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Sinai Water Resources Study.

Arish-Rafah Groundwater Management Study

Supplementary Report on Recommendations
for Further Investigations (Phase B)

Institute of Hydrology
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Contents

List of tables

List of figures

SINAI WATER RESOURCES STUDY ARISH-RAFAH GROUNDWATER MANAGEMENT STUDY

Supplementary Report on Recommendations for Further Investigations (Phase B)

1. Background

1.1 GENERAL

Groundwater abstraction has increased significantly in the coastal area of northeast Sinai between Arish and Rafah, particularly over the past decade. However, this development has taken place without adequate planning or sufficient knowledge on the groundwater resources available.

The demand for groundwater is continuing to increase and abstraction has spread into new areas in both the Arish and Rafah areas over the past ten years. However, the groundwater quality in the Quaternary aquifer at Arish is reported to be deteriorating and there is now growing concern as to whether the aquifer can continue to support even the present level of abstraction. Recently, Nile water has begun to be imported by pipeline to serve a new urban development in the western part of Arish.

A monitoring network has not yet been established to determine the effects of current levels of abstraction, whether a redistribution of abstraction would be desirable, or whether further development of the aquifer system would be possible.

Several groundwater studies have been carried out in the area since the early 1950's but have drawn varying conclusions as to the resources available for development. In view of the concern regarding abstraction in the Arish area in particular, we recommended that a groundwater management study should be undertaken as a matter of some urgency to plan future abstraction in the area and to thereby assist development plans for this region. This was extended subsequently to include the Sheikh Zuwayid-Rafah area to the east of Arish.

The consulting services of the Faculty of Engineering of Cairo University were appointed by RIWR in November 1987 to assist with a groundwater management study of the Arish-Rafah area, with particular emphasis on the Quaternary aquifer at El Arish, as part of the Sinai Water Resources Project, which is supported by EEC funding. The study comprises three phases:

Phase A. The assembly, review and analysis of existing information and preparation of a new inventory of water points. The information would be used to describe the present situation and make recommendations for further data collection.

- Phase B. Collection of new data from further field investigations and establish a monitoring network.

Phase C. Analysis of the new information to develop a numerical model, if possible, which would be used to assess the availability of groundwater and to examine alternative abstraction strategies.

An Interim Report on Phase A was submitted by Cairo University in March 1988. This presented the information available from previous studies and included a well inventory. Four pumping tests were also undertaken in January 1988, together with several infiltration tests in the dune areas. Unfortunately, the well head levelling survey had to be repeated and some difficulty was encountered with obtaining data from the privately owned wells.

A mission by staff from the Institute of Hydrology (IH), a component organisation the UK Natural Environment Research Council (NERC), was undertaken to Egypt on behalf of the European Economic Community (EEC) from 18 September to 10 October 1988. The terms of reference of this mission included an assessment of the conclusions and recommendations of the Arish-Rafah Groundwater Management Study.

However, due to the delays in completing the well surveys, the University team had not been able to complete their preliminary evaluation of the information nor been able to draw any firm conclusions at the time of the mission. However, it was decided, with the agreement of the EEC Delegation in Cairo, that the mission should attempt if possible to draw some preliminary, independant conclusions which could then be compared to those made by the University team. These were included in the mission report presented in November 1988. A more detailed review of the conclusions and recommendations from Phase A would be postponed until the final report on Phase A became available.

The Final Report on the first phase of the Arish-Rafah Groundwater Management Study by RIWR/Cairo University was received on 9 January 1989. This review of the conclusions and recommendations contained in the Final Report is presented as a supplement to the mission report of November 1988.

1.2 OBJECTIVES OF PHASE A

The ultimate objective of the Arish-Rafah groundwater management study is to prepare a strategy for groundwater abstraction in the area. This could involve numerical modelling techniques to predict the aquifer response to various alternative management options. A model also serves to focus the collection of data. Information would be required on:

(a) the physical aspects of the system to prepare a conceptual model from which an appropriate model could be designed and to prepare input data for the model

(b) time-varying changes to calibrate the model.

Water quality considerations, which are an essential aspect of the management of this aquifer system, are more difficult to include in a model and would perhaps have to be inferred from predicted head changes.

The main objective of Phase A of the study was to assemble the available hydrogeological and other relevant information and to carry out a preliminary analysis of this information in order to recommend a programme of further data collection to be undertaken during Phase B.

During the mission several meetings were held with the University team and staff from RIWR to discuss the work that had been carried out at that time and a short visit was made to the study area accompanied by the team. We suggested that at least the following aspects would need to be considered during Phase A to establish the programme of work to be undertaken during the subsequent phase of the study:

identification of gaps and weaknesses in the available data

a detailed history of groundwater development in the area, seasonal variations in demand, and the likely future demand or development plans for the region

sources of recharge and their relative contribution together with their variation seasonally and from year to year

- an evaluation of the possible sources of poor quality water and relationships between the changes in water quality with abstraction, recharge and changes in water level

- develop a conceptual model of the aquifer system

- determine the aquifer geometry (extent and thickness) and characteristics and interconnection betwen different parts of the system

- whether modelling studies would be appropriate.

Various recommendations were also made to the University team to assist them in the evaluation and presentation of the information. These included the following:

* a map to show the general availability of groundwater data, using conventional map symbols where possible, so as to highlight areas lacking data and to show where interpretation was based on only limited data

* more detailed information on the likely variation in domestic and agricultural use throughout the year, estimates of consumptive use of groundwater, together with an analysis of the likely future demands and areal distribution for the various requirements.

* more detailed graphical plots of the history of abstraction and alternative estimates of irrigation abstraction based on agricultural area and crop type/water source duty demand.

* a map to show the distribution of abstraction, perhaps using a subdivision of the grid, for each of the previous studies to show how the pattern of abstraction has varied.

* maps showing the change in water level and quality

* apply selected techniques to evaluate the available chemistry data to (a) show where and to what extent the water quality has become unacceptable for irrigation or domestic use, and (b) provide hydrochemical evidence to distinguish the possible alternative sources of poor quality water.

* examine the importance of well parameters, such as screen position or total depth, on water quality using statistical techniques if appropriate.

* differentiate seasonal from longer term changes in water quality.

* identify and distinguish the relative contribution from alternative sources of recharge, attempt preliminary estimates of groundwater inflow using the Darcy approach, and estimate the depletion in storage indicated by the decline in water levels.

* identify unconfined/confined areas of the aquifer, saturated aquifer thickness, aquifer extent and variations in the aquifer parameters of each aquifer, particularly specific yield (based on well logs if necessary).

* subdivide each area and each aquifer into zones having common features to more clearly identify where information is required and the objectives to be achieved.

These activities were proposed to highlight where further information would be needed in relation to future plans for the area and whether modelling techniques could be applied.

1.3 SUMMARY OF GENERAL CONCLUSIONS FROM PHASE A

The work undertaken during Phase A of the groundwater management study included the following:

(a) Collection and review of all existing information and reports relating to climate, topography, geology and lithology, geophysics, hydrogeology, abstraction and water quality.

(b) An inventory of existing wells, including information on their construction details, status, well logs, water level data, pumping tests, and water chemistry information.

The information available from previous studies was presented in the Interim Report of March, 1988. The Final Report includes a presentation of the well inventory data, a preliminary analysis of the information obtained and recommendations for further investigations required to overcome limitations in the available data. Table 1.1 summarises the availability of well data.

The work undertaken by the Cairo University team in conjunction with RIWR of the Arish-Rafah area presents a comprehensive assembly of the available information, much of which has been usefully presented in map form. Most of the advice given during the mission has been incorporated and a clearer picture has emerged from the detailed work regarding the aquifer system and where future investigations should be directed.

A concluding chapter on the findings of the first phase of the study is not given in the Final Report. We have attempted to summarize their conclusions regarding the general availability of information as follows:

* Information on time-varying parameters, such as water level fluctuations or detailed variations in water chemistry, is very limited.

* The less accessible areas, such as the sand dune areas, and the deeper parts of the aquifer system have only limited information.

* Abstraction, which has doubled during the 1980's and extended into new areas, has been accompanied by a decline in water levels and a deterioration in water quality in the Arish area. Saline intrusion has been identified just east of Arish and also locally along areas of the coast further east. Other areas away from the coast are indicated to contain groundwater with a limited suitability for irrigation or domestic use.

* Recharge from rainfall, floods and leakage along faultlines is considered to be less important than lateral inflow from the hinterland catchments.

It is apparent that more information is required in the dune areas in particular, on the hydraulic connection between different parts of the aquifer system and on the deeper parts of the sequence before a resource evaluation can be properly attempted. This will require further information on the aquifer geometry, hydraulic characteristics, water levels and water chemistry. A water level and water quality monitoring network is required to provide time-varying information.

The data from the pumping tests carried out during this phase have already been entered onto the groundwater data base (GRIPS) to produce drawdown plots and well logs. Analysis of the other information would be assisted by entering as much of the data as possible onto the data base, particularly the chemistry data, if this has not already been undertaken. Time-varying data should also be transferred onto the data base in due course.

Certain general aspects will require further data or more detailed analysis of the available information. These include:

- development plans for the region
- consumptive use
- preliminary estimates of storage and recharge
- maps of transmissivity and estimates of permeability
- specific yield estimates
- water level and water quality changes
- conceptual model of the aquifer

- aquifer geometry
- influence of well construction, pumping rate etc on local variations in water quality
- identification of risk areas

In the subsequent sections of this report we have examined the conclusions drawn from the work carried out under Phase A and the recommendations proposed for further work to be undertaken during Phase B.

2. El Arish

2.1 GENERAL

Previous studies have indicated a decline in water levels and a deterioration in water quality in the area around Arish indicating the need for a groundwater management strategy to control future abstraction. An appropriate monitoring network is required for this purpose but the application of numerical modelling techniques would greatly assist estimates of the available resources and future development planning.

The work undertaken during Phase A can be divided into: (a) the presentation and description of available information for the area, which was presented in the Interim Report of March 1988; and, (b) the collection of new data to describe the present situation accompanied by a preliminary analysis of this information leading to recommendations for further data collection, which are given in the Final Report of December 1988.

A considerable amount of information has now been assembled and presented at a suitable map scale accompanied by various other methods of presentation, such as profiles and chemistry diagrams. However, the main emphasis during Phase A has been to describe and discuss the hydrogeology of the area rather than as yet attempting to draw firm conclusions.

In our view more analysis could have been undertaken at this stage with the data available to show more clearly where and why more information is required. Important time-varying data could also have been obtained during the course of this first part of the study. The analysis has not proceeded sufficiently far enough to prepare a conceptual model of the system, to indicate recharge from possible alternative sources, relate the change in storage to changes in water quality, or to define the source(s) of poor quality water. Furthermore there is no discussion of future plans for the area which is undergoing rapid development, including the recent introduction of piped supplies from the Nile, so as to relate the purpose of future data collection to the needs of the area.

2.2 SUMMARY OF CONCLUSIONS

The main conclusions from the study can be summarised as follows:

- most of the information is restricted to the central area north of the Airport between the wadi channel and the Arish- Lahfan road.

- there is a lack of routine time-varying data on water levels and water chemistry, although historical changes can be examined using a number of studies which have been undertaken since 1954.

- the Quaternary sequence forms the main aquifer. This is penetrated by most wells such that the water level configuration represents a composite of the two main parts of the aquifer system, although these are probably in hydraulic continuity. The older formations contain very poor quality water.

a number of geophysical surveys have been undertaken but their accuracy is considered doubtful. Only 10 boreholes penetrate the base of the aquifer and thus there is limited information overall with which to define the aquifer geometry or saturated thickness or the aquifer characteristics of the lower part of the aquifer. Due to the lack of data west of the wadi channel it is not yet possible to determine whether the aquifer extends westwards.

- silty loams between 10 to 20m thick limit recharge along the flood plain of the wadi, although the adjacent sand dune areas offer favourable conditions for infiltration of rainfall.

- silt lenses, often of apparently fairly wide extent within the alluvial deposits, may act as semi-confining layers within this sequence. Grain size analyses would appear to be unavailable.

- water levels are now below sea level over a wide part of the area but data are lacking in certain important areas, such as the coastal area, just east of Arish and in the southwest. There are insufficient data to show seasonal variations to indicate recharge sources or to estimate lateral inflow. There is a possibility that recharge is taking place from domestic wastewater beneath Arish itself but there is insufficient water level or water quality information to confirm this.

- aquifer tests have been undertaken at five sites, of which three were carried out during the present study. These sites do not include a representative sample of the different parts of the aquifer sequence in different areas and as a result a transmissivity distribution has been derived from less reliable specific capacity data.

- present abstraction is now about 52000 m^3/d from 145 pumped wells. About 25000 m^3/d is abstracted by 33 wells for domestic use mainly close to Arish and about 26700 m^3/d is abstracted from 112 wells for irrigation mainly in the central and southern part of the area.

- abstraction apparently doubled from 1981 to 1982, mainly for irrigation. Total abstraction in 1988 is the same as that in 1982 but there has been a 30% decrease in irrigation abstraction and an increase of 85% in domestic abstraction. The distribution of abstraction has also altered with new abstraction taking place south of the airport for irrigation and southwest of Arish for domestic abstraction.

- zones of differing salinity have been identified. High salinities east of the Lahfan road may be due to limited recharge in this area, induced flow of poor quality water from the area to the east due to high abstraction or from the recycling of irrigation water. An area of saline intrusion has been identified just east of Arish along the wadi channel extending about one km inland, but there is insufficient data along the coast to establish whether saline intrusion is occuring over a wider area.

- sodium forms the dominant cation and chloride the dominant anion. The highest chloride concentrations occur in the north and the lowest just south of Arish. No particular pattern could be identified in the bicarbonate concentrations but the highest values occur close to the wadi channel, which could indicate recharge in this area.

an examination of ionic ratios and chemical composition indicates two main types of water chemistry which may be related to saline intrusion or the mixing of meteoric and deeper groundwaters.

water quality has deteriorated and poorer quality water now occurs over a wider area. Salinities have increased by 200 to 2800 mg/l and the area where salinities are less than 2500 mg/l has decreased since 1962.

only six boreholes of 68 sampled were considered to be suitable for domestic use based on WHO criteria and these are located southwest of Arish or south of the airport.

only limited areas are suitable for irrigation, most will require frequent leaching.

previous estimates of recharge are considered doubtful and unreliable. The geological conditions seem to preclude recharge from the east, southeast or west. Instead it is suggested that recharge is derived from the south and southwest from run-off in the Hasana catchment via gravel deposits beneath a cover of dunes.

No comments are made regarding the application of modelling techniques nor has a conceptual model of the system been attempted.

2.3 COMMENTS ON CONCLUSIONS

Overall we would agree with the broad conclusions obtained from the work carried out during Phase A. However, in our view, more analysis and presentation of data could have been attempted before recommendations for further work were considered.

More detailed analysis should continue during the second phase of the study. This could be assisted by transferring the data to the data base system, which has already been undertaken for the pumping test and well log data. Several aspects which require more analysis include:

- greater use of the grid square approach to smooth point variations which may be due to unreliable data and would also form preparatory input data for a numerical model. The changing pattern of abstraction over the past 34 years could be demonstrated by repeating the grid technique for the earlier surveys.

- preparation of maps showing transmissivity and/or permeability.

- maps showing changes in water levels or water chemistry for selected surveys.

- as yet, despite a number of profiles, it is difficult to judge the geometry of the system. An attempt should be made, if possible, to prepare some preliminary maps of the thickness of the main aquifer, areas of confined conditions, and by assigning specific yields to well logs, indicate variations in specific yield. More use could be made of the geophysical information to assist in defining the geometry of the system and whether more geophysical surveys are required.

the present situation still needs to be set in the context of longer term variations in potential recharge. Climatic data are not given for recent years, although information should be available from the GMA station. Long term trends need to be established and the frequency of floods considered in relation to recharge.

- the first part of the study has indicated a deterioration in water quality due to overabstraction but further work is required to link the origin and effect of this deterioration. Changes in water chemistry need to be compared to well parameters, such as screen position, as well as the geographic location. Better quality water in the west compared to the east could be a function of well depth rather than recharge.

- information is required to examine seasonal variations in water quality resulting from recharge or variations in abstraction.

In our view there are several important aspects not considered by the analysis undertaken during Phase A that have a bearing on the collection of further data:

* some of the observed changes in water quality may be due to seasonal variations in recharge and abstraction. Comparison of salinity data from 38 boreholes sampled in April, July, and November 1965 indicate a variation averaging 770 mg/l (or 50%) between April and July. Peak values occur in the summer months when water demands are high and are lowest in March-April following rainfall or flood recharge between November and January and when demands are relatively low. The recent sampling was carried out in October 1987 and April 1988.

* the decline in water levels indicates that abstraction is exceeding recharge and is being supported by flow induced from the adjacent areas, particularly from the west, and from a depletion in storage. The change in water quality is probably associated with a greater proportion of the total abstraction being derived from deeper parts of the aquifer. Hence, the change will be more marked in the areas of lower elevation where abstraction is also concentrated.

* the sand dune areas may contain groundwater accumulated over a long period. The water level configuration in the western area, which would seem to indicate inflow from the south west, is more likely to be a disturbed condition due to abstraction in the central area. The groundwater in the dune areas could be water held in storage rather than being replenished by flow from the south or southwest. If so, the water quality will deteriorate further east as storage in the dune area is depleted.

* estimates of recharge based on a water balance approach are likely to be misleading due to the uncertainty and variability in the components of the water balance. A Darcy approach would be more reliable and this requires data on water level gradients and transmissivity. In addition, since groundwater mining is indicated, it is also essential to obtain reliable information on specific yield variations and to make maximum use of abstraction/consumptive use information.

* a recharge mound is likely to have formed beneath Arish and may be acting as a barrier to saline intrusion. This could account for the intrusion being restricted apparently to the area just east of Arish. The urban area is expanding rapidly and an estimate of wastewater return in these areas is required. In part, this will be water abstracted and transferred from other parts of the area and hence is not strictly speaking an additional component of recharge.

* flood recharge is indicated by the improvement in water quality following floods in the 1960's, although a decrease in abstraction occured at the same time. This recharge will occur mainly through the wadi bed itself.

* the lack of floods in recent years may be contributing to the deterioration in water quality since a greater proportion of abstraction will be derived from storage or lateral inflow. Hence, although the volume of total abstraction has not apparently increased since 1982, water quality will continue to deteriorate with the depletion in storage until significant recharge from floods occurs again. Annual recharge is therefore rather misleading in these semi-arid conditions. The safe yield of the aquifer will be related to the volume of abstraction that can be supported from storage and lateral inflow without an unacceptable decline in water quality or heads until a further recharge event takes place. However, the frequency of recharge or the combination of climatic conditions that will give rise to a recharge event cannot be predicted. A management strategy therefore has to depend on establishing a relationship between abstraction, consumptive use, the decline in water level and the deterioration in water quality within pre-set constraints.

* the groundwater contours indicate inflow along the alluvial deposits south of the airport. New abstraction in this area will be intercepting groundwater that would otherwise continue into the area of abstraction north of the airport thereby aggravating the decline in heads and water quality in this area. Hence, the boreholes south of the airport are not developing a new resource. A similar situation would occur by developing the western dune area.

* it is not necessary to assume that flood recharge necessarily has to occur in the area of abstraction. The Wadi Arish channel represents a low point in a large area and groundwater could be entering the alluvial deposits from a wide catchment area as well as conveying recharge that has infiltrated from floods upstream but which have not necessarily been of sufficient magnitude to reach the Arish area.

* abstraction at Arish will intercept water that would otherwise be lost at the coast. As more of this is intercepted, either by excessive abstraction between recharge events or by a continued increase in abstraction, the saline front will move inland, although not necessarily by the same extent along the coast. Usually this is preceded by upconing of saline water at individual deep or

high abstraction wells. Water levels are now below sea level over a large area and therefore there is a strong possibility that saline water will continue to move inland. The recharge of water beneath the urban area may be slowing the advance of saline water intrusion but the situation needs careful monitoring if groundwater supplies are to be safeguarded.

* it is important to distinguish consumptive use of groundwater from borehole abstraction and to include the recharge from domes tic wastewater originating from the import of Nile water since October 1987, which should occur in the new urban area to the west of Arish.

* recently there have been attempts to introduce drip irrigation methods but apparently with limited success. The use of such methods, or water conservation measures in general, should be encouraged to reduce abstraction, although often the water saved is used to extend the area of cultivation so that the net abstraction still remains the same and with a greater consumptive use. It is important that the groundwater management study should work closely with agricultural and other organisations, particularly since these are collecting routine information on abstraction rates and irrigation development.

* supplies are at risk from several different but interrelated conditions: the upward movement of poor quality water from deeper parts of the aquifer, lateral inflow of poor quality water from the eastern area, recycling of irrigation water and from saline intrusion. Domestic wells close to Arish could also become contaminated from wastewater recharge.

* the relative risk for each well will depend on the geographical location, well depth, screen position, and abstraction rate. Areas at risk from a deterioration in water quality need to be defined from the available information. This should take account of the type of demand, crop type, well depth, well location aquifer conditions and any trend in water quality changes.

There are three particular aspects of the study which require further comment. These concern the transmissivity estimates, recharge, and changes in salinity.

Transmissivity

The tests undertaken on RIWR wells 2-5, 5-2 and 5-4 have produced a consistent set of results and would appear to be reliable interpretations. Longer tests will be required to obtain the necessary values of specific yield.

The transmissivity values were used in conjunction with the results of step tests on the same wells to obtain a relationship between transmissivity and specific capacity. In this way the results of 31 other step tests could be used to derve transmissivity. This is a common approach where aquifer test data are limited.

However, well 5-2 is screened in older formations whereas the other two wells are screened in the alluvial sequence. The low value of transmissivity for well 5-2 confirms the low permeability of the older deposits. The correlation between specific capacity and transmisivity was based on the average of all three results and this limited information on which to base a correlation must be considered as very approximate. A map showing the specific capacity based on the drawdown due to aquifer losses would indicate the relative distribution of transmissivity.

The specific capacity values were not adjusted to the aquifer loss component. When this is used to derive specific capacity rather than the total drawdown then the correlation for the two wells tapping the alluvium reduces to 1.5 and not 2.6 as given in the report. This gives lower transmissivity values.

The correlation is based on only two results and should only be applied to the wells tapping the alluvial aquifer and to the specific capacity adjusted to the formation loss. A similar correlation cannot be established for wells tapping the kurkar or kurkar and alluvium.

The calculated transmisivity values were not plotted in map form. A more reliable correlation needs to be established from the further work.

Recharge

Resource estimates from previous studies are summarised in Table 2.1. These suggest that recharge is approximately the same as abstraction and are all based on a water balance approach.

Rainfall at Arish averages about 100mm/y. Only exceptional events are likely to give rise to infiltration, mainly in the permeable dune areas. In general very limited recharge is likely to occur with such low rainfall and would probably not exceed 5 to 10% of the annual rainfall.

Upward leakage through faults has been proposed as a source of recharge but previous estimates have been based erroneously on the water level and hydraulic characteristics of the Quaternary sequence. This is considered also on the basis of salinities to be a minor component of recharge.

Flood recharge should not be discounted and there is some water level data to support recharge from this source. However, this will be infrequent and variable in amount and cannot be estimated without monitoring and specific yield data.

The study discounted lateral inflow from the east, west and southeast on geological grounds. Although this is probably the case the reason is more likely to be due to the reduced saturated thickness in these directions rather than due to the occurence of older clays and shales.

It was considered that recharge must originate from a south or southwest direction via gravels underlying the sand dunes from infiltration in the El Hasana catchment some 25 km southwest of Arish. It is conjectural as to whether there is hydraulic connection between the two areas and what proportion of the potential recharge reaches the aquifer system at Arish. This could be estimated from the Darcy approach.

However, we have strong reservations as to the contribution from the Hasana catchment and indeed whether it is necessary to consider this area as a source of recharge for the following reasons:

- the decline in water levels indicates a depletion in storage

- the change in head is inducing flow from adjacent areas

- water beneath the dune areas may be palaeo-recharge accumulated over a long period from recharge

- recharge from floods has not occured for several years

- any groundwater reaching the Arish area from Hasana would probably have a relatively high salinity

- the fanglomerate gravel deposits could be partly cemented

In addition the volume held in storage in the Arish aquifer (estimated by Paver in 1954 as 50 Mm^3) is not an upper limit to recharge as suggested by the study team. This comparison is quite misleading.

Using the available information we have applied the Darcy approach to indicate lateral inflow from adjacent areas at the zero water level elevation contour:

Transmissivity	$1000m^2d$
Average gradient	0.0013
Width	17 km

Inflow = 1000*0.0013*17000 = 23000 m^3/d, or 8.27 M^3/y

This is similar to some of the earlier estimates of recharge from rainfall and other sources but is only 50% of the present total abstraction. Actual consumptive use could be rather less than the total abstraction but this estimate would suggest that consumptive use in excess of this estimate of inflow is being supported from storage, which is suggested by the decline in water levels.

The aquifer area has not been fully defined, but assuming this to be about 28 km2 (within the zero contour), a storativity of 10% and an average decline in water level of 1.5m since 1981 (Figure 2.1) then the depletion in storage between 1981 and 1988 was 4.2 Mm^3 or 0.6 Mm^3/y (1644 m^3/d), assuming no recharge.

A simplified balance on the basis of these figures would be: (in Mm^3/y)

Recharge-Borehole Abstraction= Change in storage
(>8.3) - <18.25 = >0.6

The recharge only includes lateral inflow and does not take account of recharge from other sources. Abstraction is based on a daily rate and does not represent consumptive use. Over-or underestimates are indicated but the discrepancy in this balance could be due to several factors: there could be recharge from rainfall and floods; the change in storage may be occuring over a wider area; the annual abstraction could be less on an annual basis than indicated from the well survey; consumptive use may only be, say, 70% of the annual abstraction; both transmissivity and specific yield could be greater; and there could be upward leakage, which cannot be defined with the available water level data. However, it is not necessary to assume that additional recharge is occuring from the south or southwest as this would be included in the inflow.

At present the available information and level of data analysis are insufficient to indicate which parameters are in error and this needs to be examined during the next phase. Overall the present consumptive use (without accounting for recharge from rainfall or floods) is being supported by an expanding cone of depression which will continue until inflow balances the consumptive use.

The total volume in storage assuming an average saturated thickness of freshwater of 50m within this area would be about 140 Mm^3. Only a proportion of this storage would be available due to water quality constraints. Due to the risk of saline intrusion the minimum effective storage is that proportion above sea level, most of which has now been removed by abstraction. The water level south of the airport is about 2m above sea level so assuming an average originally of 1m thickness above sea level over the area then the usable storage may only be about 3 Mm^3, if water levels are retained at sea level.

These estimates must be considered as very tentative and do not account for the present abstraction. It would be useful to express the various components as annual volumes. The frequency and contribution from rainfall and floods needs to be quantified and distinguished from lateral inflow, storage depletion and possibly upward leakage from deeper parts of the aquifer.

It would appear that abstraction is being supported by lateral inflow and depletion of storage, perhaps accumulated over a long period of time. Isotopic dating might distinguish the different recharge sources.

Changes in Salinity

The present situation is compared to that in 1962. This might be slightly misleading as abstraction has apparently been relatively constant since 1982. Flood recharge and reduced abstraction also occured during the 1960's and this may have influenced the water quality.

The change in salinity between 1981 and 1988 is shown in Figure 2.2, where positive values indicate an increase in salinity. This would generally suggest that water quality has deteriorated in the northern part of the central area. This is more likely to be due to saline intrusion, the greatest increase being along the wadi channel just east of Arish. Aside from a few local areas, the water quality over a large part of the central area has actually improved or has not shown any significant change since 1981 despite the decline in water level (Figure 2.1).

These results indicate that abstraction in the central area is causing a decline in heads which has resulted in inflow from the surrounding area and hence the water quality change will be related to the different water quality in the surrounding areas. Thus those sites in the north would be affected by saline intrusion, those to the east by poorer water in the eastern dune areas (with slightly better quality water along the Wadi Mazar), those in the south by good quality water entering as inflow along the alluvium of the Wadi Arish, and those in the west by reasonable quality water entering from the western dune area. Detailed hydrochemical studies should be able to identify the

El Arish Groundwater Management Study

Change in water level (m) 1981–88

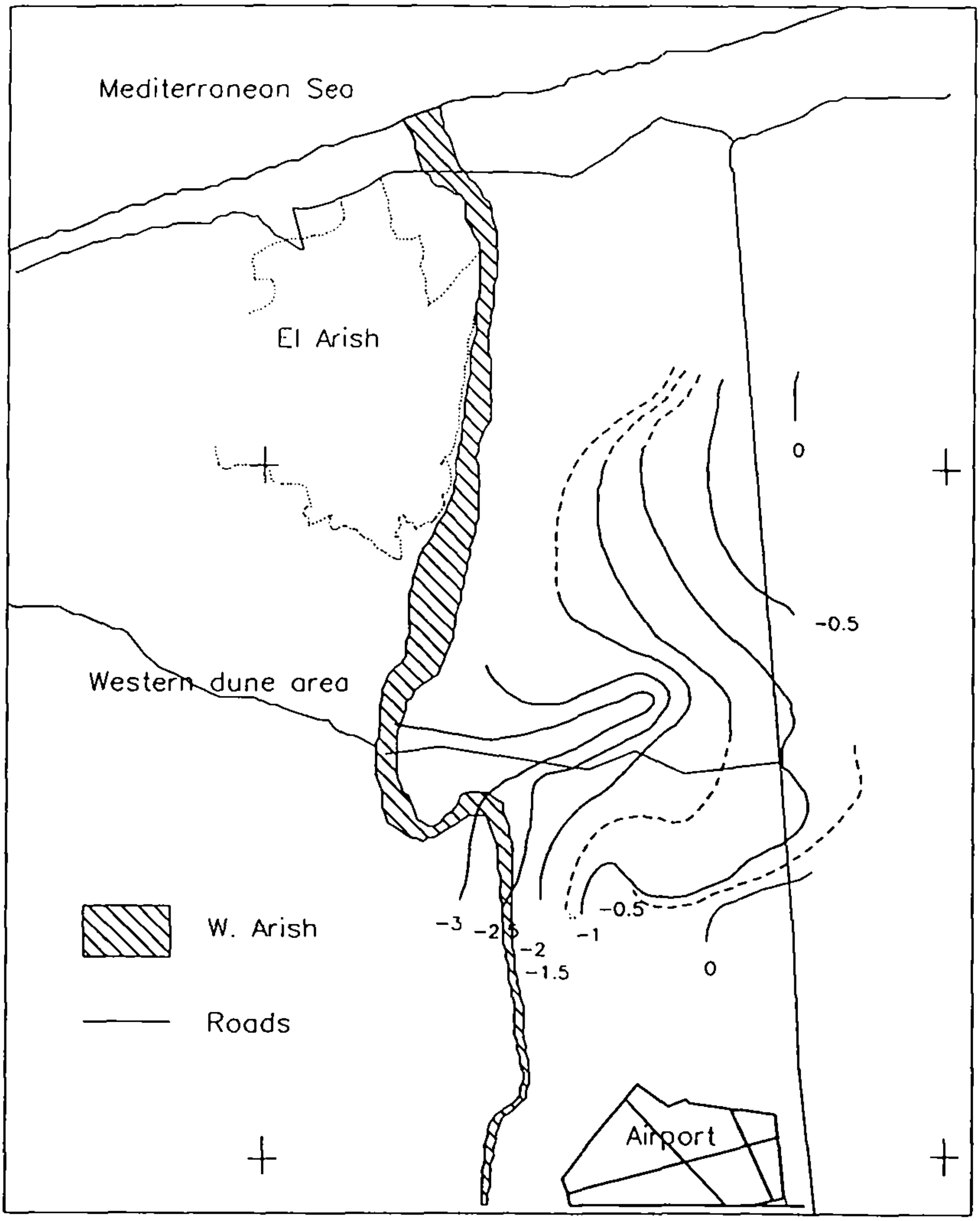

Figure 2.1

El Arish Groundwater Management Study

Change in salinity (mg/l) 1981–88

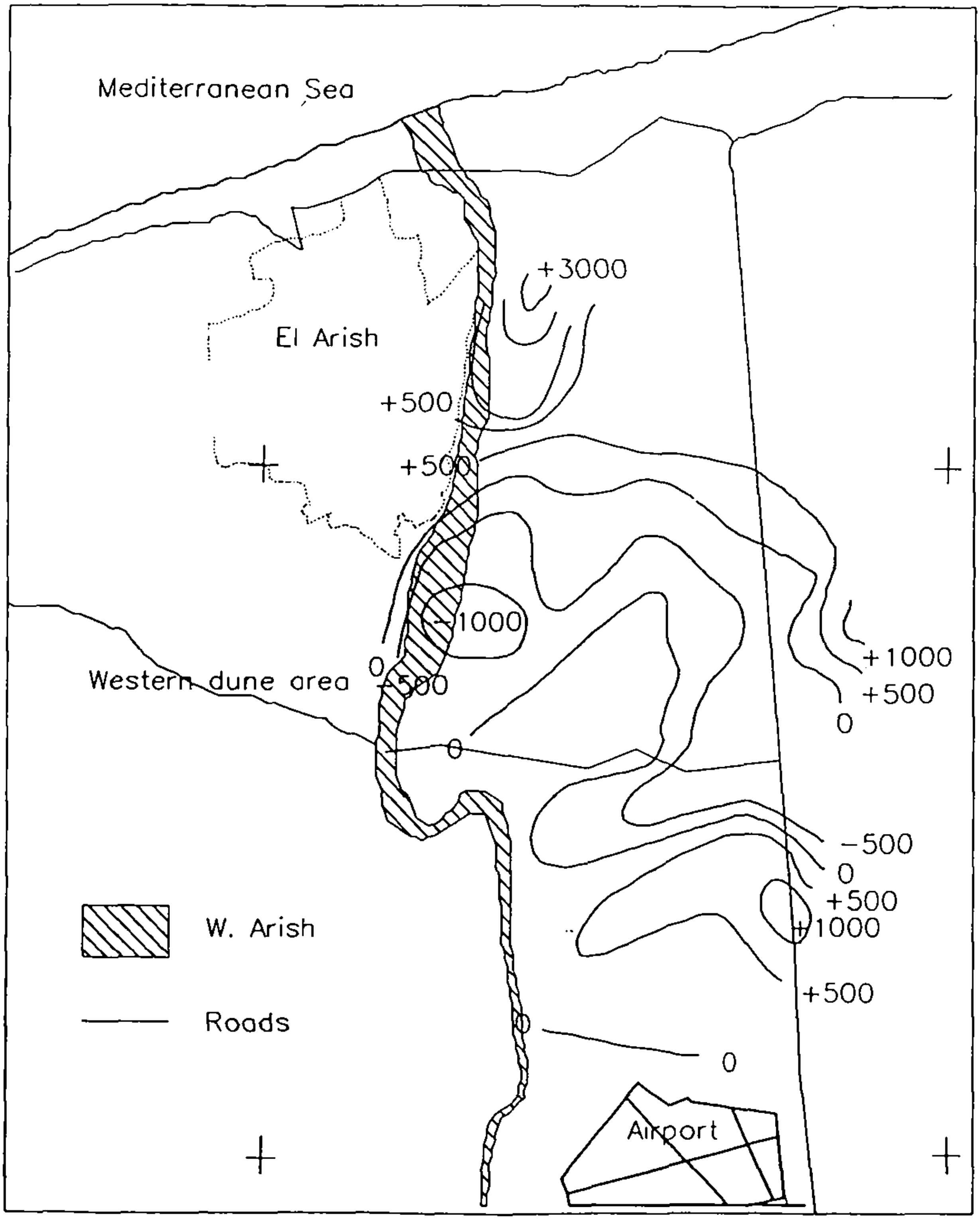

Figure 2.2

relative contribution from each area.

However, an additional factor is the thickness of freshwater in the central area and other factors, such as well depth or abstraction rate. It may be necessary to take account of these different water qualities in proposing the allowable abstraction and the distribution of such abstraction in the management strategy.

It is still uncertain as to whether water quality is still deteriorating at the current level of abstraction. This can only be resolved by further monitoring of the situation taking into account seasonal variations.

2.4 SUMMARY OF PROPOSALS FOR FURTHER INVESTIGATIONS

The following recommendations were made by the University team:

- the situation requires immediate monitoring, which should be carried out for a period of one year

- a geophysical survey is required along the coastal area

- test drilling should be carried out where there is only limited information on aquifer characteristics

The proposed programme of work, which is to be carried out over a one year period, is summarised in Table 2.2. We have examined this programme and can suggest various amendments for consideration. A more detailed programme will need to be prepared.

For convenience, we have subdivided the area into five sectors to reflect differences in the water quality, aquifer types, abstraction, and programme objectives:

N - the northern coastal region, including the urban area of Arish
W - the western dune area, including the area of abstraction immediately south west of Arish
C - the central area north of the Airport
D - the area of the wadi channel south of the Airport
E - the eastern dunes area

We would recommend that the data base is used to store and process the new information.

2.5 COMMENTS ON PROPOSED GEOPHYSICAL SURVEYS

The available geophysical data should be reinterpreted if the raw data can be obtained using the information which may have become available from further drilling since the surveys were undertaken as well as new information from the drilling programme. In practice the aquifer extent and configuration can perhaps only be defined from further geophysical surveys given the difficult access into some areas and the otherwise high drilling costs to collect such information. The application of geophysical surveys should be given further consideration.

We would suggest an extension and some modifications to the proposed geophysical survey:

1. It is probably unnecessary to have traverse lines at the coast at the spacing proposed. We would suggest EM as well as ER traverses spaced 1 to 1.5 km apart extending to 2km inland along the coast from the new urban area west of Arish at about 177.5E eastwards to 190E. Supplementary drilling and borehole logging will be required to provide the necessary control for interpret ing this geophysical survey.

2. Access is difficult into the western dune area and may require expensive road construction. We would suggest an ER suvey, if ground contact is possible, extending south from the coast at about 180E through piezometer 82 to site 9 and then eastwards across the airport area to site 14.

3. A further survey of the eastern dune area where access is also difficult could be considered. This should be made southwards from site 3 through GDDO A, to site 14 to GDDO 3. Some earlier work has been undertaken in this general area.

2.6 COMMENTS ON DRILLING PROGRAMME

In general we would agree with the objectives of the proposed drilling programme. Most of the drilling is to be undertaken in the western dune area which lacks information. Nonetheless, we suggest the following amendments to target the drilling and testing programme and ensure as far as possible that the necessary information is obtained.

A detailed programme needs to be prepared to the exact requirements at each site since all include several objectives.

Area D

The area south of the airport is undergoing development for new irrigation supplies which will intercept water that would otherwise contribute to the abstraction further north. However, there are several RIWR test sites in this area already and we would agree that no further drilling is required in this particular area. We would recommend that a recorder is installed on test well 2-5 to monitor flood recharge. Recorders could also be installed on the other two RIWR test wells in this area with monthly monitoring on the piezometers at all three test sites, including deep piezometers 5-3 and 5-5 to indicate any response of the deep aquifer to abstraction.

Area N

We would suggest additional sites in the coastal area where data are very limited. Sites 1, 2 and 3 are acceptable but monitoring of the saline intrusion will require at least one line of piezometers extending inland and more information is required on the geology and water levels in this coastal area. We propose a total of seven sites in this area as follows, all of which should be fully screened from the water table:

- one piezometer to 60m in Arish itself (at about 185.75/1226), providing a suitable site can be located, to obtain water level and chemistry data and to monitor the possible return of wastewater beneath Arish.

a line of two piezometers just east of Arish to monitor saline intrusion incorporating site 2 with another site at about 187.25/1225.75 (depending on the EM and ER survey). Depths to be 40 and 60m.

- a line of two piezometers just west of Arish to also monitor saline intrusion between the coast and the area of abstraction on the southwestern edge of Arish. Depths to also be 40 and 60m and incorporating site 1.

- one site to 40m in the urban area west of Arish and incorporating site 3 to 50m east of Arish. These are mainly for geological and water level control.

This programme incorporates wells 1,2, and 3 plus four additional sites giving a total meterage of 350m. Water level data in this general area would assist in estimating groundwater outflow at the coast and the lithological data may distinguish the prescence of older beach deposits.

Area W
The location of new wells 15 and 16 southwest of the Arish area is not unfortunately shown on the report maps. This site is intended to indicate a postulated connection to the Hassana catchment beneath the sand dunes. In our view, as discussed above, we do not think such a connection would play a significant role in recharge to the Arish area in the way proposed. Consequently, we do not recommend the drilling of this site.

Most of the proposed drilling programme is intended to collect information on the western dune area, which appears to contribute to the area of main abstraction to the east, but for which there is little information on the characteristics of the dune aquifer, water levels and water quality, or the general sequence.

However, access into the area is difficult and may require road construction. We would suggest a more condensed programme of drilling and testing in this area as follows:

1. A test well in the area of abstraction just south west of Arish using well 1-131 as a piezometer. Data on the aquifer characteristics in this area are lacking. The test well should be drilled to 50m to test the alluvial aquifer (if this is the main aquifer being tapped by the wells in this area) and would be subsequently fitted with a recorder to monitor the water level situation in this area of abstraction.

2. A test well and piezometer just south of the tarmac road approximately at site 7. This would be drilled to about 50m to test the characteristics of the dune aquifer, particularly the specific yield. A recorder should be fitted on the test well. Samples of the dune sands should be taken in the western area

for grain size analysis to estimate permeability.

3. A full test site approximately at site 8. This should first have a slim exploration hole for logging purposes to a depth of at least 100m. This would be reamed out and completed as a test well in the alluvium. Two piezometers should be drilled adjacent to this well, one completed at 50m in the dune sand aquifer and the other completed at about 100m in the alluvial aquifer. The pumping test and subsequent monitoring would be used to indicate the interconnection between the dune sand and alluvial aquifer. A recorder should be fitted on the test well and water levels measured monthly on the two piezometers. These would indicate whether rainfall recharge occurs.

4. Site 9 should be drilled initially as an exploration hole to 100m, or at least to prove the occurence of alluvium and if possible the kurkar. This would be completed however at 50m in the dune sand aquifer for monitoring.

5. Water level control data are lacking in the area of the wadi channel/edge of the western dunes west of the airport. We would suggest a site at about 1865/1220 drilled to 50m. This site would also be used to indicate flood recharge and should be protected accordingly if necessary.

This programme gives a total drilled meterage of 550m and comprises three test wells and five piezometers. It excludes sites 5, 6 and 11 and concentrates on providing information on the aquifer characteristics and geometry with less information on the water level configuration in this general area. It may still be considered desirable to drill sites 5, 6 and 11 for water level data, although all three need only penetrate the dune aquifer. This would increase the total meterage to about 700m for this area.

The drilling depths are based on those proposed by the University team but given the elevation of the dunes we consider that it may be necessary to drill to greater depths than generally suggested. The pumping tests must also be of sufficient duration to obtain information on the specific yield.

Area C

This includes the main irrigated area where water levels are below sea level. Monitoring is the main requirement in this area together with information on the aquifer characteristics of the underlying kurkar. We would propose the following amendments to the proposed programme in this area:

1. Piezometer 4 should be moved slightly further north to provide water level fluctuation data within the area of abstraction just south east of Arish which is at risk from saline intrusion. The drilled depth should be about 50m.

2. A full test site should be constructed at about the location of sites 12/13. This should first have a slim exploration hole drilled up to 150m completed as a test well screened in the kurkar at about 100m. Two piezometers should then be drilled, one to the same depth and screen position as the test well and the other to about 50m with screen in the alluvium. The pumping test and subsequent water level data should indicate the extent of hydraulic connection between the alluvium and kurkar as well as providing information on the transmissivity and specific yield of the kurkar. The test well should be fitted with a recorder.

The total drilled meterage for the wells in area C would be 350m.

Area E
Only limited information exists in this area, mainly because of difficult access. Most of the information is limited to the Wadi Mazzar. One new site has been proposed in the area south of this wadi to explore the sequence underlying the dunes and to provide important water level and water quality information.

We suggest that the site is drilled as a slim exploration hole for geophysical logging but should be completed in the Quaternary sequence. It will only be necessary to prove the underlying bedrock formation, which could occur at a depth of less than 150m. If drilled at 8 inch diameter a pumping test could be undertaken to monitor water quality changes with pumping and to estimate transmissivity from a recovery test.

2.7 COMMENTS ON MONITORING AND SUPPLEMENTARY INFORMATION

The proposed network and frequency of measurements is acceptable for the water level monitoring programme but should be adjusted if necessary as data are obtained and as further analysis is carried out. The network should include all available disused sites and all new RIWR boreholes and eventually should be modified to form a long term monitoring network.

We would suggest that recorders are fitted to all test wells of 8-inch diameter, particularly those in areas of high abstraction or adjacent to the wadi channel.

The wells drilled to monitor saline intrusion should be screened from the water table to the completed depth. EC logging should be undertaken on these wells at 6-weekly intervals.

We consider that repeat suveys of water levels, water quality and abstraction every three months is perhaps rather excessive. It may be preferable to select a representative sample of the domestic and irrigation wells and monitor these more frequently. We would suggest at least 10 domestic and 10 irrigation wells for this purpose to obtain information on variations during the year. The abstraction data from the Government wells should be collected and 10 irrigation wells fitted with meters. Areas of irrigation, irrigation method, information on crop types and irrigation development plans may be available from the agricultural staff, but if not then a survey should be carried out to obtain such information in cooperation with agricultural staff.

The conductivity should be measured at hourly intervals over 24 hours (or the pumping period) at the selected irrigation wells, once during low irrigation demands and repeated on the same wells when demands are high. Water samples for full analysis should be taken every four hours. The sites selected should include deep wells and high abstraction sites and in areas where there has been a significant decline in water quality. Water samples for full analysis should be taken every six weeks from these sites.

Information is also required on the pattern of domestic demand and future water requirements for the urban area as well as the general development plans for the area.

We recommend that an isotope survey is undertaken throughout the whole area to help distinguish the age and origin of the different groundwaters. This should be accompanied by water samples for detailed hydrochemical analysis.

3. Sheikh Zuwayid-Rafah Area

3.1 GENERAL

The Quaternary deposits also form the main aquifer system in the Sheikh Zuwayid- Rafah area. There are three aquifer units:

Holocene dune sands, which occur along the coast
Upper Pleistocene old beach deposits, underlying the dunes
Lower Pleistocene calcareous sandstone (kurkar)

Alluvial deposits of any significant thickness are absent. The aquifer system is underlain by Pliocene cherts. The old beach deposits are 5 to 25m thick whilst the kurkar, which is the main aquifer at Rafah, is up to 80m thick. The kurkar can be divided into an upper continental facies about 10m thick and a lower marine facies up to 50m thick. The exploitable aquifer would appear to extend some 15 to 20km inland.

Information on these aquifers is available from several previous studies undertaken in 1954, 1962 and 1982, although the most detailed survey was made in 1984 by GARPAD. The information from these earlier studies was presented in the Interim Report of March 1988.

Some 330 wells have been constructed in the area, including shallow collector systems in the coastal area. However, despite the number of wells the amount of available data is rather limited, particularly in the central area, and flow directions are rather difficult to define.

Rainfall ranges from 150 to 300 mm/y in this area and forms a more important source of recharge than in the Arish area. There are no large wadis entering the area, although a number of wadis drain the higher relief areas further south. Most recharge will be derived from rainfall and lateral inflow but it is possible that local abstraction may also draw upon storage.

3.2 SUMMARY OF CONCLUSIONS

There are 44 wells in the area having lithological descriptions, of which only 15 fully penetrate the kurkar. The information from 36 wells was used to construct six profiles. It would have also been useful to integrate the information in map form to provide a more suitable indication of the aquifer geometry and inter-relationships between the different parts of the sequence.

A water level and well inventory was carried out between April and May 1988. Water levels were measured on some 123 wells, mainly located around Zuwayid and Rafah. In parts of the coastal area the zero contour extends about 1 km inland indicating overabstraction in these areas. A comparison of nine wells in the coastal area where water levels were measured in 1983 indicated water level declines of -0.3 to - 1.8m. Water level declines of 1.5m are also indicated in the area west of Rafah.

The degree of interconnection within the sequence has not been properly established. Abstraction at Rafah has disturbed the natural pattern, although the data for 1985 indicate a general flow northwards over most of the area but with flow northeastwards in the area north of Rafah indicating a recharge area east of the border.

Two RIWR boreholes were tested. One site taps the old beach deposits whilst the other draws upon the kurkar. The analysis of the tests carried out at the sites gave consistent results, indicating a transmissivity of 350 m^2/d for the old beach deposits and 700 m^2/d for the kurkar. The results from earlier tests were not applied.

The results of four tests were used to calibrate specific capacity data available for 22 wells. However, the same comments given in Section 2.3 apply. The correlation is based on an average of only four sites which penetrate different aquifers and relate to the total drawdown rather than the component due to aquifer losses. The correlation factor of 3.0 derived from their approach will overestimates the transmissivity. A value of about 2.5 is more accurate but should be derived separately for each aquifer.

Only one value of specific yield is apparently available and the system generally appears to be leaky confined. The dune areas are more likely to be perched and show water table conditions.

Total abstraction has been estimated to be 43320 m^3/d from 280 wells. This abstraction is derived almost equally from the dune sand/old beach deposits and the kurkar. Although abstraction from the dune sands/old beach deposits occurs equally for domestic and irrigation purposes, the abstraction from the kurkar for irrigation is over three times that abstracted for domestic use. Most abstraction for domestic use occurs along the coast and irrigation is concentrated around Zuwayid and Rafah.

The main increase in abstraction occured between 1962 and 1982 but has doubled since 1982, due almost entirely to increased abstraction from the dunes/old beach deposits.

Water samples were obtained from 64 wells between April and June 1988. Only four samples were rejected after checks on their accuracy. The data are presented by various methods. The salinity increases from north to south but local areas of upconing are indicated. For the most part the water quality is suitable for domestic use but is only marginally suitable for irrigation in local areas of the old beach deposits and kurkar. The water quality is likely to be poorer with increased depth or near sabkah areas.

Estimates of recharge were not attempted during the recent study. In 1983 GARPAD estimated recharge from rainfall in the coastal area to be 7800 m3/d and lateral inflow to the aquifer at Rafah to be 48600 m^3/d. This could suggest that the coastal aquifer is being overexploited.

3.3 COMMENTS ON CONCLUSIONS

No firm conclusions regarding the aquifer system were obtained by the recent survey. The reports concentrate mainly on presenting the available data and a general description of the system. The information from the previous studies needs to be integrated with the new survey.

A multi-aquifer system is present and probably in overall hydraulic continuity, except at the coast where local perched aquifers may occur in the dunes. The degree of interconnection within the system and the thickness of freshwater are not yet properly understood. The information on specific yields is inadequate. Large areas still lack hydrogeological data.

There is a lack of time-varying data on water quality and water level variations. There are indications of falling water levels in several areas due to overabstraction and in our view the freshwater resources may have accumulated over a prolonged period.

3.4 SUMMARY OF PROPOSALS FOR FURTHER STUDIES

The following activities have been recommended by the University team to obtain more information from the area:

- six geophysical traverses extending from the coast to on average about 8km inland covering the whole area with a VES spacing sufficient to a depth of 25m below water level. Each traverse is linked to a well having lithological data.

- construction of test wells at eight locations, each having a piezometer and all located to test the old beach deposits together with a single piezometer just south of the irrigated area at Rafah to monitor water levels in the kurkar. Most of the wells range in depth from 50 to 100m and the total meterage recommended is 700m.

- monitoring of 30 wells, including the new wells to be drilled, for water level changes at monthly intervals and on all wells at three monthly intervals.

monitoring of EC, temperature and pH on 30 selected wells and all operating wells to be sampled for chemical analyses every three months

- monitoring of extraction on all producing wells every three months.

3.5 COMMENTS ON PROPOSED PROGRAMME

Geophysical Survey

The survey proposed is acceptable but should include another traverse through proposed wells 3 and 4. Ground contact may be difficult in the dune area.

We would also suggest that EM surveys extending about 1 km inland are undertaken in the areas of concentrated abstraction along the coast, particularly where water levels are below sea level, to define the saline interface. We would suggest three traverses at 750m spacings at the coast north of Zuwayid just west of the road at the coast and another three traverses at the same spacing where the road from Rafah reaches the coast with the central traverse along the road.

Drilling and Testing

The proposed drilling programme concentrates on the old beach deposits, although the reason for this is not clear. Where pos^sible it may be appropriate to locate test wells next to existing piezometers. It may be also be possible to undertake recovery tests on three wells in each aquifer where accessible for water level measurements to obtain transmissivity estimates. Further drilling needs to provide information on water levels where data are currently lacking, such as the central area, and in areas of concentrated abstraction. The longer term monitoring of the sys^tem should also be taken into account to safeguard supplies in the main areas of irrigation and domestic abstraction.

We do not consider that a water balance approach to estimate the available resources is appropriate in these semi-arid conditions. This means that the water level configuration, gradients and variations in transmissivity need to be determined to estimate inflow and loss at the coast. This will also require a more detailed knowledge of interconnection in the system and general aquifer conditions. Specific yield data are required for each aquifer to estimate storage.

We would suggest the following modifications to the drilling programme to obtain water level data where there is presently little or no information (mainly the central area) and to increase the amount of information regarding the hydraulic characteristics of each aquifer. The well depths are indicative only and should be confirmed. Where possible test well sites have been selected to use existing wells (but away from other abstracting wells) which are to be incorporated into the monitoring network. It would be preferable to drill each site to, say, 100m for logging and water quality information but completed and screened at an appropriate shallower depth in the target aquifer.

We have subdivided the area into the coastal zone, the central area, Zuwayid and Rafah, and the new area of abstraction northwest of Rahfah.

Coastal zone: Drill shallow test wells (each about 30m depth) adjacent to existing wells 12-1 and 12-68 in the Zuwayid area and 16-6 in the Abu Shinar area for aquifer tests of the dune sands and to obtain information on the water levels and quality of the underlying sequence. Each test well could be fitted with a re5order to monitor rainfall recharge. Construct exploration well to 50m for subsequent use as a piezometer at 220/1242 in area of abstraction and to investigate deeper aquifer.

Zuwayid: Sites 1 and 2 accepted but consider depths of 60m for each well. Construct test well to 50m adjacent to existing RIWR well 12-93 for aquifer test.

Central area: Sites 3 and 4 and 5 and 6 accepted, but consider depths of 60m for each. Construct test well to 60m adjacent to existing well 17-1 for aquifer test. Two piezometers are required to monitor the wellfields extending from 16-8 to 16-73 and westwards from 16-112. Site 7 and 8, both drilled to 60m could be moved south for this purpose and to obtain aquifer data relating to the aquifer tapped by this wellfield, with a recorder fitted on the test well to monitor the wellfield. Specific capacity data are available for almost all the wells of the wellfield further north and only an additional piezometer is required to a depth of 50m or less.

Rafah: Test wells, each to say 80m (depending on water quality with depth), are required to obtain information on the aquifer characteristics of the Kurkar aquifer in this area. A test well could be located adjacent to well 16-106 and also included with the proposed piezometer site 9.

This revised programme is more extensive than that proposed and will require a total of about 1000m of drilling and 11 aquifer tests. However, this area is much larger than Arish, includes several different aquifers and lacks water level and water quality data over much of the central area in particular.

Monitoring

The proposed monitoring network for water level fluctuation data is considered acceptable and concentrates on areas where saline intrusion may be occuring or in areas of high abstraction. Use is made of existing disused wells and the network includes the new wells to be drilled. We do not consider that all wells need to be resurveyed every quarter and instead we would suggest a representative sample of wells in each area is selected for this purpose taking factors such as the aquifer type or type of demand into account. The main increase in abstraction is for domestic use and monitoring of the wellfields in the area should have a high priority.

We suggest that recorders are installed on a selection of the available sites, especially on the new test wells, in particular to examine rainfall recharge in the shallow coastal aquifers and to monitor water levels in areas of concentrated abstraction.

Other comments regarding monitoring and supplementary information described in Section 2.7 are applicable. We would also recommend an isotope survey of the different aquifers and more definition if possible of the aquifer(s) tapped by each well. This should include at least five samples from each aquifer across the area.

Abstraction records should be obtained for all government wells fitted with meters. Meters should also be fitted to at least five representative irrigation wells at both Rafah and Zuwayid.

4. Conclusions

The work undertaken during the first phase of the study is a detailed and useful account of the hydrogeological information available for the Arish-Rafah area. The reports highlight where more information is required, but relatively few conclusions can be drawn from the present level of analysis.

The information could be analysed in more detail, particularly if that from the earlier studies is integrated more fully with the new surveys and entered onto the GRIPS data base.

The proposed programme of further investigations and data collection is generally acceptable but the objectives need to be more clearly defined. Supplementary information is needed, such as on the future water requirements or to distinguish aquifer relationships and recharge contributions.

We have outlined a number of modifications to the programme of further work for consideration by RIWR. A detailed programme should now be prepared, particularly for each drill site and the tests to be undertaken.

Numerical models of each area would be the most appropriate way of planning a management strategy for future development. As yet, a conceptual model of the system has not been attempted and no conclusions have been obtained regarding the application of numerical models. Implementation of the strategy selected will depend on establishing a long term monitoring network.

Arish Area

Abstraction is exceeding recharge in the Arish area and storage is being depleted. Water levels are now below sea level over much of the area of abstraction and there is a consequent risk of a continued decline in water quality in a situation where supplies are already rather marginal for irrigation or domestic use. It is uncertain as to whether the deterioration in water quality is still occuring and the pattern of abstraction has altered in recent years.

The deterioration in water quality would appear to be linked to several different origins related to the occurrence of poor quality water in peripheral areas and in the sequence underlying the main aquifer. Local variations may be due to well depths, abstraction rates and other factors.

Additional information is required on the aquifer parameters, in particular in the western dune area and on the kurkar aquifer. Water level data are needed to estimate lateral inflow from the dune areas and for the coastal area.

Previous resource estimates are questionable but we consider it unlikely that significant recharge originates in the Hassana catchment as proposed by the University team. A water balance approach to estimate the resources is often inappropriate in this arid zone, particularly where limited information is available on the highly variable components of recharge. Lateral inflow and storage depletion would seem to be supporting the current level of abstraction.

We have proposed a subdivision of the area to reflect different aspects of the system and the type or amount of data still required. The monitoring network proposals are acceptable, although we propose some changes in the frequency of sampling surveys concentrating instead on a representative sample of sites for more detailed work. The application of geophysical surveys has been extended to include the dune area. The proposed drilling programme has been modified to concentrate on certain aspects, such as the water level configuration in the coastal area and on detailed test sites for aquifer characteristics. The total required meterage for the revised programme is about 1300m, subject to further detailed examination of the depths required in the dune areas. A suggested programme is given in Table 4.1.

Sheikh Zuwayid-Rafah Area

The aquifer system is not yet fully understood in this area. Time varying data is very limited but there are indications from the recent survey that water levels have declined in several areas. Abstraction for domestic use has increased considerably in recent years. The situation will require careful monitoring, particularly in certain areas of the coast.

Large parts of the central area lack information and the proposed further investigations stress the need for water level data, geological control and information on the aquifer characteristics of the old beach deposits as well as on regional geophysical surveys to define the aquifer geometry.

Rainfall recharge is more important in this area but lateral inflow from the south is an important source of recharge. Water level configurations of the different parts of the aquifer system need to be defined to estimate inflow. More information is also required on the aquifer parameters and water quality of each aquifer.

We have proposed various additions to the programme of further work which will require about 1000m of drilling. The area has been subdivided to indicate priorities of further data collection. These are summarised in Table 4.2.

Table 1.1 Summarry of well data in El-Arish and El-Sheikh Zuwayid - Rafaa Areas

Type of Data	Arish: Number of Collected Well Data	Arish: %*	Sheik Zuwayid-Rafah: Number of Collected Well Data	Sheik Zuwayid-Rafah: %*
Inventoried Wells	176	100	319	100
Well Use Data	176	100	319	100
Well Geological Data	40	22	36	
Tehnical Well Data	168	95	293	92
Production Data	145	82	280	88
Water Level Measurement	40	23	123	39
Water Sample	68	39	64	20
Aquifer Test			2	
Previous Well Test Data			22	

* Percentage of number of well data witrespect to the total number of wells for each study area.

Table 2.1 Resource estimates from previous studies (m^3/d)

	Paver (1956)	Saad (1962)	SDS (1980)	GARPAD (1984)
Rainfall		1000	8700	46700 (Rainfall + Floods)
Floods			9800	
Upwards leakage along faults		20000	4300-12800	4300 (by difference)
Total	25000	30000	27000	51000

Table 2.2 Arish : RIWR proposed programme of further work at Arish

Activity	Objectives	Method
Geophysical Survey	(a) Detect saline interface (b) Further information on aquifer sequence	Resistivity VES at 200 m spacings 17 traverse lines at 500 m intervals extending 1.5 km inland
1. Testing	(a) To obtain information on extent of saline intrusion · hydraulic interconnection · source and direction of recharge · aquifer geometry · water levels and water quality · aquifer characteristics (b) Provide monitoring wells	Drill 16 wells at 13 locations, all to the base of alluvium. Total meterage 1250 m. · 3 in coastal area to monitor intrusion and to assist calibration of resistivity survey · 6 in western area for aquifer geometry and recharge, water quality (3 in dune areas, 3 penetrating the alluvial thickness) · 2 in south of study area(1), each fully penetrating the alluvium, one for long duration test · 2 to study aquifer interconnection in central area, one in alluvium, other in kurkar · 2 to study dune · Quaternary sequence interconnection in south-west 1 in Wadi Mazzar for aquifer geometry
3. Monitoring	(a) Water level fluctuations	Monitor 40 wells monthly for water levels and for EC, Temperature, pH
	(b) Water quality variations	Monitor all wells every 3 months together with water samples for full analysis
	(c) Abstraction patterns	Re-estimate abstraction every 3 months (yield and duration) with further information on area irrigated, water duty and irrigation method.

Source: Final Report, December 1988 Vol. V

(1) Location not shown in report

Table 4.1 Arish : Suggested amendments of further investigations

Sector			Drilled
Coastal (Zone N)			
1 Geophysical Survey	(a) Detect saline interface (b) Aquifer information	EM and ER traverses at 1 to 1.5km apart (10_11 traverses) and up to 2km inland along coast from 177.5 to 190.	
2. Drilling and Testing	(a) Identity and monitor wastewater beneath Arish	Piezometer to 60m at about 185.75/1226	60
	(b) Monitor intrusion and lithological data to calibrate geophysicall survey	Two lines of piezometers - first line on eastern edge of Arish, incorporating site 2	40 + 60
		second line on western edge of Arish, incorporating site 1	40 + 60
	(c) Lithological data towards western and eastern boundaries	One site in new urban area where possible Nile water return	50
		One site in east at site 3	40
3. Monitoring	(a) Saline intrusion	EC logging of 7 sites above at 6 weekly intervals	
	(b) Water levels	As proposed, incorporating additional sites above, at monthly intervals	
	(c) Water quality	Depth sampling of site 2(a) every two months	
		Sub-total	350
Western Dunes (Zone W)			
1. Geophysical Survey	(a) Explore geology of dune area	ER survey (if possible) from coast through piezometer 82 to site 11 then east through airport area to site 14	
2. Drilling and Testing	(a) Aquifer characteristics just SW of Arish where high borehole density	Test alluvum at 50m, using 1 - 131 as piezometer	

Table 4.2 Sheikh Zuwayid - Rafah: Suggested ammendments to further investigations

		Meterage
1. Geophysical Survey	As proposed but with additional traverse through wells 3, 4. EM surveys comprising three lines at 750m spacings to 1km inland on coast north of Zuwayid and north of Rafah	
2. Drilling and Testing	Drill test wells where possible next to selected, existing piezometers. Possibilities include:	
	12 - 1 (coastal area for dune sand characteristics)	30
	12 - 68 (coastal area for dune sand characteristics)	30
	16 6 (Abu Shinar)	30
	12 - 93 (Zuwayid)	50
	17 - 1	60
	16 - 106 (Rafah)	80
	Site 9	80 + 80
	Other sites:	
	Exploration well at 220/1242, completed as piezometer	50
	Sites 1, 2 Test well and piezometer in beach sands in central area	60 + 60
	Sites 3, 4 Test well and piezometer in beach sands in central area	60 + 60
	Sites 5, 6 Test well and piezometer in beach sands in central area	60 + 60
	Sites 7, 8 moved into new wellfield area	60 + 60
	Total meterage	970
3. Monitoring	As proposed. Select representative wells for meters and water quality monitoring. EC logging of 12 - 1, 12 - 68 if possible All test wells to have recorders	
	3 rainfall recorders: 2 in coastal areas and at Zuwayid Obtain meteorological data from GMA stations at Rafah	

	(b) Just south of road south of 2(a)	Test dune sand at approximately site 7. Test well plus piezometer	50 + 50
	(c) In dune area near site 8	Test dune sand-alluvium interconnection. Major test site involving explorator well to 100m converted to test well in alluvium at approximate depth (say 100m)	100
		Piezometer to 100m with screen in alluvium	50
		Piezometer to 50m with screen in dune sands	50
	(d) In more southerly part of dune area near site 9	Exploration well to 100m, completed in dune aquifer at, say, 50m	100
	(e) At dune edge just west of airport	Piezometer to 50m	
		Sub-total	450
3. Monitoring		As proposed, incorporating above site. Monthly water levels. Recorders on all test wells	
<u>Central (Zone C)</u>			
1. Geophysical Survey		Included in W1	
2. Drilling and Testing	(a) North of site 4	Move site 4 north into area of abstraction. Piezometer only to 50m	50
	(b) At site 12/13	Exploration well 150m, completed as test well screened in kurkar at about 100m	150
		Piezometer screened in kurkar at, say, 100m	100
		Piezometer screened in alluvium at, say, 50m	50
		Major test site to investigate characteristics of kurkar and interconnection with alluvium	
3. Monitoring		As proposed, incorporating above sites. Recorder on test well. Monitor water quality and abstraction on selected representative wells	
		Sub-total	350

Eastern (Zone E)

1. Geophysical Survey		ER traverse from coast at site 3, through GDDO A to site 14 to GDDO 3	
2. Drilling and Testing	(a) As site 14	Drill to 150m (or prove bedrock) but complete in kurkar. Recovery test only.	150
3. Monitoring		As proposed. Recorder on site 14	
		Sub-total	150

Southern (Zone S)

No additional work required but install recorders on existing RIWR wells and monitor piezometers monthly.

Total meterage 1,300

Note: All test wells at 8"
All piezometers at 4", except site 14 to be at 8"

Obtain meteorological data for Arish station from GMA