TDS
Palace Well 1/8 91											
07/12/71	1400	46	70	160	5	306	120	269	2	0.17	-
03/05/73	1200	34	61	117	6	244	120	183	1	0.24	-
29/01/74	-	16	71	-	-	-	-	380	-	-	1000
01/03/74	1085	26	68	100	-	-	136	207	12	-	-
Bandsmans Well 1/8 73											
01/03/74	1460	36	91	140	-	-	152	302	24	-	-
29/01/74	-	19	93	-	-	-	-	480	-	-	1200
Well 1/8 16 Wadi Arash	7200[1]) 6500[2])	190	430	830	26	201	480	2300	4	2.3	4500
Well 1/8 90	2620[1]) 2200[2])	80	129	248	17	174	200	560	4	1.6	1460

1. Field measurement at 25°C
2. Laboratory measurement at 20°C

AREA BETWEEN SIB AND MANUMAH   Figures A9-A14 Sheets 1/19-1/14

In terms of abstraction and cultivation, the area west of Sib is characterised by poorer quality water, fewer wells, and scattered, less intensive cultivation. The cause of this is undoubtedly related to the hydrogeology. The Wadi Al Arash at Sib marks the western limit of the modern alluvial fan of the Samail and also the probable western limit of the main groundwater area associated with the wadi. The standard of living in this area is lower; quite large areas of barren scrub separate the gardens and a broad strip of dune sand and sabkha up to 2 km wide separates the gardens from the sea.

A rapid increase in groundwater salinity is indicated by the conductivity observations. This build-up from 1 000 umho often to values in excess of 10 000 umho occurs across about 500 m of garden. The appearance of abandoned and disused gardens corresponds to those areas where the groundwater conductivity is above 5 000 umhos although small date yields and a smaller variety of crop types seem to be associated with a conductivity of about 3 000 umho.

The area of Halat Sidra, sheet 1/9, marks the westward limit of the modern alluvial fan of the Samail. Although generally similar in character to the gardens to the east, it should be emphasised that there was much concern and discontent in this area regarding the deteriorating water quality. 52 wells with pumps, 20 bailed wells and about 26 domestic wells occur within the "catchment" of the modern Samail fan.

The cultivated areas stretch westwards for a further 10 km to the main catchment divide of the Samail proper. 96 pumping wells were recorded, many of them were located in the eastern portion covered by sheets 1/10 and 1/11. Water availability clearly decreased beyond the influence of the main wadi. The depth to water table varied between 2 m and 9 m and superficially there does not appear to be any marked lithological change except for the disappearance or reduction in the amount of recent wadi sediment.

The cultivated area is not continuous and a break in cultivation exists between Ghursheba and Manumah. No wells were found within the area of sheet 1/13 which was an area of scrub with sizeable acacia trees up to 8 m. Two villages exist in the Wadi Manumah vicinity; both obtain drinking water from a single well in the wadi bed inland from the gardens. The irrigation wells yield a brackish water and comments were received regarding a change from fresh to saline groundwater following pump installation.

The scarcity of good quality groundwater in the Manumah area is being reflected in the results being obtained from exploration borehole DW2 located to the south of the new road opposite the area of acacia scrub. 100 m of gravels, sands and boulders overlie marly and clayey gravels to about 190 m, fine gravels, silts and silty sands being present between 190 m and 300 m. Groundwater conductivity measurements indicate a trace of water at the water table of less than 2 500 umho underlain by 40 m with conductivity of about 3 000 umho. A very sharp interface occurs at 48 m and groundwater between 50 m and 60 m has a conductivity of about 6 000 umho. The occurrence of these clayey horizons at 73 m and 84 m corresponds to a point where conductivity begins to decrease and currently we are recording a gradual decline in groundwater conductivity from 5 300 umho at 90 m to 3 600 umho at 296 m.

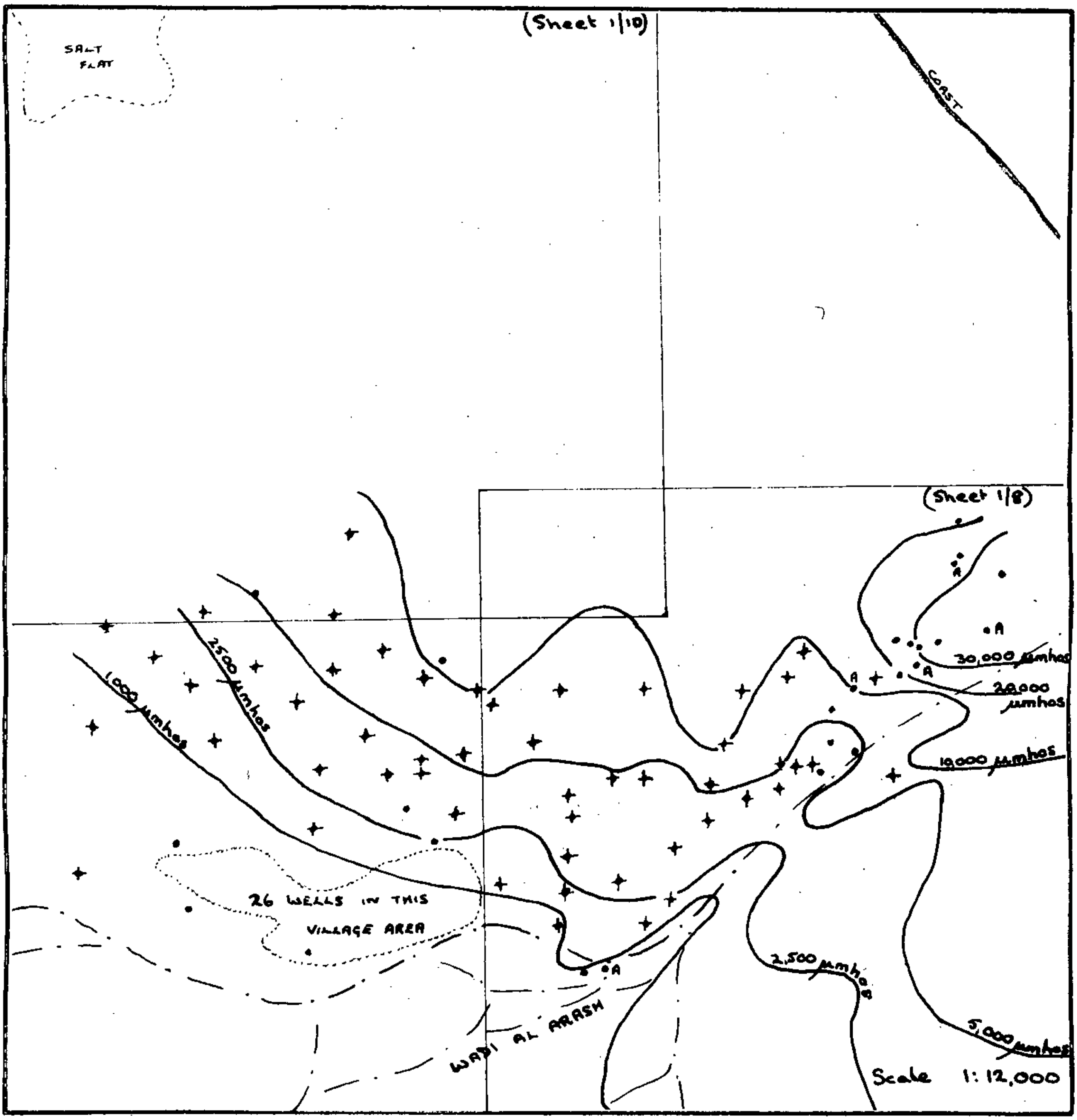
Chemical analyses from samples taken at selected wells in the area between Sib and Manumah are given below. Generally these were collected from the better quality wells but demonstrate the increase in chloride and sulphate concentrations which characterises the salinity build-up.

VILLAGE WELLS SIB-MANUMAH WATER QUALITY (mg/1)

Conductivity (umhos)	Ca	Mg	Na	K	CO_3	SO_4	C1	NO_3	Boron	TDS
Well 1/9 65 Halat Sidra										
3000[1]) 2600[2])	80	156	320	10	138	225	760	7	1.0	1750
Well 1/10 11 Sur Rad Hadid										
4200[2]	105	250	640	25	168	360	1450	4	1.7	3050
Well 1/10 34 Sur Rad Hadid										
4360[1]) 3500[2])	84	184	525	54	138	375	1100	8	2.1	2490
Well 1/11 1 Ma'abilah										
1160[1]) 930[2])	40	61	90	7	102	110	180	12	0.85	650
Well 1/11 18 Ma'abilah										
3380[1]) 2600[2])	100	169	297	14	114	430	680	11	0.25	1870
Well 1/12 10 Ghursheba										
5800[1]) 4800[2])	194	305	640	14	114	250	1850	8	0.44	3400
Well 1/14 9 Manumah										
2210[1]) 1350[2])	54	66	180	8	90	120	375	2	1.7	920

[1] Field sample at 25°C   [2] Laboratory sample at 20°C

FIGURE A 9



VILLAGE SURVEY
SHEET 1/9

HALAT SIDRA

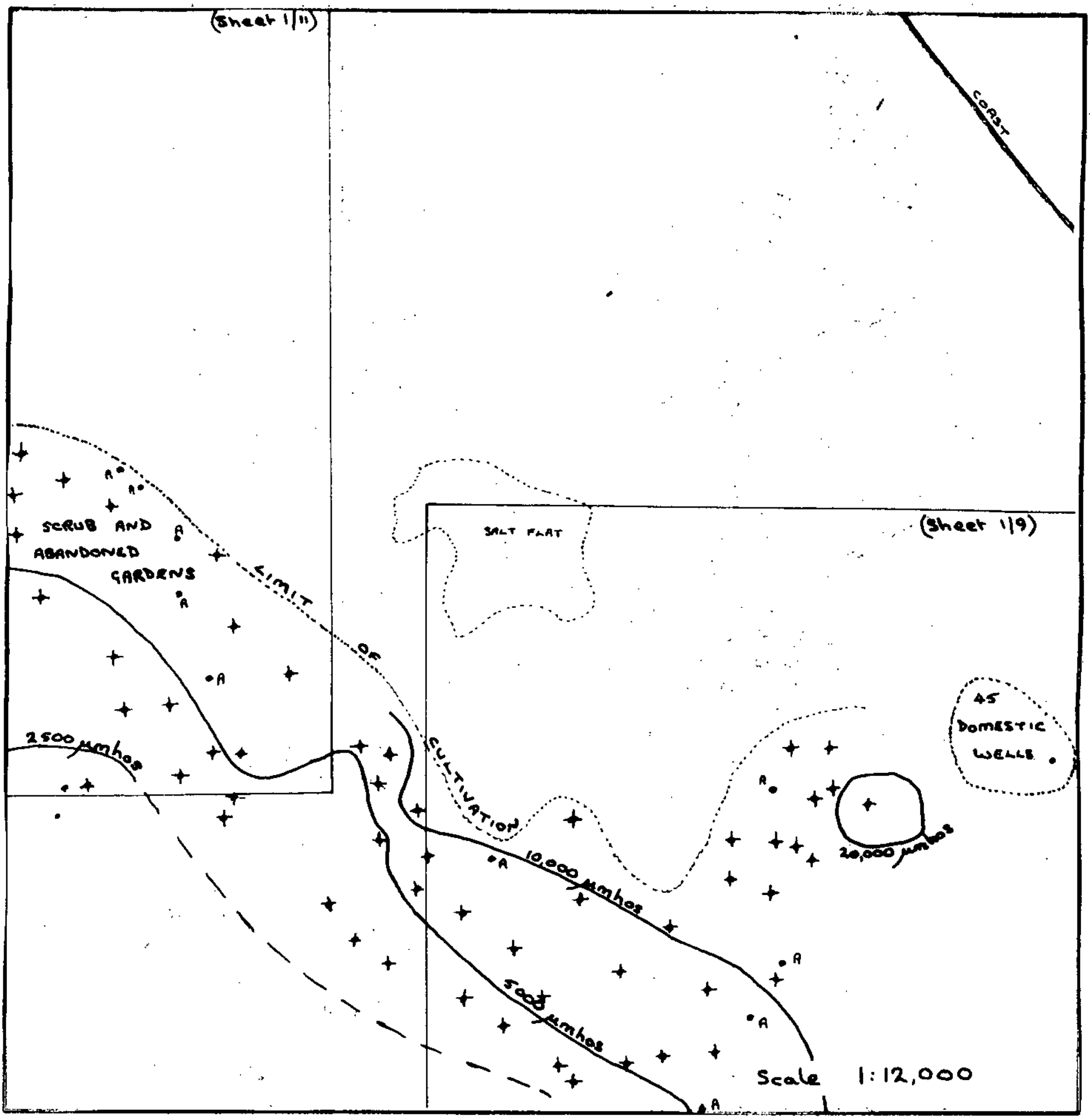
Domestic well •

Well with pump ✦

Abandoned well A•

Groundwater conductivity in µmhos at 25°C ———— — —

FIGURE A10



VILLAGE SURVEY
SHEET 1/10

SUR RAD HADID

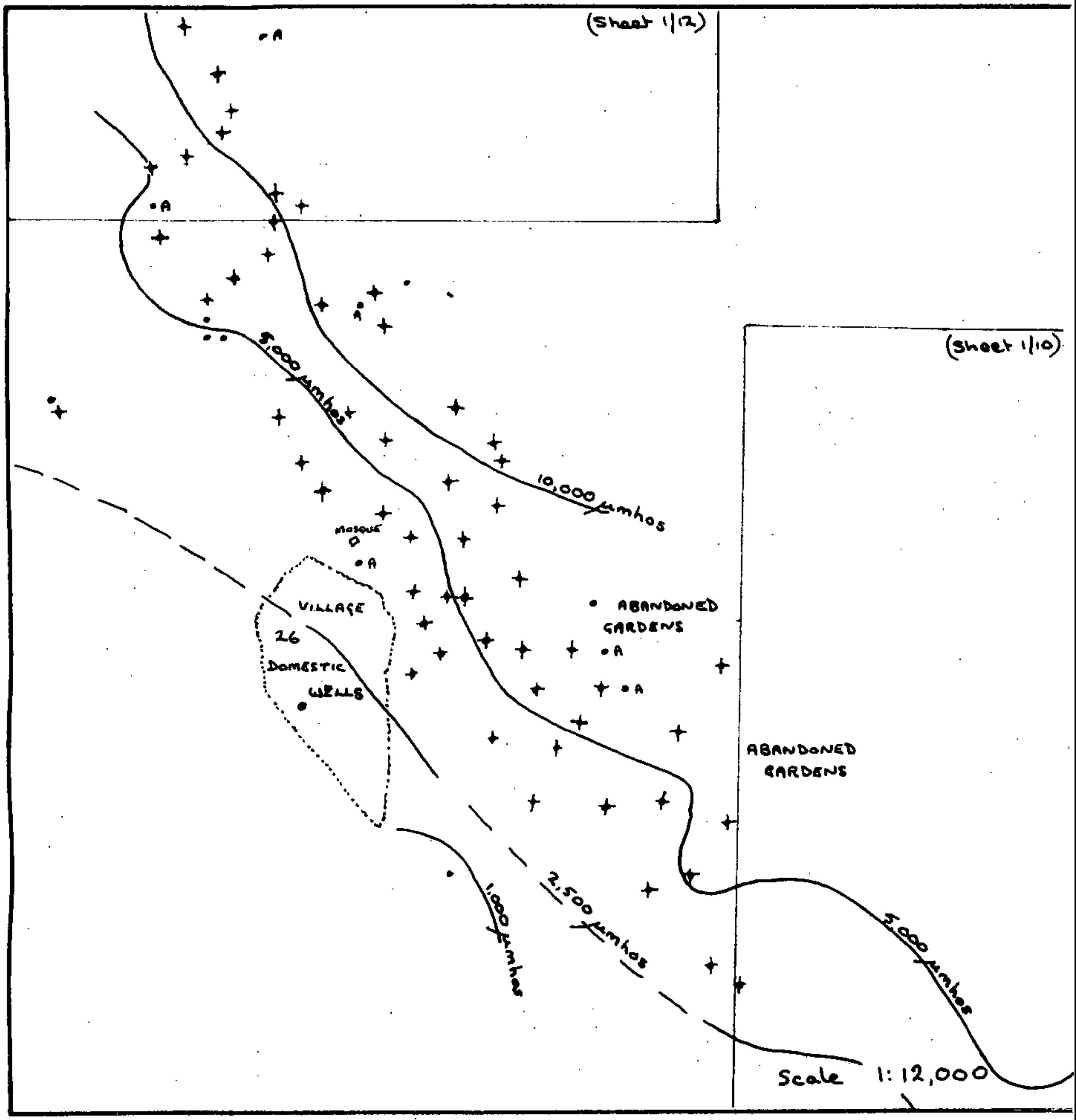
Domestic well •

Well with pump +

Abandoned well A•

Groundwater conductivity in µmhos at 25°C ——— — —

FIGURE A11



VILLAGE SURVEY
SHEET 1/11

MA'ABILAH

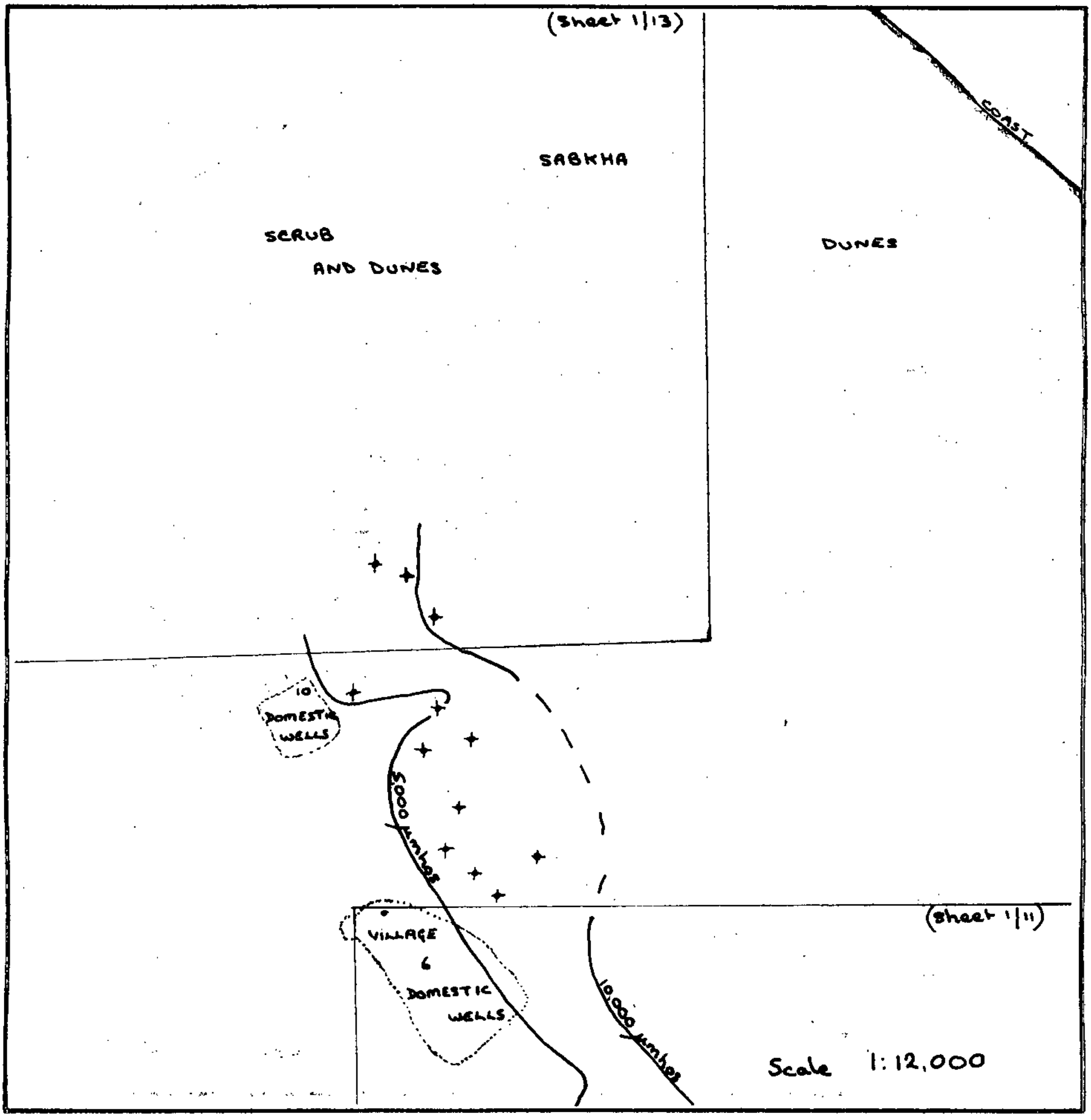
Domestic well •

Well with pump ✦

Abandoned well A•

Groundwater conductivity in µmhos at 25°C ——— — —

FIGURE A12



VILLAGE SURVEY
SHEET 1/12

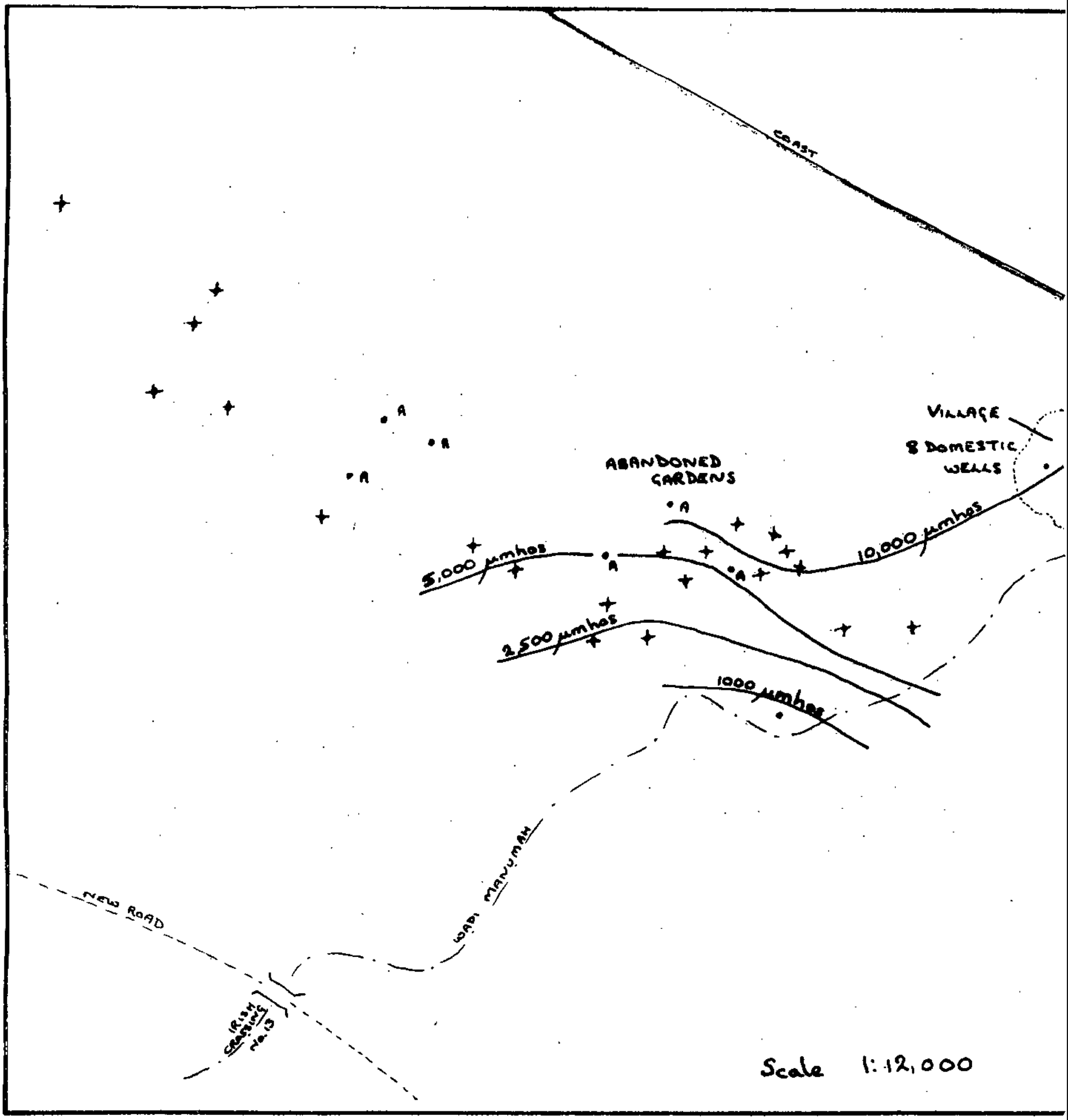
GHURSHEBA

Domestic well •

Well with pump ✦

Groundwater conductivity in µmhos at 25°C ——— — —

FIGURE A1



VILLAGE SURVEY
SHEET 1/14

MANUMAH

Domestic well •

Well with pump ✦

Abandoned well A•

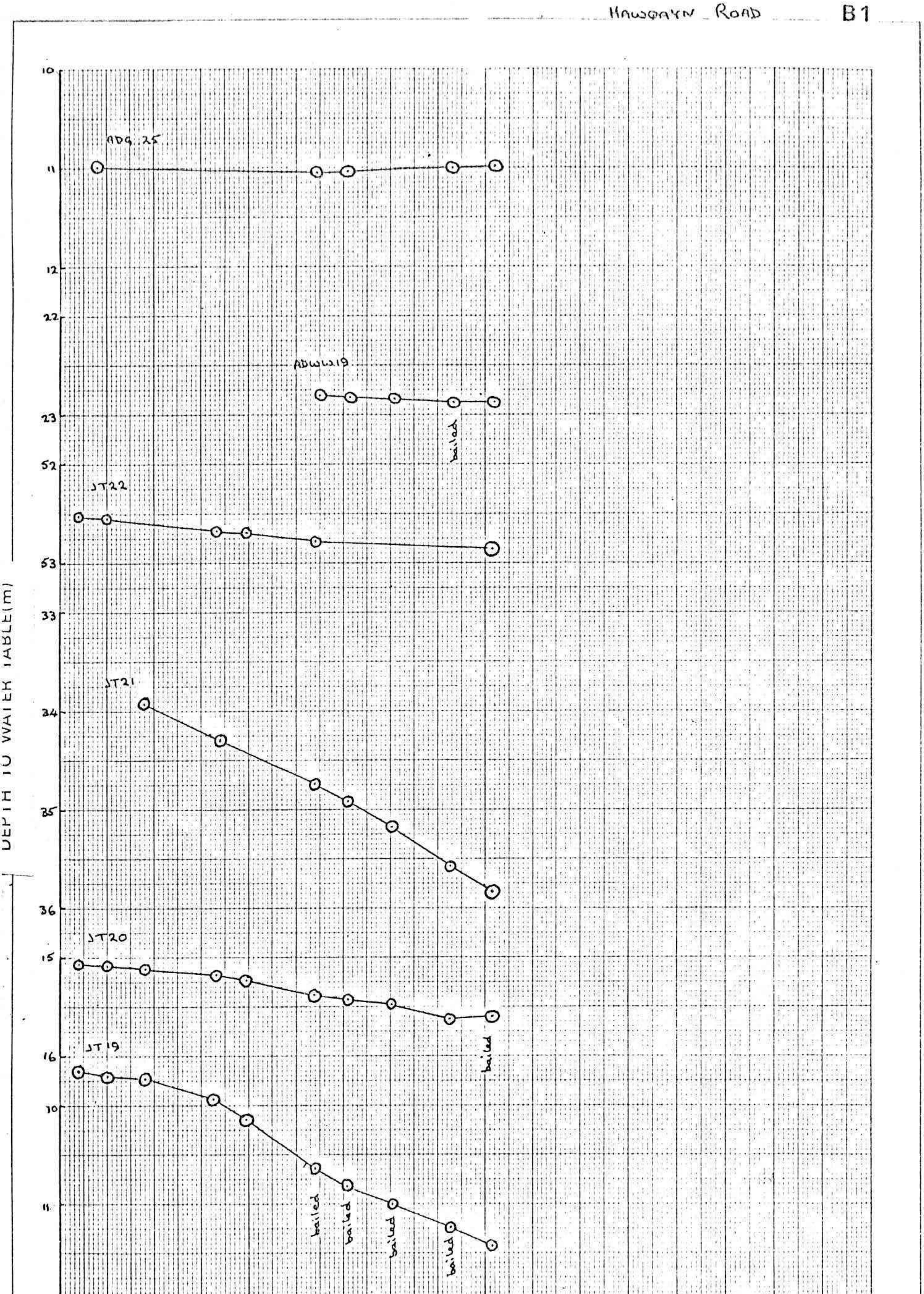
Groundwater conductivity in µmhos at 25°C ——— — —

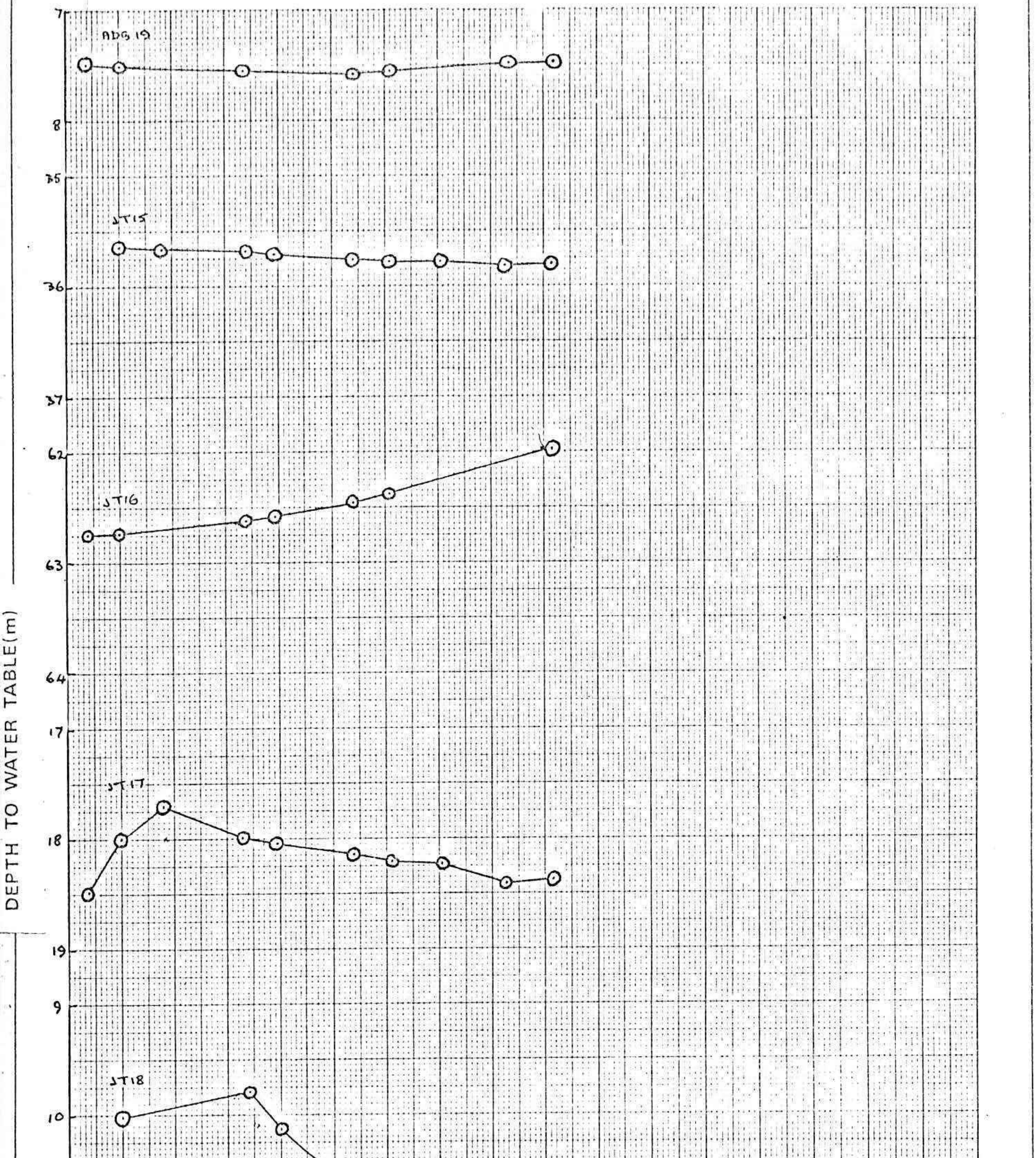
APPENDIX B

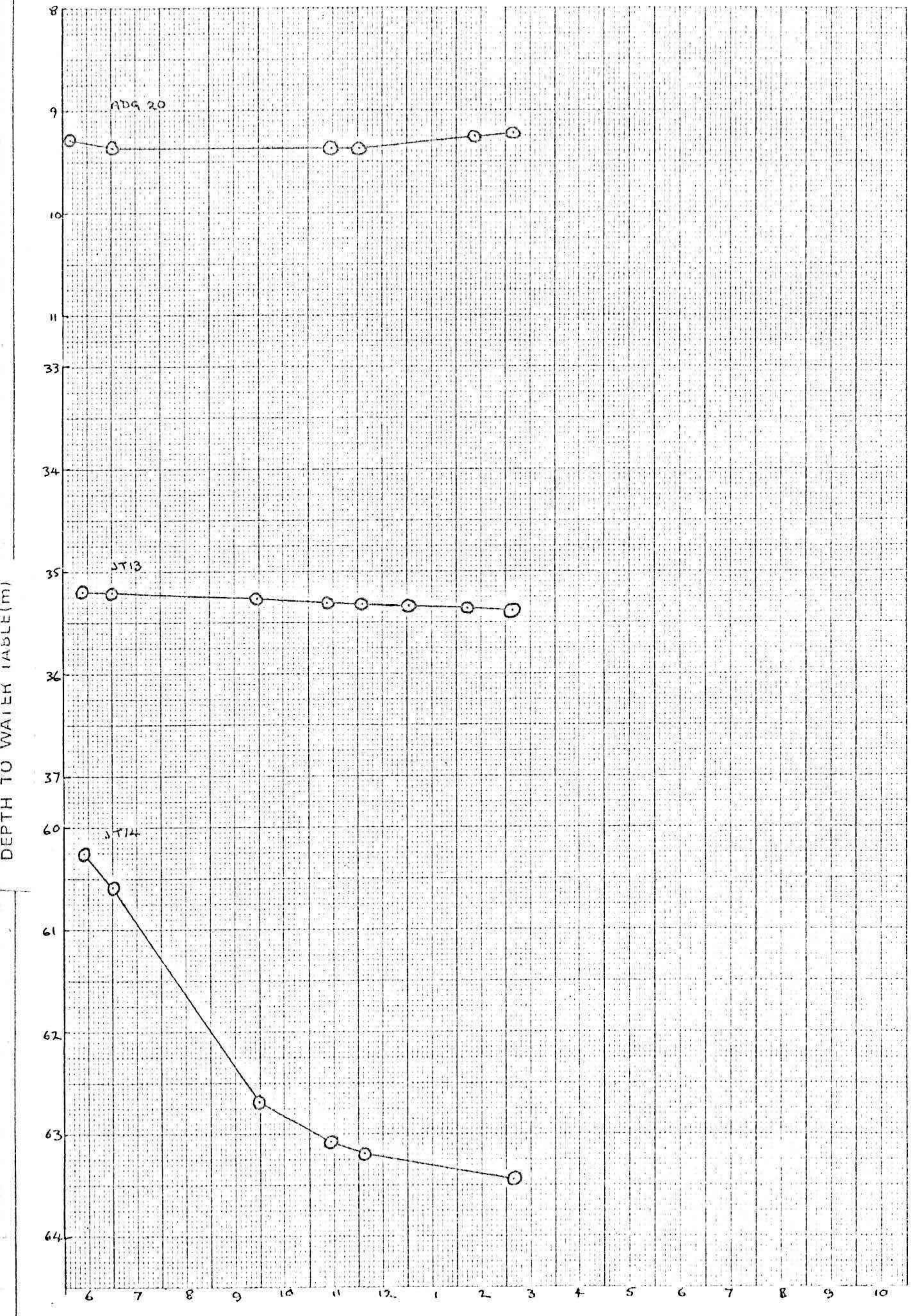
FIGURES B1 - B18

GROUNDWATER HYDROGRAPHS FROM THE WELL NETWORK

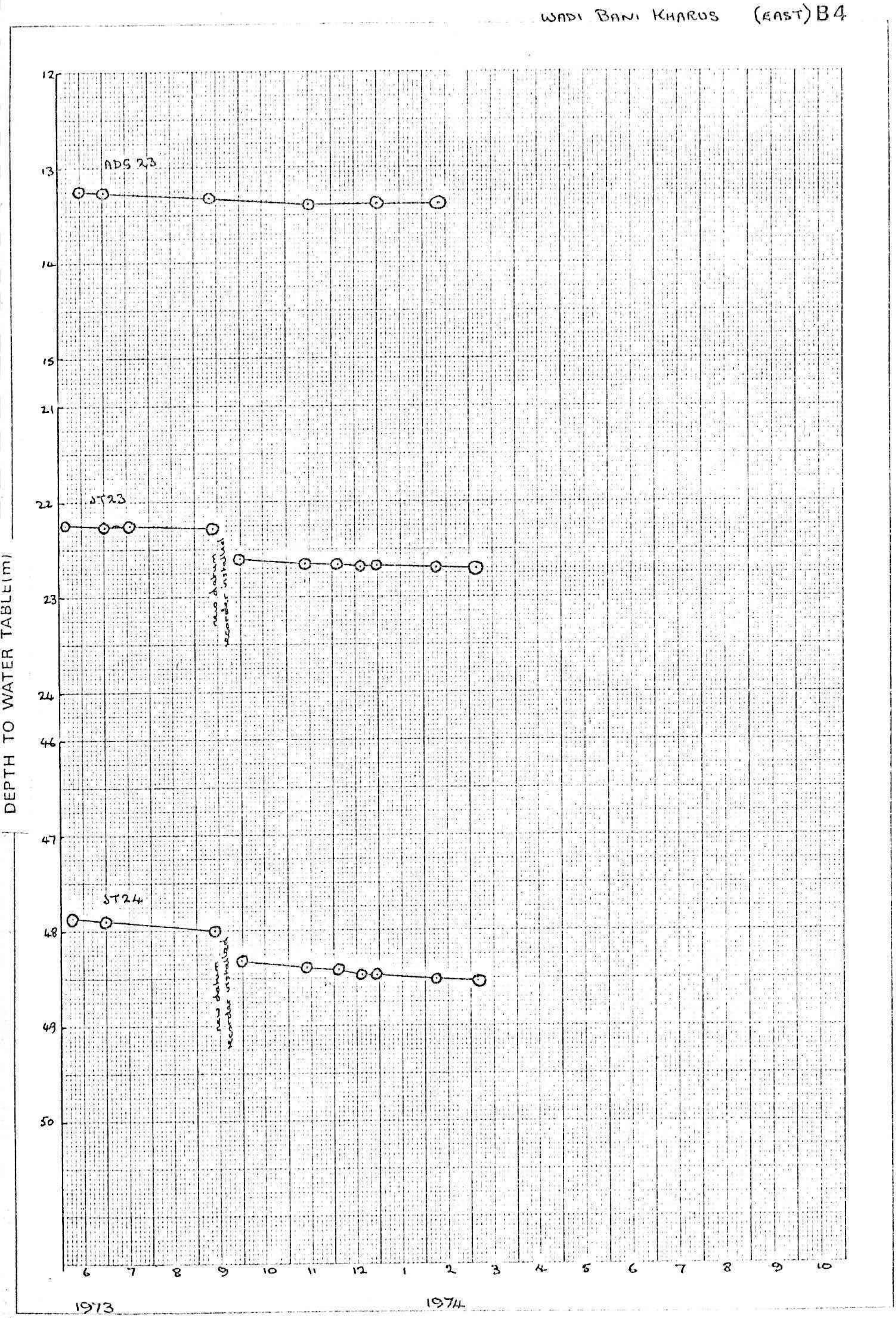
HAWQAYN ROAD B1



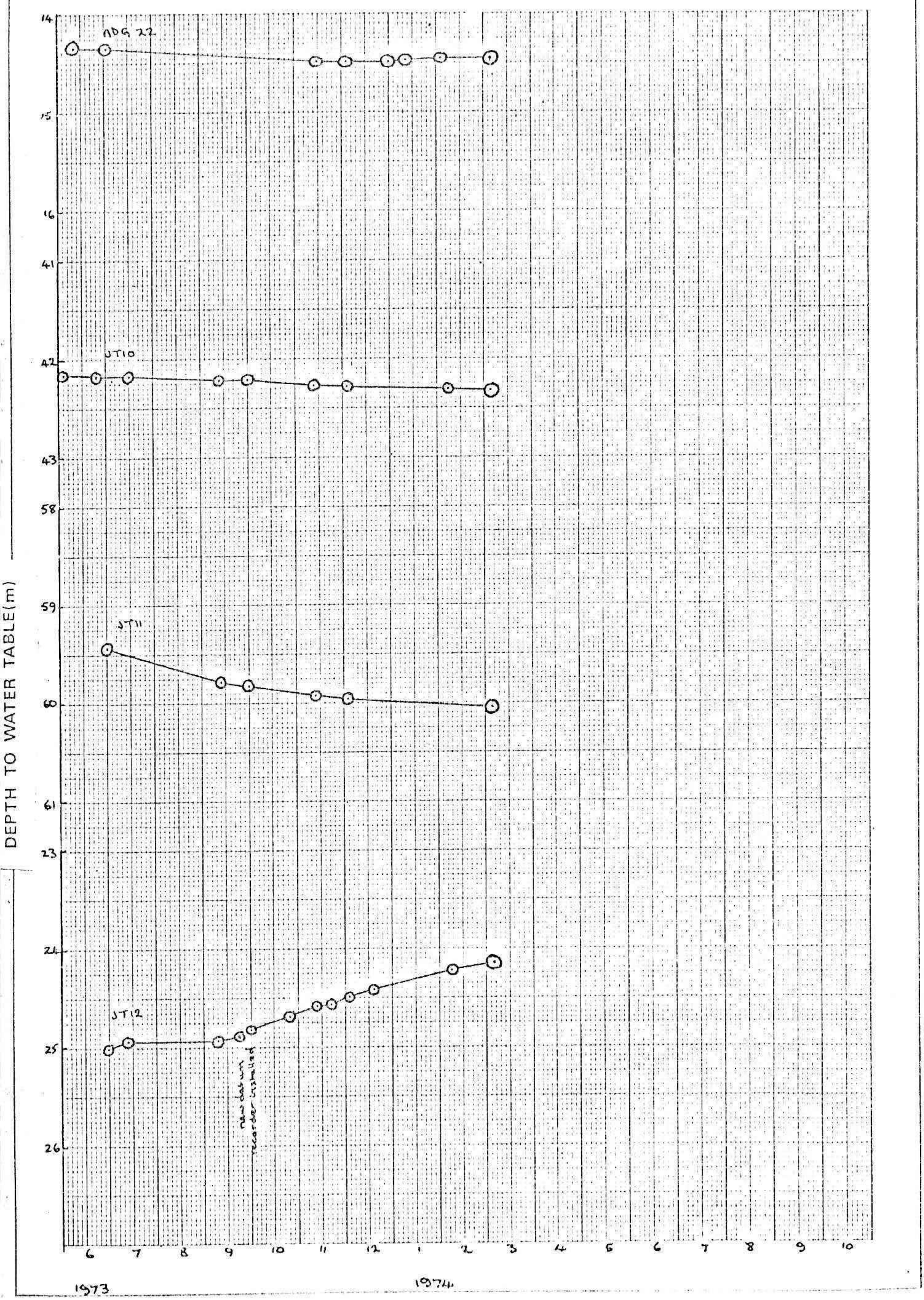

ADG 19
JT15
JT16
JT17
JT18
DEPTH TO WATER TABLE(m)
7
8
35
36
37
62
63
64
17
18
19
9
10
11
12
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974

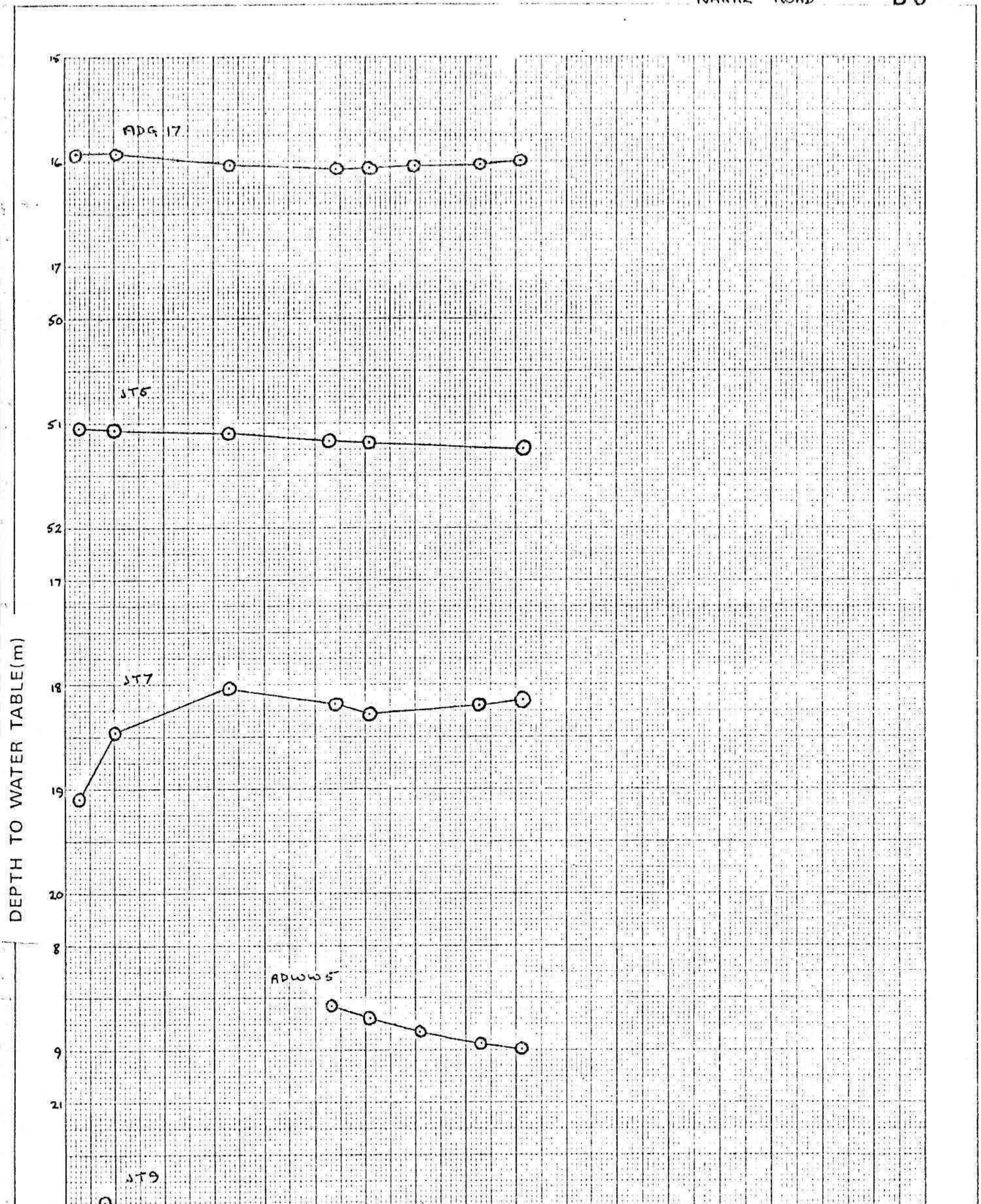


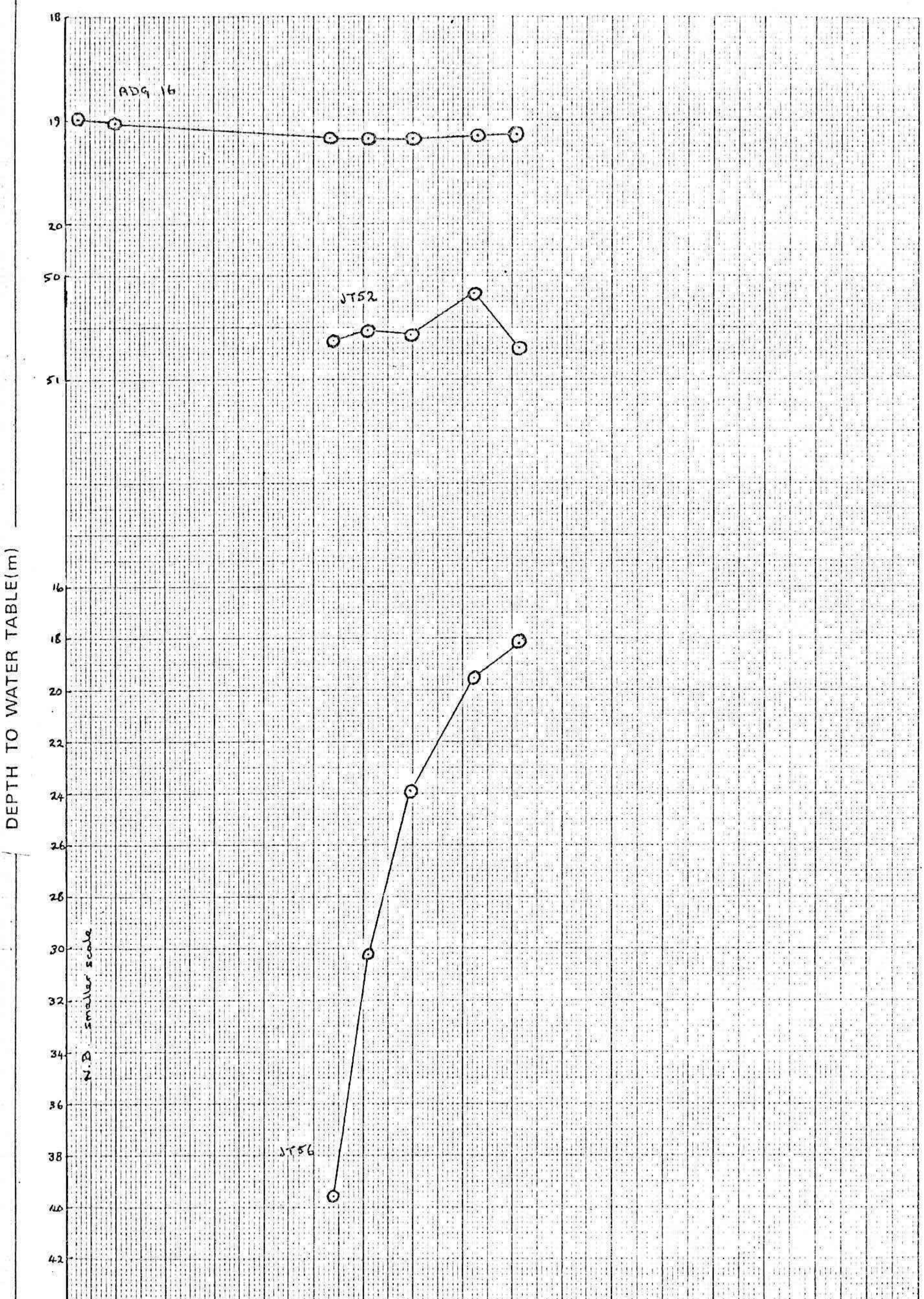
DEPTH TO WATER TABLE (m)
ADG 20
JT13
JT14
8
9
10
11
33
34
35
36
37
60
61
62
63
64
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974

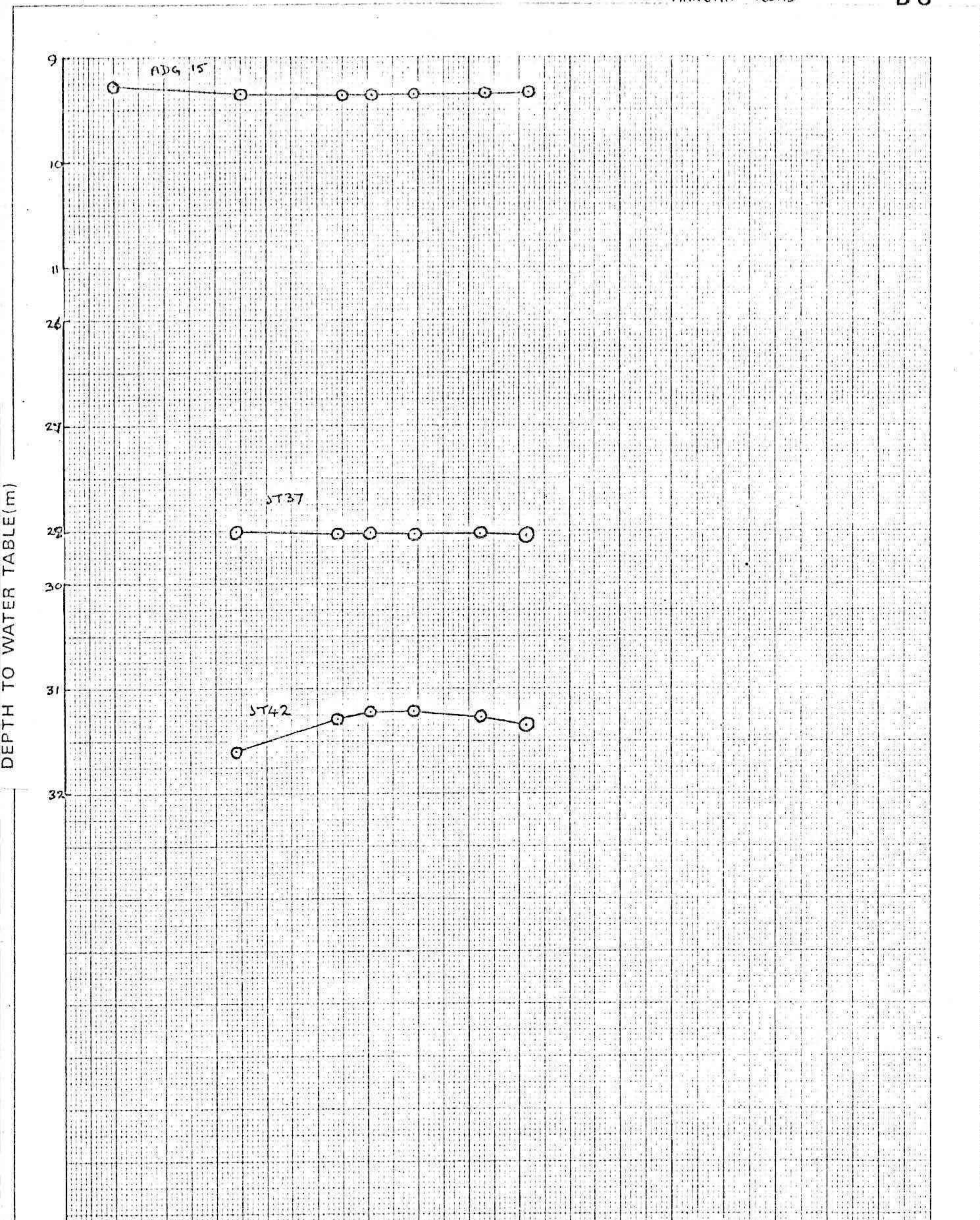


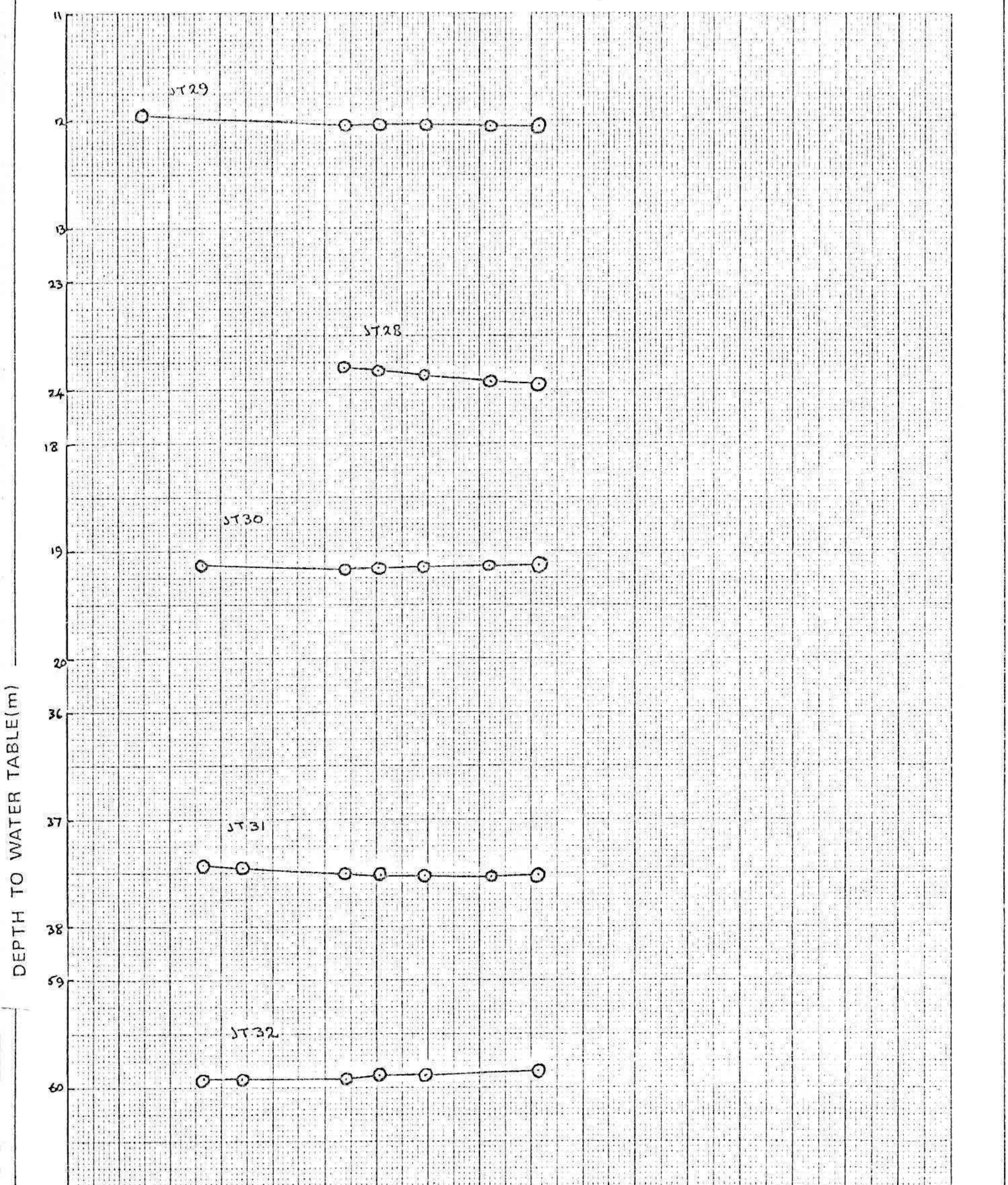
WADI BANI KHARUS (EAST) B4
DEPTH TO WATER TABLE (m)
ADS 23
ST23
ST24
new datum recorder installed
new datum recorder installed
12
13
14
15
21
22
23
24
46
47
48
49
50
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
1973
1974

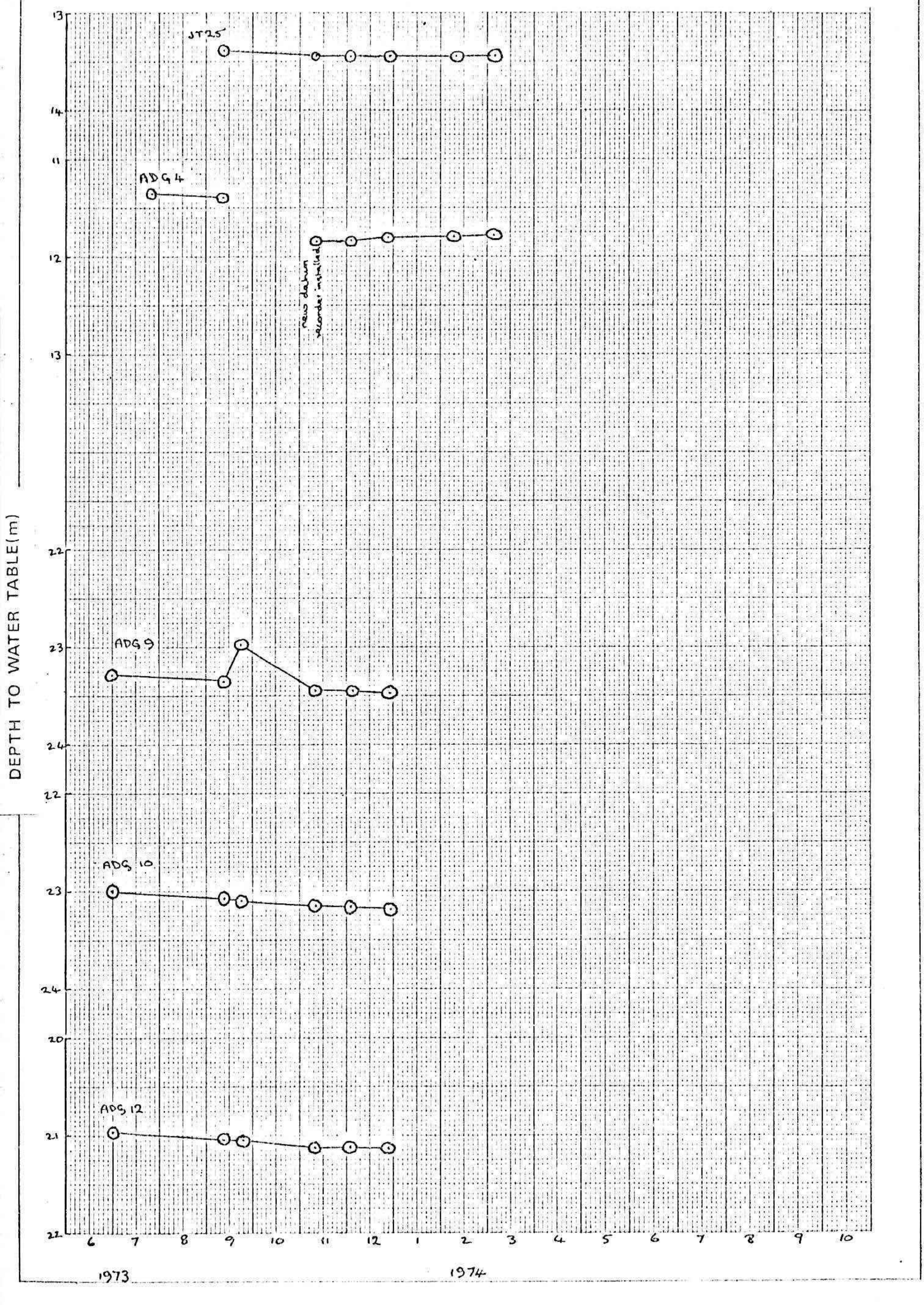

ADG 22
JT10
JT11
JT12
new datum recorder installed
DEPTH TO WATER TABLE (m)
14
15
16
41
42
43
58
59
60
61
23
24
25
26
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
1973
1974

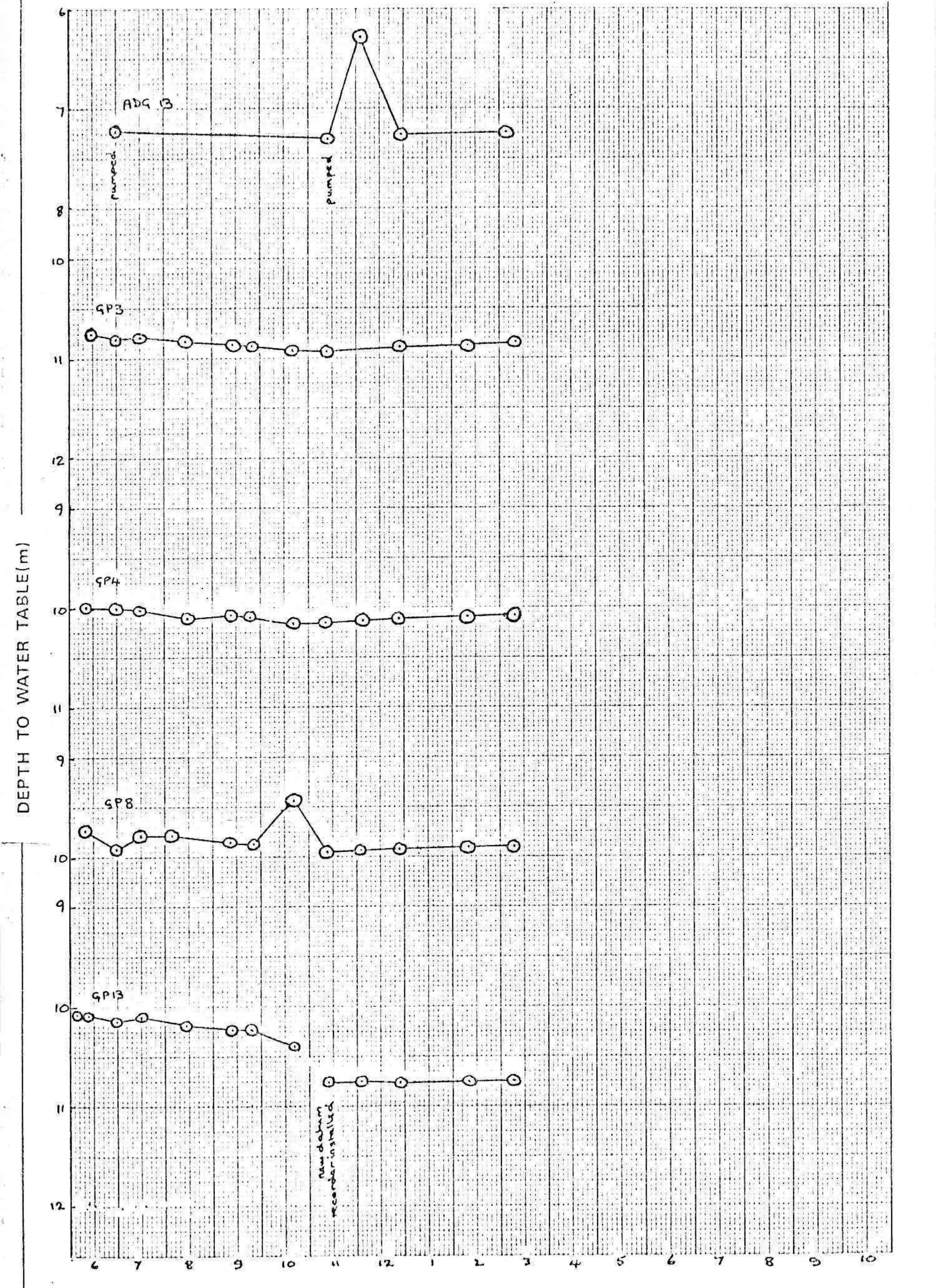

DEPTH TO WATER TABLE (m)
ADG 17
JT5
JT7
ADWW5
JT9
new datum recorder installed
15
16
17
50
51
52
17
18
19
20
8
9
21
22
23
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
1973
1974

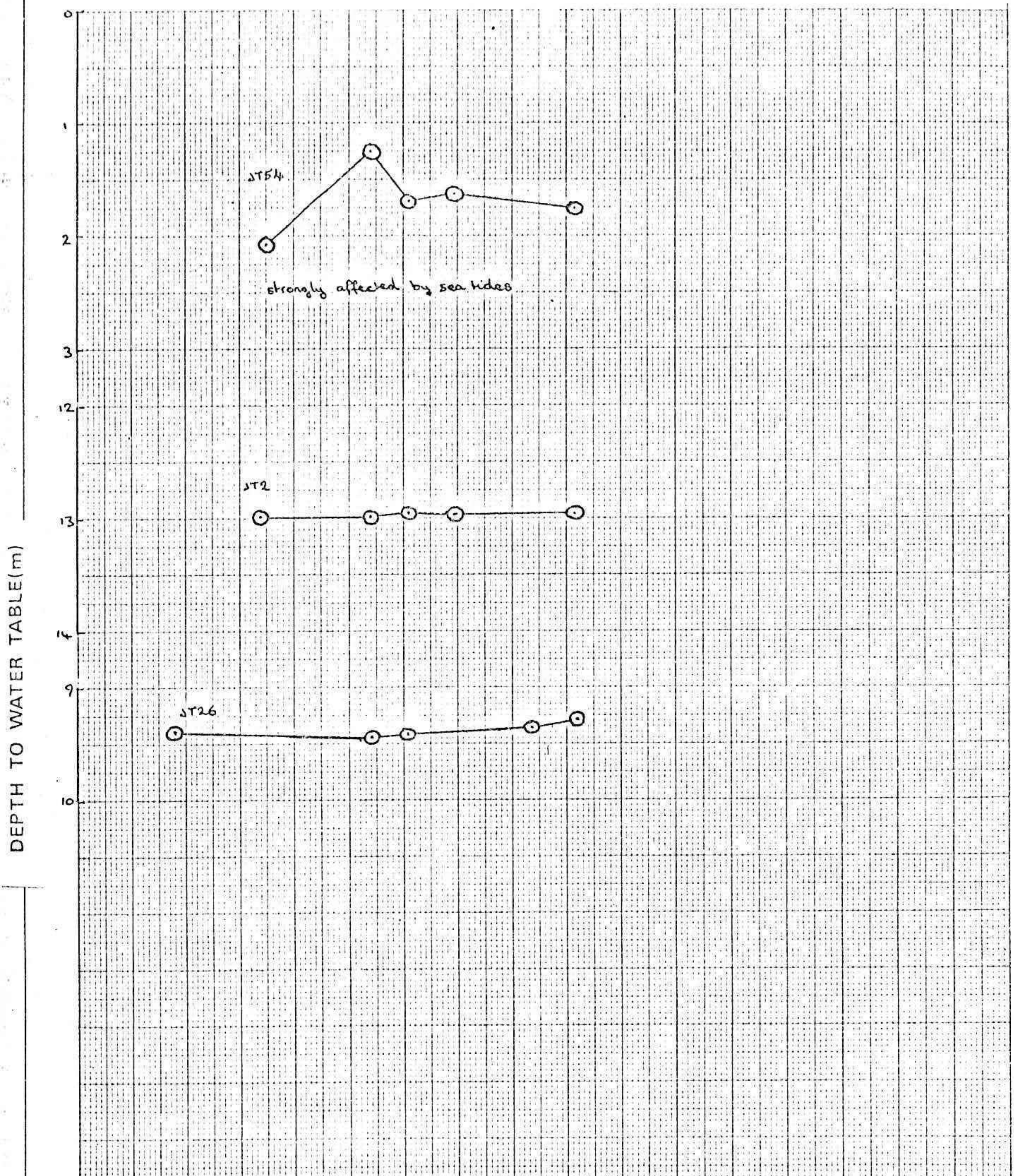

ADG 16
JT52
JT56
DEPTH TO WATER TABLE (m)
N.B. smaller scale
18
19
20
50
51
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
1973
1974


ADG 15
JT37
JT42
DEPTH TO WATER TABLE (m)
9
10
11
26
27
28
30
31
32
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
1973
1974


DEPTH TO WATER TABLE(m)
JT29
JT28
JT30
JT31
JT32
JT39
11
12
13
23
24
18
19
20
36
37
38
59
60
61
1
2
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974

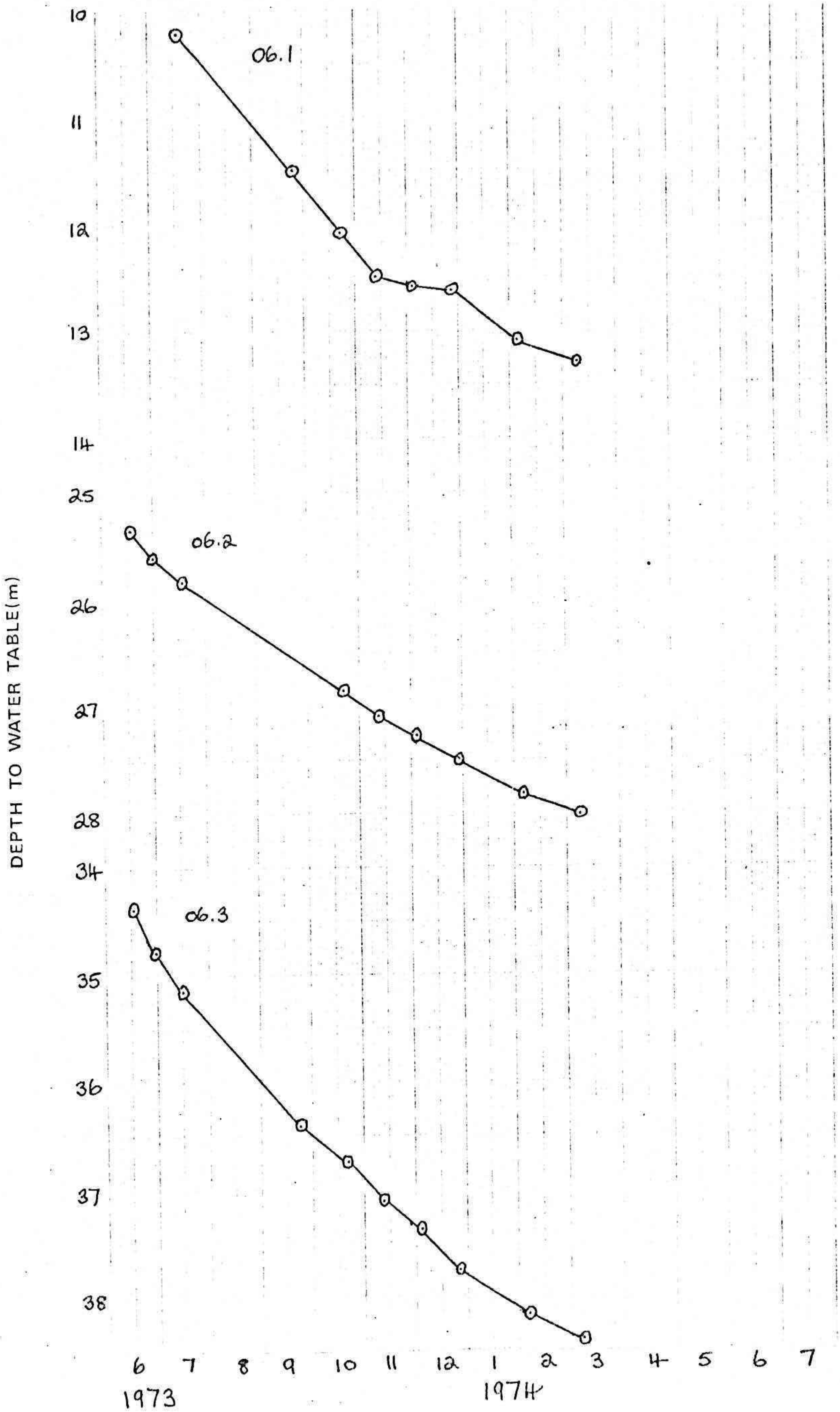

DEPTH TO WATER TABLE (m)
JT25
ADG 4
new datum recorder installed
ADG 9
ADG 10
ADG 12
13
14
11
12
13
22
23
24
22
23
24
20
21
22
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974

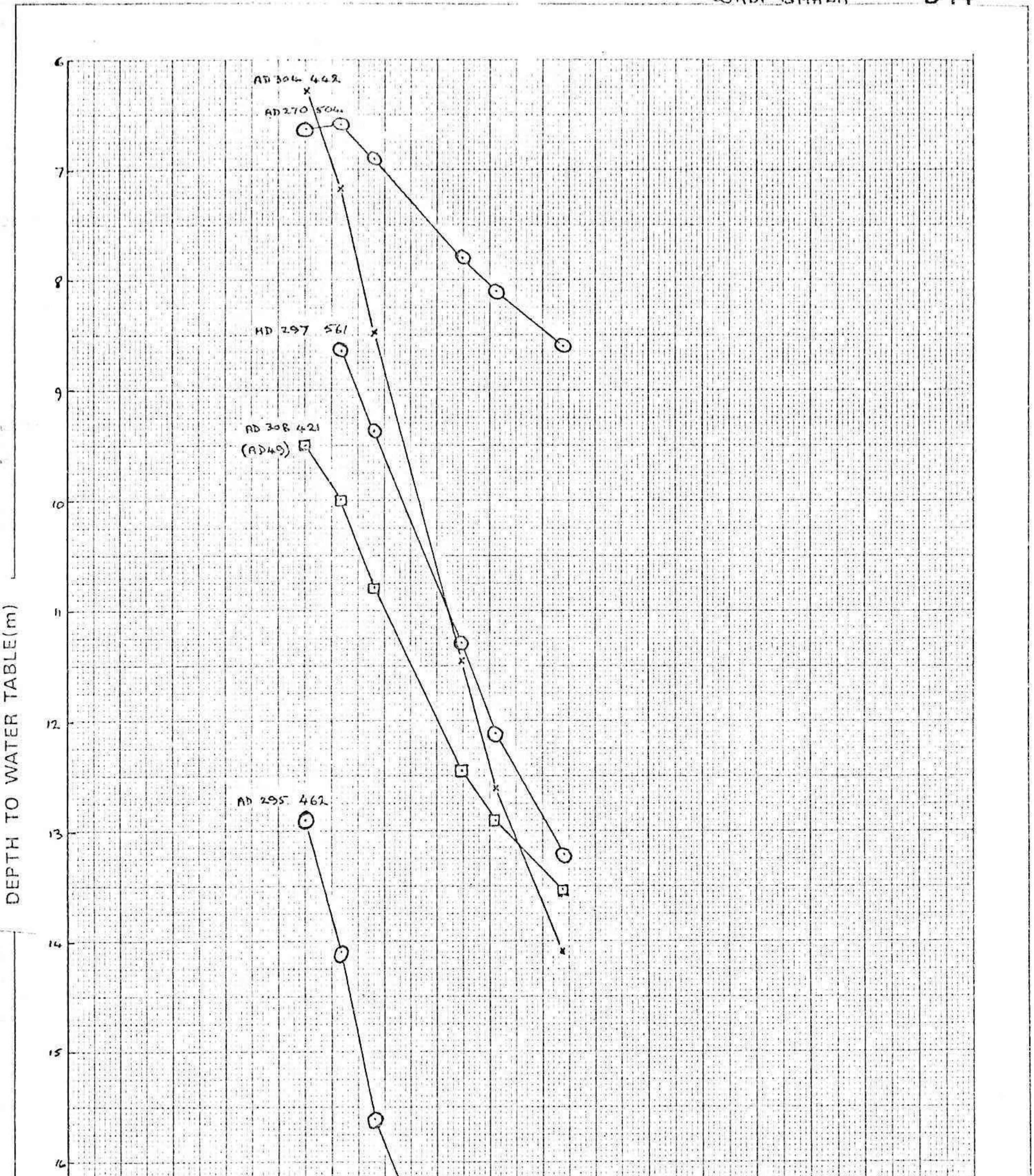

DEPTH TO WATER TABLE(m)
ADG 13
pumped
pumped
GP3
GP4
GP8
GP13
new datum recorder installed
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974



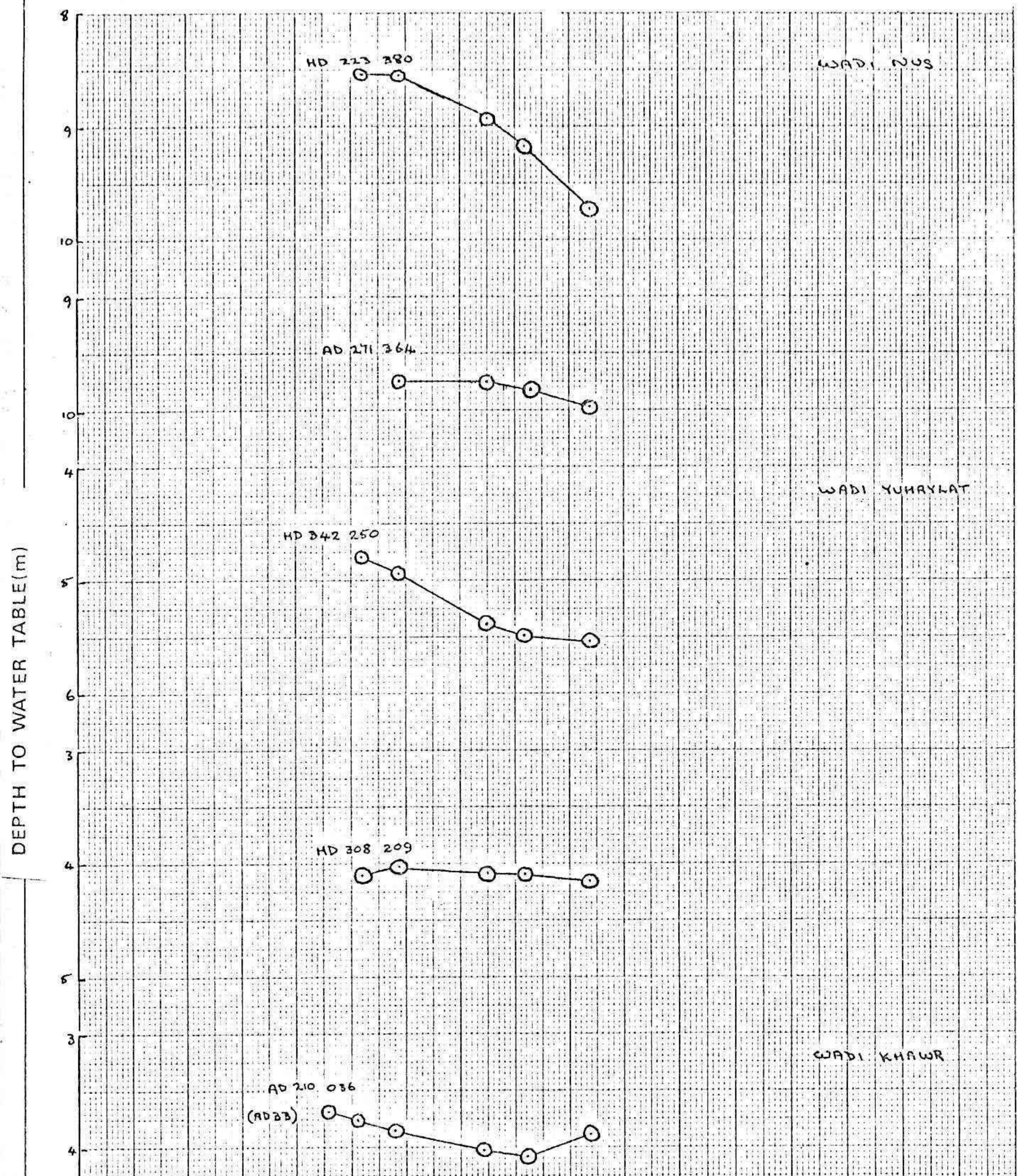
DEPTH TO WATER TABLE(m)
0
1
2
3
12
13
14
9
10
JT54
strongly affected by sea tides
JT2
JT26
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
1973
1974

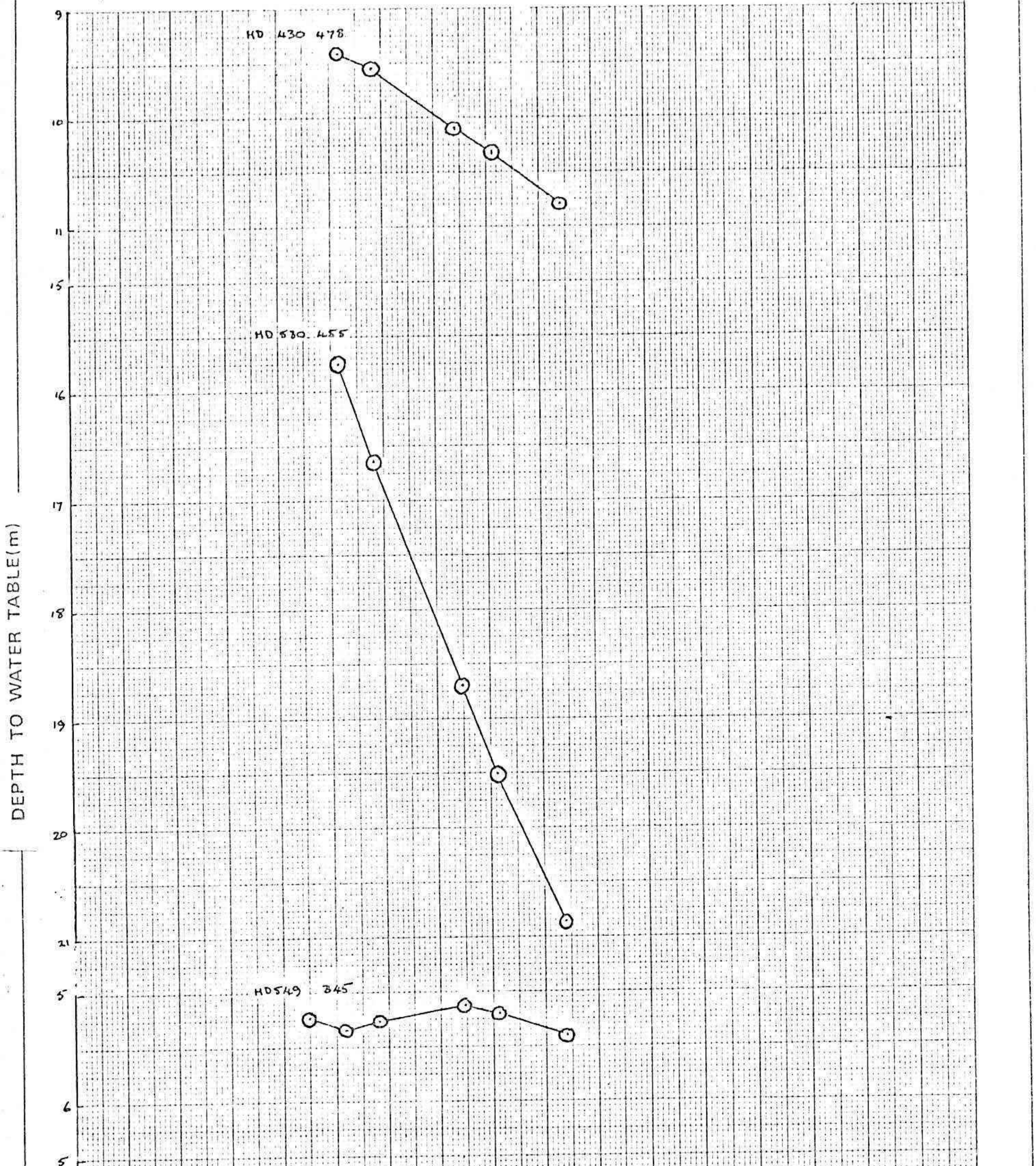
WELL HYDROGRAPHS P.D.O. OBSERVATION WELLS

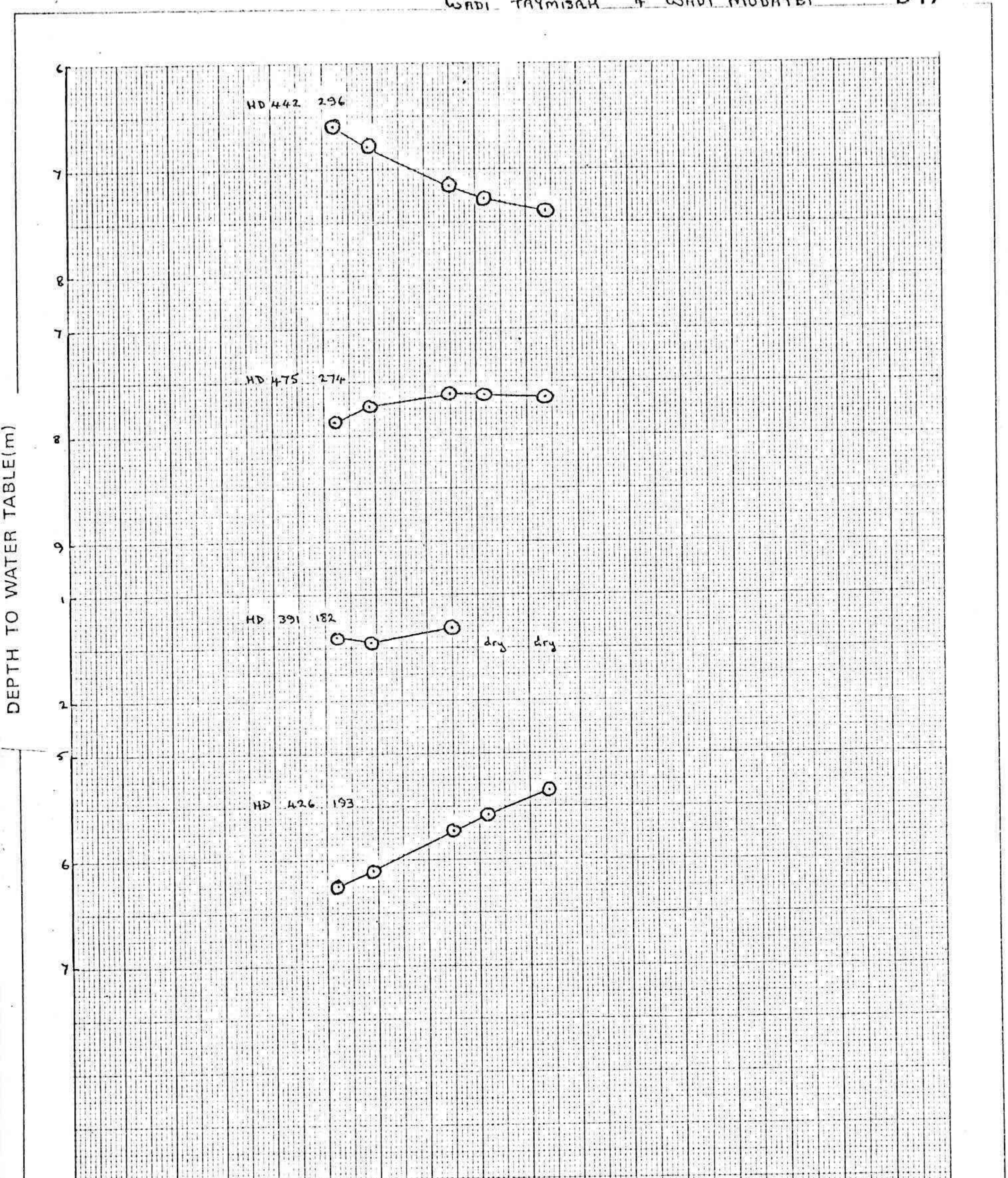


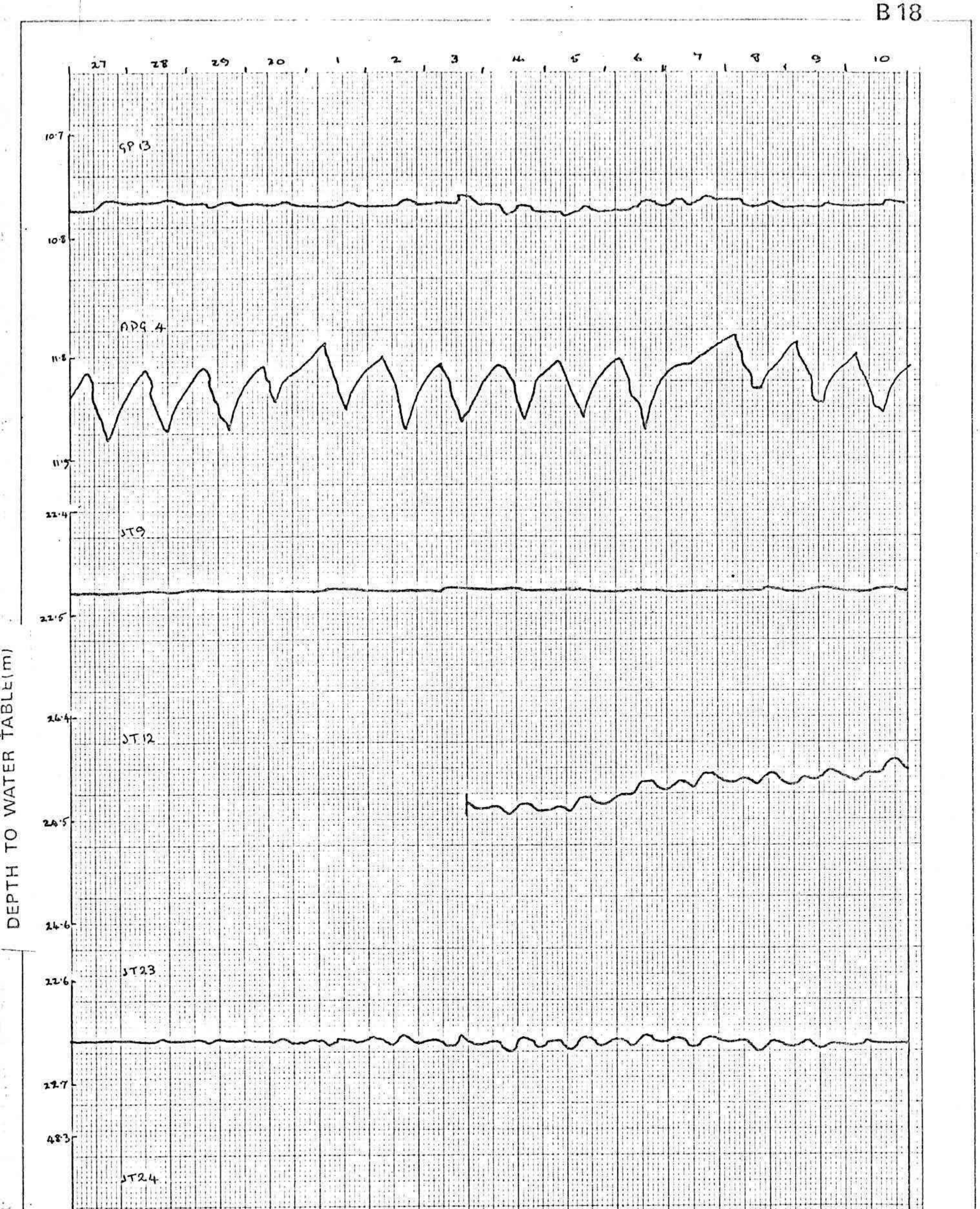


AD 304 442
AD 270 504
AD 297 561
AD 308 421
(AD49)
AD 295 462
DEPTH TO WATER TABLE (m)
6
7
8
9
10
11
12
13
14
15
16
17
18
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974


DEPTH TO WATER TABLE (m)
HD 223 380
WADI NUS
AD 271 364
WADI YUHAYLAT
HD 342 250
HD 308 209
WADI KHAWR
AD 210 036
(AD 33)
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974


HD 430 478
HD 580 455
HD549 345
AD 43
DEPTH TO WATER TABLE(m)
1973
1974


WADI TAYMIBAH + WADI MUDAYBI
DEPTH TO WATER TABLE(m)
HD 442 296
HD 475 274
HD 391 182
dry
dry
HD 426 193
6
7
8
7
8
9
1
2
5
6
7
6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10
1973
1974



27 28 29 30 1 2 3 4 5 6 7 8 9 10
DEPTH TO WATER TABLE (m)
GP13
10·7
10·8
APG 4
11·8
11·9
JT9
22·4
22·5
JT12
24·4
24·5
24·6
JT23
22·6
22·7
JT24
48·3
48·4
48·5
NOVEMBER
1973
DECEMBER

APPENDIX C

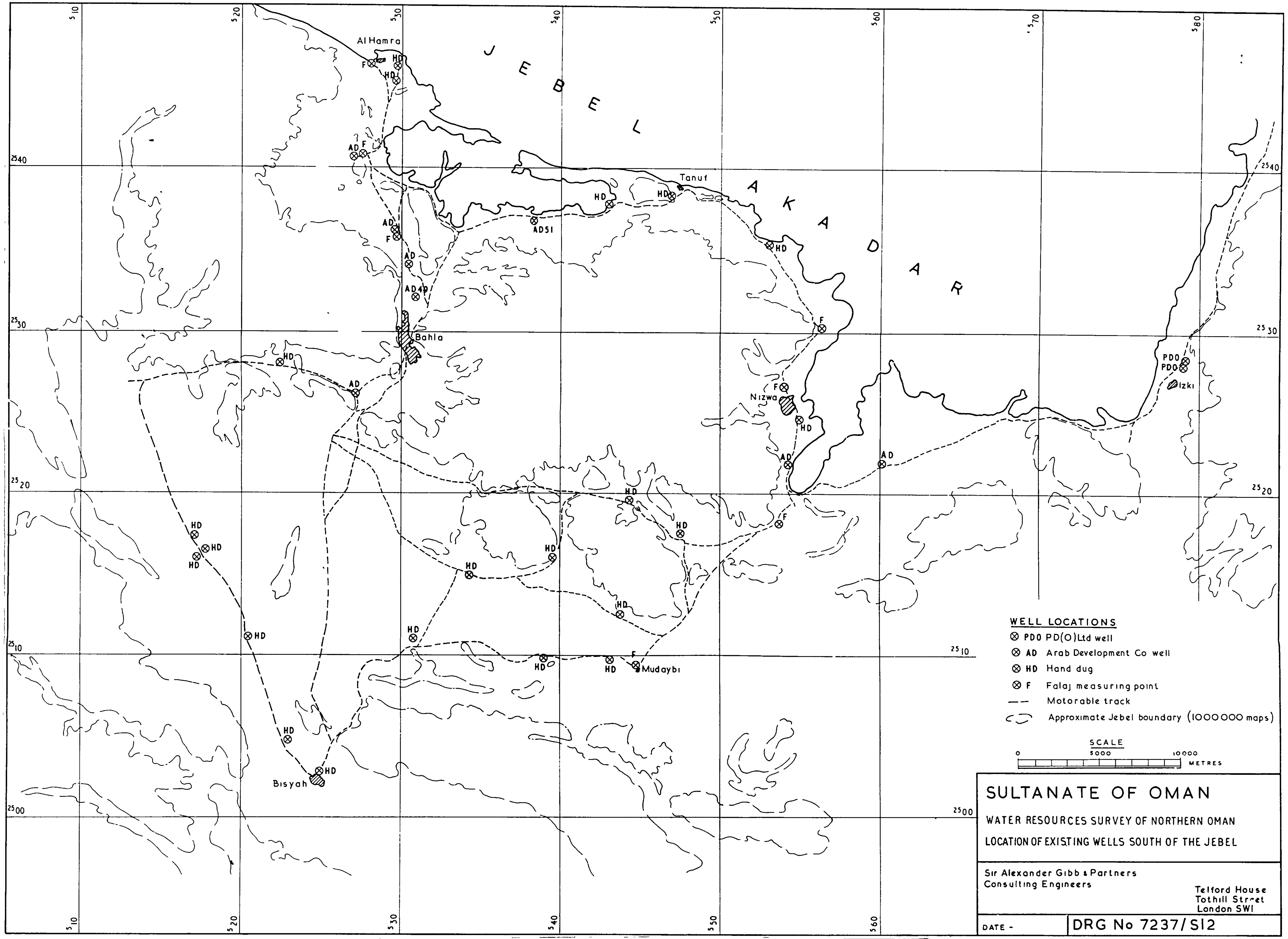
RECORDS OF WELL DATA

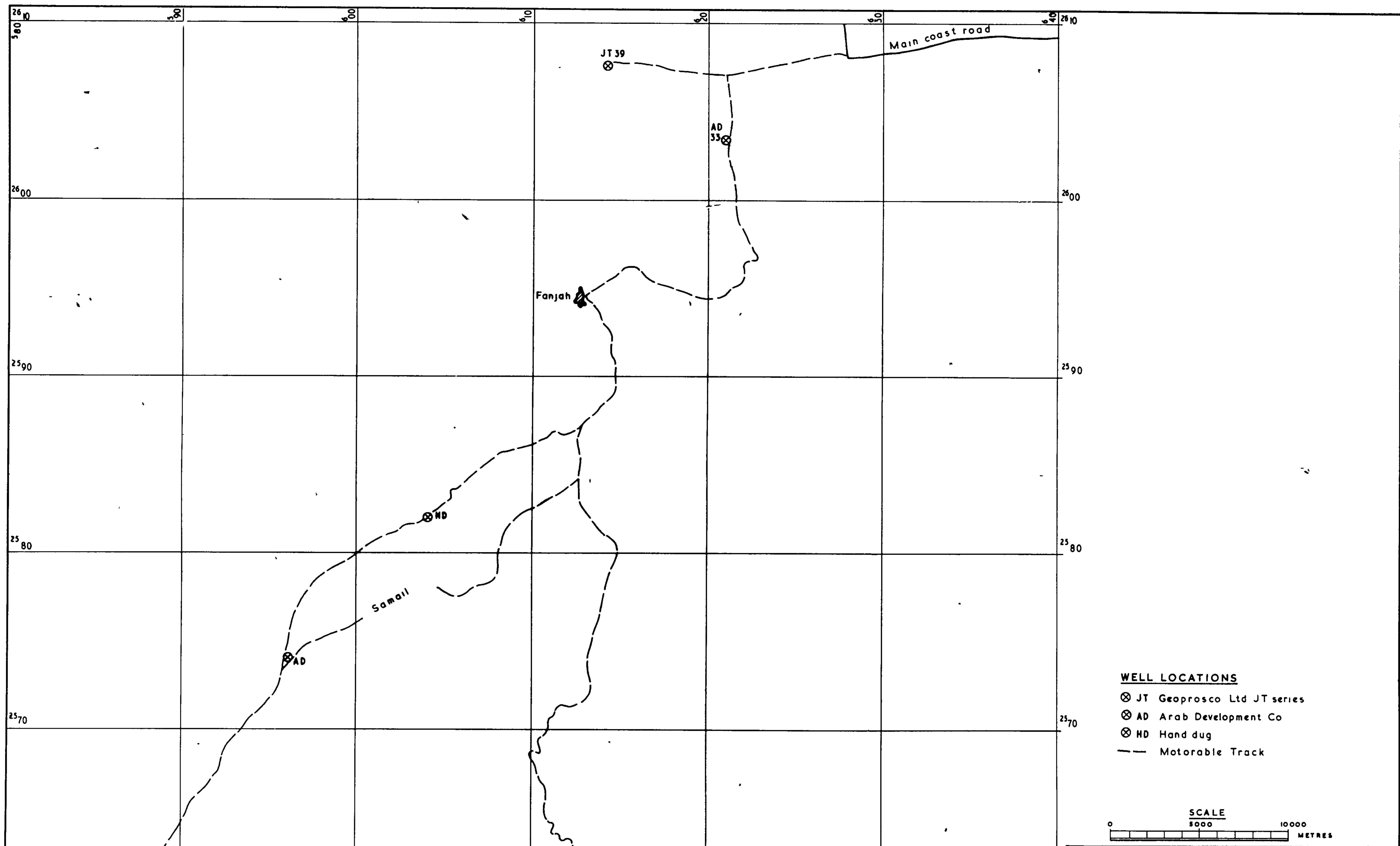
See separate volume

APPENDIX D

WATER ANALYSIS RECORD SHEETS

See separate volume


JEBEL AKADAR
Al Hamra
Tanuf
Bahla
Nizwa
Izki
Bisyah
Mudaybi
AD51
AD40
WELL LOCATIONS
⊗ PDO PD(O)Ltd well
⊗ AD Arab Development Co well
⊗ HD Hand dug
⊗ F Falaj measuring point
Motorable track
Approximate Jebel boundary (1000 000 maps)
SCALE
0 5000 10000 METRES
SULTANATE OF OMAN
WATER RESOURCES SURVEY OF NORTHERN OMAN
LOCATION OF EXISTING WELLS SOUTH OF THE JEBEL
Sir Alexander Gibb & Partners
Consulting Engineers
Telford House
Tothill Street
London SW1
DATE -
DRG No 7237/S12



SULTANATE OF OMAN

WATER RESOURCES SURVEY OF NORTHERN OMAN

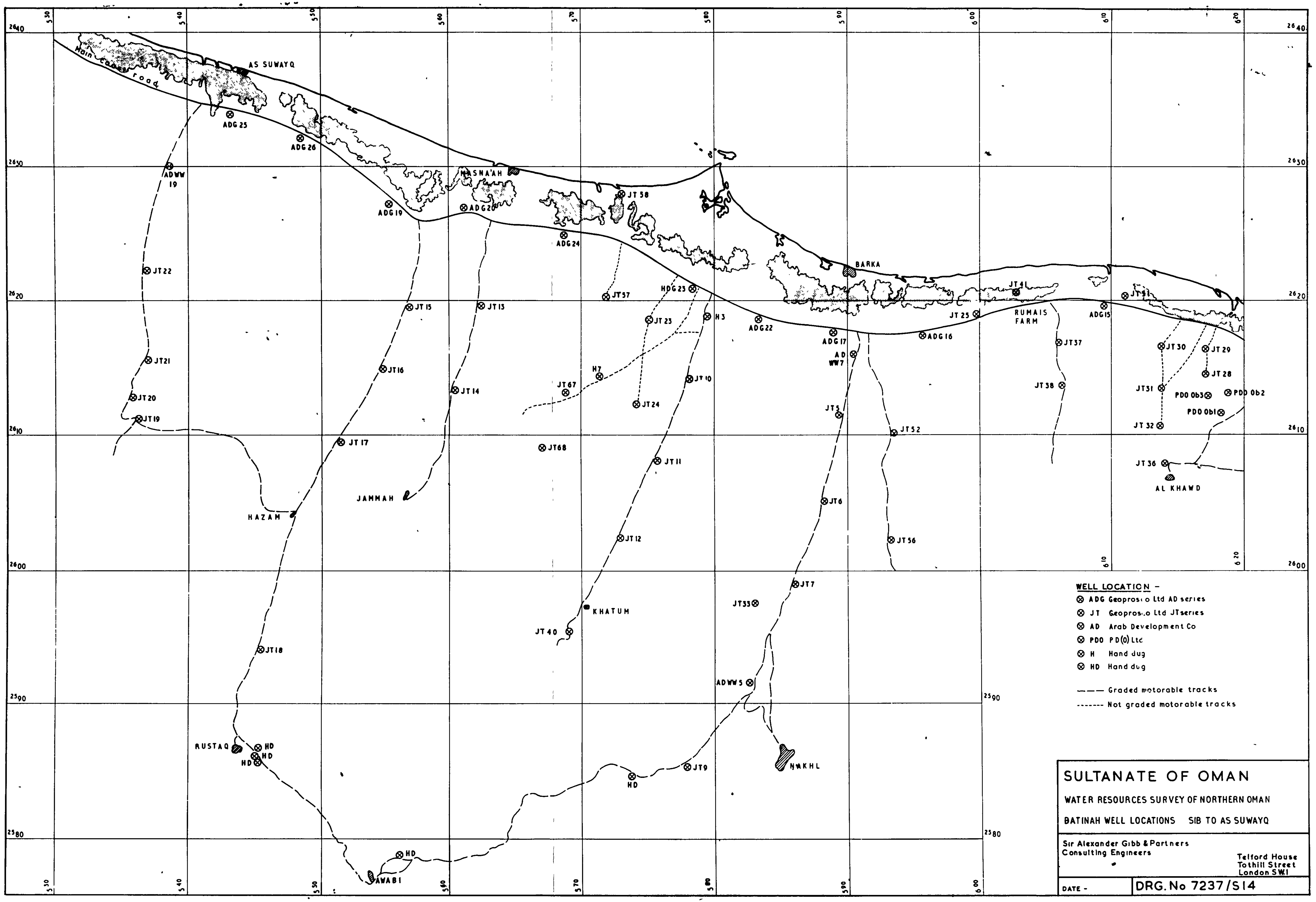
WELL LOCATIONS IN THE WADI SAMAIL

Sir Alexander Gibb & Partners
Consulting Engineers

Telford House
Tothill Street
London SW1

DATE -

DRG. No. 7237/S13



SULTANATE OF OMAN

WATER RESOURCES SURVEY OF NORTHERN OMAN

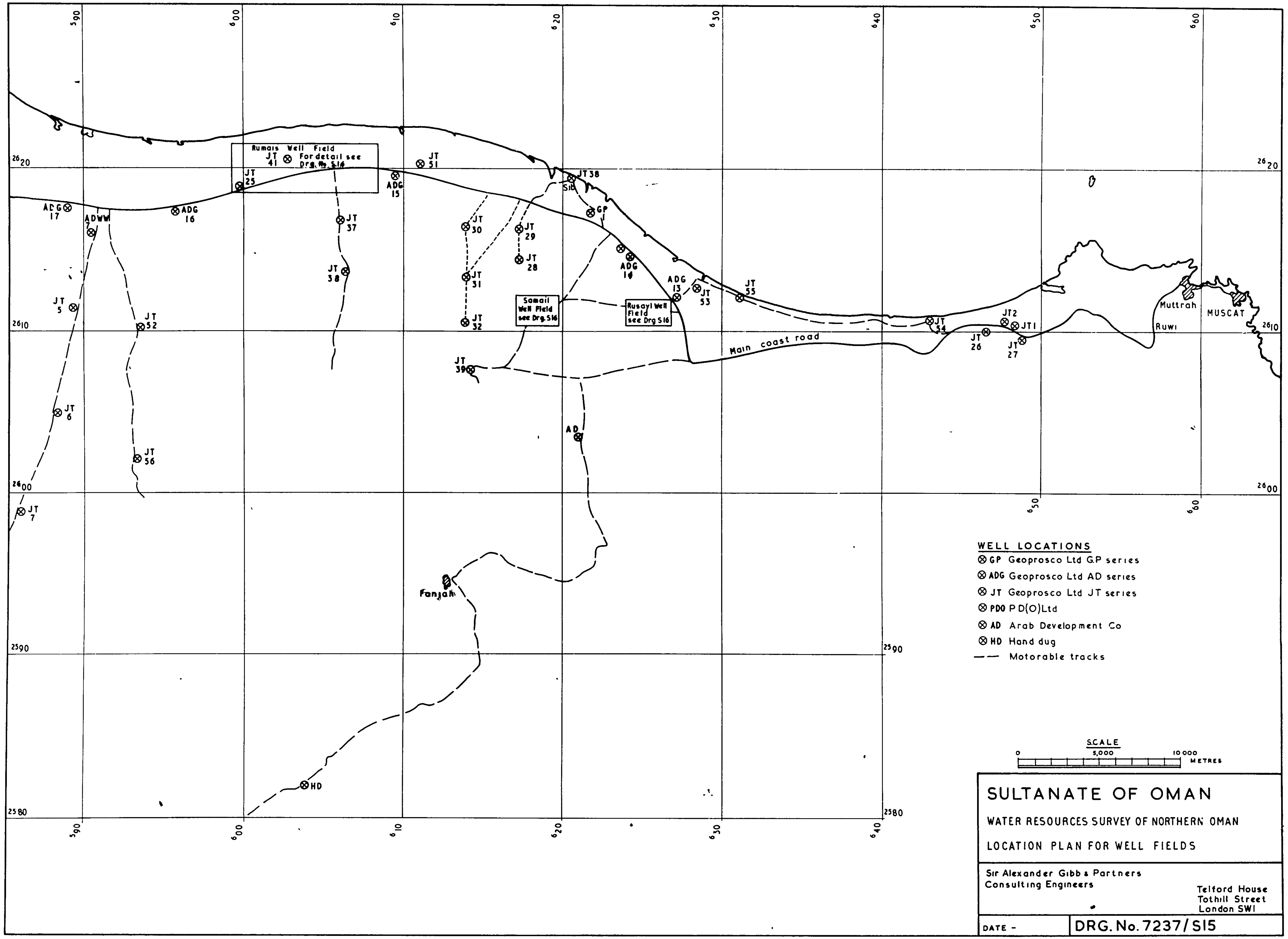
BATINAH WELL LOCATIONS SIB TO AS SUWAYQ

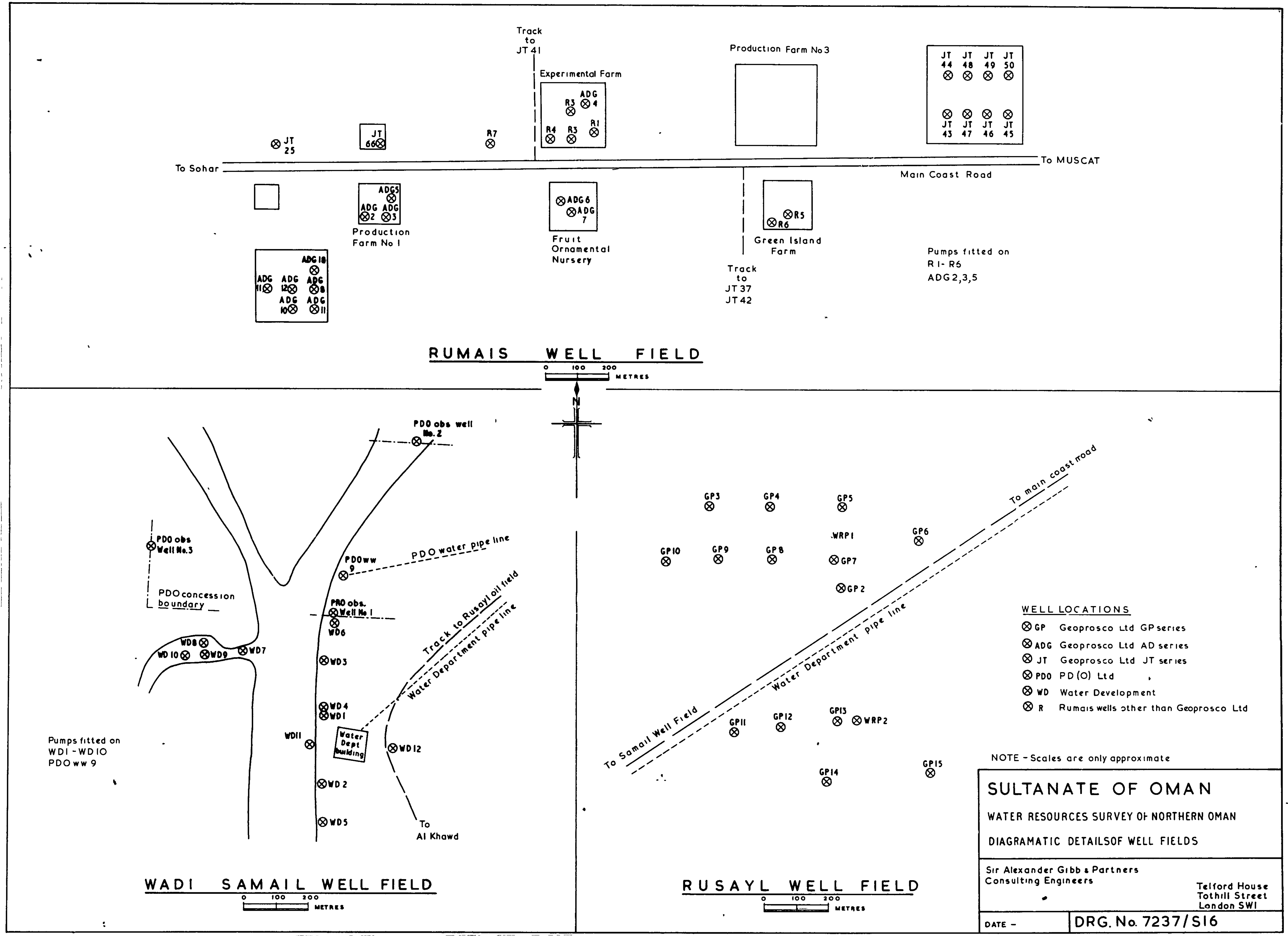
Sir Alexander Gibb & Partners
Consulting Engineers

Telford House
Tothill Street
London SW1

DATE -

DRG. No 7237/S14


Rumais Well Field
For detail see Drg. No. S16
Samail Well Field see Drg. S16
Rusayl Well Field see Drg S16
Main coast road
Sib
Fanjah
Muttrah
MUSCAT
Ruwi
WELL LOCATIONS
GP Geoprosco Ltd GP series
ADG Geoprosco Ltd AD series
JT Geoprosco Ltd JT series
PDO P D(O)Ltd
AD Arab Development Co
HD Hand dug
Motorable tracks
SCALE
0 5,000 10 000 METRES
SULTANATE OF OMAN
WATER RESOURCES SURVEY OF NORTHERN OMAN
LOCATION PLAN FOR WELL FIELDS
Sir Alexander Gibb & Partners
Consulting Engineers
Telford House
Tothill Street
London SW1
DATE -
DRG. No. 7237/S15



SULTANATE OF OMAN

WATER RESOURCES SURVEY OF NORTHERN OMAN

DIAGRAMATIC DETAILS OF WELL FIELDS

Sir Alexander Gibb & Partners
Consulting Engineers

Telford House
Tothill Street
London SW1

DRG. No. 7237/S16